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SINGLE-CIRCUIT ACTIVE SCREENING OF MAGNETIC FIELD GENERATED BY SEVERAL OVERHEAD TRANSMISSION LINES IN RESIDENTIAL AREA

***Purpose.** The synthesis of active screening system of magnetic field, generated by several high voltage overhead transmission lines, with the help of single compensation cables is presented. **Methodology.** The initial parameters for the synthesis of active screening system parameters are the location of the high voltage overhead transmission lines with respect to the protected transmission line space, geometry and number of cables, operating currents, as well as the size of the protected space and normative value of magnetic flux density, which should be achieved as a result of screening. The objective of the synthesis of the active screening system is to determine their number, configuration, spatial arrangement, wiring diagrams and compensation cables currents, setting algorithm of the control systems as well as the resulting value of the induction magnetic field at the points of the protected space. Synthesis of active screening system is reduced to the problem of multi objective nonlinear programming with constraints in which calculation of the objective functions and constraints are carried out on the basis of the Maxwell equations solutions in the quasi-stationary approximation. The problem is solved by a stochastic multi swarm multi agent particles optimization, which can significantly reduce the time to solve it. **Results.** Active screening system synthesis results for reduction of a magnetic field generated by several high voltage overhead transmission lines are presented. The possibility of a significant reduction in the level of source magnetic flux density within a given. **Originality.** For the first time the synthesis of the active screening systems of magnetic field generated by the several high voltage overhead transmission lines within a given region of space is carried out. **Practical value.** Practical recommendations on reasonable choice of the number and spatial arrangement of compensating cables of active screening systems of the magnetic field generated by the several high voltage overhead transmission lines is given.* References 10, figures 7.

Key words: **high voltage overhead transmission lines, power frequency technogenic magnetic field, active screening system, multiobjective synthesis.**

Получил дальнейшее развитие метод синтеза систем активного экранирования магнитного поля, генерируемого несколькими воздушными ЛЭП, на основе многокритериального подхода. При синтезе используется упрощенная математическая модель магнитного поля, генерируемого несколькими воздушными ЛЭП, идентификация которой выполнена по экспериментальным значениям индукции магнитного поля в заданных точках на основе решения задачи оптимизации. Приведены результаты синтеза одноконтурной системы активного экранирования магнитного поля, генерируемого несколькими воздушными ЛЭП. Показана возможность уменьшения индукции магнитного поля с помощью синтезированной системы до уровня санитарных норм Украины. Библ. 10, рис. 7.

Ключевые слова: **воздушные линии электропередачи, магнитное поле промышленной частоты, система активного экранирования, многокритериальный синтез.**

Introduction. Ukrainian electricity networks are characterized by high density, and especially near high-voltage power substations. There is usually a group of overhead transmission lines (TL), in the immediate vicinity of which can be located residential buildings. In this case, the level flux density of the magnetic field (MF) created by a group of TL in residential areas may exceed sanitary standards [1], which creates a threat to public health and requires the adoption of appropriate measures to normalize the MF.

For Ukraine, the method of active circuit screening of MF is economically the most acceptable method of reducing the MF in a residential area of operating overhead TL [2].

Analysis of existing active screening systems. At present, in many countries, active screening systems (ASS) for MF generated by overhead TL [3-7] have been developed and implemented. In such systems with different control algorithms [8, 9], special compensation windings – active cables, the number of which is determined by the specific nature of the problem being solved – are used as the executive body of the ASS.

The simplest single-circuit ASS with one compensating winding are the most widely used [3], however, the synthesis methods of such ASS are currently developed only for single TL [10].

In connection with this, the problem arises of synthesizing single-circuit ASS for efficient screening of MF generated by a group of overhead TL.

The goal of the work is synthesis and investigation of single-circuit active screening systems of the magnetic field of the power frequency created in a residential area by several overhead TL.

Problem definition. Let us consider the construction of an ASS for protection against MF created by several TL the layout of which is shown in Fig. 1.

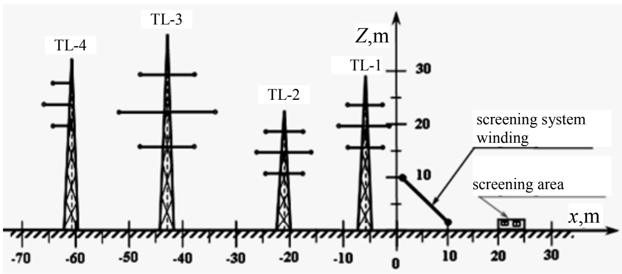


Fig. 1. The layout of several TL and protected area

In the immediate vicinity of the screening are there are two double-circuit TL 110 kV (TL-1 and TL-2), a two-circuit TL 330 kV (TL-3) and a single-circuit TL 330 kV (TL-4).

Method of synthesis. We synthesize the ASS of MF generated by several TL on the basis of the method developed in [10]. In this case, the synthesis of the ASS is reduced to solving the problem of multicriterion nonlinear programming with constraints in which the calculations of objective functions and constraints are performed on the basis of the solution of the Maxwell equation in the quasi-stationary approximation [1]. This problem is solved on the basis of constructing Pareto-optimal solutions with the help of algorithms of stochastic multi-agent optimization by multiswarm of particles [10].

For the synthesis of ASS, in addition to the geometrical dimensions of the TL, the location of the residential zone, where it is necessary to shield the MF, it is necessary to determine the complex values of the currents in the wires of the TL. Moreover, when the currents in different power lines change, not only the level of the total MF generated by several TL changes, but also the space-time electromagnetic field characteristics (STC) of the MF due to the relative redistribution of the vertical and horizontal components of the magnetic flux density vector created by different TL.

The complexity of solving the problem of synthesizing the ASS is determined by the number of wires of the TL. Naturally, taking into account all the wires of the TL creating the MF in the screening zone, the problem of synthesizing the ASS is complicated.

Let us consider an approach to the synthesis of the ASS which makes it possible to simplify the solution of the synthesis problem on the basis of taking into account a smaller number of wires compared with the original problem. To this end, we first carry out experimental studies of the MF level both in the screening zone and near the TL. On the basis of the data obtained, we solve the problem of identifying the currents in the wires of the TL under which the sum of the squared errors of the measured and model values of the flux density of the MF at the given points is minimized.

In fact, this approach solves the problem of approximating the initial MF measured as a result of experimental studies, with the help of several TL. Depending on the required accuracy of the approximation, the number of TL taken into account can be reduced to two or even one which makes it possible to substantially simplify the solution of the problem of synthesis of the ASS.

On the basis of the obtained simplified model of MF created by several TL the problem of synthesis of ASS can be solved on the basis of the method described in [10].

Mathematical model of the initial MF generated by several TL. Mathematical model of MF created by several TL on the basis of a quasi-stationary solution of Maxwell equation [1] can be represented in the following form

$$\vec{B}_o(P_i,t)=\sum_{k=1}^{K}\sum_{l=1}^{L_k}\vec{B}_{lk}(P_i,I_{lk}(t)), \qquad (1)$$

where $\vec{B}_o(P_i,t)$, $\vec{B}_{lk}(P_i,I_{lk}(t))$ are the instantaneous values of the flux density vectors of the resultant magnetic field at the point of space P_i and the magnetic field created at the same point in space by k-th current line of lk-th TL, K is the number of TL; L_k is the number of wires in k-th TL; $I_{lk}(t)$ is the instantaneous current in k-th wire of the lk-th TL.

Fig. 2 shows the lines of the same level of the magnetic flux density calculated for the rated currents of the TL.

Experimental studies of the MF created by these several TL in a residential area in which it is necessary to reduce the level of the magnetic field to sanitary standards have shown that the flux density values of the MF calculated at the rated values of the currents of the TL and the measured values are very different.

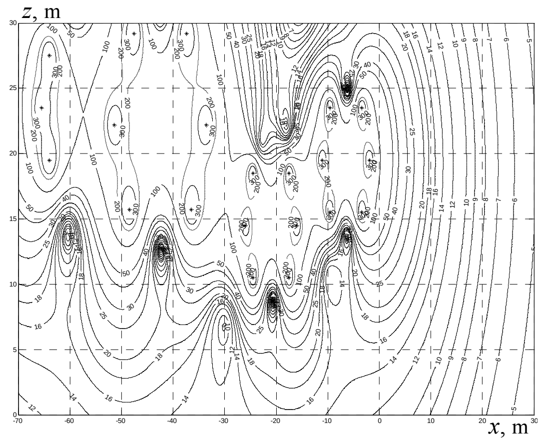


Fig. 2. The distribution of the flux density of the initial magnetic field generated by several TL at rated currents

Simulation of the MF created by individual TL in the screening zone was carried out. Fig. 3 shows the results of calculating the distribution of the flux density of the magnetic field in the screening zone at the operation: *a*) of one TL-4; *b*) at the operation of two TL-3 and TL-4; *c*) when three TL-2, TL-3 and TL-4 are operating; and *d*) when four TL-1, TL-2, TL-3 and TL-4 are operating. In this case, the currents in the wires of all TL were assumed the same and equal to 500 A.

Based on the analysis of the dependencies shown in Fig. 3 it can be seen that as the TL is removed from the screening, the level of the flux density of the magnetic field created by this TL in the screening zone decreases. However, in the system under consideration, the rated currents in the TL-3 and TL-4 wires are 2000 A, and the rated currents in the TL-1 and TL-2 wires are 1000 A. Therefore, despite the fact that TL-3 and TL-4 are removed from the screening zone for a longer distance than TL-1 and TL-2, the effect of TL-4 and especially TL-3 on the level of the flux density of MF in the screening zone can be significant.

Let us now consider the construction of a simplified mathematical model of the initial MF generated by several TL, and its identification from experimental data. In order to determine the required number of TL wires to be considered and the current values in these wires, we construct a simplified model of the magnetic field based on the simulation of the MF distribution in the screening zone, taking into account the different number of wires and the results of experimental studies.

We define the current $I_{lk}(t)$ in the k-th wire of the lk-th TL in the following form

$$I_{lk}(t) = A_{lk}\sin(\omega t + \varphi_{lk}). \qquad (2)$$

To determine the amplitudes A_{lk} of the currents $I_{lk}(t)$ we introduce the vector of the required parameters $\vec{Z} = \{A_{lk}\}$, the components of which are the amplitudes A_{lk} of the currents $I_{lk}(t)$ in the k-th wire of the lk-th TL.

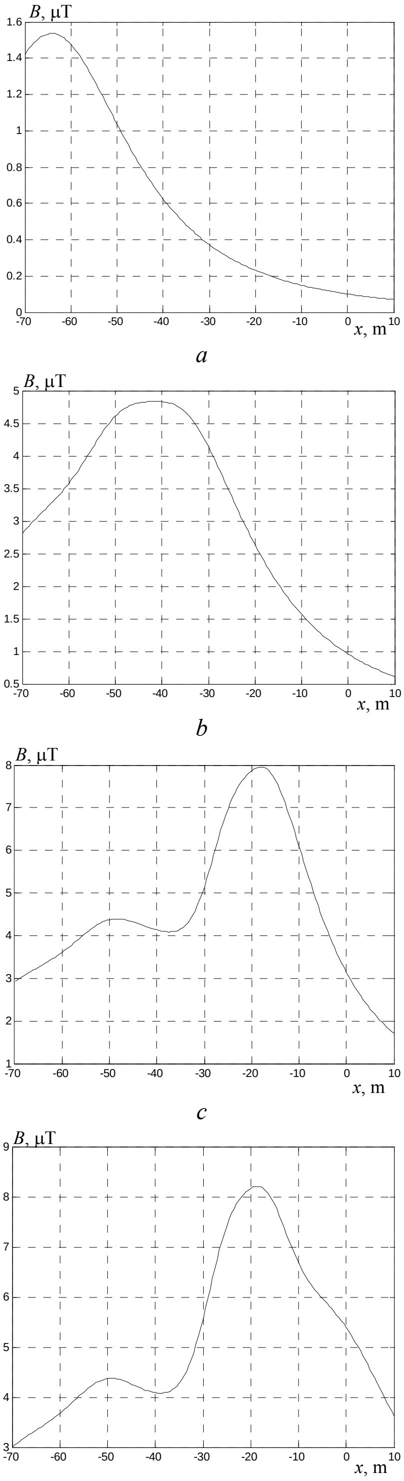


Fig. 3. Distribution of the magnetic flux density in the screening zone during operation: *a*) one TL-4; *b*) two TL-3 and TL-4; *c*) three TL-2, TL-3 and TL-4; *d*) four TL-1, TL-2, TL-3 and TL-4

Then the identification of the mathematical model (1) can be reduced to minimizing the quadratic criterion

$$\vec{Z}^* = \arg\min \sum_{i=1}^{I} \left|\vec{B}_0(P_i) - \vec{B}_e(P_i)\right|^2, \qquad (3)$$

where $\vec{B}_e(P_i)$ is the measured magnetic flux density vector in the point P_i.

For the problem under consideration, an approximated mathematical model of the initial MF is constructed, in which the influence of only two 110 kV L on the MF is taken into account. Fig. 4 shows the flux density distribution of the MF of this approximated model.

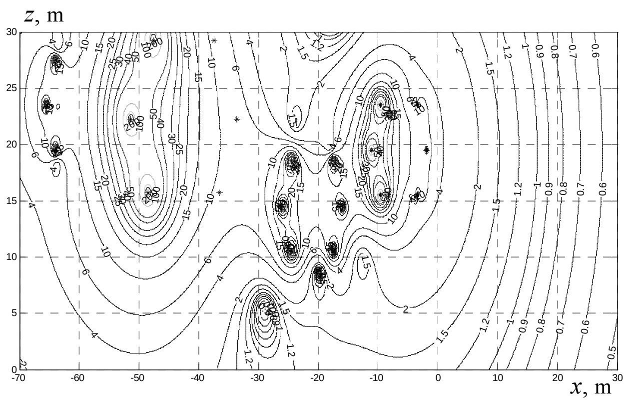


Fig. 4. Flux density distribution of the approximated model of the magnetic field created by several TL

Fig. 5 shows the dependence of the flux density of the MF of *1* – approximated model and *2* – measured values. Comparison of simulation results and experimental studies of the MF distribution in the screening zone showed that when only the first two TL-1 and TL-2 of voltage of 110 kV are taken into account, the error between such an approximated model and the experimental values of the MF level does not exceed 4 %.

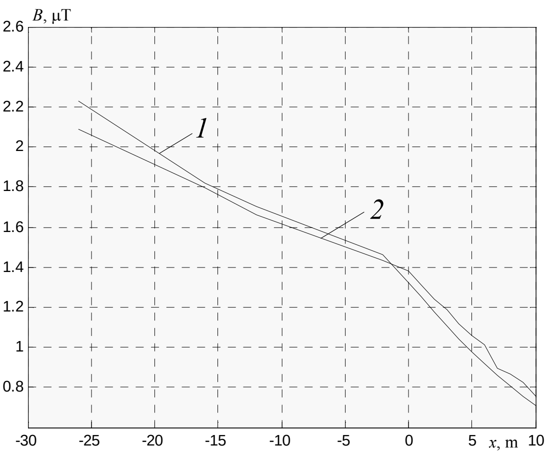
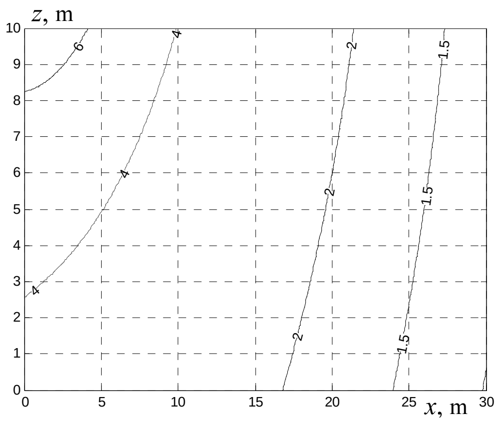


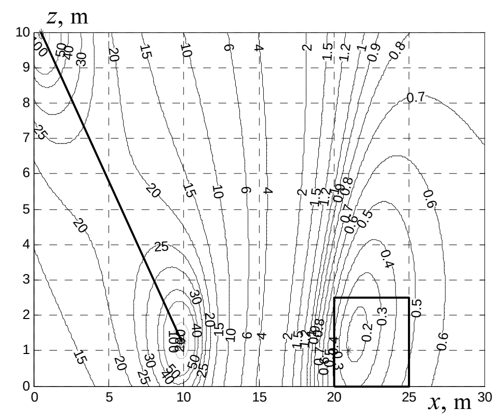
Fig. 5. Dependencies of the MF flux density: *1* – calculated and *2* – measured values

Results of synthesis of ASS. We consider the synthesis of the ASS of the MF created by several TL the layout of which is shown in Fig. 1. This figure also shows the residential area in which the MF screening is required, and the location of the compensation winding. Based on experimental studies, it was found that in the screening zone, the MF generated by these TL has a negligible polarization, which makes it possible to construct a single-circuit ASS with one compensation winding. It should be noted that such systems have become most widespread in the world practice [3-7].

Fig. 6 shows the lines of equal level of the magnetic flux density module: *a*) of the initial MF created by several TL and *b*) with the active screening system turned on. The initial flux density of the MF in the residential space under consideration is 1.8 μT which is 3.6 times higher than the sanitary norms of 0.5 μT [1]. When the active screening system is turned on, the flux density level of the MF does not exceed 0.4 μT.



a



b

Fig. 6. Flux density distribution: *a*) of the initial MF created by several TL and *b*) of the MF with the ASS turned on

Fig. 7 shows the STC of the MF created: *1* – by several TL; *2* – by compensating winding and *3* – total MF with the system turned on. As can be seen from this figure, in the space under consideration, the initial MF created by several TL has a negligible polarization, so that its STC represents a strongly elongated ellipse, and the ellipse coefficient (ratio of the smaller semi-axis of the ellipse to the larger semi-axis) is about 0.4, that is confirmed by experimental research. Naturally, such a MF can be effectively compensated with a single-circuit ASS. With the help of one winding, the lager semi-axis of the STC ellipse of the original MF is compensated, so that the STC of the resultant MF remaining after the operation of the ASS is an ellipse with an ellipse coefficient equal to 0.8.

In conclusion, we note that the calculated screening efficiency of the synthesized ASS in a residential zone has been experimentally confirmed in the field on its full-scale model and is more than four.

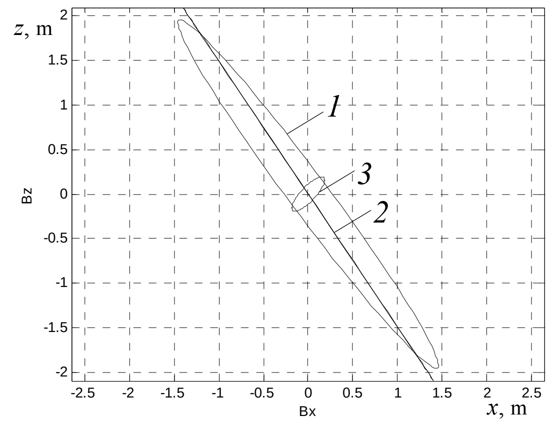


Fig. 7. Space-time characteristics of the flux density vector of MF created: *1* – by TL; *2* – by compensating winding and *3* – of total MF with ASS turned on

Conclusions.

1. Methods for the synthesis of active screening systems of the MF generated by several TL on the base of multicriteria approach and methods for constructing a mathematical model of the MF generated by several TL based on the experimental values of the flux density of the MF at given points of space, based on solving the optimization problem, have been further developed.
2. On the basis of the proposed methods, a single-circuit active screening system for the MF created by several overhead TL in a residential zone was first synthesized.
3. The possibility of a significant (by 4 or more time) reduction of the flux density of the MF with the help of a synthesized single-circuit screening system and achieving the sanitary standards for the MF in the residential zone located near the TL group is shown.

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