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INNOVATIVE CONTROL OF THE DEVELOPMENT OF AN ERGATIC ELECTRIC POWER SYSTEM BASED ON FUZZY LOGIC

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***Abstract*—*This article deals with the search for a palliative optimal solution to the optimization of the electric power problem. A mathematical model of planning by the development of a hierarchical ergatic electric power system is proposed to be presented as an optimization problem of minimizing vectors. An innovative direction in modeling the control system of an ergatic electric power system based on artificial neural networks is also considered. It is noted that intelligent control systems for power supply systems are robust. The innovative concept of a smart power system is due to the integration into a hierarchical power system of renewable energy sources based on modern computer technologies. It is noted that during the operation of an intelligent electric power system, control systems must provide adaptive qualities in relation to the topology of the power supply system. It is proposed to investigate the solution to the optimization of electric power problems using methods of fuzzy mathematical programming.*

Index Terms—Electric power system; mathematical programming.

I. INTRODUCTION

Control of hierarchical ergatic electric power system (EPS) predetermines the search for a palliative optimal solution. In this case, the decision maker should choose the most rational among the set of palliative optimal solutions. Palliative optimal decision is made in the process of multipurpose planning with fuzzy information. In these problems of mathematical programming, many conflicting objective functions are simultaneously optimized. At the same time, to optimize the objective function in the hierarchical structure of the EPS, the decision maker makes a decision (palliative optimal), which does not take into account one of several objective functions. For this purpose, it is advisable to apply the methods of fuzzy mathematical programming, according to which the problem of multipurpose planning in the control of a hierarchical ergatic EPS can be formalized as the problem of minimizing vectors with fuzzy information. The implementation of methods of fuzzy mathematical programming involves an approximation of real systems. To minimize the error of this approximation, the following is proposed in the literature: if the coefficients of the objective functions, as well as the constraints are represented by trapezoidal fuzzy numbers, then the optimal solution can be found by linear programming methods [1].

II. PROBLEM STATEMENT

As you know, the basis of the classical methods of synthesis of control systems is the mathematical apparatus of integro-differential calculus. Artificial neural networks, as well as genetic algorithms for their functioning, are an innovative direction in modeling ergatic control systems, in particular, control of an electric power system. Currently, neurocontrol is used in neurocontroller control systems; artificial neural networks can be implemented in the form of neuroemulators that simulate the functioning of the control object, as well as its characteristics, for which it is difficult to perform mathematical modeling [2].

In accordance with genetic algorithms, the parameters of neurocontrollers are adjusted. Neural networks are characterized by the versatility of their approximating properties. An innovative process for managing dynamic objects is based on a combination of computational technologies - genetic algorithms and artificial neural networks. As noted in the literature, based on genetic algorithms and artificial neural networks, it is possible to synthesize a mathematical model of a control object characterized by transient characteristics. The use of neural network models – predictors allows predicting its subsequent states using the flow and previous vectors of the state of the operated object. In this case, it is expedient to search for a solution to the optimization problem, which consists in optimizing the structure and parameters of artificial neural networks.

Adaptive iterative control algorithms for a hierarchical ergatic EPS simulate the process of finding a solution to the optimization of electric power problems, while the optimization process should be convergent. The use of numerical methods in the extremization of target functionals

predetermines a set – a population of solutions, on the basis of which the selection is carried out. Intelligent control systems are robust. The criterion for the adequacy of the model of the electric power plant of management is the accuracy of the model. If the neurocontroller synthesized on the basis of the model is able to control the object, then the accuracy of the model satisfies the criterion of its adequacy.

The design of intelligent control systems is based on evolutionary modeling, which is a direction in mathematical modeling, which is a superposition of computer modeling methods, as well as heuristic programming methods based on genetic algorithms, artificial neural networks, and fuzzy logic.

III. Mathematical Model of the Process of Control an Innovative Intelligent EPS

The mathematical model of the multi-purpose planning process by the development of a complex ergatic EPS can be presented as a vector minimization problem:

$$\min f(x) = \{f_i(x)\},\ i = \overline{1,k}$$

given that:

$$x \in X = \left\{x \in E^n / g_j(x) \le 0,\ j = \overline{1,m}\right\},$$

where x is an n-dimensional vector of variables; $\{f_1(x), f_2(x), ..., f_k(x)\}$ is the mutually contradicting target functions; $\{g_1(x), g_2(x), ..., g_m(x)\}$ are restriction functions; X is the area of limitation [1].

In multipurpose planning, objective functions are vectors. The goal of solving this problem is to find a palliative optimal solution x^*.

Fuzzy mathematical programming methods consider a more rigorous formulation of problems of fuzzy multi-purpose planning for the development of a hierarchical ergatic EPS with fuzzy parameters:

$$\min f(x, \tilde{a}) = \{f_i(x, \tilde{a}_i)\},\ i = \overline{1,k}$$

given that

$$x \in X(b) = \left\{x \in E^n / g_j(x, \tilde{b}_j) \le 0, j = \overline{1,m}\right\},$$

where $\tilde{a}_i, \tilde{b}_j, i = \overline{1,k}, j = \overline{1,m}$ are vectors of fuzzy numbers.

Fuzzy parameters included in the mathematical model of this control problem predetermine the search for a α-palliative optimal solution.

In order to search for a α-palliative optimal solution to the problem of multipurpose planning when controlling a complex ergatic EPS, a set of α-level is introduced, which can be represented as:

$$L(\alpha) = \left\{\frac{(a,b)}{\mu_{\tilde{a}_i}(a_i)} \ge \alpha,\ \mu_{\tilde{b}_j}(b_j) \ge \alpha\right\},$$

where $\mu_{\tilde{a}_i}(a_i), \mu_{\tilde{b}_j}(b_j), i = \overline{1,k},\ j = \overline{1,m}$ are vectors of membership functions.

Then the mathematical model of the process of fuzzy multipurpose planning of the development of an ergatic EPS can be considered a model representing the problem of clear α-multipurpose planning:

$$\min f(x,a) = \left\{f_i(x,a_i), i = \overline{1,k}\right\}$$

given that

$$x \in X(b) = \left\{x \in E^n / g_j(x,b_j) \le 0, j = \overline{1,m}\right\},$$

$$(a,b) \in L(\alpha)$$

That is, the solution $x^* \in X(b^*)$ is a α-palliative optimal solution if there is no clear α-multipurpose planning problem $x \in X(b), (a,b) \in L(\alpha)$, such that $f(x,a) \le f(x^*, a^*)$, and $f(x,a) \ne f(x^*, a)$, where (a^*, b^*) are optimal coefficients of the α-level [1].

The approximation error of the real process of electric power process control can be expressed as a discrete signal $e^*(t)$, the steady-state value of which can be represented as [3]:

$$e^*_{st} = \lim_{t\to\infty} e^*(t) = \lim_{k\to\infty} e[kT].$$

In the case of linear continuous control systems, the steady-state error is a function of the input action and the parameters of the operating system. The steady-state approximation error of a discrete control system of a real control process does not depend on the quantization period; this error is a function of the parameters of the continuous control system and the type of input action.

Currently, an innovative concept of smart power system is being developed in the energy sector. This is due to the integration into the hierarchical ergatic EPS of renewable energy sources based on information computer technologies, as well as control systems. The concept of intelligent EPS is used in distribution electric networks based on monitoring systems for the operation of adaptive control systems, as well as intelligent computer technologies. At the same time, in the EPS, the process of operation of smart electricity meters, modern devices for processing information about energy consumption in the power supply system is carried out.

In an intelligent ergatic EPS, electricity generation is carried out during the operation of intelligent equipment diagnostics, systems for integrating renewable energy sources, distributed generation while ensuring the reliability of the EPS, the efficiency of electricity generation, and improving the quality of electricity. In the transmission electric network, modern technologies for electricity transmission, systems for diagnosing the state of electrical equipment, intelligent monitoring of power consumption modes are being introduced while ensuring the reliability of electricity transmission and the functioning of control systems. The operation of substations is carried out on the basis of their automation with the use of intelligent systems for diagnostics, monitoring, and the functioning of control systems based on information technologies in order to ensure the reliability of the operation of electrical equipment. During the operation of the electrical distribution network, its controllability and reliability are increased using power electrical equipment, protection and automation systems operating on the basis of microprocessor technology, innovative information technologies [4]. At the same time, electrical consumers are equipped with intelligent systems for monitoring and metering electricity consumption, its regulation, systems for managing electrical loads in normal and emergency modes of operation of the power supply systems.

The design and operation of innovative intelligent EPS requires the introduction of distributed power generation devices, modern systems, means and technologies for controlling the modes of operation of power supply systems based on microprocessor technology. Modern control systems for intelligent EPS should provide flexible adaptive qualities in relation to its topology and parameters. In a market economy, unpredictability of operating modes of an ergatic EPS is also possible. All of these factors confirm the feasibility of modernizing mathematical models and methods for predicting the development of hierarchical intelligent EPS.

The study of intelligent ergatic EPS is advisable to carry out from the standpoint of a systems approach due to the complexity of the hierarchical structure of these systems. In a market economy, integrated resource planning is used in the power industry. The development of intelligent EPS provides for the creation of a hierarchical organizational structure of the power supply systems with the priority of consumer requirements. The development of innovative electric power industry is taking place in conditions of uncertainty and multi-criteria; at the same time, the extremization of target functionals when solving optimization electric power problems should be investigated using methods of fuzzy mathematical programming. The optimization tasks that justify the development of EPS are: maximizing the profits of power generating and sales companies in the electricity market, minimizing electricity tariffs from its consumers, and minimizing the environmental impact of power facilities.

Mathematical modeling of the development of complex intelligent EPS in conditions of uncertainty predetermines the multivariance of acceptable solutions. The hierarchical technology for solving the problem of developing innovative EPS should take into account the multicriteria of complex ergatic power supply systems. When solving the problem of multipurpose planning of the development of these systems, it is advisable to select its admissible variant on a set of alternatives, as well as to search for the optimal values of the EPS parameters relative to a certain variant. For the lower levels of the hierarchical ergatic EPS, it is advisable to apply the aggregation procedure – disaggregation of the mathematical model, which is based on the method of nodal voltages. At the upper level of the hierarchical complex EPS, it is advisable to apply the aggregation procedure – disaggregation of the flow model on the graph, which makes it possible to linearize the mathematical model of a complex EPS [4].Mathematical modeling of a hierarchical EPS makes it possible to search for a solution to the optimization of electric power problems, taking into account the requirements of the reliability of the operation of the power supply systems and standardizing directives in relation to indicators of the quality of electricity.

The hierarchical technology for modeling complex ergatic EPS provides for the use of multi-criteria methods for finding optimal solutions to the problems of evaluating the efficiency of energy facilities. At the same time, it is advisable to present a multi-criteria optimization electric power problem as a single-criteria one with the definition of the main criterion of efficiency and the transfer of other criteria to the category of restrictions. The integral optimization criterion, as a rule, is the annual reduced costs. Reduction of a multi-criteria problem to a single-criterion one with the transfer of optimization criteria to the category of restrictions is based on the procedures for identifying restrictions in the form of standards in relation to indicators of power quality, reliability of the power supply

system, ecology [4]. If it is impossible to reduce a multicriteria problem to a single-criterion problem, the electric power optimization problem should be analyzed as a multicriteria problem based on the analysis of the Pareto set. As you know, the solution is Pareto – optimal if the value of any criterion of efficiency can be improved, provided that the values of the other criteria deteriorate.

Methods of heuristic programming, used in the mathematical modeling of intelligent EPS, predetermine a fuzzy choice of options for feasible solutions of multi-criteria optimization electric power problems. The search for a solution to these problems is carried out by building membership functions of indicators of options for admissible solutions; construction of membership functions of undefined values of criteria values; determination of the Pareto set – effective options, which, as a rule, allows to reduce the sample size of alternative solutions or to determine the optimal solution to the EPS optimization problem.

The optimization problem of the development of electric networks of a hierarchical complex EPS can be analyzed as a transport problem of linear programming, while the criterion of optimality will be the criterion of the minimum of the reduced costs for the development and operation of the electric network.

In the process of optimizing the development of electrical networks, the method of structural analysis of EPS should be applied, the indicators of which are the mutual structural capacities of generators, as well as their own structural capacities, which determine the upper estimates of the areas of static aperiodic stability of EPS [4]. It is also advisable to apply an ergonomic technique for optimizing the development of electrical networks, based on iterative algorithms for selecting rational options for solving an optimization problem for an electrical energy problem.

In a market economy, the mathematical model of the development of electrical networks becomes more complicated due to the complication of the decision-making process in complex systems, if it is necessary to take into account the interests of all stakeholders with an increase in the uncertainty of supply and demand for consumed electricity. Mathematical models for calculating steady-state power consumption processes, as well as analysis of static stability, mathematical models of electrical modes that model the patterns of flow distribution in electrical networks are used at the initial stage of decision-making. The solution to the problem of the development of electrical networks is to ensure the power balances of all nodes of the hierarchical ergatic EPS. The optimization problem of the electric power at certain indicators of generation and consumption of electric energy is reduced to minimizing the costs of the development and operation of electric networks.

The search for optimal options for the development of complex EPS should be carried out on the basis of optimization mathematical models that implement the search for the extremum of a function of many variables.

IV. CONCLUSIONS

An innovative direction in modeling ergatic control systems, in particular, control of an electric power system, are artificial neural networks, as well as genetic algorithms for their functioning.

The design of intelligent control systems is based on evolutionary modeling, which is a direction in mathematical modeling, which is a superposition of computer modeling methods, as well as heuristic programming methods based on genetic algorithms, artificial neural networks, fuzzy logic.

Design and operation of innovative intelligent EPS require the introduction of distributed power generation devices, modern systems, tools and technologies for controlling the modes of operation of power supply systems based on microprocessor technology.

Optimization of the electric power problem with certain indicators of generation and consumption of electric energy is reduced to minimizing the cost of developing and operating electric networks.

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О. Й. Чуріна. Іноваційне керування розвитком ергатичної електроенергетичної системи на основі нечіткої логіки
У запропонованій статті розглядаються питання пошуку паліативного оптимального розв'язку оптимізаційної електроенергетичної задачі. Пропонується математичну модель планування розвитком ієрархічної ергатичної електроенергетичної системи уявити як оптимізаційну задачу мінімізації векторів. Також розглянуто інноваційний напрям в моделюванні системи управління ергатичної електроенергетичної системи на основі штучних нейронних мереж. Відмічено, що інтелектуальні системи керування системами електропостачання є робастними. Іноваційна концепція інтелектуальної енергосистеми обумовлена інтеграцією в ієрархічній електроенергетичній системі джерел енергії, що поновлюються, на основі сучасних комп'ютерних технологій. Відмічено, що в процесі експлуатації інтелектуальної електроенергетичної системи керування повинні забезпечувати адаптаційні якості стосовно топології системи електропостачання. Запропоновано розв'язок оптимізаційних електроенергетичних задач досліджувати з застосуванням методів нечіткого математичного програмування.
Ключові слова: електроенергетична система; математичне програмування.

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А. И. Чурина. Инновационное управление развитием эргатической электроэнергетической системы на основе нечеткой логики
В предлагаемой статье рассматриваются вопросы поиска паллиативного оптимального решения оптимизационной электроэнергетической задачи. Предлагается математическую модель планирования развитием иерархической эргатической электроэнергетической системы представить как оптимизационную задачу минимизации векторов. Также рассмотрено инновационное направление в моделировании системы управления эргатической электроэнергетической системы на основе искусственных нейронных сетей. Отмечено, что интеллектуальные системы управления системами электроснабжения являются робастными. Инновационная концепция интеллектуальной энергосистемы обусловлена интеграцией в иерархической электроэнергетической системе возобновляемых источников энергии на основе современных компьютерных технологий. Отмечено, что в процессе эксплуатации интеллектуальной электроэнергетической системы системы управления должны обеспечивать адаптационные качества в отношении топологии системы электроснабжения. Предложено решение оптимизационных электроэнергетических задач исследовать с применением методов нечеткого математического программирования.
Ключевые слова: электроэнергетическая система; математическое программирование.

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