THE CONCEPT OF CREATION THE PROTECTIVE CLOTHING, AIMED AT LIMITING THE INFLUENCE OF THE ELECTROMAGNETIC FIELD OF THE INDUSTRIAL FREQUENCY

TOKAR Galina[1], TRETIAKOVA Larisa[2], MITUK Lyudmila[3]
[1] Kyiv national university of technologies and design, Kyiv, Ukraine
[2, 3] *National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»* Kyiv, Ukraine

Abstract: *When working at high-voltage electrical facilities (110 - 750 kV), electrical workers fall under the influence of the electromagnetic field of the industrial frequency. The purpose of the article is to evaluate the levels of hazardous effects and develop approaches to the creation of individual protective clothing. The current limitations to the parameters of the electromagnetic field in international and Ukrainian regulatory documents were analyzed. The proposed concept envisages the implementation of the certain stages of the research: analysis of working conditions and monitoring of dangerous factors; assessment of the risks of occupational diseases; properties of the existing protective clothing: development of requirements for the material and construction of conductive clothing. The design of the new conductive clothing made of composite textile material is proposed, which is used in combination with head, hand and foot protection.*

Key words: *high-voltage electrical installations, working conditions, permissible levels of intensity, material and construction.*

1. INTRODUCTION

At the present time, the problem of electromagnetic safety and limiting the influence of the electromagnetic fields (EMF) of the industrial frequency on human and on the environment have acquired urgent and social significance at the international and national levels. Taking into consideration the importance of this problem, the World Health Organization (WHO) in 1995 introduced the term "global electromagnetic pollution of the environment". The questions of the EMF influence on the environment and ecosystem elements were included in the WHO program "WHO International EMF Project" in 1998, the task of which is to develop the scientifically based assessments, recommendations and regulatory restrictions that deal with the biological effects of the EMF.

The sources of high-power EMF of the industrial frequency are air lines (AL) and powerful electric equipment with voltage of 110-750 kV, located in the open area. The total length of the high voltage AL in Ukraine equals to 85 thousand km, more than 200 open transformer substations are built. Numerous studies of the biological impact of EMF have identified the nervous, endocrine and genital systems among the most sensitive systems of the human body.

During the operation of the electrical networks, certain preventive maintenance and post-emergency operations can be performed under the impact of the voltage:

oil circuit breaker prevention, check and adjustment of relay protection systems, insulation testing of switching circuits, measurement of the resistance of grounding devices, testing and replacement of insulators. When performing work on the elements and near the open electrical installations under the voltage, workers are in the zone of increased EMF influence of the industrial frequency.

2. EXPERIMENTAL

Researches, conducted in the recent years, have shown that the mechanism of the external EMF influence on the humans is determined due to the formation of the internal induced currents. The level of the influence depends on the electrical and magnetic properties of the human clothing, on the orientation of the body relative to the vectors of electric (EF) and magnetic (MF) fields, as well as on the distance to the electrical installations, on the duration of the influence and on the availability of the protective equipment. The intensity of the EF is proportional to the intensity of the electrically-powered equipment and inversely proportional to the distance to the object of the influence. External EF affects the charges in the human body and this leads to the flow of the currents in the internal tissues and to the appearance of the additional internal MF [1]. Measured values of currents flowing through the body of the worker, who is in open 500 kV switchgear and has contact with the ground (through his shoes) or with earthed parts of the equipment, are 130 ... 250 mcA. During the time of finding the employee on the 500 kV transmission line support at the wire level, the currents reach 500 ... 600 mcA.

The most grounded are the CEU ENV 50166 standards, proposed by the Technical Committee of the European Committee for Electrical Standardization (CENELEC), which were used in the development of national standards for the protection of electrical workers from the EMF impact at the workplace [1]. When working under the EMF influence for eight hours, the current density of 10 mA/m^2 in the human body is set as a baseline value, to which the voltage of 20 kV/m and the intensity of 4 kA/m correspond at a frequency of 50 Hz. The current was standardized for the first time, which flows through a person when in contact with conductive objects that are under the induced voltage of 3.5 mA at the workplace and 1.5 mA for the population.

For designers of protective clothing, the maximum permissible values of the intensity and density of the induced current for individual organs of the human body are the matter of the interest (Table 1). The permissible impact of the MF on limbs (arms and legs) is from 800 to 6,400 A/m, depending on the time of the influence. The normative document [2] sets even higher standards for electrical workers. When exposed to the whole body, 25 kV/m and 6 kA/m, respectively, are allowed. In view of these provisions, the task is to create conductive protective clothing.

Table 1: Recommendations for limiting the influence of the EF, MF and current density on separate human organs

Type of limitation	Type of influencing factor	Human organs	Permissible value
Basic level of influence	EF intensity, kV/m	Brain	0.0531
		Heart and other internal organs	0.943
		Palm, wrist, leg, knee	2 100
	Current touch, mA	Footstep	3.0
		Contact by hand (grab)	3.0
		Contact by hand (touch)	1.5
	MF intensity, A/m	Whole body for 8 hours	400
		Whole body for 2 hours per working shift	4 000
Maximum permissible level	EF intensity, kV/m	On average, all over the body	20
	MF intensity, A/m	Head, torso	2 170
		Hands, legs	5 000

The proposed concept is based on the provisions, which provide for the implementation of certain stages of the research:

– analysis of the working conditions in open electrical installations and determination of the basic parameters of the EMF intensity, microclimate, static, dynamic and vibration loads at workplaces;

– assessment of the risk of performance of work without switching off the voltage in the existing electrical installations;

– evaluation of the effectiveness of existing means of protection;

– definition of the set of requirements to the properties of materials, which can be used in protective clothing of a given purpose;

– optimization of the design, aimed at the provision of modular-differentiated protection of individual areas of the human body.

3. RESULTS

Works under the influence of the intension during the periodic inspections or in case of emergency situations are performed in accordance with the regulatory documents. Workers dress a protective set, which consists of protective clothing, helmets, gloves, shoes and safety belts. Electrician when performing its operations spends 60 % of his working time in the working position “standing upright” and 40 % of his working time in the “bent” working position. The conducted studies of the structure of injuries considering the topographical areas of the electrician` body showed that the most injured are: hands and fingers (up to 40 %); shin of the leg (18 %); head (5 %); spinal column (3%).

Monitoring of the EMF parameters at the workplaces has shown that the levels of the EF and MF intensity reach significant values. When locating in the middle of

the span under the AL at the altitude of 1.5 m, the following levels were experimentally recorded: voltage 500 kV – EM intensity E = (6 ... 10) kV/m, MP intensity MP – H = (35 ... 40) kA/m; voltage 220-330 kV – E = (6 ... 8.5) kV/m, H = (28 ... 36) kA/m; voltage 110 kV – E = (0.45 ... 0.75) kV/m, H = (12 ... 16) kA/m; 35 kV – E = (0.25 ... 0.30) kV/m, H = (0.8 ... 0.82) kA/m [3].

The most dangerous factors are the effect of the external EMF and the possibility of direct or remote impact of the electric current. The risk of occupational diseases depends on the likelihood of the undesirable events and their consequences. Theoretically possible risk at work, which is understood as the basic risk, can be evaluated as follows:

$$R_i = P_i \cdot D_i, \tag{1}$$

where R_i – certain kind of risk; P_i – probability of the occurrence of *i*-risk; D_i – consequence of the occurrence of *i*-risk.

Under the EMF influence, the basic risk is very high $(3…6)10^{-2}$ [4]. For example, the current assessment system recommends the following levels when determining the risk in energy: residual risk is $(1 \cdot 10^{-6})$ per year; acceptable risk is $1 \cdot 10^{-4}$; the upper limit of individual risk is (1 ... 5) 10^{-5}. Therefore, the reduction of the risk to the level of $(1 \cdot 10^{-4})$ by using protective clothing is obligatory.

It is offered to estimate the residual risk at use of the protective clothing, using the following formula:

$$R_r = \sum P_r \cdot w = (P_p \cdot w) + (P_c \cdot w), \tag{2}$$

where P_r – probability of the negative EMF impact, P_p – probability of working under the conditions that do not correspond to the permissible ones; P_c – probabilities of loss of the protective properties by means of protective clothing; w – the value of the energy flow that dissipates in the worker`s body. The permissible value of w, when the body of the worker is been fully exposed, is set at the value of 4 W/kg, during the local irradiation of the limbs – 10 W/kg (head) and 20 W/kg (hands and legs).

The indicators of working conditions and the risk of occupational diseases significantly exceed the permissible standards and it is necessary to introduce measures to reduce them. The reduction of the probability of $P_{оп}$ and irradiation energy is achieved by increasing the quality and reliability of protective clothing, which in turn requires its improvement and value appreciation.

4. DISCUSSION

The main methods of protecting workers from the EMF influence of industrial frequency include individual protection sets of clothing (conductive clothing, footwear, protection of hands, head and eyes).

It is proposed to make protective conductive clothes from composite textile two-layer materials. In order to limit the influence of the EMF, the material must have a

high electrical conductivity and a minimum possible magnetic permeability. For clothes, a two-layer material is used, which consists of a non-woven polypropylene fabric (inner layer) and a layer of carbon fabric (outer layer). Polypropylene fabric has an electrical resistance of (10^8 ... 10^{10}) Ohm and is used as an insulating layer. Carbon fibers have a small electrical resistance (12 ... 25) 10^{-3} Ohm and are a conductive material. The protection of the worker in the conductive set takes place as follows: when the wave passes through the first conductive layer, a partial absorption and reflection of the wave occurs. Further, the wave passing through the nonwoven layer, is partially absorbed and further weakening occurs.

When creating the protective clothing, it is important to assess the levels of the intensity directly on the human body. The person, who is near the AL, strongly distorts the picture of the distribution of intensity around him. The real environment contains elements that have electromagnetic properties and significantly affect the propagation of the radiation. Because of the difference in the magnitude of the resistances for individual parts of the human body and, correspondingly, in the magnitude of the induced currents, the EMF inside the person is inhomogeneous and its parameters differ from the external EMF. The method for mathematical modeling of the EMF near and within a person's body has been developed, which is surrounded by air on the surface of the earth or by the conductive element (tower). As the simulation results showed, the intensity of the EF on the surface of the worker`s body can exceed the strength of the external field E_0 by (7 ... 12) times. The zone of the increased intensity is located near the head (up to 12 E_0), near the in chest – up to 7 E_0 and decreases near the hip to 1 E_0.

The designed type of the protective clothing consists of the suit (elongated jacket and pants) or of the straight hooded twinset [5]. The design features of protective clothing include the absence of pockets, fasteners, buttons and fittings, which can be hooked in the limited space of a special, isolated cradle that is brought to the workplace. The construction of the twinsets and jackets provided the hoods that fit snugly to the face. During the optimization of the design, the uneven distribution of the EMF over the body of the worker was taken into account. In the hood area and in the front of the jacket, a layer of conductive fabric from the PROTEKTA™ series is additionally inserted. Such kind of cotton fabric is reinforced by the addition of polyester fibers and a conductive thread woven into the fabric and forming a grid with a 0.8 mm cell on the surface. The increased content of the cotton provides fabrics with such characteristics as hygroscopicity, air permeability and heat-resistant properties. Polyester fibers impart additional durability to the fabrics.

The minimum risk for the worker to be dirty, ease of dressing and removing the jacket and twinset is achieved by using a central double closed zipper to protect the thyroid, thorax and abdominal cavity. A one-piece sleeve is offered in the jacket that will reduce the load on the armhole line and allow the worker to raise and lower his hands freely. A lock for the thumb in the sleeves of the jacket and overalls and a band along the lower part of the trousers are used to fix the parts of the product while moving. Protective clothing is put on the underwear, and for the good contact of the human body with conductive base, conductive clothing cuffs are provided, tightly covering the arms above the hands. The compatibility of protective clothing with gloves and shoes (leather boots or boots made of conductive material) is ensured. Over the hood the helmet made of insulating material with conduc-

tive spraying can be used. All elements of the set of the clothing are connected by conductive ribbons. The effectiveness of the conductive set is determined by the conductive coefficient, which shows how many times the current, flowing through a person under the EMF influence, decreases. The tests of the prototype under the laboratory conditions showed a reduction in current not less than four times.

5. CONCLUSIONS

1. The norms of the influence of the electromagnetic field of the industrial frequency, recommended by the International Organizations, limit the current density in the internal organs of the worker at the level of 10 mA/m^2, which corresponds to the electric field strength of up to 20 kV/m and to the magnetic field strength of up to 4 kA/m.

2. The concept of creation the protective clothing for limiting the influence of the electromagnetic field of the industrial frequency is proposed, which provides for the: analysis of working conditions; definition of hazardous production factors; assessment of the risks of occupational diseases; creation of a design, taking into account the modular-differentiated protection of the employee.

REFERENCES

[1] IEC 62226-1:2004: Exposure to electric or magnetic fields in the low and intermediate frequency range. Methods for calculating the current density and internal electric field induced in the human body. Part 1: General., ISBN 0-642-79405-7.

[2] ДСанПіН 198-97: Державні санітарні норми і правила при виконанні робіт в невимкнених електроустановках напругою до 750 кВ включно, Держстандарт, 1997, Київ.

[3] Бржезицький В., Сулейманов В та ін.: Експериментальні дослідження електричного поля повітряної лінії електропередавання змінного струму класу 330 кВ, *Енергетика: економіка, технології, екологія,* 2016, № 2, p.p. 7–12*, ISSN 1813-5420.*

[4] Бондаренко Є.А.: Математична модель для оцінювання ризику електротравматизму, *Вісник Вінницького політехнічного інституту*, 2012, № 5), p.p. 64–69, ISSN 1997-9266.

[5] Третякова Л., Мітюк Л.: Способи удосконалення системи захисту працівників від впливу електромагнітного поля промислової частоти. *Вісник НТТУ «КПІ», серія «Гірництво»,* 2017, Вип. 32, p.p. 93–102, ISSN 2079-5688.