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MULTICRITERIA OPTIMIZATION PROBLEM STATEMENT IN ELECTRIC POWER INDUSTRY

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***Abstract*—*In this paper, optimization problems of the electric power industry, modeled on the basis of nonstationary nonlinear systems, are considered. The analysis of admissible solutions of the optimization problem is performed on the basis of the composition of subsets of coordinated and compromise solutions. At the same time, the change in the objective functional of the optimization problem is due to variations in the states of the environment without changing the system of constraints that determine the set of admissible values of the controlled variables. It is proposed to take into account the nonlinearity and discreteness of optimization problems in the process of modeling electric power systems.*

Index Terms—Electric power system; mathematical programming.

I. INTRODUCTION

Planning the development of electric power systems, their efficient operation, reliability of operation, and the uninterrupted power supply of consumers is impossible without mathematical modeling of the operating modes of electric power systems.

In the process of developing these systems, mathematical models become more complicated due to the complication of the electrical circuits of power systems, and also because of the increase in the requirements for the accuracy of calculations.

Mathematical modeling of active and reactive power flows in the power system in normal and emergency modes, load sharing between power plants, static and dynamic stability, short-circuit currents, and processes associated with nonstationary phenomena is quite complicated due to the complexity of the configuration of power system networks, and nonlinearity of the equations describing the modes of operation of the electric power system.

Modeling of energy systems includes approximation using linear and dynamic programming models, the equivalent of an optimized system, and the simulation of energy processes. Modeling is an instrument for system analysis of complex energy systems. The purpose of modeling is to provide the process of managing a complex energy system necessary for decision-making information.

The choice of the mathematical method used in modeling systems is determined by the classification characteristics of mathematical models, namely: static and dynamic models (the relation to time), and also by the degree of certainty of information (certainty, risk, uncertainty).

Modeling of complex energy systems as physical and technical systems allows to take into account the nonlinearity and discreteness of optimization problems. When using the probabilistic description of energy processes, modeling problems are solved by stochastic programming methods.

Physicotechnical systems, for which the requirements of precise definiteness, smoothness of functions, continuity of time are met, are described by deterministic dynamic models. They include the selection of the laws governing the control of excitation, as well as the speed of synchronous generators in the electric power system, installations of automation devices [1].

II. PROBLEM STATEMENT

The setting of the problem is as follows. It is necessary to determine the set of permissible solutions for the optimization problem of the power industry, the search for the solution of which should be carried out in the decision-making process of managing the hierarchical power-generating system.

One of the main tasks of managing a complex energy system is the problem of decomposition and aggregation of mathematical models. The procedures of these operations, applied to mathematical models of energy systems, carry out the division of a common task into interrelated subtasks. An example is the separation of the general task of controlling the modes of the electric power system for control tasks in the normal, emergency and post-emergency modes [1].

Decomposition and aggregation procedures depend on the type of mathematical model. One of the approaches to decomposition and aggregation of mathematical models are systems of linear algebraic equations. Aggregation consists in exclusion of certain variables of algebraic equations (for example, using the Gauss method) for the system as a whole, or as a result of the decomposition of subsystems [1].

To perform the decomposition of electric power systems models, which are described by systems of nonlinear algebraic equations, it is necessary to observe the following conditions in the places of separation [1]:

- balance conditions;
- conditions for the equality of boundary parameters.

An example of a balance condition is the equality of the sum of the overflows of the power of the subsystems in the boundary node and its nodal power.

The condition of equality of boundary parameters is fulfilled when the decomposition procedure is carried out: the complex of the boundary node voltage, which is simultaneously included in several subsystems, must be the same in different subsystems of the hierarchical electric power system.

The implementation of the functions of electric power systems associated with the uninterrupted supply of regulated quality to consumers requires the solution of optimization problems [2]. Such tasks are to ensure the reliability of the operation (parallel operation) of power connections.

III. OPTIMIZATION PROBLEMS OF ELECTRIC POWER INDUSTRY

The safety of electric power equipment is ensured by monitoring, as well as regulation of voltage levels in order to prevent wear of insulation, as well as current values in the elements of electric power equipment on the condition of heating.

Ensuring the continuity of power supply to consumers is achieved by improving primary connection schemes, using automatic devices, improving central management systems.

The survivability of power systems is ensured by their reliable parallel operation, as well as the prevention of the development of local accidents in the system.

The optimization tasks that need to be addressed in the process of the operation of the electric power equipment can be classified according to the type of perturbations that arise [2]. Control actions such as changing the input coordinates of the process of power consumption, changing the values of the physical parameters of the electric power equipment, changing the composition of the elements of the electric power equipment, and also the connections between them are investigated.

The task of controlling the efficiency of electric power equipment is to analyze the impact of these impacts on the reliability of the functioning of the technological facility.

When estimating the probability of failure-free operation, hypotheses are constructed about the distribution laws, the correspondence of these hypotheses to statistical data is checked, and the parameters of the probability distribution laws are determined.

At the same time, the conditions for failure-free operation of electric power equipment or its failure are formulated. At the heart of the evolution model of the working capacity of the electric power equipment – generator, transformer, substation - is the health state graph of the control object [2].

The reliability of the functioning of the electric power system can be improved by introducing methods and means of technical diagnostics. Diagnostic support in the energy sector allows you to perform an assessment of the state of the equipment at any time, obtain data on the process of its change and make a transition to the management of the state of electric power equipment. Thus, the technology of operating electric power systems is based on the introduction of expert systems.

The tasks of choosing optimal modes of operation of electric power systems are solved, as a rule, with the help of an automated dispatch control system; the optimal operating conditions are determined using an automated system of technical diagnosis. Electric power equipment, as an object of diagnosis, is characterized by the complexity of the processes of changing the technical state. As a consequence, together with mathematical models that operate on quantitative parameters, it is necessary to analyze qualitative diagnostic data. This becomes possible when doing research with the help of logical-linguistic models of heuristic programming.

When implementing heuristic programming methods, a sequential analysis is used when selecting diagnostic parameters, diagnostic tools and methods for processing diagnostic data; multilevel functions and tools, as well as diagnostic information concentrators in the form of a knowledge base. The method of sequential analysis is the multi-stage procedure for deciding the state of a technological object. In this case, expert object-based systems are used, which are combined in an integrated diagnostic system.

The possibility of constructing an automated system of technical diagnosis as a set of multifunctional integrated expert diagnostic systems is achieved by integration and functional integration.

Compatibility of tasks solved by integrated expert diagnostic systems, the presence of multifunctional modules, adaptive organization of the system, which possesses the necessary speed and algorithms of functioning, determine the degree of functional integration.

The speed of the reaction of the integrated expert diagnostic system as a real-time system to the time-varying states of the controlled process is such that timely information flow, decision-making and effective impact on the process are ensured. The functioning of integrated expert diagnostic systems is based on the structuring of the electric power industry.

The integrated expert diagnostic system is a means of implementing the integrated activity of individual subsystems at different levels of the hierarchy and is a system of purposefully interacting through the exchange of information of individual subsystems and electric power equipment.

A feature of the such systems is the organization of a structure that allows the implementation of new devices within the elements of the diagnostic system that enhance the properties of the system's adaptation to the controlled electric power equipment.

Due to the distribution of diagnostic facilities, the task of creating diagnostic systems is to build a distributed network that reflects the location of the diagnosed electrical equipment. This is the topological aspect of the concept of "integration".

The functional aspect of this concept is that the diagnostic system is an element of the information management system. From the point of view of modeling in the construction of integrated expert diagnostic systems, integration consists in the joint application of various types of diagnostic models - deterministic, based on the investigation of cause-effect relationships, as well as models of diagnostics obtained using empirical data based on the use of inductive methods.

Modeling is understood as the problem of minimizing the complexity of the model with limitations on the degree of reliability of the model under study. Electric power equipment, as an object of modeling, is characterized by functional diversity. The information characterizing the diagnostic procedure can be processed by the following types of models: computational, expert, set-theoretic. Computational models describe the relationship between the state of the electric power equipment, its elements and parameters of the output signals. Expert models cover decision-making tasks. The set-theoretical models cover the field of description of data elements characterizing the procedures for diagnosing and forecasting the state of complex electric power equipment.

The rationality of a mathematical model is understood as a property of the model, which consists in its convenience for analysis and obtaining the final result [2]. The theoretical basis of the modeling process is the theory of similarity.

The electric power equipment are investigated for the purpose of determining the effect of defects on them and solving engineering problems in the development of diagnostic tools.

Diagnostic models are developed as formal models in a multidimensional parameter space based on experimental data. The analysis of information characterizing the serviceable condition of the diagnosed electric power equipment and a state with malfunctions allows the development of models for their recognition. For the purpose of data analysis, dispersion, correlation, regression, and cluster analysis are used in the planning of the experiment.

The choice of the method of analysis is determined by the statement of the problem, the properties of the technological object under study, and also by the nature of the qualitative or quantitative factors. The technical state of the object being diagnosed can be described using a linguistic variable [2].

The implementation of the principle of self-organization in the study of the model for diagnosing electric power equipment allows solving the problem of diagnosing for automatic diagnostic systems as an optimization task, in which the optimization criterion is the minimum damage caused by equipment malfunctions.

Numerical modeling of the energy processes occurring in the technological object of the electric power system assumes that the mathematical description of the object under study is known. Thus, probabilistic models for predicting the state of electric power equipment require the calculation of the probabilistic characteristics of random energy processes, which are multidimensional probability density, as well as correlation functions.

Methods for forecasting the functioning of the electric power system are based on the analysis of statistical information. The operation of complex electric power facilities is random.

To describe the transitions of the electric power system from state to state, the theory of random processes is used, which is the basis of probabilistic modeling of the processes of diagnosing complex technological objects.

The set of admissible solutions X of the optimization problem is a composition of a subset of coordinated solutions and a subset of compromise solutions [3].

The area of compromises X^c is a subset of the set of admissible solutions in which no particular criterion can be improved without degrading the value of at least one particular criterion.

The mathematical model for determining the exact area of compromises is [3]:

$$X^c = \bigcup_{a\in A} \arg\max_{x\in X} \sum_{i=1}^{n} a_i k_i(x),$$

where a_i are the weight coefficients of the partial criteria k_i (x) ($i=\overline{1,n}$); A is the domain of definition of particular criteria:

$$A = \left\{ \begin{matrix} 0 \le a_i \le 1, \\ \sum_{i=1}^{n} a_i = 1, \forall i = \overline{1,n} \end{matrix} \right\}$$

The study of this mathematical model reduces to determining the extrema of a linear functional $L(x)=\sum_{i=1}^{n} a_i k_i(x)$ for different values of the weight coefficients $a_i \in A, \forall i=\overline{1,n}.$ At the same time, the area of compromises X^c is formed by performing the procedure for combining these extreme solutions.

When solving problems of stochastic programming, weighting coefficients are set on the interval of possible values of the probabilities of the characteristics, that is, they are random variables. At the same time, for each weighting factor, the deviation from its expectation *M* (*a_i*) should be minimized [3]. Thus, it is necessary to choose such weights for which the conditions are true:

$$a_i^0 = \arg\min_{a_i} \sum_{i=1}^{n} (a_i - M(a_i))^2 ;$$

$$\sum_{i=1}^{n} a_i^0 = 1$$

These conditions can be met if the weights are defined as:

$$a_i^0 = M(a_i) - \frac{\sum_{i=1}^{n} M(a_i) - 1}{\sum_{i=1}^{n} \Delta a_i} \Delta a_i,$$

where $\Delta a_i = a_{i\max} - a_{i\min}$, $M(a_i) = \frac{a_{i\min} + a_{i\max}}{2}$.

The mathematical model for determining the exact area of trade-offs is adequate if the set of admissible solutions *X* of the optimization problem is convex. The following mathematical models of multi-criteria evaluation and optimization: additive, sequential analysis, minimax and maximin, as well as a combination of these models [3], depend on the degree of informability of the decision-maker regarding the weighting coefficients of the importance of the particular criteria a_i.

The decision-making task is structured using the following steps:

– the stage of formation of a set of admissible solutions;

– the stage of finding the solution of the estimation problem;

– the stage of finding the solution of the optimization problem.

The task of evaluation is to determine the metric intended to compare solutions $x \in X$, where *X* is the set of admissible solutions. A set of admissible solutions is given on the basis of an analysis of this problem and is, as a rule, a subregion of the region of existence of the electric power system.

This area is limited by the inequalities [3]:

$$h_s(x,q_h) \le 0, \quad s=\overline{1,S} \tag{1}$$

and equalities:

$$g_l(x,q_g) = 0, \quad l=\overline{1,L}, \tag{2}$$

where *x* is an *N*-dimensional controlled variable, $x \in R^N$; h_s, g_l are operators defining the structure of the mathematical model of constraints (1), (2); q_h, q_g are quantitative parameters of these constraints.

The processes of managing a complex electric power system are nonlinear [4]. The optimization model of a nonlinear nonstationary system has the form [3]:

$$x^0 = \arg\operatorname*{extr}_{x\in X} G[a_i, k_i(x), y, t], \quad x \in R^N, \quad y \in R^M,$$

$$h_s(x, q_h, y, t) \le 0, \quad s=\overline{1,S},$$

$$g_l(x, q_g, y, t) = 0, \quad l=\overline{1,L},$$

where x^0 is the effective solution; $y(t)$ is the scenario of development of the external environment; $k_i(x)$ is the partial criteria; a_i are weighting factors.

From the analysis of the presented mathematical model it follows that variations in the scenario of the development of the external environment cause the change in the target functional without changing the constraints that determine the range of admissible values of the controlled variables, the transformation of these constraints with the unchanged target functional, and also the change of the target functional and constraints.

Example

Consider a situation in which part of the weights is distributed according to a uniform law, and part according to a normal law [3]. In this case, the weights can be determined as follows. Since the reliable probability *P* = 0.997 with a normal distribution law is provided by an interval of $6\sigma_N$, and with a uniform distribution law of $4\sqrt{3}\sigma_U$, the interval recalculation factor is defined as:

$$6\sigma_N = 4\sqrt{3}\sigma_U ; \quad \sigma_U = \left(\sqrt{3}/2\right)\sigma_N .$$

Then the weights are determined as follows:

$$a_i^0 = M(a_i) - \frac{\sum_{i=1}^{n} M(a_i) - 1}{\sum_{i=1}^{m} \frac{\sqrt{3}}{2} \Delta a_i + \sum_{j=m+1}^{n} \Delta a_j} R_i,$$

$$i=\overline{1,n}, \ m<n,$$

$$R_i = \begin{cases} \dfrac{\sqrt{3}\Delta a_i}{2}, \ i = \overline{1,m}, \\ \Delta a_i, \ i = \overline{m+1,n}, \end{cases}$$

where a_j are weights distributed according to a uniform law.

IV. CONCLUSIONS

Decision-making processes in the management of complex electricity systems it is advisable to analyze on the basis of models of non-linear non-stationary systems.

In the development of integrated systems for diagnosing electric power objects, a number of acceptable solutions to the optimization problem should be modeled as a composition of a subset of agreed solutions and a subset of compromise solutions.

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О. Й. Чуріна. Багатокритеріальна задача оптимізації електроенергетики

У даній статті розглянуто оптимізаційні задачі електроенергетики, що моделюються на основі нестаціонарних нелінійних систем. Здійснено аналіз допустимих рішень оптимізаційної задачі на основі композиції підмножин узгоджених і компромісних рішень. При цьому зміна цільового функціоналу оптимізаційної задачі обумовлено варіаціями станів зовнішнього середовища без зміни системи обмежень, що визначають множину допустимих значень керованих змінних. Нелінійність і дискретність оптимізаційних задач запропоновано враховувати в процесі моделювання електроенергетичних систем.

Ключові слова: електроенергетична система; математичне програмування.

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А. И. Чурина. Многокритериальная задача оптимизации электроэнергетики

В данной статье рассмотрены оптимизационные задачи электроэнергетики, моделируемые на основе нестационарных нелинейных систем. Выполнен анализ допустимых решений оптимизационной задачи на основе композиции подмножеств согласованных и компромиссных решений. При этом изменение целевого функционала оптимизационной задачи обусловлено вариациями состояний внешней среды без изменения системы ограничений, определяющих множество допустимых значений управляемых переменных. Нелинейность и дискретность оптимизационных задач предложено учитывать в процессе моделирования электроэнергетических систем.

Ключевые слова: электроэнергетическая система; математическое программирование.

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