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Synthesis of an effective system of active shielding of the magnetic field of a power transmission line with a horizontal arrangement of wires using a single compensation winding

Aim. *The theoretical and experimental studies of the effectiveness of reducing the level of the magnetic field in two-storey cottage of the old building of a power transmission line with a horizontal arrangement of wires by means of active shielding with single compensation winding.* ***Methodology*** *Spatial location coordinates of the compensating winding and the current in the shielding winding were determined during the design of systems of active screening based on solution of the vector game, in whith the vector payoffs is calculated based on Biot-Savart's law. The solution of this vector game calculated based on algorithms of multi-swarm multi-agent optimization.* ***Results*** *The results of theoretical and experimental studies of the effectiveness of reducing the level of the magnetic field in two-storey cottage of the old building of a power transmission line with a horizontal arrangement of wires by means of active shielding with single compensation winding are presented.* ***Originality.*** *For the first time, the theoretical and experimental studies of the effectiveness of reducing the level of the magnetic field in two-storey cottage of the old building of a power transmission line with a horizontal arrangement of wires by means of active shielding with single compensation winding are considered.* ***Practical value***. *From the point of view of the practical implementation it is shown the possibility to reduce the level of magnetic field in two-storey cottage of the old building from power transmission line with a horizontal arrangement of wires by means of active shielding with single compensation winding to the sanitary standards of Ukraine.* References 48, figures 14.
Key words: **power transmission line, horizontal arrangement of wires, magnetic field, system of active screening, computer simulation, experimental research**.

Мета. *Проведено теоретичні та експериментальні дослідження ефективності зниження рівня магнітного поля в двоповерховому котеджі старої будівлі ЛЕП з горизонтальним розташуванням проводів за допомогою активного екранування з однією компенсаційною обмоткою.* ***Методика***. *Просторові координати розташування компенсуючої обмоти і струму в обмотці визначено при проектуванні системи активного екранування на основі рішення векторної гри, в якій вектор ціни розраховуються за законом Біо-Савара. Рішення цієї векторної гри розраховано на основі алгоритмів багаторойової багатоагентної оптимізації.* ***Результати.*** *Наведено результати теоретичних та експериментальних досліджень ефективності зниження рівня магнітного поля в двоповерховому котеджі старої будівлі ЛЕП з горизонтальним розташуванням проводів за допомогою активного екранування з однією компенсаційною обмоткою.* ***Оригінальність***. *Вперше проведено теоретичні та експериментальні дослідження ефективності зниження рівня магнітного поля в двоповерховому котеджі старої будівлі ЛЕП з горизонтальним розташуванням проводів за допомогою активного екранування з однією компенсаційною обмоткою.* ***Практична цінність***. *З точки зору практичної реалізації показана можливість зниження рівня магнітного поля в двоповерховому котеджі старої будівлі від ЛЕП з горизонтальним розташуванням проводів за допомогою активного екранування з однією компенсаційною обмоткою дорівня санітарних норм України.* Бібл. 48, рис. 14.
Ключові слова: **повітряна лінія електропередачі, горизонтальне розташування проводів, магнітне поле, система активного екранування, комп'ютерне моделювання, експериментальні дослідження.**

Introduction. The most dangerous source of technogenic magnetic field of power frequency for the population are high-voltage power lines. Without taking special measures, they create an intensive magnetic field (MF), which has carcinogenic properties at distances up to 100 m from the transmission line. Therefore, the world is tightening sanitary standards for the maximum allowable level of MF induction 50–60 Hz (less than 1 μT) and intensive work is being done to ensure them for the population. Currently, strict sanitary norms on the induction of MF (0.5 μT) are introduced in the regulations of the Ministry of Energy of Ukraine. However, at present in Ukraine these norms are often exceeded, which poses a threat to the health of millions of people living closer than 100 m from high-voltage power lines.

Comprehensive experimental studies of 10–330 kV overhead transmission lines conducted by the A. Pidhornyi Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine showed [1-4], that their MF are 3-5 times higher than the normative level at the border of previously formed sanitary zones by electric field.

This situation requires urgent measures to reduce by 3-5 times the MF of existing transmission lines within the cities of Ukraine. A similar situation is typical for most industrialized countries of the world, but in these countries have already created and widely used technologies for normalization of existing transmission lines.

The most effective technology is the reconstruction of power lines by removing them to a safe distance from residential buildings, or replacing overhead power lines with a cable line. However, such reconstruction requires huge financial resources. Therefore, less expensive for Ukraine are less expensive methods of shielding MF operating power lines, of which the required efficiency is provided by methods of active contour shielding of the magnetic field [5-10].

The technology of active contour shielding of magnetic field power lines has been developed [11-18] and used in developed countries for more than 10 years, such as the United States and Israel. In Ukraine at present, both such technology and the scientific basis for its creation are absent [19]. This does not allow relatively inexpensive methods to protect the population from man-made industrial frequency industrial power generated by transmission lines. Therefore, the creation of scientific bases of domestic technology of active shielding of industrial frequency magnetic field in buildings to a safe level is an urgent scientific and technical problem.

Many residential buildings and structures are located in close proximity to high-voltage power lines so that the level of induction of the MF inside them exceeds modern sanitary standards. In addition, due to the constant rise in land prices, the construction of residential, administrative and other public buildings and structures in the areas of the existing high-voltage power lines continues. One of the possible ways to operate such buildings is the use of active shielding systems.

At present, various systems of active shielding of the technogenic magnetic field of power frequency are being intensively researched and implemented all over the world. In such systems, special windings are used as the executive body of the active shielding system – active winding, the number of which is determined by the specifics of the problem to be solved.

The simplest system is one that uses only one single compensating winding.

The aim of the work is to synthesize and study the effectiveness of the simplest system of active shielding of the magnetic field of a single-circuit power line with a horizontal arrangement of wires using only one compensation winding to reduce the magnetic field to a safe level.

Problem statement. As a source of technogenic magnetic field in the development of a power transmission line layout, we will take a single-circuit three-phase power transmission line 110 kV with a horizontal arrangement of current conductors, the dimensions of the supports of which are shown in Fig. 1.

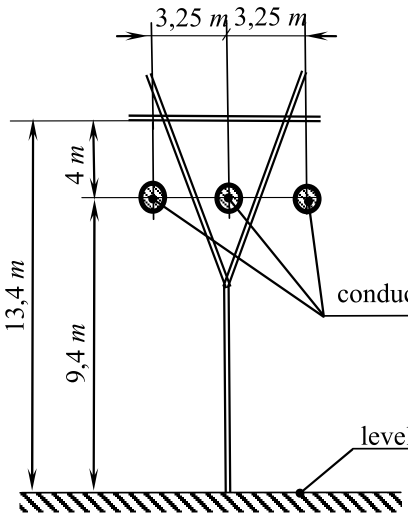

Fig. 1. Dimensions of the power transmission line with horizontal arrangement of wires

The choice of the dimensions of the suspension of current conductors on the supports of the power transmission line is carried out based on the condition for creating the maximum external magnetic field created by the current conductors of the power transmission line along the passage of the power transmission line route, namely, for the option with a minimum height of the location of the current conductors and the maximum distance between them. Based on the stated conditions, as the calculated dimensions of the power transmission line support, we select the dimensions of the anchor cable support (Fig. 1), while taking into account the height of the insulators (1 m) and the amount of sag of the conductors in the middle part between the supports (3 m).

The calculated dimensions of the anchor cable support of the «glass» type, taking into account the sag of the current conductors and the height of the insulators, are shown in Fig. 1. We do not take into account the «dance» of current conductors under the action of wind load, assuming the projection of current conductors in a vertical plane perpendicular to the base of the power transmission line support.

On Fig. 2 are shown the layout of the power transmission line, compensating winding and protected area.

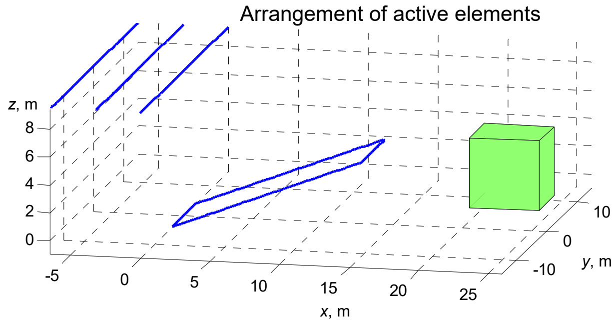

Fig. 2. Layout of the power transmission line, compensating winding and protected area

On Fig. 3 are shown lines of equal level of the induction module of the initial magnetic field of a three-phase single-circuit overhead power line. This induction is computed at a power line current of 1000 A. The induction of initial magnetic field in the considered space is 1.8 μT, which is 3.6 times higher than sanitary norms.

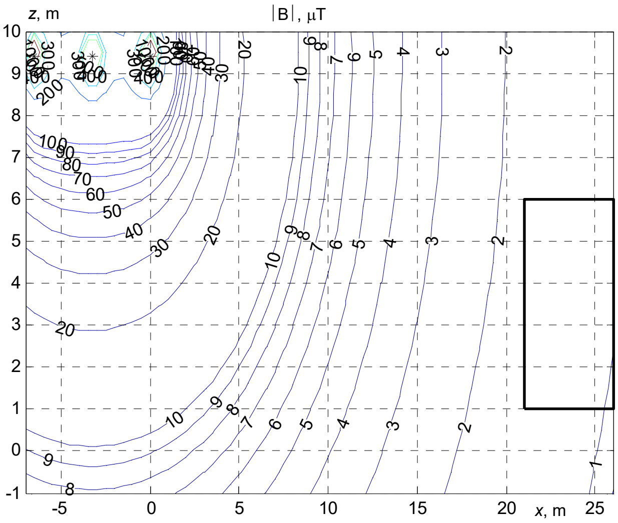

Fig. 3. Lines of equal level of the induction module of the initial magnetic field of a three-phase single-circuit overhead power line

To reduce the level of the magnetic field around the world, systems of active shielding of the magnetic field are used with the help of a system of special controlled magnetic field sources – windings with adjustable current, installed in the area where it is necessary to maintain internal magnetic field parameters [11-14].

For a given shielding space, in particular an two-storey cottage of the old building located in the immediate vicinity of an overhead power line, it is necessary to create a magnetic field by means of active shielding, which would compensate for the original magnetic field.

Consider a system of active shielding of magnetic field using a system of special controlled sources of magnetic field – windings with adjustable current, installed in the area where it is necessary to maintain the parameters of the internal magnetic field within specified limits.

Computational method. We introduce the vector of the required parameters of systems of active shielding, the components of which are vector of coordinates of the spatial location of the compensation windings and regulators parameters [20-24]. Also we introduce vector of the parameter of uncertainty of external magnetic field model [23, 24]. Then the problem of synthesis of systems of active shielding is associated with computation of such vector of the required parameters of systems of active shielding which assumes a minimum value from maximum value of the magnetic flux density at selected points of the shielding space [25-29]. However, in this case, it is necessary to simultaneously determine such a value of vector of the parameter uncertainty, at which the maximum value of the same magnetic flux density is maximum. This is the worst-case approach when robust systems synthesis [30-33].

This problem is the multi-criteria two-player zero-sum antagonistic game [40, 41]. The vector payoffs are the magnetic flux density in points of the shielding space. The vector payoff is the vector nonlinear functions of vector of the required parameters of systems of active shielding and vector of the parameter of uncertainty of external magnetic field model and calculated based on Biot-Savart's law [1]. In this game the first player is the parameters of systems of active shielding and its strategy is the minimization of vector payoff. The second player is the vector of parameter uncertainty and its strategy is maximization of the same vector payoff. The decision of this game is calculated on based of multi-swarm stochastic multi-agent optimization algorithm [42-48]. This decision is choose from systems of Pareto-optimal decisions [42].

Simulation results. Let us study the efficiency of the synthesized system of active shielding for this power transmission lines. To compensate for this technogenic magnetic field in the space under consideration, only one single compensation winding is used, the spatial arrangement of which is shown in Fig. 2. The distribution of the resulting magnetic field with the active screening system turned on is shown in Fig. 4.

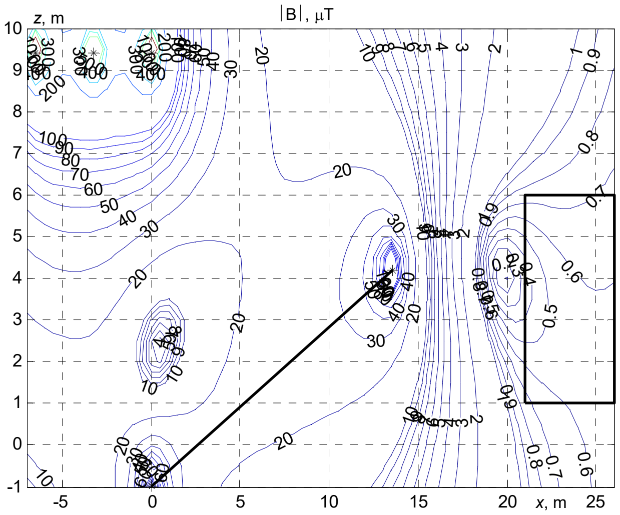

Fig. 4. Lines of equal level of the magnetic field induction module of a three-phase single-circuit overhead power line with active shielding system enabled with one winding of the magnetic actuator

As can be seen from this figure, using the active screening system, it was possible to reduce the induction level of the initial magnetic field to the level of 0.6 μT in the space under consideration. In this case, the efficiency of the active shielding system is more than 2.

On Fig. 5 are shown the dependences of the induction value of the initial magnetic field and the magnetic field with the active shielding system turned on as a function of the distance from the extreme current conductor of the power line.

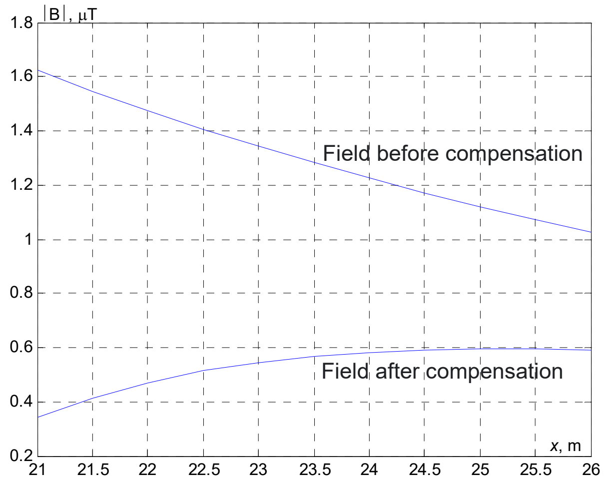

Fig. 5. Dependences of the induction value of the initial magnetic field and the magnetic field with the active shielding system turned on as a function of the distance from the extreme current conductor of the power line

On Fig. 6 are shown the space time characteristics of the magnetic field created by: *1*) power lines; *2*) compensating winding; *3*) the total magnetic field with the system turned on.

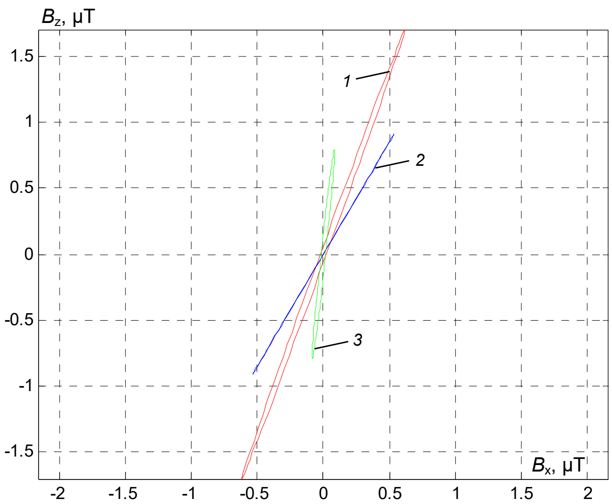

Fig. 6. The space time characteristics of the magnetic field created by: *1* – power lines; *2* – compensating winding; *3* – the total magnetic field with the system turned on

Experimental studies. To conduct experimental studies of the efficiency of the synthesized system, models of power transmission lines and systems have been developed. Using the geometric dimensions of the power transmission line (Fig. 1), the relative position and dimensions of the protected area, we calculate the dimensions of the overhead line layout. The obtained dimensions for placing the windings and installing three-phase wires for modeling the field of an overhead line are shown in Fig. 7.

An example of the developed layout of the current conductors of the power transmission line, the compensating winding and the protected area is shown in Fig. 7. The area in which it is necessary to shield the magnetic field also is shown by a rectangle located on the right side of the Fig. 7.

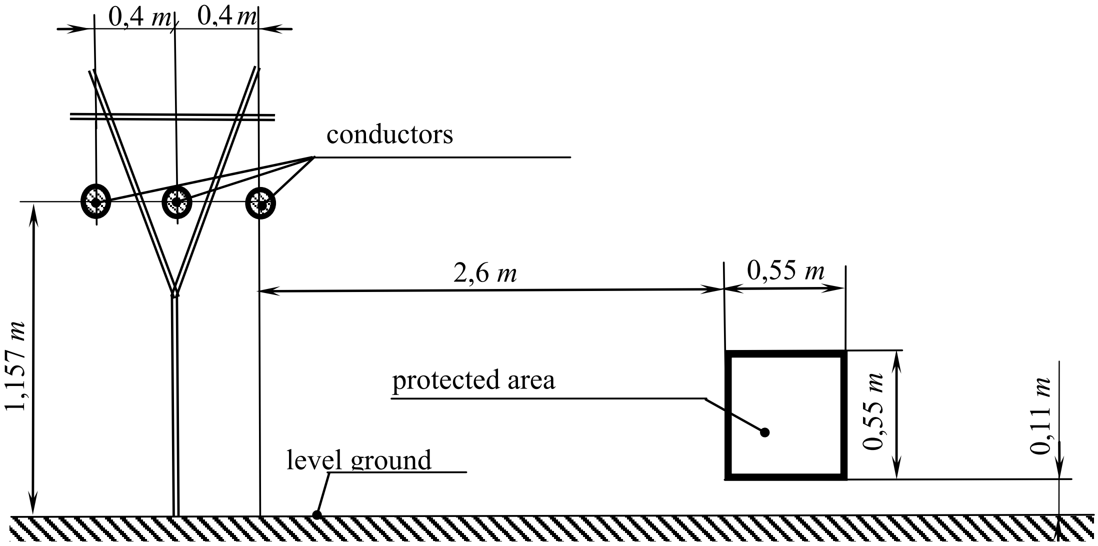

Fig. 7. Estimated dimensions of models of anchor cable support and shielding area

Simulation of model of system of active shielding. Let us study the efficiency of the synthesized model of system of active shielding for this power transmission lines. In Fig. 8 are shown the calculation scheme for the layout of power transmission lines, compensating winding and protected area.

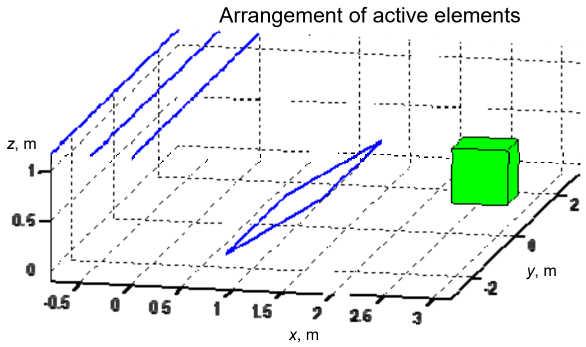

Fig. 8. The calculation scheme for the layout of power transmission lines, compensating winding and protected area

The distribution of the resulting magnetic field with the active screening system turned on is shown in Fig. 4. As can be seen from this figure, using the active screening system, it was possible to reduce the induction level of the initial magnetic field to the level of 0.6 μT in the space under consideration. In this case, the efficiency of the active shielding system is more than 2.

On Fig. 9 are shown the lines of equal level of the induction module of the initial magnetic field of the model of three-phase single-circuit overhead power line. This induction is computed at the model power line current of 100 A. The induction of initial magnetic field of model in the considered space is 1.6 μT.

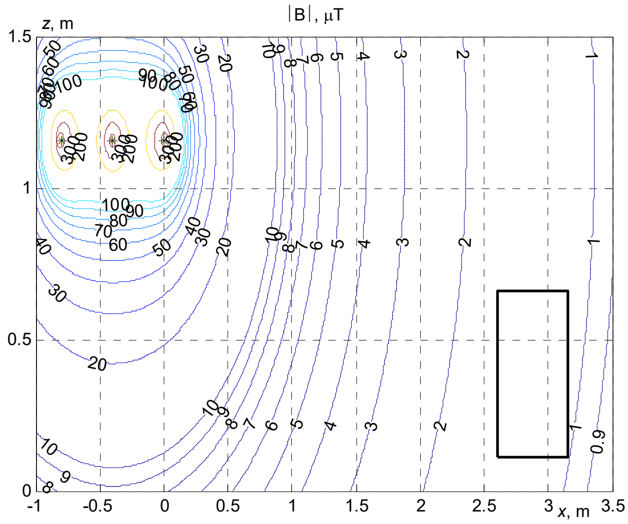

Fig. 9. The lines of equal level of the induction module of the initial magnetic field of the model of three-phase single-circuit overhead power line

The distribution of the resulting magnetic field with the model of active screening system turned on is shown in Fig. 10. As can be seen from this figure, using the active screening system, it was possible to reduce the induction level of the initial magnetic field to the level of 0.4 μT in the space under consideration. In this case, the efficiency of the active shielding system is 4.

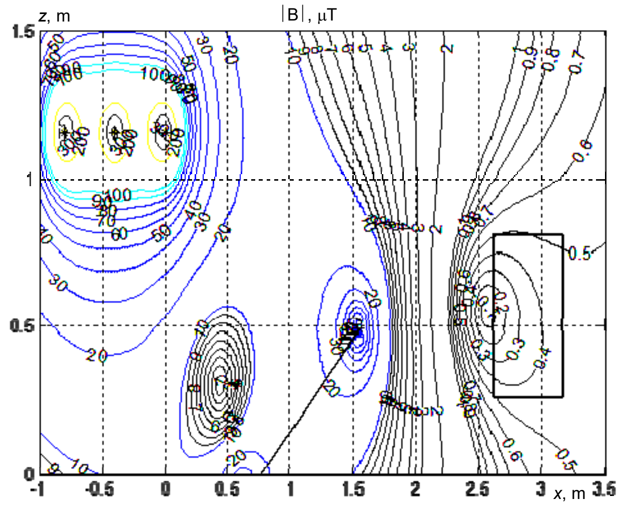

Fig. 10. The distribution of the resulting magnetic field with the model of active screening system turned on

On Fig. 11 are shown the dependences of the induction value of the initial magnetic field and the magnetic field with the active shielding system turned on as a function of the distance from the extreme current conductor of the power line.

Note that as follows from the comparison of Fig. 5 and Fig. 11, the shielding factor of the system layout is 4, which is greater than the shielding factor of the original system.

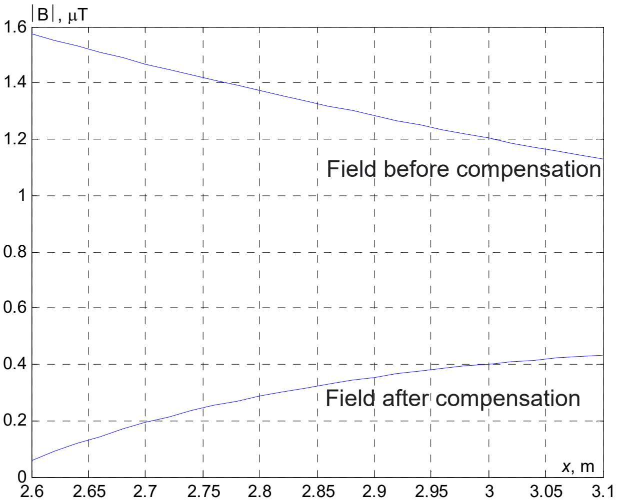

Fig. 11. Dependences of the induction value of the initial magnetic field and the magnetic field with the active shielding system turned on as a function of the distance from the extreme current conductor of the power line

On Fig. 12 are shown the space time characteristics of the magnetic field created by: *1*) power lines; *2*) compensating winding; *3*) the total magnetic field with the system turned on.

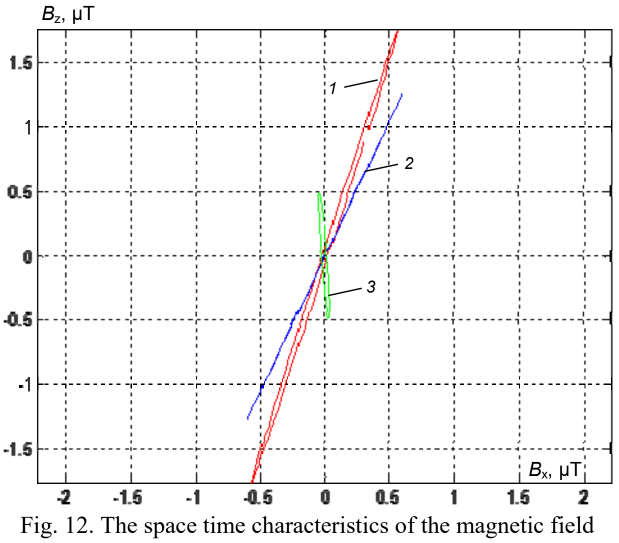

Fig. 12. The space time characteristics of the magnetic field created by: *1* – power; *2* – compensating winding; *3* – the total magnetic field with the system turned on

Results of experimental studies of model of system of active screening. Let us now consider the results of experimental studies of model of system of active screening.

The layout of the models of power transmission lines, compensating winding and protected area are shown in Fig. 13.

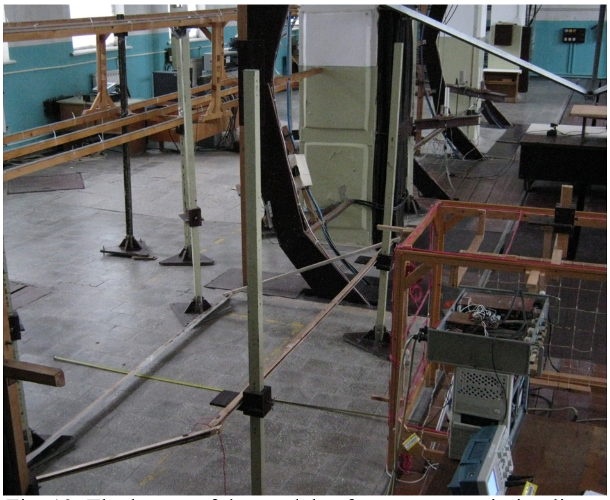

Fig. 13. The layout of the models of power transmission lines, compensating winding and protected area

On Fig. 14 are shown the experimental dependences of the induction of the initial magnetic field of the layout *1*) and the magnetic field when the layout of the active shielding system is turned on *2*)–*4*) as a function of the distance from the extreme current conductor of the power transmission line.

It has been experimentally established that the system with the open control circuit has the greatest shielding factor – more than 3, as it is shown curve *2* in Fig. 14. The screening factor with a closed control loop (curves *3*) and (curves *4*) depends on the position of the sensor, with which the resulting magnetic field is measured.

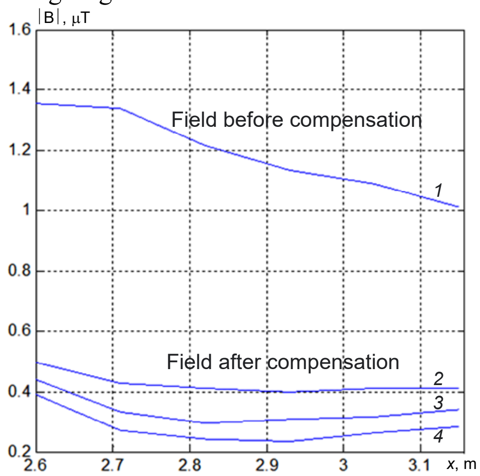

Fig. 14. The experimental dependences of the induction of the initial magnetic field of the layout and the magnetic field when the layout of the system of active shielding is turned on

Conclusions.

1. For the first time, the theoretical and experimental studies of the effectiveness of reducing the level of the magnetic field in two-storey cottage of the old building of a power transmission line with a horizontal arrangement of wires by means of active shielding with single compensation winding.

2. The space-time characteristics of the magnetic field generated by a power transmission line with a horizontal arrangement of wires have been studied. It is shown that these characteristics have the shape of an elongated ellipse, which confirms the possibility of effective compensation of such a magnetic field using single compensation winding.

3. The synthesis of single-circuit systems of active shielding of the magnetic field created by single-circuit

overhead power lines 110 kV with a horizontal arrangement of wires in a two-story cottage of an old building was carried out. As a result of the synthesis, the coordinates of the location of single compensation winding, as well as the current and phase in these compensation winding, were determined to ensure high shielding efficiency.

4. For the synthesis of robust systems of active shielding, the vector game solution was calculated based on stochastic multi-agent optimization algorithms. The calculation of the game payoff vector and restrictions was carried out on the basis of the Biot–Savart law.

5. Theoretically and experimentally confirmed the possibility of reducing the magnetic field to a safe level of sanitary standards of Ukraine in a two-story cottage of an old building from power lines with a horizontal arrangement of wires using a synthesized simple system of active shielding with a single compensation winding.

Conflict of interest. The authors declare that they have no conflicts of interest.

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