BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
BUDAPEST, HUNGARY
20 October 2017

REVISION OF THE REQUIREMENTS REGARDING TO CONDUCTIVE CLOTHING DURING LIVE-LINE MAINTENANCE

Author/s: **DR. GÁBOR GÖCSEI, DR. BÁLINT NÉMETH, DÁVID SZABÓ**
Company or institution: **BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS**
Position: GÁBOR GÖCSEI (senior lecturer), BÁLINT NÉMETH (associate professor, Head of High Voltage Laboratory), DÁVID SZABÓ (developmental associate)

KEY WORDS: electric field, health effects, measuring, live-line maintenance, high voltage

COMPANY'S DATA
Address: Egry József u. 18.
Zip Code: 1111
Phone: +36 1 463 3236
Fax: +36 1 463 3231
E-Mail: gocsei.gabor@vet.bme.hu

SUMMARY

Live-line maintenance has several different working methods depending on the voltage level and the task to be executed. While using so-called bare-hand method – when potential of the worker is connected directly to the energized parts – use of conductive clothing is essential and required.
Conductive clothing act as Faraday-cages: in optimal case, extra-low frequency (ELF) electric fields – like 50 or 60 Hz which is commonly applied in power transmission worldwide – are zero inside the clothing. In practice, this special protective equipment must contain some openings and have to guarantee the proper ventilation during the whole period of work.
One of the main aim of the inspections executed in the High Voltage Laboratory of Budapest University of Technology and Economics is to determine the maximal allowed size of openings.

The revision of the current regulation of inspection was a part of an EU Framework Programme Project in co-operation with the Hungarian TSO. The result of the inspections is a proposed modification of the related IEC standard 60895.
From the other hand, it is also necessary to review the current way of regulations regarding to the use of conductive clothing. Although some suggestions are available for the limits of ELF electric fields by international commissions, in some countries stricter laws may apply.
From the aspect of health effects, it is suggested to re-examine the current limitations and extend the requirements for example for substation works, as well. It is also suggested to unify the recommendations for working near the energized parts or on tower structures.

Introduction

Conductive clothing used during high voltage live-line maintenance have to be examined periodically. Investigations carried out in the High Voltage Laboratory of Budapest University of Technology and Economics have shown that the current way of screening efficiency measurements is not efficient enough. Therefore, various researches were executed to suggest modifications in the current arrangement described of the related standard, IEC 60895.

On the other hand, safety of working personnel has to be guaranteed during any kind of work. In this case, it is important to determine the affecting electric field which mainly depends on the size of openings on the conductive surface. The main aim of these investigation to keep the exposures below the limits specified in the current guidelines [1].

Inspection of conductive clothing

In the European Union (EU), limits of exposures – both public and occupational cases – are defined by International Commission on Non-Ionizing Radiation Protection (ICNIRP) based on the research of World Health Organization's (WHO) International Agency for Research on Cancer (IARC) [2], [3], [4], [5], [6]. Current limits for electric fields are summarized in Table 1.

Table 1. Current limits of ICNIRP regarding to ELF electric fields

Type of exposure	Electric field limits [kV/m]
Public exposure (24 hours/day)	5
Occupational exposure (max. 8 hours/day)	10

Table 1. shows that extra-low frequency electric fields shall not exceed 10 kV/m, even in case of occupational exposure.

In the High Voltage Laboratory of Budapest Univesity of Technology and Economics several calculations, simulations and measurements have been made to examine the critical opening size of the conductive clothing. Based on the results, a critical "Farady-hole" size can be established. If the size of openings exceeds this critical size, electric field strength also exceeds its limits inside the clothing – even with orders of magnitudes.

Figure 1. shows the maximal electric filed strength values as a function of the nominal voltage level of the power line in the vicinity of an energized conductor. As it can be determined from the figure, in case of large openings, electric fields may endanger the safety of the worker by exceeding their limits significantly [7], [8], [9], [10].

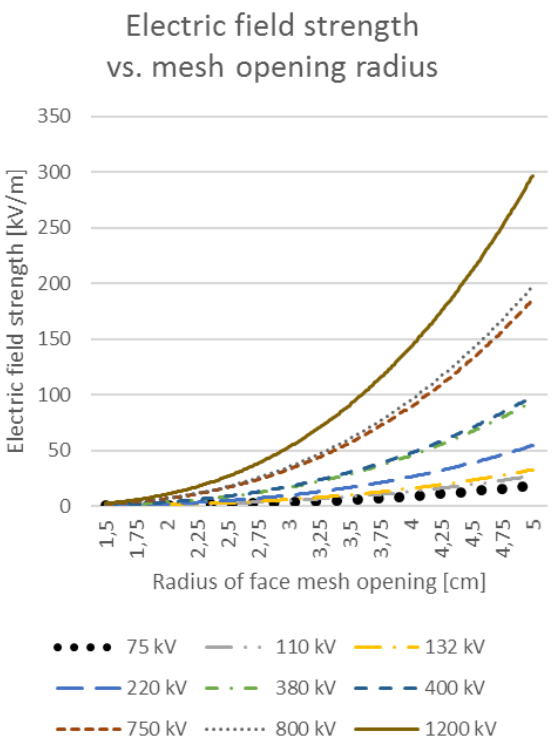

Figure 1. Electric field strenght inside the clothing as a function of face mesh opening radius

During the inspection of conductive clothing it is important to identify those parts, which can endanger the health of the worker. In this case the screening efficiency describes the protective effect of the Faraday-cage. This kind of examination has to simulate worst-case working conditions and has to separate acceptable and unacceptable results clearly from each other.

Current way of measurements

In the European standard – IEC/EN 60985 – the acceptance criteria specified as ratio of leakage current. During measurements a mannequin with conductive surface shall be dressed in a conductive clothing, insulated from the body. The conductive clothing shall be energized and leakage currents has to measured in the high voltage side of the arrangement. Figure 2. shows the current measurement arrangement during a conductive clothing inspection in the High Voltage Laboratory of Budapest University of Technology and Economics.

Figure 2. Inaccurate and dangerous way to measure leakage current by "shielded" micro-ammeters

In this measurement the efficiency of the shielding micro-ammeters influence the result accuracy. It is also dangerous to read the measured values of the micro-ammeters.

Figure 3. shows the variation of electric field distribution – so measured leakage current values – as the base of determination of screening efficiency. The results show that the vicinity of the measurement arrangement may distort the results significantly; even so-called "shielded" areas may be formed, as it can be seen in the figure above the mannequin. This

phenomena make measurements hard to compare and repeat.

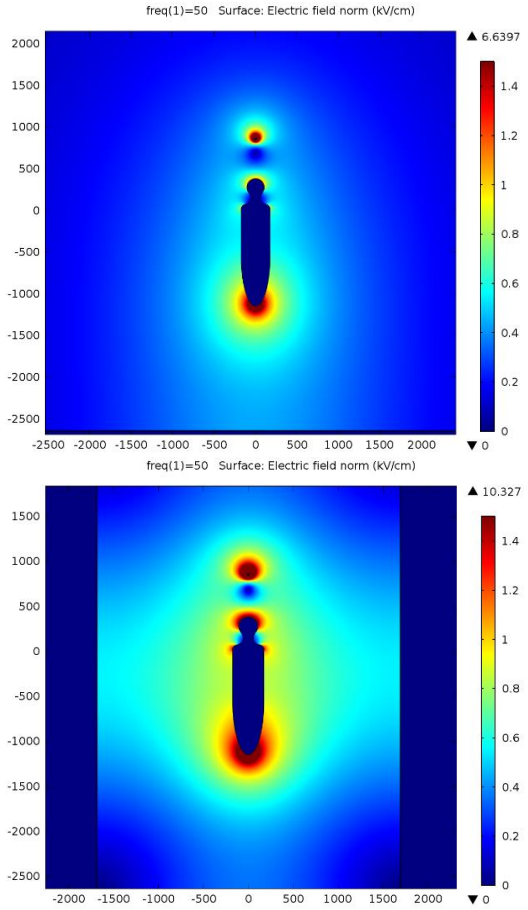

Figure 3. Electric field distribution with (above) and without (bottom) gorund object in the vicinity of the arrangement

Tha major disadvantage of the current way of measurement is that the conductive cloth can pass the test without any face mesh, even with large with a large opening in front of the face. As the result of this issues regarding to current way of measurement, many of the poorly designed conductive clothing may pass the test.

Suggestions to improve masurement arrangement

In the High Voltage Laboratory of Budapest Univesity of Technolgy and Economics, a new model has been developed to make the isnpection of the screening efficiency safer, more accurate and more repetable.

Figure 4. shows the principle of the new arrangement. As it can be seen from the picture, micro-ammeters are grounded both in the branch clothing and body currents. Shape, position and distance of the energized electrode is also clearly determined. To simulate the worst-case scenario, a conductor-shaped electrode is advised to be placed in the height of the face. Distance between the energized and grounded parts shall be equal to the minimum phase-to-ground approach distance of the applied voltage, which shall be the maximum nominal voltage of the inspected clothing.

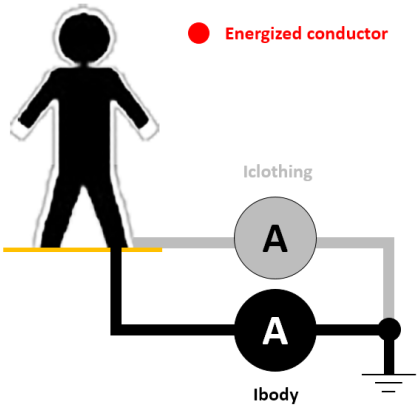

Figure 4. Suggested way of conductive clothing measurement

Suggested way of calculation of protective effect has remained the same as it is introduced in the current standard.

Electric field distribution in the suggested arrangement is shown in Figure 5. As it can be seen, distortion effect of the grounded parts in the surroundings of the arrangements is negligible, compared to the current way of inspection shown in Figure 3.

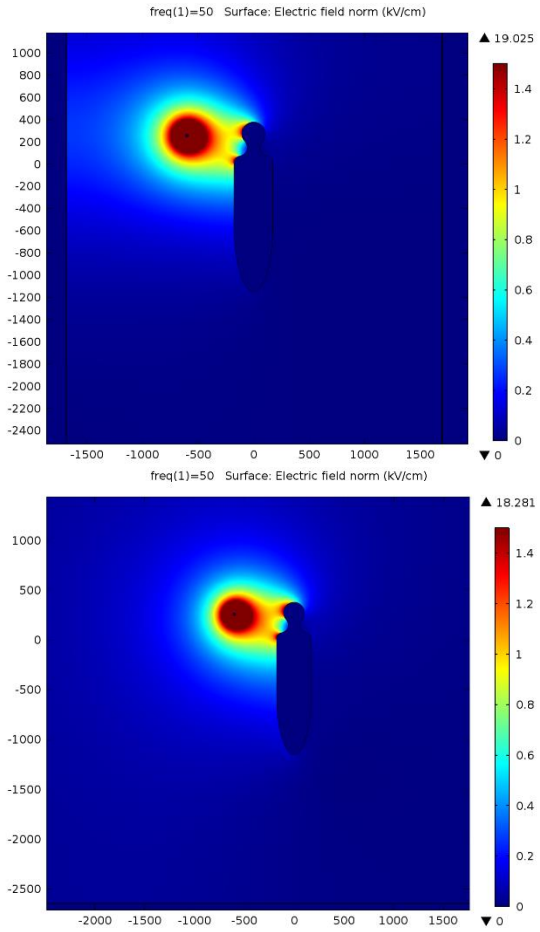

Figure 5. Electric field distribution with (above) and without (bottom) gorund object in the vicinity of the arrangement

In case of the proposed model, conductive clothing without any face mesh cannot pass the screening efficiency test. There is a solution to that case if a conductive cloth made without face screen to meet the screening efficiency test criteria. As it shown in Figure 5. a face mesh can be installed on a conductive clothing retrospectively.

Figure 5. Additional face mesh installed on an existing type of conductive clothing (originally made without any face screen)

Suggestions

To shield electric fields properly, face mesh is an essential accessory of all conductive clothing regardless of the voltage level to keep the size of so-called “Faraday-holes” as low as possible. Face and neck are very sensitive parts of the human body, so efficient protection of them is curious.

By the application of the suggestions introduced in this paper, inspection of the screening efficiency of conductive clothing may become safer, more accurate and more repeatable than it is currently.

Summary

Extra-low frequency electric fields may cause health effects above their exposure limits. The

main task of a responsible expert in the field of live-line maintenance is to keep these exposures below their limits. Some guidelines are internationally accepted. Although the limits used in this paper are based on ICNIRP's guidelines, there are some stricter local regulations, as well. By the proper handling of these kinds of risks, electric field related sources of dangers can be eliminated effectively.

A new model has been introduced to measure and compare the screening property of conductive clothing in a more efficient way than the current one. Calculations, simulations and laboratory measurements for validation have been introduced to increase of the safety of any bare-hand live-line activities, applied widely around the world.

Acknowledgements

In the High Voltage Laboratory of Budapest University of Technology and Economics a new type of conductive clothing inspection method is researched and developed within the confines of the BEST PATHS project, which aims to develop novel network technologies to increase the pan-European transmission network capacity and electricity system flexibility. BEST PATHS stands for ''BEyond State-of-the-art Technologies for rePowering Ac corridors and multi-Terminal HVDC Systems''. It is co-funded by the European Commission under the Seventh Framework Programme for Research, Technological Development and Demonstration.

„ SUPPORTED BY THE ÚNKP-17-2-II NEW NATIONAL EXCELLENCE PROGRAM OF THE MINISTRY OF HUMAN CAPACITIES"

References

[1] CIGRÉ Report 561: Live Work – A Management Perspective, Joint Working Group, B2/B3.27, December 2013

[2] International Commission On Non-ionizing Radiation Protection, ICNIRP Statement, General Approach to Protection Against Non-Ionizing Radiation Protection, Health Physics 82(4):540-548, 2002

[3] International Commission On Non-ionizing Radiation Protection, ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz – 100 KHz), Health Physics 99(6):818-836, 2010

[4] World Health Organization International Agency For Research On Cancer: IARC Monographs On The Evaluation Of Carcinogenic Risks To Humans, Volume 80, Non-Ionizing Radiation, Part 1: Static And Extremely Low-Frequency (ELF) Electric And Magnetic Fields, IARCPress, Lyon, France, 2002

[5] Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive

89/391/EEC) and repealing Directive 2004/40/EC

[6] IEC 62233 ed1.0: Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure, International Electrotechnical Commission, 2005

[7] Gábor Göcsei, Bálint Németh, Dániel Tarcsa: Extra low frequency electric and magnetic fields during live-line maintenance, IEEE Electrical Insulation Conference, Ottawa, Ontario, Canada, 2013

[8] Gábor Göcsei, Bálint Németh: New challenges in live-line maintenance, IEEE Electrical Insulation Conference, Seattle, WA, USA, 2015, doi: 10.1109/ICACACT.2014.7223498

[9] Göcsei G., Németh B., Kiss I., Berta I.: Shielding efficiency of conductive clothing in magnetic field, Journal of Electrostatics 71:(3) pp. 392-395, DOI: 10.1016/j.elstat.2013.01.001

[10] Gábor Göcsei, Bálint Németh, Dr. Zoltán Ádám Tamus, Dr. István Kiss, József Meixner: Shielding efficiency of conductive clothing during live-line maintenance, International Conference on Live Maintenance (ICOLIM), Budapest, Hungary, 2014, doi: 10.1109/ICOLIM.2014.6934339

[11] Gábor Göcsei, Bálint Németh, Dr. István Berta: Electric fields and arc protection during live-line maintenance, 19th International Symposium on High Voltage Engineering, Pilsen, Czech Republic, 2015

[12] P. W. Hotte, G. Gela, J. D. Mitchell Jr., P. F. Lyons: Electrical performance of conductive suits; IEEE Transactions on Power Delivery, Vol. 12, No. 3, July 1997