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ASSESSMENT OF THE IMPACT OF ELECTROMAGNETIC RADIATION IN LOW-FREQUENCY ENERGY FACILITIES ON THE RESIDENTIAL ECOLOGICAL ZONE

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ABSTRACT: Nowadays, one of the key issues in the ecological field and environmental protection is the influence of the electromagnetic field distribution intensity generated by low-frequency energy objects on the urban system. The purpose of environmental monitoring is to establish sanitary protection zones, taking into account the necessary maximum permissible conditions, during the construction and commissioning of new energy facilities. The agglomeration environment of the Shymkent city in the Republic of Kazakhstan where there is an increased electromagnetic pollution propagation generated by 110 and 220 kV high-voltage lines has been taken as the object under study. At the initial stage, the geometric parameters of power transmission lines have been determined by ground-based laser scanning and were later used in the main calculations to determine the electric and magnetic field distribution intensity. The mirror image method has been used to determine the electric and magnetic field levels in high-voltage transmission lines. As a result of the calculations obtained a geoinformation map was constructed based on the gradient of electric and magnetic fields in the studied territories using the inversely weighted distance method with the use of the ESRI ARC Gis application program. A three-dimensional characteristic is constructed that visually shows the dependence of the time spent by people in the zone of electromagnetic radiation, which depends on the radiated object. This characteristic is a sanitary protection zone that restricts the routing of line workers.

Keywords: Electric and magnetic fields, Electromagnetic pollution, Environmental monitoring, Geoinformation map

1. INTRODUCTION

In connection with the growth of electricity consumption, the main task is the construction and laying of high-voltage lines, which in turn lead to the emergence of new foci of electromagnetic radiation. The article [1] analyzes static electric fields associated with adverse health effects, and deduces various criteria for limiting the strength of a static electric field. In the article [2], an assessment was mainly given on the duration of the effect of electric and magnetic fields on the biological system. The effects that occur when these physical agents interact with biological systems depend on the frequency, amplitude of the fields, and exposure time. In the article [3], the installation of a safe distance of high-voltage power lines from residential complexes that are potentially in the zone of its influence is formulated. Measurements of the level of electric and magnetic field strength were carried out taking into account seasonal and daily fluctuations in electrical loads. As a result, a safe distance from the power lines of 132 and 300 kV, respectively, was determined.

In the article [4], high-voltage power transmission lines with a voltage of 110 kV were taken as the objects under study in the city of Chongqing. As a result, it was experimentally proved that with increasing distance of residential complexes from high-voltage lines, the probability of manifestation of carcinogenic risks decreases, and accordingly the degree of its impact on the ecosystem decreases. In the article [5], static data on the population living near high-voltage power lines were selected. The data show that residents living near a high-voltage transmission line at distances of 0-200 m, in a comparative nature, complain more about the state of health, compared to residents living at distances of 200-500 m from high-voltage lines. In the study [6], fifteen residential properties were randomly selected in the Thaba Nchu areas of Mangaung: 9 in Bloemfontein and 6 in Botshabelo. The measurements were carried out at distances of 3.6 and 9 m from the electrical substation. The obtained data showed slight differences in the level of electric field strength. The data show that with increasing distance from the source, the produced effect of the electric field leads to a sharp decrease. The article [7,8] specifies the maximum permissible values of electric and magnetic fields for occupational exposure, and for exposure of the General population, established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Were also considered methods of determining electric and magnetic fields in power lines of high voltage, namely, method of moments, finite element method, boundary element method, finite difference time-domain method simulation of charge.

In a scientific study [9], a static positive relationship was found between childhood leukemia and the distance of residential buildings from high-voltage lines. As a result, it was proved that the magnetic fields produced by high-voltage lines directly increase the risk of childhood leukemia at a certain remote level.

The article [10] clearly States the effects: climatic (temperature, wind speed, terrain) and technological (daily and seasonal changes in electrical loads) on the increase in the level of electric and magnetic fields produced by high-voltage lines. The results of the study [11-18] determined the safe terms of exposure to the electromagnetic field online workers who are directly in contact with high-voltage lines.

The purpose of our study was to determine the safe zone of influence of electric and magnetic fields produced by high-voltage lines on the example of specific, point objects. The conducted environmental surveys allow us to take into account the necessary maximum permissible conditions for the construction of new energy facilities and their impact on the environment in the future. The construction of geoinformation maps based on the ArcGIS application program allows you to visually conduct remote monitoring in selected areas, from the point of view of changes in the background of the radiation zone in residential areas, with subsequent consideration of the main requirements, as well as the introduction of additional data during the construction of new energy facilities.

To date, the main issue has been the optimal routing of line personnel in areas of carcinogenic risk of electric fields generated by high-voltage lines, during installation, construction, repair and cleaning operations. We have proposed a three-dimensional model, which describes the change in the residence time of linear workers depending on their distance from electric radiation. In turn, this makes it possible to prevent the effects of an electric field on the biological system and reduces the risk of the emergence of various types of occupational diseases.

2. THE RESEARCH OBJECTS AND METHODS

The Shymkent City of the Republic of Kazakhstan is taken as the study area in this paper, i.e. the Northern, North - Central, and West – Central parts of the city. High-and ultra-high-voltage power transmission lines have been installed in these districts,. They originate from the following energy hubs: Substation – 220/110/10 kV "South", "Shymkent", -110/10 kV "No. 6 Central", "Nursat", "Astana – 1", "Astana - 2".

This is since this city is being transformed into a megacity of the country resulted in an impetus for economic development. The construction of new industrial structures and the appearance of new residential areas has led to an electricity consumption increase, given that the city's territory has increased 3 times over the past 10 years (by almost 770 km^2). One of the key tasks became the commissioning of new energy hubs to cover the electric energy shortage.

These territories have insignificant, medium, and critical hazards of origin under the electric and magnetic radiation danger level [19, 20].

Fig. 1 shows the Nursat microdistrict with high-voltage power transmission lines and a geoinformation map based on the danger gradient of electric and magnetic fields.

Fig. 1. General view of the 110 kV overhead line power pole installed in the Nursat microdistrict and a geoinformation map based on the danger gradient of electric and magnetic fields

During an environmental assessment in high-voltage power transmission lines, it was necessary to obtain the main geometric parameters for main calculations to determine the electromagnetic field strength level.

The required geometric parameters include the distance between the initial and end wires; the height of the suspensions on the power pole; the dimensions of high-voltage electric transmission lines; the horizontal distance from the power lines to the point of interest. It should be noted here that several low-frequency energy objects were taken during environmental monitoring for comparative analysis and obtaining reliable indicative characteristics.

Source data for 110 kV high-voltage transmission lines are U - rated voltage of power transmission lines, 110 kV; H_p - the height of suspensions on a power pole, 19, 495 m; H_0 - the size of power lines 12.3; γ - coefficient that takes into account the conductor length finiteness, 0.3; $x-$ distances from the end wire of power lines to the point of interest, i.e. from 0 m to 100 m, respectively; d-distances between the initial and end wire, 7.8 m; h-high-altitudinal zones of electric and magnetic field distribution 1,2,4 and 6 m.

I_c – calculated, the average daily value of electric current in high-voltage electric transmission lines, 250 A. In turn, the calculated average daily value of the electric current is determined by the following formula:

$$I_c = \frac{S_c}{\sqrt{3} \cdot U}$$

where:

S_p - estimated average daily load capacity in high-voltage electric transmission lines that was 27.5 MW.

Source data for 220 kV high-voltage power transmission lines: U - rated voltage of power transmission lines, 220 kV; H_p - the height of suspensions on the power pole, 25, 1 m; H_0 - the size of power lines 9.3; γ - coefficient that takes into account the conductor length finiteness, 0.4; distances from the end wire of power lines to the point of interest: from 0 m to 100 m, respectively; d - distances between the initial and end wire, 11.45 m h – high-altitude distribution zones of electric and magnetic fields 1,2,4 and 6 m.

I_c – calculated, the average daily value of electric current in high-voltage electric transmission lines, 420 A. In turn, the calculated average daily value of the electric current is determined by the following formula:

$$I_c = \frac{S_c}{\sqrt{3} \cdot U}$$

where:

S_c - the estimated load capacity in high-voltage electric transmission lines that was 92.4 MW.

When the geometric parameters of high-voltage power transmission lines have been determined using the mirror image method, the electric and magnetic field strengths were calculated, and their characteristics were determined. The mirror image method is applicable for any number of wires stretched parallel to each other and parallel to a flat surface that restricts the conducting medium. Each wire must be mirrored on the conducting medium surface with a change in the charge sign, and then the conducting medium can be mentally removed and the field of the set of real wires and their mirror images is considered [24].

Electric field strength:

$$E = \frac{C \cdot U_\phi}{4 \cdot \pi \cdot \varepsilon_0} \cdot \sqrt{(2 \cdot k_1 - k_3 - k_5)^2 + 3(k_3 - k_5)^2 + (2 \cdot k_2 - k_4 - k_6)^2 + 3(k_4 - k_6)^2} \quad (1)$$

Magnetic field strength:

$$H = \frac{I \cdot \gamma}{2 \cdot \pi} \cdot \sqrt{(2 \cdot k_1 - k_3 - k_5)^2 + 3(k_3 - k_5)^2 + (2 \cdot k_2 - k_4 - k_6)^2 + 3(k_4 - k_6)^2} \quad (2)$$

where: k_1, k_2 – coefficients that take into account the geometric parameters of high voltage power lines

A safe, reliable, and uninterrupted power supply system is provided by line service employees who work directly in the active impact zone of electric and magnetic fields generated by a high-voltage electric transmission line. In this case, the main task is the line workers' safety and health directly dependent on the time they are in the electric field zone. Therefore, the time spent by line workers in areas affected by electric and magnetic fields on high-voltage lines was assessed.

The time spent by line workers in hazardous areas is determined by the following formula:

$$T_{add.prof} = \frac{50}{E} - 2 \quad (3)$$

where: $T_{add.prof}$ - permissible time of line workers' stay in electric field zones

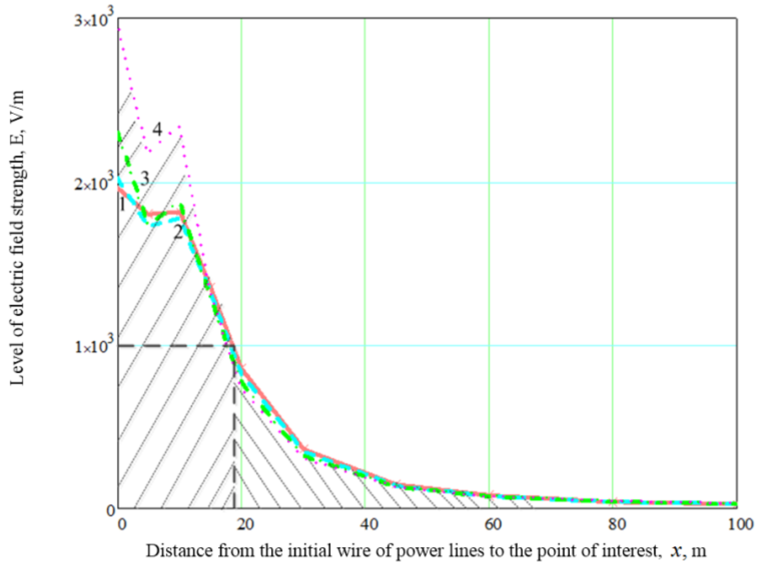
E - electric field strength level

Under the researches the time spent by line workers in the electric field exposure zone is the main parameter intended to determine the hazard category of electric field exposure to the anthropogenic environment.

3. RESULTS AND DISCUSSION

The characteristic distribution zones of electric and magnetic fields in high-voltage electric transmission lines were determined using the mirror image method with the help of the PTC MathCad 15.01 software product. Thus, dangerous and safe zones of electromagnetic radiation propagation are clearly described.

Fig. 4 shows the intensity characteristic of the electric field distribution in low-frequency power objects of 110 kV overhead lines is used to analyze the electric field impact strength on the environment, depending on its propagation in the atmospheric environment. High-voltage 110 kV power transmission lines located in the Nursat microdistrict and N. Nazarbayev avenue were taken as the objects under study.



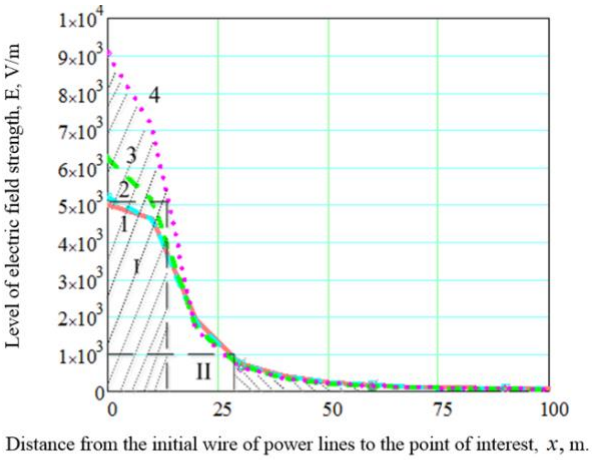
1 – the altitudinal zones of the electric field distribution equal to 1 m; 2 – the altitudinal zones of the electric field distribution equal to 2 m; 3 – the altitudinal zones of the electric field distribution equal to 4 m; 4 – the altitudinal zone of the electric field distribution equal to 6 m

Fig. 4. Characteristics of the electric field distribution intensity in low-frequency energy objects around the 110 kV overhead line

Figs. 1, 2 and 4 show that the characteristic electric field distribution zones have an impact on the ecosystem. In studies it was determined that an electric field with a voltage of $1 \cdot 10^3$ V/m is dangerous for the health of the population living in residential buildings. Depending on the propagation of the electric field E from $1 \cdot 10^3$ to $2.987 \cdot 10^3$ V/m, dangerous zones are located at distances from the initial wire of the power line to the point of interest within 0 – 18 m. Figs. 1 and 8 show that the high-voltage power transmission line in the Nursat microdistrict has an insignificant danger due to the electric field origin. It should be noted that new facilities are being built in the residential area of the Nursat microdistrict, which will contribute to increase the danger degree of the electric field in the future.

Figs. 2 and 4 show that the high-voltage power transmission line installed along Nazarbayev Avenue has a uniform electric field distribution intensity under the danger degree (insignificant and average) of its impact on the anthropogenic environment. In turn, commercial buildings and other social facilities contribute to increased electrical pollution.

Fig. 5 shows the characteristic of the electric field distribution intensity in low-frequency power objects of the 220 kV overhead line that shows the impact of the electric field distribution intensity on the environment, depending on its distribution in the atmospheric environment. A 220 kV high-voltage power transmission line in the Kazygurt microdistrict was taken as the object under study.

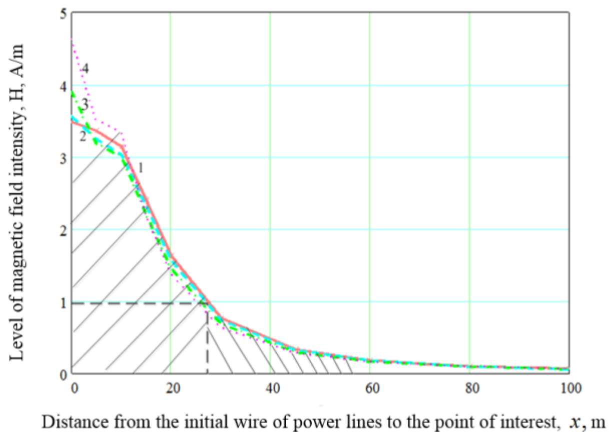


I, II – the category of electric field hazard for the population living in residential buildings and for working personnel, respectively
1– the altitudinal zones of the electric field distribution equal to 1 m; 2 - the altitudinal zones of the electric field distribution equal to 2 m; 3 - the altitudinal zones of the electric field distribution equal to 4 m; 4 - the altitudinal zone of the electric field distribution equal to 6 m

Fig. 5. Characteristics of the electric field distribution intensity in low-frequency power objects of the 220 kV overhead line

Figs. 3 and 5 show that the characteristic electric field distribution zones have their effects on the ecosystem. Depending on the propagation of the electric field E, starting from $1 \cdot 10^3$ to $9.037 \cdot 10^3$ V/m, dangerous zones are located at distances from the initial wire of the power line to the point of interest within 0 – 25m – for the population living in residential buildings (hazard category I). Starting from $5 \cdot 10^3$ to $9.037 \cdot 10^3$ V/m, the dangerous zone is located from the initial wire of the power line to the point of interest within 0-15 m-for line personnel working outside the area of residential buildings (category II hazard). Figs. 3 and 5 show that the intensity of the distribution of the electric field generated by a high-voltage power transmission line located in the Kazygurt microdistrict is uniform in terms of the danger degree (high, medium, and insignificant) of the residential environment impact.

Fig. 6 shows the characteristic of the magnetic field distribution intensity in low-frequency power objects of the 110 kV overhead line. The object under study is a 110 kV high-voltage power transmission line located in the Nursat microdistrict and Nazarbayev Avenue.

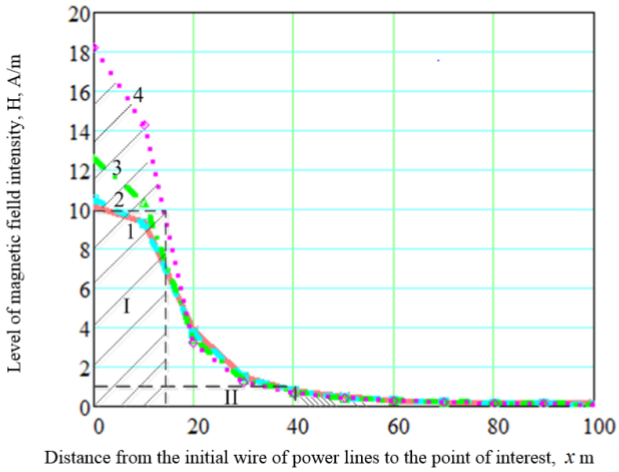


1– altitudinal zones of the magnetic field distribution equal to 1 m; 2 - altitudinal zones distribution of the magnetic field equal to 2 m; 3 - altitudinal zone of the magnetic field distribution is 4 m; 4 - high-altitudinal zone of the magnetic field distribution of equal to 6 m

Fig. 6. Characteristics of the magnetic field distribution intensity in low-frequency power objects of the 110 kV overhead line

Figs. 1, 2 and 6 show that the characteristic distribution zones of the magnetic field have their impact on the ecosystem. It was determined in studies that a magnetic field with a strength of 1A/m is dangerous for the health of the population living in residential buildings. Depending on the propagation of the magnetic field *H*, starting from 1A/m to 4.625 A/m, dangerous zones are located at distances from the initial wire of power lines to the point of interest within 0 – 25 m. Figs. 1 and 6 show that the high-voltage power transmission line installed in the Nursat microdistrict has a minor danger, only a small part of the residential area falls into the average danger due to the magnetic field origin. It should be noted that new facilities are being built in the residential area of the Nursat microdistrict that will increase the magnetic field danger degree in the future. Figs. 2 and 6 show that the high-voltage power transmission line along Nazarbayev Avenue has an average danger due to the magnetic field origin, and only a small part of objects in the residential area falls into the critical and insignificant dangerous zone. In turn, commercial buildings and other social facilities contribute to increased magnetic pollution.

Fig. 7 shows the characteristics of the magnetic field distribution intensity in low-frequency power objects of 220 kV overhead lines and the impact of the magnetic field strength on the environment, depending on its propagation in the atmospheric environment. A high-voltage power transmission line with a voltage of 220 kV was taken as the object under study in the Kazygurt microdistrict



1– altitudinal zone of the magnetic field distribution equal to 1 m; 2-the high-altitudinal zone of the magnetic field distribution equal to 2 m; 3 - altitudinal zone of the magnetic field distribution equal to 4 m; 4 - altitudinal zone of the magnetic field distribution equal to 6 m.
I, II – the category of electric field hazard for the population living in residential buildings and for working personnel, respectively

Fig. 7. Characteristics of the magnetic field distribution intensity in low-frequency power objects of 220 kV overhead lines

Figs. 3 and 7 show that the characteristic distribution zones of the magnetic field have their impact on the ecosystem. Depending on the propagation of the magnetic field H, starting from 1 A/m to 18.246 A/m, the dangerous zones are located at distances from the initial wire of power lines to the point of interest, within 0 – 40 m – for the population living in residential buildings (hazard category I). Starting from 10 to 18.246 A/m, dangerous zones are located from the initial wire of power lines to the point of interest, within 0-15 m – for line workers working outside the area of residential buildings (category II hazard). Fig. 3 and 7 show that the residential area of the Kazygurt microdistrict located near high-voltage electric transmission lines, is mainly in the high and insignificant danger zone, and 1/3 of residential facilities are in the medium danger zone due to the magnetic field origin.

The dangerous zones for people staying in residential areas of the Nursat microdistrict, Nazarbayev Avenue, and Kazygurt microdistrict were considered above. It can be concluded under the geoinformation maps obtained that the main characteristic factor in reducing the electromagnetic field impact on the environment is the optimal location of high-voltage electric transmission lines relative to the object or objects to power lines that contributes to the creation of a safe zone in the anthropogenic environment.

It was noted above that when the electric field impact on the anthropogenic environment was assessed, one of the main factors is the time spent by line personnel working in its active impact zones. Therefore, when the dangerous areas of the intensity distribution of the electric and magnetic fields were identified, the allowable time of the line personnel of Ontustik Zharyk Transit LLP was determined in the characteristic electric field distribution zones.

Table 1 shows the permissible time of stay of people in the electric field zones, Fig. 15 shows the dependence of the line personnel's stay time in the electric field impact zones on its distribution intensity level. It should be noted that the electric fields, in this case, are distributed over several zones under the danger degree. 1-5 kV/m – minor hazard, 5-8 kV/m – medium hazard, 8-12 kV/m-high hazard, 12-25 kV/m – critical hazard under.

Table 1. Parameters of line personnel's stay in the electric field impact zones by hazard categories

E, V/m at h=1 m	E, V/m at h=2 m	E, V/m at h=4 m	E, V/m at h=6 m	Tadd.prof, hours at h=1 m	Tadd.prof, hours at h=2 m	Tadd.prof, hours at h=4 m	Tadd.prof, hours at h=6 m	Distance from the objects, m
$5.008 \cdot 10^3$	$5.217 \cdot 10^3$	$6.24 \cdot 10^3$	$9.037 \cdot 10^3$	7 h 54 min	7 h 30 min	6 h	3 h 30 min	0
$4.674 \cdot 10^3$	$4.635 \cdot 10^3$	$5.04 \cdot 10^3$	$6.757 \cdot 10^3$	8 h 48 min	8 h 42 min	7 h 54 min	5 h 20 min	2
$4.393 \cdot 10^3$	$4.205 \cdot 10^3$	$4.398 \cdot 10^3$	$6.06 \cdot 10^3$	9 h 18 min	9 h 48 min	9 h 20 min	6 h 10 min	4
$4.474 \cdot 10^3$	$4.308 \cdot 10^3$	$4.669 \cdot 10^3$	$6.66 \cdot 10^3$	9 h 6min	9 h 30 min	8 h 45 min	5 h 30 min	6
$4.694 \cdot 10^3$	$4.615 \cdot 10^3$	$5.2 \cdot 10^3$	$7.804 \cdot 10^3$	8 h 48 min	8 h 48 min	7 h 40 min	4 h 25 min	8
$4.641 \cdot 10^3$	$4.601 \cdot 10^3$	$5.117 \cdot 10^3$	$7.086 \cdot 10^3$	8 h 56 min	11 h	7 h 50 min	5 h	10
$4.211 \cdot 10^3$	$4.156 \cdot 10^3$	$4.384 \cdot 10^3$	$5.189 \cdot 10^3$	9 h 48 min	12 h 20 min	9 h 25 min	7 h 42 min	12
$3.572 \cdot 10^3$	$3.495 \cdot 10^3$	$3.497 \cdot 10^3$	$3.706 \cdot 10^3$	12 h	14 h 42 min	12 h 10 min	11 h 20 min	14
$2.919 \cdot 10^3$	$2.834 \cdot 10^3$	$2.734 \cdot 10^3$	$2.724 \cdot 10^3$	15 h	18 h 20 min	16 h 18 min	16 h 20 min	16
$2.352 \cdot 10^3$	$2.272 \cdot 10^3$	$2.144 \cdot 10^3$	$2.065 \cdot 10^3$	19 h 20 min	23 h	21 h 20 min	22 h 15 min	18
$1.895 \cdot 10^3$	$1.826 \cdot 10^3$	$1.702 \cdot 10^3$	$1.609 \cdot 10^3$	24 h 20 min	25 h 20 min	27 h 20 min	29 h	20

The following functional dependencies were obtained during the environmental surveys, and $T = f(E^{-1})$. It should be noted that the time spent by the working personnel in this zone was 3.5 hours with the maximum electric field strength E= 9.037 kV/m and the height of the high-altitudinal zone h=6 m. Under the sanitary and epidemiological requirements, the maximum permissible level of time spent by line personnel in areas affected by an electric field is 8 hours per 5 kV/m.

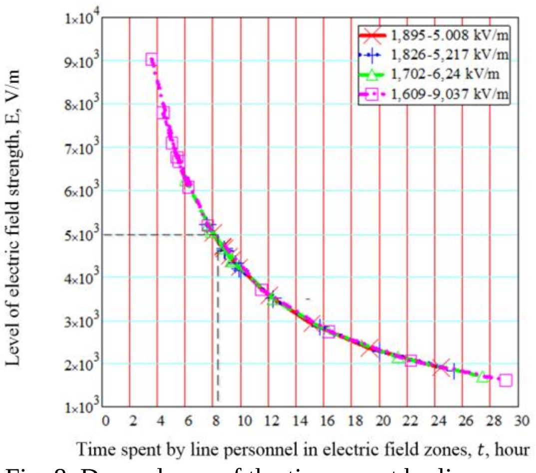


Fig. 8. Dependence of the time spent by line personnel in the electric field zones on its distribution level

Fig. 8 clearly shows the range of time spent by people in electric field exposure zones. It should be noted that the time spent by people is reduced to minimum values with an increase in the danger zone.

Fig. 9 shows a three-dimensional time response describing the electrical radiation hazard in its different ranges. The resulting coordinates are the time spent by the line personnel in the electrical radiation hazard areas, the level of the electric field strength, and the distance of the electrical radiation hazard in descending order from a low-frequency energy facility.

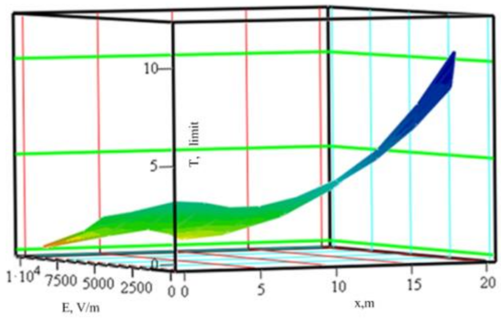


Fig. 9. Dependence of the time spent by people in the danger zone of electrical radiation ($T_{пр}$, hour) from the electric field distribution intensity level (*E V/m*) and the distance of the radiating low-frequency energy object *x, m*

Fig. 9 clearly shows that the time spent by line personnel in such zones is reduced to minimum values with an increase in the dangerous zone of electric radiation (E, V/m). It should be noted that the electromagnetic field distribution intensity directly depends on the disturbing factors, i.e. climatic (wind speed, rain settling, drizzle, ambient temperature) and technological (sagging wires, the difference in the daily redistribution of electrical energy, exceeding the permissible current load, deterioration, and wear of electrical insulation units) ones.

In turn, it increases the electromagnetic pollution level, increases its distribution over a certain radius, and reduces the time spent by people in the electromagnetic field impact zones increasing the risk of various types of diseases: cancer, reduced female reproduction, leukemia in children, white blood, psychological diseases of various kinds, etc. Therefore, a reasonable ranking should be performed to determine the dangerous zones of the electromagnetic field when establishing a security zone for high-voltage electric transmission lines.

4. CONCLUSION

Dangerous zones of electromagnetic radiation propagation were determined by comparative analysis. Experimental calculations enabled us to identify the values that affect the ranking by the hazard gradients of electric and magnetic fields, depending on the level, respectively.

The ranking of gradients under the danger degree of electric and magnetic fields for 110 kV and 220 kV high-voltage electric transmission lines are presented below.

Ranking of gradients under the danger degree of electric and magnetic fields in 110 kV high-voltage electric transmission lines:

High danger zone 0-10 m - for electric field, 0-20 m-for magnetic field; medium danger zone 10-20 m - for electric field, 20-35 m-for magnetic field; insignificant danger zone 20-30 m – for electric field, 35-50 m-for magnetic field.

Ranking of gradients under the danger degree of electric and magnetic fields in 220 kV high-voltage electric transmission lines:

High danger zone 0-15 m - for electric field, 0-30 m-for magnetic field; medium danger zone 15-30 m - for electric field, 30-50 m-for magnetic field; insignificant danger zone 30-45 m – for electric field, 50-80 m-for magnetic field.

Based on the data obtained, a geoinformation map was made for the territory under study. In turn, it made it possible to identify the discrepancy between the size of sanitary and epidemiological zones and the data obtained during experimental studies. Residential facilities that are in danger of electric and magnetic fields were identified using the geo-local data sampling method in the ArcGIS program. The data show that it is necessary to install high-voltage lines that will be built and operated in the selected territories optimally to ensure a safe zone without the effects of electric and magnetic fields generated by a high-voltage electric transmission line.

The safety and health of line personnel working directly on high-voltage electric transmission lines are one of the main tasks of environmental monitoring. The permissible time spent in the zone of active electric field impact was determined to select the optimal routing for line personnel, and it directly depends on the distance of high-voltage lines.

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