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Comparison of the effectiveness of thriple-loop and double-loop systems of active shielding of a magnetic field in a multi-storey old buildings

Aim*. The issues of comparing the effectiveness of reducing the level of the magnetic field in a five-storey old buildings generated by a single-circuit overhead power transmission lines with a triangular suspension of wires using a thriple-loop and double-loop systems of active screening, which respectively contain three or two compensating windings are considered.* ***Methodology.*** *Spatial location coordinates of the compensating windings and the currents in the shielding windings were determined during the design of systems of active screening based on solution of the maximin vector optimization problem, in whith the vector of objective function is calculated based on Biot-Savart's law. The solution of this problem is calculated based on algorithms of multi-swarm multi-agent optimization.* ***Results.*** *The results of theoretical and experimental comparing the effectiveness of reducing the level of the magnetic field in a five-storey old generated by a single-circuit overhead power transmission lines with a triangular suspension of wires using a thriple-loop and double-loop systems of active screening, which respectively contain three or two compensating windings are presented.* ***Originality.*** *For the first time, the comparison the effectiveness of reducing the level of the magnetic field in a five-storey old using a thriple-loop and double-loop systems of active screening 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 induction in a five-storey old buildings to the sanitary standards of Ukraine for real overhead power transmission lines currents with the help of a synthesized double-loop systems of active screening. A double-loop active screening system is simpler in comparison with a thriple-loop active screening system when implementing.* References 48, figures 7.
Key words: **overhead power line, magnetic field, system of active screening, computer simulation, experimental research**.

Мета*. Розглянуто питання порівняння ефективності зниження рівня магнітного поля в п'ятиповерховому домі старої забудови, генеруйомого одноконтурною повітряною лінією електропередачі з трикутним підвісом проводів з використанням трьохконтурної та двоконтурної систем активного екранування, які відповідно містять три або дві компенсаційні обмотки.* ***Методика****. При проектуванні системи активного екранування визначалися координати просторового розташування екрануючих обмоток і струми в екрануючих обмотках на основі рішення задачі максиміної векторної оптимізації, в якій вектор цільової функції розраховується за законом Біо-Савара. Рішення цієї задачі розраховано на основі алгоритмів багаторойової багатоагентної оптимізації.* ***Результати.*** *Наведені результати теоретичного та експериментального порівняння ефективності зниження рівня магнітного поля в п'ятиповерховому домі старої забудови, генеруйомого одноконтурною повітряною лінією електропередачі з трикутним підвісом проводів з використанням трьохконтурної та двоконтурної систем активного екранування, які містять відповідно три або дві компенсаційні обмотки.* ***Оригінальність****. Вперше розглянуто порівняння ефективності зниження рівня магнітного поля в п'ятиповерховому домі старої забудови, за допомогою трьохконтурної та двоконтурної систем активного екранування.* ***Практична цінність****. З точки зору практичної реалізації показано можливість зниження рівня індукції магнітного поля в п'ятиповерховому домі старої забудови до санітарних норм України для реальних струмів повітряної лінії електропередачі за допомогою синтезованої двоконтурної системи активного екранування. Двоконтурна система активного екранування в порівнянні з трьохконтурною системою активного екранування при впровадженні простіша.* Бібл. 48, рис. 7.
Ключові слова: **повітряна лінія електропередачі, магнітне поле, система активного екранування, комп'ютерне моделювання, експериментальні дослідження.**

Introduction. Many existing overhead power transmission lines in Ukraine run near the zones of old residential buildings. Often old residential buildings are located in the immediate vicinity of residential buildings, as shown in Fig. 1. Naturally, in such residential buildings the level of magnetic field (MF) induction exceeds the sanitary standards of Ukraine by two or three times [1–4]. For the safe operation of many old residential buildings, it is economically expedient to reduce the induction level of the initial MF to the level of sanitary standards of Ukraine by means of active shielding [5–18].

These lines generate a magnetic field with a circular space-time characteristic [6] to compensate for which by means of active shielding at least two compensation windings are required [14].

To compensate for this magnetic field in a multi-storey old building, three or more compensation windings may be needed [16–18]. In [19], the issues of reducing the level of the magnetic field generated by a single-circuit power transmission line with a triangular arrangement of wires in a five-story building of an old building are considered. With the help of such a system of active shielding, it is possible to reduce the level of the initial magnetic field by 8 times from the induction level of the initial magnetic field of 4 μT to the level of sanitary standards of Ukraine of 0.5 μT. At the same time, sanitary standards are met throughout the entire space of the five-story building.

Fig. 1. Location of a residential building near overhead power transmission lines

This active screening system has been synthesized for the rated current of the transmission line. However, the real currents in the power transmission lines of Ukraine are two to three times less than the rated currents. In this regard, it is advisable to synthesize an active screening system, with the help of which it is possible to reduce the level of magnetic field induction in old buildings to the sanitary standards of Ukraine at real power transmission line currents.

From the point of view of practical implementation, in comparison with a three-circuit active screening system, a two-circuit active screening system is simpler. When implementing a two-circuit system, firstly, fewer supports are needed to suspend only two rather than three compensating windings. Secondly, to supply the compensating windings of the windings, only two power amplifiers are needed instead of three, and a smaller number of sensors are needed to measure the magnetic flux density of the of magnetic field.

The objective of the work is to synthesize and to compare the effectiveness of triple-loop and double-loop systems of active shielding of the magnetic field generated by single–circuit overhead power lines with a triangular suspension of wires in a multi-story old building.

Problem statement. 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].

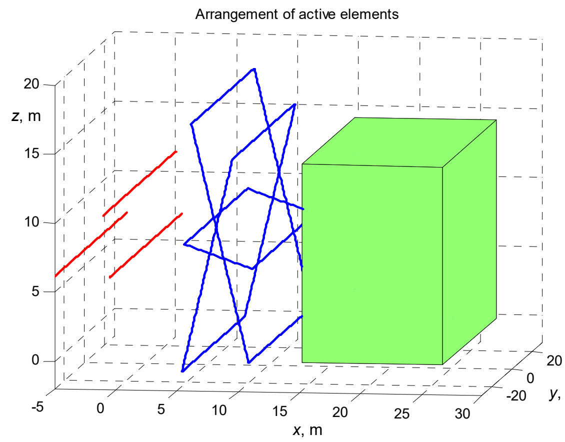
For a given shielding space, in particular an old multi-storey residential building located in the immediate vicinity of an overhead power line, it is necessary to create a magnetic field by means of active shielding, which would compensate for the original magnetic field.

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. The man-caused magnetic field is created by a three-phase high-voltage power line.

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].

Method of synthesis. 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].

Computer simulation. Let us consider the result of synthesis of triple-loop and double-loop systems of active shielding of the magnetic field generated by single-circuit overhead power lines with a triangular suspension of wires in a multi-story old building. In Fig. 2 are shown the layout of the power transmission line, a five-story building, in which it is necessary to reduce the level of the magnetic field, and the location of three (*a*) and two (*b*) compensating windings of systems of active screening.



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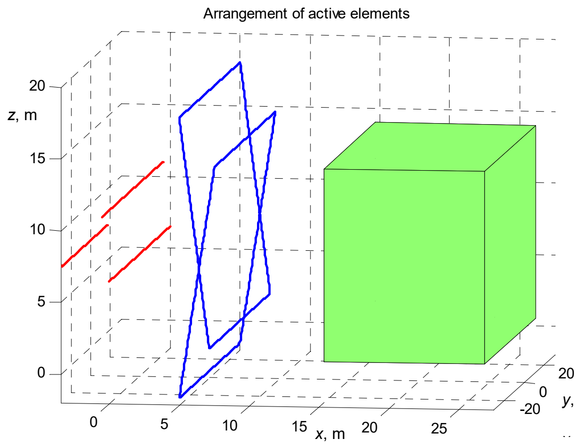
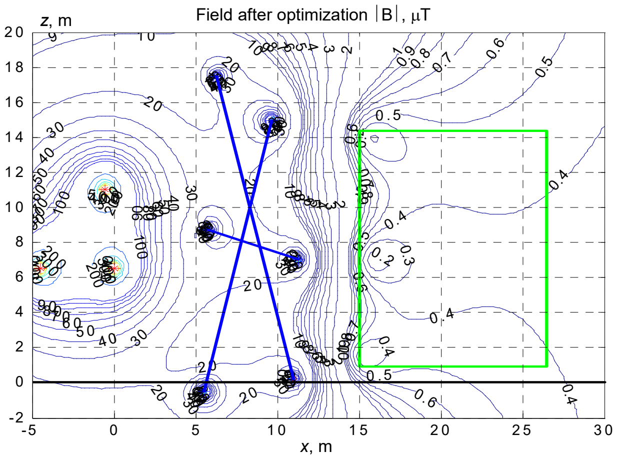


b

Fig. 2. Layout of the power transmission line, a five-story building, in which it is necessary to reduce the level of the magnetic field, and the location of three (*a*) and two (*b*) compensating windings of systems of active screening

The coordinates of the spatial position of the compensation windings, the parameters of the regulators and the currents in the compensation windings are calculated as a result of solving the problem of vector optimization in the synthesis of the systems of active shielding.

In Fig. 3 are shown the distributions of the resulting magnetic field for triple-loop (*a*) and double-loop (*b*) systems. When operating a triple-loop system, as follows from Fig. 3,*a*, using the systems of active screening, the induction level of the resulting magnetic field in the entire space of a five-story building does not exceed the level of 0.5 μT, which corresponds to the sanitary standards of Ukraine. However, when operating a double -loop system, as shown in Fig. 3,*b*, the level of induction of the resulting magnetic field at the border of a five-storey building exceeds the level of sanitary standards of Ukraine in 0.5 μT. In general, the implementation of sanitary standards is carried out on 90 % of the area of five-story old building.



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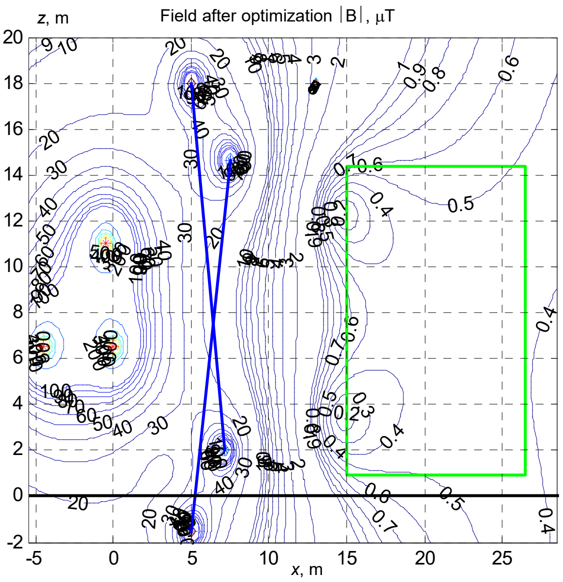

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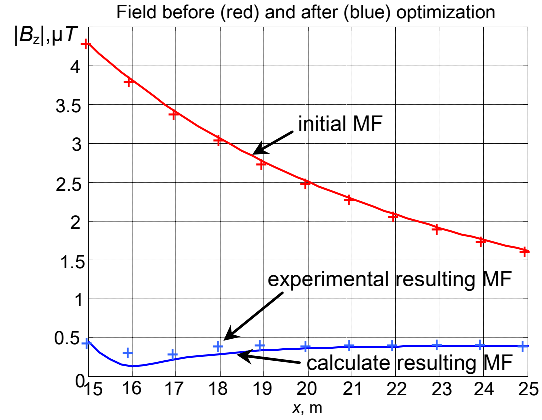
Fig. 3. Distributions of the resulting magnetic field for triple-loop (*a*) and double-loop (*b*) systems

In Fig. 4 are shown the dependences of the induction level of the initial MF and the resulting magnetic field as a function of the distance from the power transmission line. When operating a triple-loop systems of active screening, as follows from Fig. 3,*a*, the induction level in the entire space of a five-story building does not exceed 0.5 μT. However, during the operation of a two-circuit systems of active screening, the level of induction is slightly higher than the level of 0.5 μT inside a five-story building near a power transmission line, as it shown in Fig. 3,*b*.



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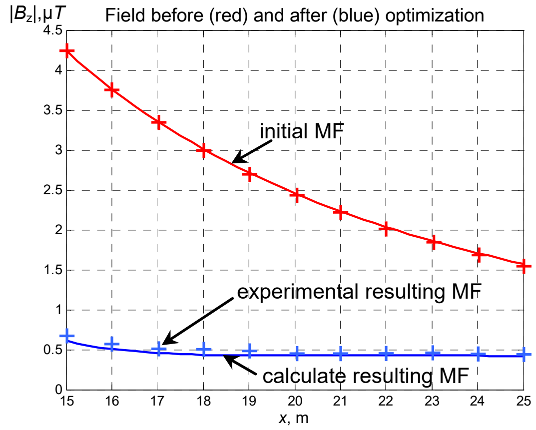

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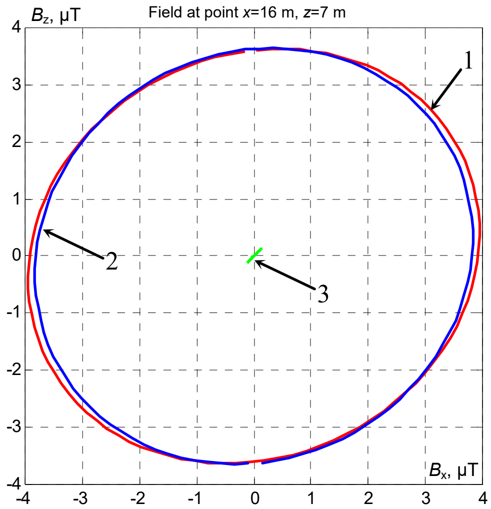
Fig. 4. Dependences of the induction level of the initial MF and the resulting magnetic field as a function of the distance from the power transmission line

In Fig. 5 are shown the spatio-temporal characteristics of the initial magnetic field (1), the magnetic field generated by the compensation windings (2) and the resulting magnetic field (3), respectively, for three-circuit (*a*) and two-loop (*b*) active screening systems. As follows from Fig. 5,*a*, during the operation of a three-loop active screening system, the initial magnetic field is almost completely compensated by the screening windings so that the spatio-temporal characteristic of the resulting magnetic field remaining after the operation of the three-loop active screening system is a point.

This results in a high shielding factor of more than 20 units in a limited area of the shielding space under consideration. However, when a two-loop active screening system operates in this limited area of the screening space, the screening factor is about 6 units. Therefore, the spatio-temporal characteristic of the resulting magnetic field remaining after the operation of the two-loop active screening system is a line.

Experimental results. For experimental research, models of three-loop and two-loop active shielding systems were developed, as well as a model of a single-loop overhead power line with a triangular suspension of wires.



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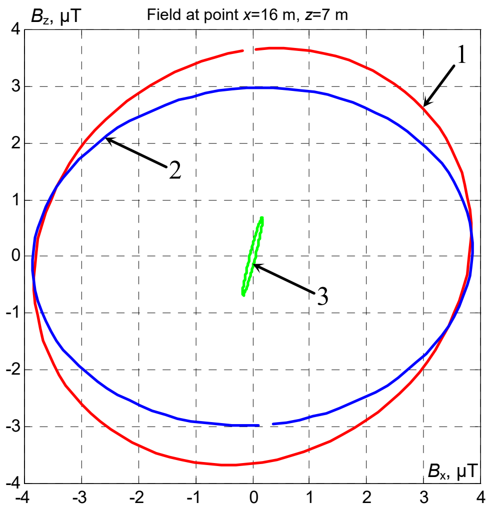

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Fig. 5. The spatio-temporal characteristics of the initial magnetic field (1), the magnetic field generated by the compensation windings (2) and the resulting magnetic field (3), respectively, for three-circuit (*a*) and two-loop (*b*) active screening systems

Let us consider the field experimental model of systems of active screening. In Fig. 6 are shown three compensation windings (*a*) a triple-loop active screening system and two compensation windings (*b*) a double-loop active screening system.

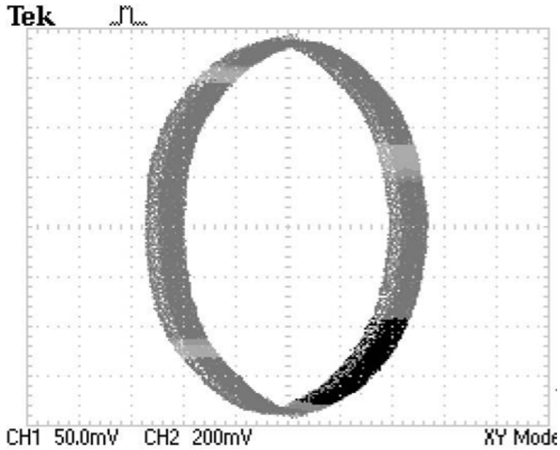

a *b*

Fig. 6.Three compensation windings (*a*) for triple-loop active screening system and two compensation windings (*b*) for double-loop system of active screening

The special measuring system for experimental measurement of space-time characteristics was developed. This measuring system includes two measuring windings, the axes of which are perpendicular to each other. An important issue in tuning this measuring system is the precise setting of the gains and phase shifts of the individual measurement channels. In Fig. 7 are shown experimental measurement space-time characteristics of magnetic field.

In Fig. 7,*a* is shown experimental measurement space-time characteristics of initial magnetic field. The shape of this characteristic is close to a circle, which corresponds to the calculated space-time characteristics of initial magnetic field characteristic, which are shown in Fig. 5.

In Fig. 7,*b* is shown experimental measurement space-time characteristics of resulting magnetic field with double-loop system of active shielding is on. The shape of this characteristic is close to to the calculated space-time characteristics of resulting magnetic field with double-loop system of active shielding is on, which is shown in Fig. 5,*b*.



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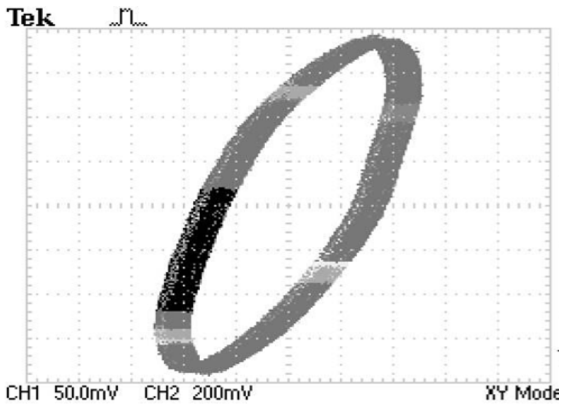

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Fig. 7. The experimental measurement space-time characteristics of initial magnetic field (*a*) and resulting magnetic field (*b*) with double-loop system of active shielding is on

Note that experimental measurement space-time characteristics of resulting magnetic field with triple-loop system of active shielding is on_quite small compared to experimental measurement space-time characteristics of initial magnetic field. The shape of this characteristic is close to a dot, which corresponds to the calculated space-time characteristics of resulting magnetic field with triple-loop system of active shielding is on, which are shown in Fig. 5,*a*.

In Fig. 4 also are shown the level of induction of magnetic field calculated (solid line) and measured with and without systems of active screening.

The difference of magnetic flux density found by measurements and simulations in the shielding zone does not exceed 20 %. The experimental shielding factor of systems of active screening is more than 8.

Note that real power transmission line currents are two to three times less than the rated currents. That's why from the point of view of the practical implementation it is shown the possibility to reduce the level of magnetic field induction in a five-storey old buildings to the sanitary standards of Ukraine for real overhead power transmission lines currents with the help of a synthesized double-loop systems of active screening. A double-loop system of active screening is simpler in comparison with a triple-loop active screening system when implementing.

Discussion. Note that during the operation of a three-circuit systems of active screening in the distribution of the induction of the resulting magnetic field there is a minimum with an induction value of 0.2 μT at the point with coordinates (16.0, 7.0), for which the screening factor is 20 units. In addition to this global minimum, there are two more local minima with an induction value of 0.4 μT at points with coordinates (16.0, 1.5) and (16.0, 14.0), the screening factor of which is 10 units.

During the operation of a two-circuit systems of active screening in the distribution of the induction of the resulting magnetic field, there are also two local minima with an induction value of 0.2 μT at points with coordinates (15.0, 3.5) and (15.5, 12.5) on the border of a five-storey building, of which the screening factor is 20 units.

The presence of such local minima in the magnetic field induction distribution imposes specific requirements on the algorithms used for solving optimization problems. In particular, in the synthesis of the systems of active screening under consideration, stochastic multi-swarm multi-agent optimization algorithms were used.

Conclusions.

1. The synthesis of triple-loop and double-loop systems of active shielding of the magnetic field generated by 110 kV single-circuit overhead power lines with a triangular suspension of wires in a five-story old building has been performed. As a result of the synthesis, the coordinates of the location of three and two compensation windings, respectively, were determined, as well as the currents and phases in these compensation windings.
2. To synthesize robust systems of active screening, solutions to minimax vector optimization problems were calculated based on stochastic multi-agent optimization algorithms. The calculation of vector objective functions and constraints was carried out on the basis of the Bio–Savart's law.
3. The study of the efficiency of the synthesized triple-loop and double-loop systems of active screening of the magnetic field in a five-storey old building has been carried out. It is shown that with the help of a triple-loop system, the level of the initial magnetic field is reduced to the sanitary standards of Ukraine in the entire all space of a five-story building. The screening factor is more than 8 units.
4. It is shown, that for rated currents of 110 kV power transmission line with the help of a double-loop system the implementation of sanitary standards is carried out only on 90 % of the area of five-story old building.
5. For real currents of 110 kV power transmission line, which are two to three times less than the rated currents, with the help of a synthesized double-loop systems of active screening, it is possible to reduce the level of induction of magnetic field in the entire all space of a five-story old building to the sanitary standards of Ukraine.

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

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