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ACTIVE SHIELDING OF MAGNETIC FIELD Of OVERHEAD POWER LINE WITH PHASE CONDUCTORS OF TRIANGLE ARRANGEMENT

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For the first time in Ukraine the synthesis of two degree of freedom robust two-circuit system of active shielding of magnetic field, generated by overhead power lines with triangle arrangements of phase conductors is realized to reduce the magnetic flux density down to the sanitary standards level and to reduce the sensitivity of the system to plant parameters uncertainty. The synthesis is based on the multi-criteria stochastic game solution, in which the payoff vector is calculated by the solutions of the Maxwell equations as a quasi-stationary approximation. The game solution is based on the stochastic multi-swarm particle optimization algorithms. The computer simulation and field experimental results of two degree of freedom robust two-circuit system of active shielding of magnetic field, generated by overhead power lines with triangle arrangement of phase conductors are presented. References 6, figures 3.
Keywords: overhead power lines, triangle arrangement of phase conductors, magnetic field, system of active shielding, computer simulation, field experimental study

Introduction. Many 110 kV overhead power lines (OPL) in Ukraine have a triangle arrangement of phase conductors (TTPCA) and often pass in the immediate vicinity of residential districts. Such OPL are generated magnetic field (MF), the level of which often exceeds sanitary standards of Ukraine that produces a threat to public health [1]. The methods of active contour shielding of MF generated by OPL are needed to provide the sanitary standards of Ukraine. The method of synthesis of systems of active shielding (SAS) of MF generated by OPL is developed in [2, 3]. OPL with TTPCA are generated the MF, space-time characteristics (STC) of which have the circular shape approximately. For active shielding of such a MF, at least two shielding coil (SC) are required. The open loop and closed loop control – two degree of freedom (TDOF) system is used in SAS simultaneously [4]. Such system is implemented using MF sensors installed inside and out of shielding space (SS) [2]. The SAS parameters are known indefinitely and change in time. The main uncertainty is OPL bus current, which should bring to the MF STC position change in SS. Therefore the SAS must be robust.

The objective of the work is to synthesize the two-degree freedom robust two-circuit systems of active shielding of magnetic field generated by overhead power lines with a triangular arrangement of wires.

Problem statement. We introduce the vector $X=\{G,K_C,A_O,\varphi\}$ of the required parameters, the components of which are vector G as the spatial arrangement and geometric dimensions of the SC and the TDOF regulator parameters, including matrix K_C of the closed loop control gain and matrix K_O of open loop control gain and matrix φ of phase shifts. Also we introduce vector Δ with the parameter uncertainty from their nominal values used in the system synthesis. Then the problem of TDOF SAS synthesis is associated with determination of such vector of spatial arrangement and geometric sizes of SC, as well as TDOF regulator parameters X and vector Δ of the parameter uncertainty, at which the maximum value of the magnetic flux density at selected points P_j of the SS P assumes a minimum value for the vector X, but the maximum value for the vector Δ. This technique corresponds to the robust systems synthesis standard worst-case approach [5], when the vector Δ of parameter uncertainty leads to the greatest deterioration in the shielding of the initial MF generated by OPL.

Method of synthesis. The problem of synthesis can be formulated in the form of the following multi-criteria game [5] with vector payoff

$$B(X,\Delta)=\left[B(X,\Delta,P_i)\right]^T, \qquad (1)$$

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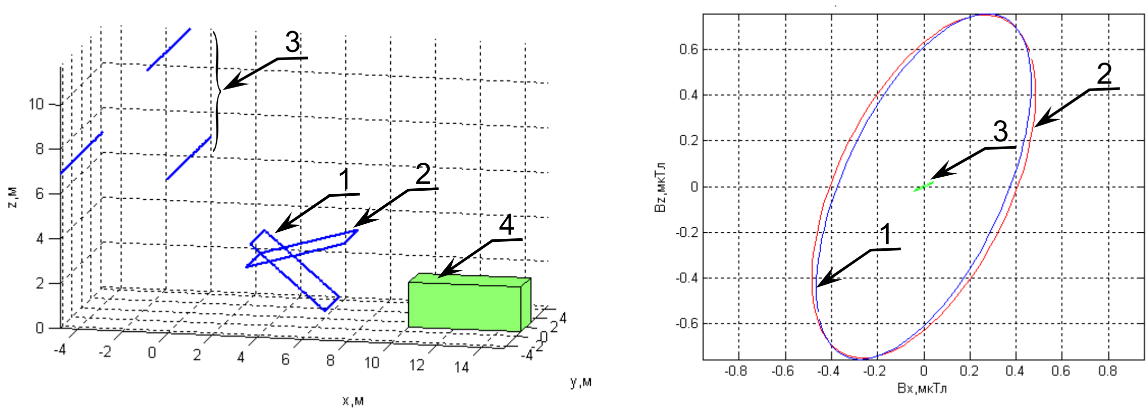
the m components of which $B(X,\Delta,P_i)$ are the magnetic flux density in m points P_i of the shielding space. The components $B(X,\Delta,P_i)$ of the vector payoff (1) are the nonlinear functions of unknown vectors X, Δ and calculated by the Maxwell quasi-stationary approximation [1].

The multi-criteria game (1) is a two-player zero-sum antagonistic game [5]. The first player is the regulator parameter vector X and its strategy is the minimization of vector payoff (1). The second player is the vector Δ of parameter uncertainty and its strategy is maximization of the same vector payoff (1). Game decision is based on multi-swarm stochastic multi-agent optimization from Pareto-optimal solutions [5, 6].

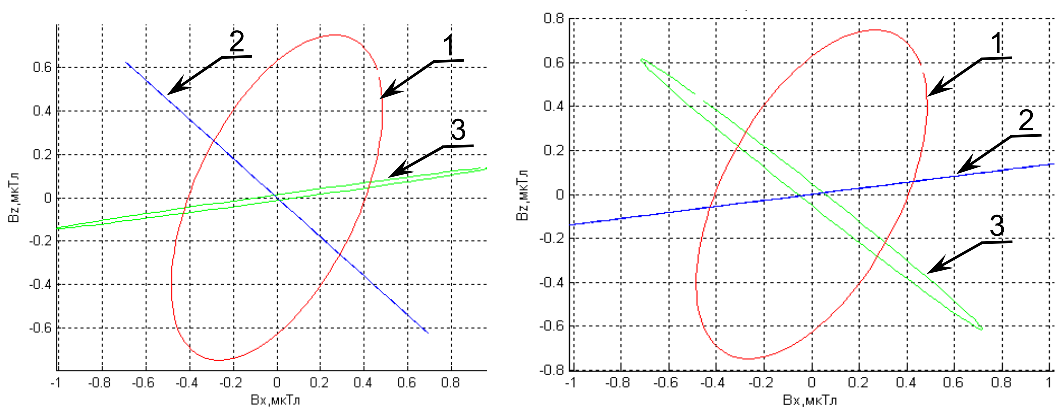
Computer simulation. Let us consider the result of synthesis of TDOF robust MF SAS, generated by OPL with TTPCA. Fig. 1, *a* shows the first SC (*1*) and the second SC (*2*) of two SC, 110 k*V* OPL with TTPCA (*3*) and SS (*4*) spatial arrangement. Both SC are square shaped and located at a height of 3.4965 *m* and 3.6818 *m* from the ground, respectively. The lower branch is located at a height of 2.4522 m and 0.6637 *m* from the ground. SC currents are 4.3122 *A* and 4.3138 *A*. Fig. 1, *b* shows the STC of MF, generated by OPL (*1*); generated by both SC (*2*) and the total MF with the SAS (*3*). As seen from this figure, STC of MF, generated by OPL (curve *1*); and STC of MF, generated by SC (curve *2*) are practically identical. But STC of total MF with the SAS (curve *3*) is significantly less than the initial MF STC, which confirms the high SAS shielding factor [3].



a ***b***

Fig. 1

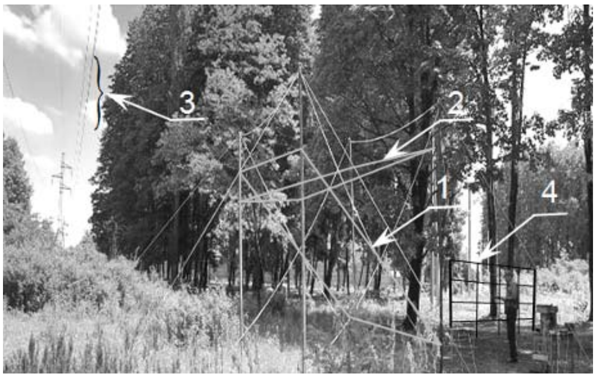
Fig. 2, *a* presents the STC of MF, generated by OPL (*1*); generated both SC (*2*) and total MF with only single first SC. Fig. 2, *b* shows the same STC with single second SC. As seen, STC of only one first SC and only one second SC are straight lines. The resulting MF STC ellipse semi-major axis in the case of single SC is strictly parallel with another SC MF STC.



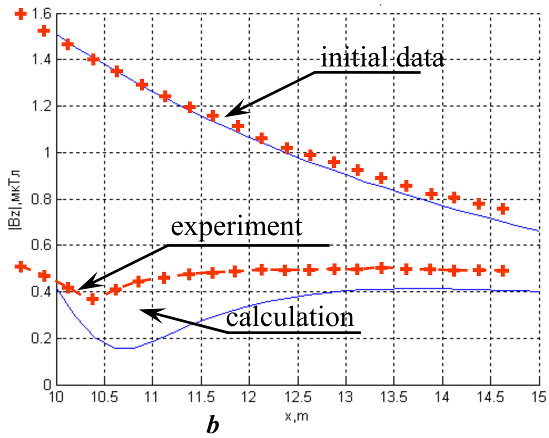
a ***b***

Fig. 2

Experimental results. Let us consider the field experimental SAS model. Fig. 3, *a* shows the first SC (1) and the second SC (2) from two SC and 110 k*V* OPL with TTPCA (3) spatial arrangement. Both SC contain 20 windings and are powered by TDA7294-typed amplifier. Both SC contain the external magnetic flux density controller and internal current controller. The inductive sensor is used as MF induction sensor. The measurement of MF is performed by "Lutron" magnetometer of EMF-828 type.



a



b

Fig. 3

Fig. 3, *b* shows the magnetic flux density obtained by measurements and simulations (solid line) with and without SAS. The experimental SAS shielding factor is more than 3. The difference of magnetic flux density found by measurements and simulations in the shielding zone does not exceed 20%.

Conclusions

1. For the first time in Ukraine the synthesis of two-degree freedom robust two-circuit system of active shielding of magnetic field, generated by overhead power lines with triangle arrangement of phase conductors is presented to decrease the initial magnetic flux density down to the Ukrainian sanitary standards level and to reduce the sensitivity of the system to plant parameter uncertainty.

2. The synthesis of the robust system of active shielding is based on multi-criteria stochastic game decision with multi-swarm stochastic multi-agent optimization from Pareto-optimal solutions.

3. As a result of synthesis of active shielding system, the spatial position of two shielding coils as well as the parameters of regulator is determined. The system reduces the magnetic flux density in shielding space down to the Ukrainian sanitary norms and has lower sensitivity to parameter uncertainty in comparison with the known systems.

4. Field experimental study of the robust two-circuit system of active shielding of magnetic field, generated by overhead power lines with triangle arrangement of phase conductors is carried out. The comparison of experimental and calculated values of magnetic flux density within shielding space shows that their variation does not exceed 20 %.

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АКТИВНЕ ЕКРАНУВАННЯ МАГНІТНОГО ПОЛЯ ПОВІТРЯНИХ ЛІНІЙ ЕЛЕКТРОПЕРЕДАЧІ ІЗ РОЗТАШУВАННЯМ ФАЗНИХ ПРОВОДІВ У ВИГЛЯДІ ТРИКУТНИКА

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Вперше в Україні виконано синтез робастної двоконтурної з двома ступенями свободи системи активного екранування магнітного поля, що генерується повітряними лініями електропередачі з фазовими проводами типу «трикутник» задля зниження індукції до рівня санітарних норм та зменшення чутливості системи до невизначеності параметрів об'єкту керування. Синтез ґрунтується на рішенні багатокритеріальної стохастичної гри, в якій вектор виграшу обчислюється на основі рішень рівнянь Максвелла в квазістаціонарному наближенні. Рішення ігри ґрунтується на алгоритмах стохастичної оптимізації мультироєм частинок. Наведено результати комп'ютерного моделювання та польових експериментальних досліджень робастної двоколової системи з двома ступенями свободи активного екранування магнітного поля, що генерується повітряними лініями електропередач із розташуванням фазових проводів у вигляді трикутника. Бібл. 6, рис. 3.
Ключові слова: повітряні лінії електропередачі з розташуванням фазових проводів типу "трикутник", магнітне поле, система активного екранування, комп'ютерне моделювання, польові експериментальні дослідження

УДК 621.3.013

АКТИВНОЕ ЭКРАНИРОВАНИЕ МАГНИТНОГО ПОЛЯ ВОЗДУШНЫХ ЛИНИЙ ЭЛЕКТРОПЕРЕДАЧИ С РАСПОЛОЖЕНИЕМ ФАЗНЫХ ПРОВОДОВ В ВИДЕ ТРЕУГОЛЬНИКА

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Впервые в Украине выполнен синтез робастной двухконтурной с двумя степенями свободы системы активного экранирования магнитного поля, создаваемого воздушными линиями электропередачи с расположением фазных проводов типа «треугольник», для снижения индукции до уровня санитарных норм и уменьшения чувствительности системы к неопределенности параметров объекта управления. Синтез основан на решении многокритериальной стохастической игры, в которой вектор выигрыша рассчитывается на основе решений уравнений Максвелла в квазистационарном приближении. Решение игры основано на алгоритмах стохастической оптимизации мультироем частиц. Приведены результаты компьютерного моделирования и полевых экспериментальных исследований робастной двухконтурной системы с двумя степенями свободы активного экранирования магнитного поля, создаваемого воздушными линиями электропередачи с расположением фазных проводов в виде треугольника. Библ. 6, рис. 3.
Ключевые слова: воздушные линии электропередачи с расположением фазных проводов типа «треугольник», магнитное поле, система активного экранирования, компьютерное моделирование, полевые экспериментальные исследования.

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