UDC 519.7:519.85(045)
DOI:10.18372/1990-5548.62.14382

O. Y. Churina

OPTIMIZATION TASKS FOR CONTROLLING AN ERGATIC ELECTRIC POWER SYSTEMS

Aerospace Faculty, National Aviation University, Kyiv, Ukraine
E-mail: kwh@ukr.net ORCID 0000-0001-5079-0563

Abstract*—This article discusses the optimization tasks of managing a complex control system of the electric power system. The problem of synthesizing the structure of the control system in the design of electrical systems using the optimization - simulation approach is considered. It has been shown that the efficiency of an energy-saving control system is its adaptability to the implementation of the target functional under disturbances. Moreover, the reliability of the functioning of the energy system is set by the system of restrictions of the objective function of the stochastic programming task. A mathematical model of a controlled ergatic electric power process based on the Bellman equation is proposed. Also considered is a mathematical model of the steady state of an electrical system.*

Index Term—Electric power system; mathematical programming.

I. Introduction

A complex control system is designed to generate control actions for executive bodies, its goal is to maximize a given performance criterion. Management strategy is a set of rules, in accordance with which the development of control actions is carried out when receiving information about the state of the control object.

Decision making under uncertainty conditions takes into account the probability of erroneous estimates of uncertain factors. The management strategy analyzes the temporal characteristics of the information used in making the decision. Markov strategy analyzes information received during the final observation time.

The optimal strategy ensures the extremization of the efficiency criterion adopted in the management system; α is the optimal strategy provides the value of the objective function, which differs from the maximum by no more than a certain value α.

The synthesis of the optimal structure of the control system involves the determination of the optimal centralization of the solution of control problems [1].

II. Problem Statement

The analysis of the controlled parameters predetermines the determination of the conditions according to which the control process is modeled. When approximating the relationship between the control parameter and the control process in a steady state by linear dependence, the following is true:

$$\lim_{t\to\infty} z_i(t) = ky_0,$$

where z_i is the control parameter; y_0 is the steady state control process cross section.

The time variability of the controlled parameters is defined as [3]:

$$z(t) = H_1\{t, H_2[t, z(t_{in.c,} y(t), b_1]x(t), b_2\}, \quad t \in [t_{in.c,} t],$$

where $z(t_{in.c})$ is the state of the control object at the moment of the beginning of the control action; $y(t)$ is the control action; $x(t)$ is the input disturbance acting on the control object; H_1, H_2 are operators that determine the dynamic characteristics of a control object; $b_{1,}$ b_2 are information aggregate parameters.

The random nature of the control process determines the appropriateness of using stochastic approximation to evaluate the stability of the control system.

When designing energy systems, a multi-circuit optimization and simulation approach to the synthesis of the control system structure is used. The basis of this approach is an aggregative-decomposition analysis of the elements of control systems, a graph formalization of the structure of control systems. The process of synthesizing the structure of the control system consists in determining the algorithms for solving control problems and in choosing the technical means for implementing the functions of control loops.

The criterion for optimizing the task of synthesizing the structure of a control system is the minimum cost of its design. The task of synthesizing the structure of the control system is an optimization problem with a nonlinear dependence of the quality indicators of the control system on the structural characteristics of its elements [1]. The task of optimizing the prediction mistake of the functioning of the control system is a nonlinear problem with a functional defined algorithmically:

$$\operatorname{extr}\theta(x),\ \ X \in G(\alpha(X)),$$

where $\theta(x), \alpha(X)$ are functions of unit costs of resources that are necessary to increase the integral characteristics of the algorithm in the amount of *X*.

The implementation of this algorithm predetermines the construction of iterative solution schemes. At the same time, it is necessary to analyze the aggregated tasks. The result of the execution of an aggregated algorithm for predicting the functioning of the control system are the parameters of the constraints of the decomposition problems, which are nonlinear problems of integer optimization.

III. Mathematical Model of the Optimal Control Process of the Ergatic Electric Power System

The functioning of the control system proceeds under the influence of disturbing factors, which predetermines changes in its structure, which is coupled with energy losses. As a consequence, it is necessary to find a solution to the problem of synthesizing structures that ensure efficient operation of the control system.

The efficiency of the energy-saving control system is adaptability of the control system to the implementation of the objective functional under perturbation conditions [1]. The operation of energy systems predetermines the property of its survivability, which consists in the ability of the power supply system to withstand extreme impacts and to provide technological objects with electrical energy in accordance with the requirements of quality.

The flexibility of the structure of a complex energy system is determined by the probability that the ergatic system will perform the functions of operation. Algorithms of functioning of these systems with a flexible structure are procedures for the transition from one variant of the structure of the power supply system to another, depending on the system of restrictions on the functioning of the system. The normal mode of operation of the power supply system corresponds to a specific procedure for operating a flexible, functionally-topological structure of the power supply system with the adopted system of restrictions.

In order to predict energy consumption, it is possible to implement an approach based on the identification of optimization simulation models. This approach is to develop an iterative ergatic procedure based on the algorithmization of a deterministic optimization simulation model.

The degree of uncertainty of the initial information when building an optimization model determines the quality of the forecasting process. Iterative ergatic decision-making procedures in the control system consist in the development of an algorithm for solving a deterministic problem.

This problem is solved on the basis of the initial probabilistic one, which characterizes the process of energy consumption, and is its deterministic approximation, taken on the basis of the decomposition approach. The objective function of a deterministic problem is the upper bound for the maximum of the objective function of a probabilistic problem.

The implementation of simulation procedures predetermines the optimal algorithm for determining the best value of the objective function of the stochastic programming problem, taking into account the system of constraints that define a higher level of reliability of the power supply system.

Decision making and management of dynamic objects of the ergatic system is implemented on the basis of solving weakly structured problems due to the uncertainty of the initial information [1].

In the control system of a complex electric power system, the problem of minimizing the average risk is an optimization problem, formulated as follows [2]:

$$R(\alpha) \to \min,$$

where $R(\alpha) = \int Q(z,\alpha)dP(z)$ is the functional; $Q(z,\alpha)$ is the known function; $P(z)$ is the probability measure; $\{z_1, z_2, ..., z_l\}$ random sample, the result of independent tests with a probability distribution $P(z)$.

Developed recurrent methods for minimizing this functional, as well as methods that analyze its empirical estimation based on the expression [2]:

$$R_e(\alpha) = \frac{1}{l}\sum_{i=1}^{l} Q(z_i, \alpha).$$

Thus, the optimal control of the electric power system is achieved when the quality control criterion is reduced to a minimum – of the functional $R(\alpha)$. This optimization problem is solved by methods of stochastic programming. The search for a solution to the problem of optimal control in dynamic electric power systems can be simplified by discretization of the control process.

The solution to this problem can be found by dynamic programming methods applied to the multi-step control process. The model of optimal control on the sampling interval of a controlled process is the Bellman equation, which is a recurrent relation [2]:

$$f_{n-l}(x_l) = \min_{u_l}[Q(x_l, u_l) + f_{n-(l+1)}(x_{l+1})],$$

where x_l is the state of the control system; u_l is the applicable management; $n-l$ is the value, meaning the number of sampling intervals until the end of the control process.

This equation is proposed to be used as a mathematical model of a controlled ergatic electric power process.

When choosing the configuration of the electric power system scheme, as well as the parameters of its elements, performing stability analysis and determining short-circuit currents, evaluating the optimal operating modes, it is necessary to perform calculations of steady-state modes.

When performing calculations of steady-state modes, the electrical network of the system is represented by a replacement circuit in the form of a linear electrical circuit. The purpose of the calculation of the steady state electrical system is to determine the power and current in the branches of the equivalent circuit and the voltages at the nodal points. This task is reduced to solving a system of nonlinear equations due to the nonlinear power from current and voltage [4].

The mathematical model of a steady electric power system is a system of nonlinear equations:

$$\underline{S} = 3\underline{U}_1 J^*, \tag{1}$$

as well as a system of linear equations [4]:

$$Y(\underline{U} - \underline{U}_2) = \underline{J}, \tag{2}$$

where $\underline{S}$ is the power column of sources or consumers connected to the equivalent circuit of the electrical system; $\underline{U}_1$ is the diagonal voltages matrix at the equivalent circuit nodes; $\underline{U}$ is the column voltages in nodes; $\underline{U}_2$ is the voltages column in the balancing node; $\underline{J}$ is the currents column.

Given the power of the nodes of the electric power system, the search for the solution of this system is carried out by iterative methods. Equations (1), (2) are combined into a single system of nonlinear equations. At the same time, at each step of the iterative process linearization of these equations is performed.

Numerical solution of a nonlinear equation with one unknown $f(x) = 0$ is the solution to the problem of finding the minimum of a function $F(x)$, for which $f(x) = \frac{dF(x)}{dx}$. The search for a solution to this problem is carried out by the methods of half-division, stochastic approximation.

The numerical method for solving a nonlinear system describing the steady state of operation consists in the transition to the determination of the extremum of a function of many variables. This analyzes the function F:

$$\frac{\partial F}{\partial x_i} = \text{const}\ f_i(x_1, ..., x_n),\ i = \overline{1, n},$$

$$F = F(x_1, ..., x_n).$$

The minimum of this function is achieved with this set of values α_i, replacing x_i, which satisfies the solution of the system of nonlinear equations.

When designing a control system for a complex electric power system, it is advisable to perform an analysis of the functional structure as well as the topological structure of the project. The functional and topological structure of the control system is determined according to the method of alternative - graph formalization. At the same time, the structure of the control system should be characterized by flexibility, that is, the ability of the system to perform its functions with external influences by a smaller number of elements. The stability of the power system management system is advisable to investigate on the basis of graph theory using the “branches and boundaries” cut-off method.

The topological structure of the project management system of the power system is determined by choosing a variant of its construction. The functional structure of this control system corresponds to the implementation of control functions in the system of restrictions. The solution of the optimization problem of choosing the structure of a control system according to the method of alternative – graph formalization is implemented on the basis of heuristic programming.

According to the criteria of optimality, the synthesis of the functional structure and the topological structure of the control system of the electric power system determines its best option. At the same time, at different stages of the synthesis of these systems, iterative procedures are applied that provide an energy-efficient solution, implying adaptability, reliability, and stability of the synthesized control system structure.

The property of flexibility of the structure of an energy-efficient control system characterizes its ability, under the action of external factors, to ensure the quality of operation of an electrical power system, which is achieved by the variability of the functionally-topological structure of the control system. The flexibility of the control system structure is estimated on the basis of probabilistic modeling of the processes occurring in the electric power system. In this case, the search for the optimal solution is carried out on the basis of stochastic programming methods.

IV. CONCLUSIONS

The criterion for optimizing the problem of synthesizing the structure of a control system for an electric power system using an optimization – simulation approach is the minimum total cost of designing and operating this system.

The task of optimizing the prediction of the functioning of the control system is a nonlinear problem with a functional defined algorithmically. The solution of this problem can be obtained on the basis of constructing iterative procedures. In this case, the result of the execution of an aggregated prediction algorithm of the management system operation are the parameters of the constraints of the decomposition problems, representing nonlinear integer optimization problems.

Sustained normal operation of the electric power system complies with the operation procedure of the flexible functional-topological structure of the power supply system in the adopted system of restrictions.

Decision making and management of dynamic objects of the ergatic system is realized on the basis of solving weakly structured problems due to the uncertainty of the initial information; the degree of uncertainty of the initial information when building an optimization model determines the quality of the forecasting process.

The Bellman equation is proposed as a mathematical model of a controlled ergatic electric power process.

The optimal variant of the control system of the electric power system is determined in the process of synthesis of the functional and topological structures of this system using the methods of stochastic programming.

REFERENCES

[1] N. M. Babynin, V. Ya. Zhikharev, V. M. Imashko, and A. Yu. Sokolov, *Application of artificial intelligence methods in project management*, ed. A. Y. Sokolov, Kharkov Aviation Institute. Kharkov, 2002, 475 p. (in Russian).

[2] V. N. Vapnik and A. Ya. Chervonenkis, *Theory of pattern recognition. Statistical problems of learning*. Moscow, Nauka, 1974, 416 p. (in Russian)

[3] S. K. Bogachev, *Aviation ergonomics: Probabilistic methods*. Moscow: Mashinostroenie, 1978, 138 p. (in Russian)

[4] *Electrical systems. Mathematical problems of electric power industry*, ed. V. A. Venikova. Moscow: vysshaya shkola, 1981, 288 p. (in Russian)

Received September 12, 2019

Churina Alexandra. orcid.org/0000-0001-5079-0563
Candidate of Science (Engineering). Associate Professor.
Department of Automation and Energy Management, Aerospace Faculty, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine, (1990).
Research area: process and systems modeling.
Publications: 31.
E-mail: kwh@ukr.net

О. Й. Чуріна. Оптимізаційні задачі керування ергатичною електроенергетичною системою

У даній статті розглянуті оптимізаційні задачі керування складними електроенергетичними системами. Розглянуто задачу синтезу структури системи керування при проектуванні електричних систем із застосуванням оптимізаційно-імітаційного підходу. Показано, що ефективністю енергозберігаючої системи керування є її адаптованість до реалізації цільового функціоналу в умовах збурень. У цьому разі надійність функціонування енергетичної системи задається системою обмежень цільової функції задачі стохастичного програмування. Запропоновано математичну модель керованого ергатичного електроенергетичного процесу на основі рівняння Беллмана. Також розглянуто математичну модель сталого режиму електричної системи.

Ключові слова: електроенергетична система; математичне програмування.

Чуріна Олександра Йосипівна. orcid.org/0000-0001-5079-0563
Кандидат технічних наук. Доцент.
Кафедра автоматизації і енергоменеджменту, аерокосмічний факультет, Національний авіаційний університет, Київ, Україна.
Освіта: Київський інститут інженерів цивільної авіації, Київ, Україна, (1990).
Напрям наукової діяльності: моделювання систем і процесів.

Кількість публікації: 31.
E-mail: kwh@ukr.net

А. И. Чурина. Оптимизационные задачи управления эргатическими электроэнергетическими системами

В данной статье рассмотрены оптимизационные задачи управления сложными электроэнергетическими системами. Рассмотрена задача синтеза структуры системы управления при проектировании электрических систем с применением оптимизационно-имитационного подхода. Показано, что эффективностью энергосберегающей системы управления является ее адаптируемость к реализации целевого функционала в условиях возмущений. При этом надежность функционирования энергетической системы задается системой ограничений целевой функции задачи стохастического программирования. Предложена математическая модель управляемого эргатического электроэнергетического процесса на основе уравнения Беллмана. Также рассмотрена математическая модель установившегося режима электрической системы.

Ключевые слова: электроэнергетическая система; математическое программирование.

Чурина Александра Иосифовна. orcid.org/0000-0001-5079-0563
Кандидат технических наук. Доцент.
Кафедра автоматизации и энергоменеджмента, аэрокосмический факультет, Национальный авиационный университет, Киев, Украина.
Образование: Киевский институт инженеров гражданской авиации, Киев, Украина, (1990).
Направление научной деятельности: моделирование систем и процессов.
Количество публикаций: 31.
E-mail: kwh@ukr.net