EXAMINATION OF ELECTRIC FIELD EXPOSURE OF LIVE LINE WORKERS

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Abstract: Recently, several studies have been reported about the adverse health effect of long-term exposure to extremely low frequency (ELF) fields, but most of these studies focus on the effect of weak EM fields. However, live line workers are exposed to intense time-varying electric and magnetic fields therefore special protective clothes worn by the workers ensure the shielding of electric fields. But these clothes do not protect against the magnetic field generated by current flowing in conductors of overhead power lines. Theoretically, these clothes act as Faraday-cage but, necessarily, there are holes on the cloths e.g. front of the face of worker. Hence, the shielding provided by protective clothes does not reach theoretical maximum i.e. the electrical field inside the Faraday-cage is zero, consequently, the live line workers are exposed to electrical field. In this study, the shielding effectiveness of protective clothes has been investigated by computer simulation and laboratory measurements. The results reveal differences between the measurements of protective effectiveness and underline the importance of face screen.

1 INTRODUCTION

The live line workers are exposed to intense, extremely low frequency electric and magnetic fields, however these fields are highly attenuated by the distance from the power lines. The main interaction model between low frequency electromagnetic fields and human beings is based on induced fields and currents inside the organs. Although, external electrical field is attenuated inside the body, internal field drives a current in the body. Since, the biological tissues have nonmagnetic characteristic, the magnetic field is not reduced inside the body. The magnetic field induces electric field, which also drives a current in conducting body. The distribution of fields and currents is affected by the conductivities of different tissues. The short-term health effects are based on the following interaction mechanism: the external fields induce internal current in the human body and if these induced currents exceed stimulation threshold of excitable tissues, physiological reactions will be occurred [1, 2]. This interaction model has established the guidelines for the electric and magnetic filed exposure [3]. The new guideline has been published, recently [4].

The possible long-term adverse health effects are investigated by epidemiological studies, a short review and evaluation of many studies can be found elsewhere [5]. Till now, generally accepted interaction model for long term effects has not been developed, since the photon energy at the ELF band of the spectrum is smaller than that needed to break even weakest chemical bonds.

In this study, the effectiveness of protective clothes worn by live line workers has been examined. The first step of this study was the determination of the fields nearby the conductor. A computer model has been developed of an overhead power line. This model based on the power line of live line working training center of BME High Voltage Laboratory. Then, the protective effectiveness of cloths without and with screening face have been investigated by numerical simulation and measurements performed in the laboratory, as well. The laboratory measurements have been carried out according to the IEC 60985 and by Csikós's recommendations [6]. This recommendation was used in Hungary before the publishing of the IEC standard.

2 MODELING OF ELECTRIC FIELD

In computer simulation, the overhead power line has been modeled as a twin bundled conductor, which distance from the ground is 4 m. The diameters of the conductors are 2 cm. These parameters have come from the geometry of the high voltage training line of BME High Voltage Laboratory. The worker's model is positioned nearby the conductor (Fig. 1.). In the calculations, the distance between the worker's hand and the conductor (d) was changed as can be seen in Fig. 2.

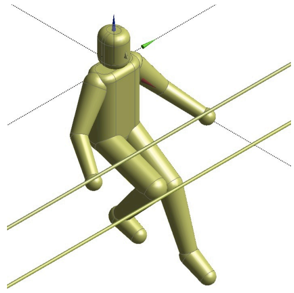


Figure 1: The model for the field calculations

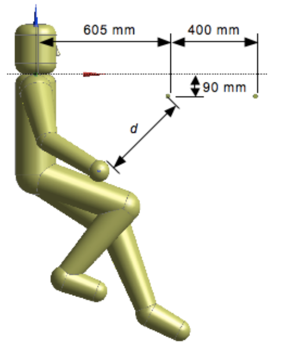


Figure 2: The geometry of the model for field calculations

Five cases of distances (d= 1, 5, 10, 20 and 40 cm), for modeling the typical movement of the worker by the conductor, have been calculated (Fig. 3.).

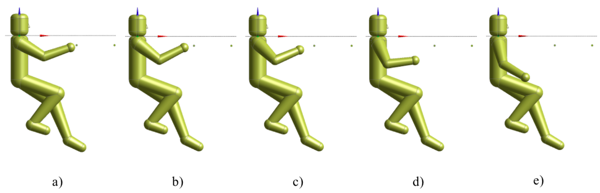


Figure 3: The distance between conductor and the workers hand: a) 1 cm, b) 5 cm, c) 10 cm, d) 20 cm and e) 40 cm

In every single case, field distribution on the surface of the body and potential of the body have been determined. Typical fields distribution is on Fig. 4.

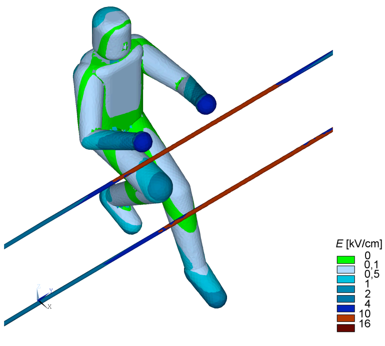


Figure 4: The field distribution, d=10 cm

The potential of the body as a function of distance can be seen in Fig. 5. In the model, the voltage of power line has been also changed and four different line voltages were assumed: 120 kV, 220 kV, 400 kV and 750 kV. These voltages are the nominal voltages of power lines, which are operated in the Hungarian transmission network. The results are more easily evaluated, if the potential is expressed in percentage of line voltage. The Fig. 6. shows the results.

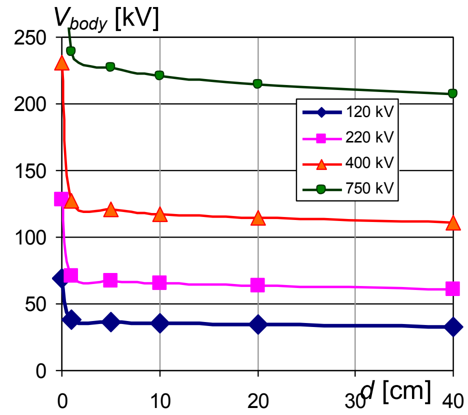


Figure 5: The potential of the body as a function of distance

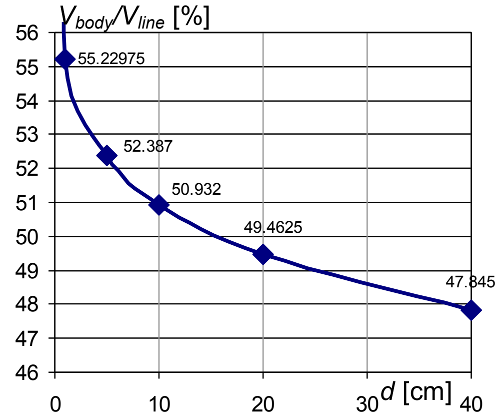


Figure 6: Relative potential of the body to the line voltage as a function of distance from conductor

The maximum electric field on the surface of the worker's body can be seen in Fig. 7.

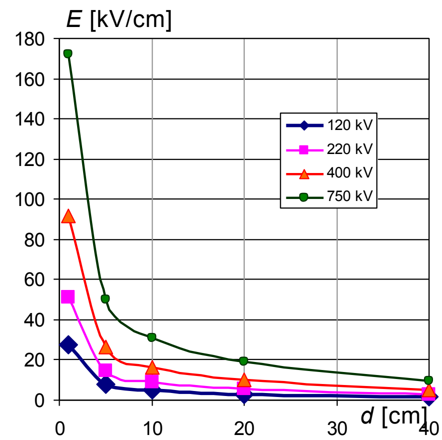


Figure 5: The electrical field on the surface of body as a function of distance from conductor

The results show that the maximum electric field on the surface of the worker's body is much higher than the 10 kV/m limit, if the worker does not wear protective cloth.

3 EXAMINATION OF SHIELDING EFFECT OF FACE SCREEN

In this examination, only the worker’s head have been modelled. In the model, the conductive head is isolated from the — also conductive — hood by 2 mm thick insulating material (Fig. 8).

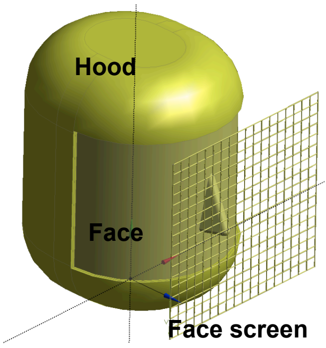


Figure 6: Model of face screen and hood

The hood does not cover the total surface of the head, it is opened the front of the face. The face screen, which is modeled by a conductive mesh, is situated front of the face. The arrangement can be seen in Fig. 9. The distance between face and conductor is 20 cm. The geometry of the conductors and the power line are same as used the previous calculations.

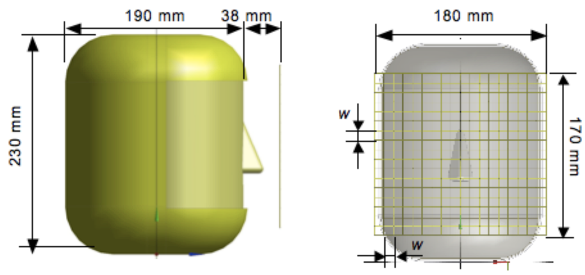
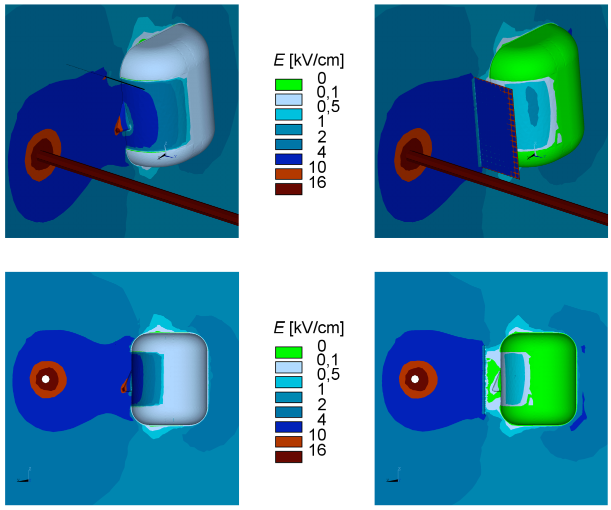


Figure 7: The arrangement of face screen

The face screen mesh is characterized by size of openings (w).

The result of the calculations can be seen in Fig 10. In this case the potential of the conductor was 433 kV and the mesh openings (w) was 0.5 cm. This voltage is the phase voltage of a 750 kV, which is the highest voltage in Hungarian transmission network.

By the changing of opening size of face screen, the shielding effectiveness has been also calculated. The results can be seen in Fig. 11.



a) b)

Figure 8: The field distribution without a) and with face screen

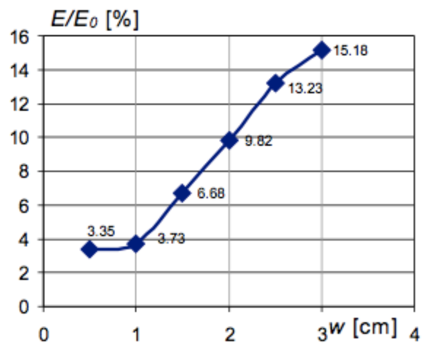


Figure 9: The shielding effectiveness as a function of openings (w)

The results of the calculations prove that without face screen the maximum electric field exceeds the threshold (10 kV/m). But, if the face screen, a mesh with 1 cm openings, is present the shielding effectiveness is satisfied, the electric field behind the face screen is lower than the reference level in guideline [3, 4].

4 LABORATORY MEASUREMENT

The shielding effectiveness of the protective cloth have been also investigated by laboratory measurements. The effectiveness has been measured by two methods:

- According to the IEC 60895
- By Csikós’s recommendations

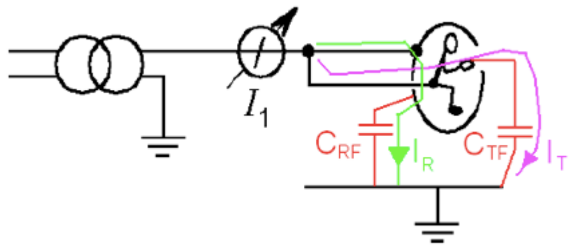
Both measurements are based on the comparison of currents i.e. current of body and shielding.

4.1 The test arrangements

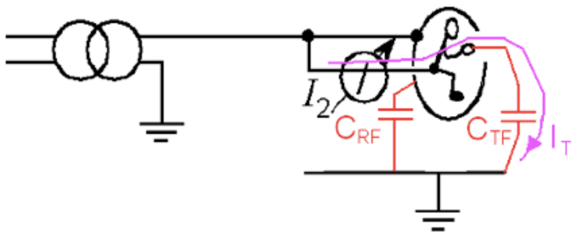
By the IEC 60895, the protective cloth is connected to a high voltage source and two currents have to be measured. The first current (I_1) is sum of the currents of protective cloth and worker. The second one (I_2) is the current of worker, only. If cloth behaves as a Faraday-cage, the current of worker should be zero. Since, the protective cloth is not a perfect Faraday-cage, the capacitance between the worker and the ground is not zero. Hence, the current of the body is not zero.

The IEC 60895 characterizes the effect of shielding by two values. The first one is the "Protective effectiveness", which is calculated by $I_1/(I_1+I_2)$ ratio. The acceptance value of "Protective effectiveness" is >99 %. The second value is the "Protective effect", which is quotient of I_1 and I_2 (I_1/I_2).

The arrangement of the measurement and measured currents (I_1, I_2) can be seen in Fig. 12.



a)



b)

Figure 12: The arrangement and current of cloth and worker a), and current of worker b) according to IEC 60895

Before the publishing of IEC 60895 standard, the shielding effectiveness of protective cloths was evaluated by Csikós's recommendation in Hungary [6]. In this measurement, the protective cloth is not connected to the voltage source, but it is placed in high electric field and the body and cloth currents are measured, too. The minimum recommended electric field is 100 kV/m. The currents are evaluated by same equations used in IEC 60895. The arrangement and the measured currents can be seen in Fig. 13.

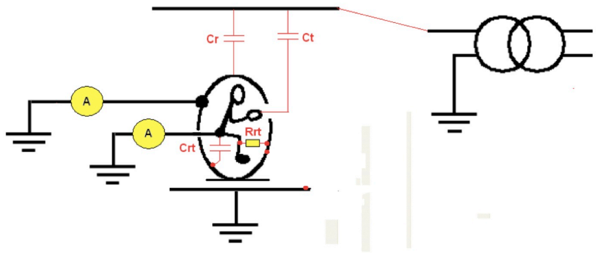


Figure 13: The arrangement and currents of body and cloth by Csikós's recommendation

The shielding effect of face screening was examined with both measurements. The test puppet was dressed and connected to the high voltage source in accordance with IEC 60895. In the case of the measurements by Csikós's recommendation, two test arrangements were examined. The first one was when test puppet standing on an insulating holder in vertical electrical field (Fig. 13.). The vertical filed was generated by the 600 kV transformer.

Figure 14: The test puppet standing on the holder under the test transformer

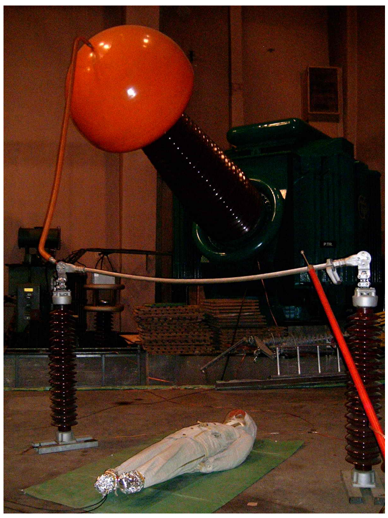


Figure 15: The test puppet lying under the line

In second case, the test puppet lying under the line and longitudinal axis of the body is perpendicular to the axis of line (Fig. 15.). Conductive cloth was tested with and without face screening in each arrangements.

4.2 Results

The results of the measurements are in Table 1…3. The results of measurements in accordance with IEC 60895 are summarized in Table 1.

Table 1: Results of the measurement by IEC 60895

Cloth	Protective effect	Protective effectiveness [%]
With face screening	491.373	99.739
Without face screening	117.62	99.089

These results show that the protective cloth with or without face screening are satisfy the requirements of the standard, because the protective effectiveness is >99 %.

The measurements by Csikós's recommendations are in Table 2 and Table 3. The former table contains the results of the measurements on standing puppet, in the latter one the results of lying puppet can be seen.

Table 2: Results of the measurement by Csikós's recommendation — standing puppet

Cloth	Protective effect	Protective effectiveness [%]
With face screening	430.040	99.75
Without face screening	40.919	97.556

Table 3: Results of the measurement by Csikós's recommendation — lying puppet

Cloth	Protective effect	Protective effectiveness [%]
With face screening	246.973	99.595
Without face screening	20.726	95.175

The results suggest that the measurement by Csikós's recommendation indicates to the "Faraday-holes" on protective clothes, since the examined cloth without face screening has lower protective effectiveness than 99 %. Moreover, if the face of test puppet is perpendicular to the electric field (in the case of second measurement arrangement, in which the puppet lying under the line), measurement by Csikós's recommendation is much more sensitive. Obviously, the measurement according to the IEC standard is not depend on the orientation of the test puppet, since the cloth is connected to the high voltage electrode.

5 CONCLUSION

The exposure of live line workers to electric fields has been studied by the examination of shielding effectiveness of protective cloth. This has been investigated by numerical model and laboratory measurements. The results emphasize the necessity of face protection grid, which reduces the field strength on face and the body current, as well. The results of investigation have revealed that the IEC standard is not enough sensitive to show the presence of the face screening, however without this protection the electric field on worker's face exceeds the ICNIRP reference levels.

6 REFERENCES

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