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Рассмотрены актуальные вопросы в области математики, информатики и управления: математического моделирования сложных систем и бизнес-процессов, исследования и разработки защищенных и интеллектуальных информационных и телекоммуникационных технологий, математической теории управления, технологий искусственного интеллекта.

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DESIGNING AN INFORMATION SYSTEM TO ENSURE THE SUSTAINABILITY OF COMPLEX ELECTRIC POWER SYSTEMS

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Annotation. *The article describes the design of an information system for complex electric power systems. Ehnologistsand software development are implemented using an object-oriented programming language. Its functions include transparency and the ability to access the details of a certain method and implementation of the algorithm, mathematical clarity of the description of a new method for the developer and user, openness and potential addition of new procedures, ease of use of the developed methods, and further developmentsand systems.*

1 Introduction

The mathematical model of the modern electric power complex, consisting of turbogenerators and complex multiconnected energy blocks, is a system of nonlinear ordinary differential equations. It is known [1-3] that this model serves as the basis for a broad and relevant class of management tasks.

It should be noted that mathematical modeling of various processes and systems, including electric power, is closely interrelated with the problems of making the best decisions. Optimization tasks, as well as the creation of algorithms for building controls on the principle of feedback for such systems, still attract the attention of many researchers and are relevant.

At the present stage of development of system methods for the development of an information system, there is a steady tendency to create unified data models: information systems built on this principle have greater opportunities for integration with other similar systems, can be organized into distributed networks. One of the main methodological means of constructing data models of subject areas is object-oriented analysis, and its language interpretation is a unified modeling language UML.

Thus, the relevance of the study is determined by the difficulties of managing and ensuring the stability of complex electric power systems consisting of turbogenerators and multiconnected energy facilities. Despite certain successes achieved in the use of information systems to solve a variety of system problems, the problem of creating specialized information systems and mathematical models of stable and optimal electric power complexes was not given enough attention, which became a decisive factor in choosing the direction of research.

2. Formulation of the problem of optimal control. It is necessary to minimize the functionality

$$J(u) = 0.5\sum_{i=1}^{l}\int_0^T\left(k_i y_i^2 + r_i u_i^2\right)dt + \Lambda\big(x(T), y(T)\big), \qquad (1)$$

under the conditions of:

$$\frac{dx_i}{dt} = y_i, \qquad \frac{dy_i}{dt} = -\lambda_i y_i + f_i(x) + b_i u_i,$$
$$x_i(0) = x_{i0}, y_i(0) = y_{i0}, i = \overline{1,l}, t \in (0,T), \qquad (2)$$
$$x(t), y(t) : (0,T) \to R^l,$$

where is the state of the system -management; – given continuously differentiable functions, functions satisfy the conditions of integrability:$\{x_i, y_i\}_{i=1}^{l} \{u_i\}_{i=1}^{l} \{f_i(x)\}_{i=1}^{l}, \Lambda(x,y)\, f_i(x)$

$$\frac{\partial f_i(x)}{\partial x_k} = \frac{\partial f_k(x)}{\partial x_i}, \forall i \neq k; \qquad (3)$$

Point in time T, the initial states will be considered specified; – positive permanent; terminal meanings are not known in advance.$\{x_{i0}, y_i\} r_i, \lambda_i, k_i, b_i x(T), y(T)$

Note that if you set the functions accordingly, then the nonlinear Cauchy problem (1) - (2) simulates an electric power system, for which the synthesis problem is an important practical problem of optimal control. $f_i(x), i = 1, \dots, l,$

3. About the algorithm for sequential improvement of the state-control pair. Following the works [9-14], we will describe the iterative method in relation to the general problem of optimal control:

$$J(x,u) = \int_0^T f^0(x,u,t)dt + F\big(x(T)\big) \to min, \qquad (4)$$

$$x^{/}(t) = g(x,u,t), \qquad (5)$$

$$x(0) = x_0. \qquad (6)$$

Let's transform the problem (4) - (6) using the Krotov function satisfying formula $\varphi(x,t)$,

$$\int_0^T \left(\frac{\partial\varphi(x(t),t)}{\partial t} + \sum_{i+1}^{n} \frac{\partial\varphi(x(t),t)}{\partial x^i} g^i(x(t),u(t),t)\right) dt = \varphi(x(T),T) - \varphi(x_0,0), \qquad (7)$$

$$L(\varphi; x,u) = -\int_0^T R(\varphi; x(t),u(t),t)dt + G\big(\varphi; x(T)\big), \qquad (8)$$

$$R(\varphi; x,u,t) = -f^0(x,u,t) + \frac{\partial\varphi(x,t)}{\partial t} + \sum_{i=1}^{n} \frac{\partial\varphi(x,t)}{\partial x^i} g^i(x,u,t), \qquad (9)$$

$$G(\varphi; x) = F(x) + \varphi(x,T) - \varphi(x_0,0). \qquad (10)$$

The transformed task requires: maximize the functionality (8) by the desired function $\varphi(x,t)$.

The sequential improvement algorithm consists of the following steps:

Step 1. Suppose the s-th approximation of the pair of functions: state-control satisfying the Cauchy problem (5) - (6) is found.$\{x_s(t), u_s(t)\}$,

Step 2. Find a function from the conditions$\varphi_s(x,t)$

$$R(\varphi_s;\ x_s(t), u_s(t), t) = \min_x R(\varphi_s; x, u_s(t), t), t \in (0,T), \tag{11}$$

$$G\big(\varphi_s;\ x_s(T)\big) = \max_x G(\varphi_s; x). \tag{12}$$

Note that the ratios (11) to (12) ensure the fulfillment of the following inequality.

$$L\big(\varphi_s;\ x_s(t), u_s(t)\big) \leq \max_\varphi L\big(\varphi_s;\ x_s(t), u_s(t)\big) \leq \min_{x,u} J(x,u),$$

for satisfying the task (5) - (6), and for satisfying equality (7). The necessary conditions for the fulfillment of the ratios (11) to (12) will be the following:$\forall\{x(t), u(t)\}, \forall\varphi\{x,t\}$,

$$\frac{\partial R(\varphi_s;\, x_s(t), u_s(t), t)}{\partial x} = 0, \tag{13}$$

$$\frac{\partial G(\varphi_s;\, x_s(T))}{\partial x} = 0. \tag{14}$$

Step 3. Find the function $\tilde{u}(x,t)$

$$\tilde{u}(x,t) \in Arg\ \max_u R(\varphi_s; x, u, t) \tag{15}$$

and solving the Cauchy problem (5)-(6) in defining the state and control functions of .$u = \tilde{u}(x,t), x_{s+1}(t) u_{s+1}(t) = \tilde{u}(x_{s+1}(t), t)$

And then, go to step 2, and so on.

Note the expression

$$J\big(x_s(t),u_s(t)\big)-J\big(x_{s+1}(t),u_{s+1}(t)\big)$$
$$=\int_0^T[\,R(\varphi_s;\ x_{s+1}(t),u_{s+1}(t),t)-\ R(\varphi_s;\ x_{s+1}(t),u_s(t),t)]dt$$
$$+\int_0^T[\,R(\varphi_s;\ x_{s+1}(t),u_s(t),t)-\ R(\varphi_s;\ x_s(t),u_s(t),t)]dt$$
$$+\,G\big(\varphi_s;\ x_s(T)\big)-G(\varphi_s;\ x_{s+1}(T))$$

positively due to the conditions (11) - (12) and the ratio

$$u_{s+1}(t)=\ \tilde{u}(x_{s+1}(t),t)\in Arg\ \max_u R(\varphi_s;x_{s+1},u,t)$$

Provided that the pair of the function does not satisfy the relations of the Portnyagin maximum principle. Thus, the described algorithm leads to an improvement in the current $\{x_s(t),u_s(t)\}$approximation.

4. **Application of iterative algorithm to solving the problem of optimal power control of steam turbines.** One of the models describing transient processes in an electrical system is the following system of differential equations [1,2]:

$$\frac{d\delta_i}{dt}=S_i,$$
$$H_i\frac{dS_i}{dt}=-D_iS_i-E_i^2Y_{ii}\,sin\,a_{ii}-\ P_i\sin\ (\delta_i-\alpha_i)-\sum_{j=1,j\neq i}^{l}P_{ij}\sin\ \big(\delta_{ij}-\alpha_{ij}\big)+u_i\,,\ i\in\overline{1,l}\,,\ t\in(0,T), \qquad (16)$$
$$\delta_{ij}=\delta_i-\delta_j,P_i=E_iUY_{i,n+1},\quad P_{ij}=E_iE_jY_{ij},$$

is the angle of rotation of the rotor of the generator relative to some synchronous axis of rotation (the axis of rotation of the DC bus, which rotates at a speed of 50 rpm:;) - the sliding of the generator; – constant inertia of the machine; – mechanical power, which is supplied to the generator; – EMF of the machine; – mutual conductivity of the th and th branches of the system; - Voltage on DC busbars; - mechanical damping; – constant values that take into account the influence of active resistances in the stator circuits of generators.$\delta_i i-S_i i-H_i i-u_i=P_iE_i i-\ Y_{ij} i-j-\ U=constD_i=const\geq 0a_{ij},a_i$

The difficulty of analyzing the model (16) lies in the accounting Since in this case , the model ($a_{ij},a_{ij}=a_{ji}.\delta_{ij}=-\delta_{ji}$16) is not conservative; it is not possible to construct Lyapunov functions for it in the form of the first interval. The system is usually called a positional model.

Let the state and control variables in the steady state after emergency mode be equal to:

$$S_i = 0, \delta_i = \delta_i^F, u_i = u_i^F, i = \overline{1, l}. \quad (17)$$

To obtain a system of perturbed motion, let's move on to equations in deviations, assuming:

$$S_i = \Delta S_i, \delta_i = \delta_i^F + \Delta\delta_i, u_i = u_i^F + \Delta u_i, i = \overline{1, l}. \quad (18)$$

Next, for convenience, the variables are redesignated through $(\Delta S_i, \Delta\delta_i, \Delta u_i S_i, \delta_i, u_i 17)$ we get:

$$\frac{d\delta_i}{dt} = S_i, \frac{dS_i}{dt} = \frac{1}{H_i}[-D_i S_i - f_i(\delta_i) - N_i(\delta) + M_i(\delta) + u_i],$$
$$i = \overline{1, l}, t \in (0, T) \quad (19)$$

Where is

$$f_i(\delta_i) = P_i\left[\sin\left(\delta_i + \delta_i^F - \alpha_i\right) - \sin\left(\delta_i^F - \alpha_i\right)\right],$$
$$N_i(\delta) = \sum_{j=1, j\neq i}^{l} \overline{N_{ij}}(\delta_1, \dots, \delta_l) = \sum_{j=1, j\neq i}^{l} \Gamma_{ij}^1\left[\sin\left(\delta_{ij} + \delta_{ij}^F\right) - \sin\delta_{ij}^F\right],$$
$$M_i(\delta) = \sum_{j=1, j\neq i}^{l} \overline{M_{ij}}(\delta_1, \dots, \delta_l) = \Gamma_{ij}^1\left[\cos\left(\delta_{ij} + \delta_{ij}^F\right) - \cos\delta_{ij}^F\right],$$
$$\Gamma_{ij}^1 = P_{ij}\cos\alpha_i, \Gamma_{ij}^2 = P_{ij}\sin\alpha_i, P_{ij} = P_{ji}, \Gamma_{ij}^k = \Gamma_{ji}^k, k = 1,2.$$

We will search for management in the form of:

$$u_i = \nu_i - M_i(\delta), i = \overline{1, l}, \quad (20)$$

where functions are to be defined.ν_i

It is necessary to minimize the functionality

$$J(\nu) = J(\nu_1, \dots, \nu_l) = 0.5\sum_{i=1}^{l}\int_0^T \left(w_{si}S_i^2 + w_{\nu i}\nu_i^2\right)dt + \Lambda\left(\delta(T), S(T)\right), \quad (21)$$

under conditions (19) to (20), where the positive constant weighting coefficients; - periodic continuously differentiable function; - periodic continuously differentiable function relative to the condition of integrability of type (3); T is the duration of the transition process, considered to be specified. In addition, the initial conditions are set:$w_{si}, w_{\nu i} - f_i(\delta_i) - 2\pi N_i(\delta) - 2\pi\delta_{ij}; N_i(\delta)$

$$\delta_i(0) = \delta_{i0}, S_i(0) = S_{i0}, i = \overline{1, l}, \quad (22)$$

and the quantities are unknown.$\delta_i(T), S_i(T)$

5 Design. Model and description of the subject area.

Whereas in the past users would submit a change request to a data processing application and be satisfied when they received a new program two years later, today a change in the software environment must be made within two weeks. Development timelines of six weeks are becoming common; there is even the concept of extreme programming (XP, extreme programming), since any system in the electric power industry must change very quickly.

That is why there is an increasing need to use UML (Unified Modeling Language), an industry standard for modeling notation used in the development of object-oriented systems, and the basis of a platform for rapid application development (RAD).

There are four phases of a project: inception, elaboration, construction, and transition. In the initial phase, information is collected and basic concepts are developed. At the end of this phase, a decision is made to continue (or not to continue) the project. In the refinement phase, use cases are detailed and architectural decisions are made. Refinement includes some analysis, design, coding, and test planning. In the design phase, the bulk of the code is developed. Commissioning is the final layout of the system and its installation by users.

UML allows you to create several types of visual diagrams. RationalRose supports the development of most of these models, namely [16]:

(a) Class and other diagrams

b) Activity diagrams;

c) Sequence diagrams.

The diagrams illustrate various aspects of the system. Each chart has its own purpose and its own audience. For example, the Activities diagram shows how objects must interact in order to implement some system functionality.

Structural models of the information system of electric power complexes based on UML-deployment diagrams

Currently, in the complex of technological problems [17] of the modern energy system, the following tasks are:

ensuring continuous monitoring of data in order to minimize errors in financial and economic calculations;

optimization of network modes and reduction of pollutant emissions by providing the consumer with the opportunity to regulate demand;

support for comprehensive measurements and continuous data monitoring;

integration of existing and new information systems, etc.

These tasks must be solved at all levels of construction of electrical networks from the electrical networks of the enterprise to regional electric networks.

To solve the selected tasks, information and communication technologies are currently used, including technologies for the creation of hardware and software measuring complexes of energy systems [18], as well as technologies and means that ensure the integration of measuring complexes into a single intelligent information system.

The creation of a unified information system can go in two directions:

integrated creation of energy facilities with parallel implementation of information technologies, their control and accounting;

creation of a single system based on a ready-made functioning energy system.

Due to the fact that there is a functioning multi-level, centralized energy system in Kazakhstan, it is obvious that the use of the first direction is justified for existing regional networks and enterprises, while the second approach is justified for newly introduced networks and enterprises.

To create a unified information system, a set of measures is required, which may include the following stages [19]:

comprehensive analysis of the structure, features and problems of the energy system;

analysis and assessment of the scope of work;

determination of the principles of decompositions of the information system into subsystems;

selection of design methodology;

identify means of implementing selected methods;

implementation of the information system.

Next, consider the representation of the functions of the organization as a whole, that is, a description of the context of the system and the formation of a basis for the development of diagrams.

you should be careful about your analysis and focus on what the problem is and not how it will be solved. a state is a position in the life of an object in which it satisfies a certain condition, performs some action, or waits for an event. The state of an object can be described by using the values of one or more attributes of a class. The state of an object is determined by examining attributes and relationships specified for it.

Software development is subject to a certain life cycle (LC). A lifecycle is an orderly set of activities that are carried out and managed within the framework of each software development project. The life cycle defines the stages, so that the software product moves from one stage to another, starting with the birth of the product concept and ending with the stage of its maintenance.

At the enlarged level, the LC includes three stages:

–analysis;

–design;

–realization.

At a detailed level, the LC can be divided into seven stages:

–setting requirements;

–specification of requirements;

–architecture design;

–detailed design;
–implementation;
–integration;
–accompaniment.

Our task is to consider in detail the first stage - the establishment of requirements. The task of the requirements determination stage is to determine the accidents at the stations. At this stage, various methods of collecting information from stations are used, and a process analyst (system analyst) is engaged in this. The methods include the study of the concept using structured and unstructuredx datax with counters.

Consider the requirements imposed by users of this system. Future users have the following requirements for the system being developed:

–the system should reduce the amount of time spent on searching and processing information;

–the ability of the user to use the software product if he has minimal knowledge of the computer;

–the system should ensure the reliability of information, all the time replenishing the database, since the information is often updated;

–the system should analyze the data taking into account various restrictions selected by the user and display the results in tabular form.

The next stage of software product development is to build a precedent chart.

The behavior of the system – as it looks to an external user – is portrayed as precedents. Models of precedents can be developed at different levels of abstraction. In the analysis phase, precedents absorb system requirements, concentrating on what the system does or should do.

A precedent performs a business function that can be observed by an external entity and that can then be separately tested during the development process. A subject (actor) is someone or something that interacts with a precedent, expecting to eventually get some useful result.

A precedent chart is a documented model of the intended behavior of a system.

Each precedent should be described using a documented stream of events. The corresponding text document defines what the system should do when an actor initiates a precedent. The structure of the document describing the precedent is different, but a typical description should contain the following sections:

–a brief description;
–preconditions;
–Detailed description of the event flow: main thread and alternate threads;
–postconditions.

An object is an entity of the real world or a conceptual entity. An object can be something specific, such as Joe's truck or my computer, or conceptual, such as a chemical process, a banking transaction, a trade order, a credit history, or a rate of return.

An object is a concept, abstraction, or thing with well-defined boundaries and meaning to the system. Every object in a system has three characteristics: state, behavior, and individuality.

The state of an object is one of the conditions in which it can reside. The state of the system usually changes over time and is determined by a set of properties called attributes, property values, and relationships between objects.

Behavior defines how an object responds to requests from other objects and what the object itself can do. The behavior is implemented using a set of operations (operations) for an object.

Identity means that each object is unique, even if its state is identical to that of another object.

A class is a description of a group of objects with common properties (attributes), behavior (operations), relationships with other objects, and semantics. Thus, the class is a template for creating an object. Figuree 1 shows a diagram of the system deployment.

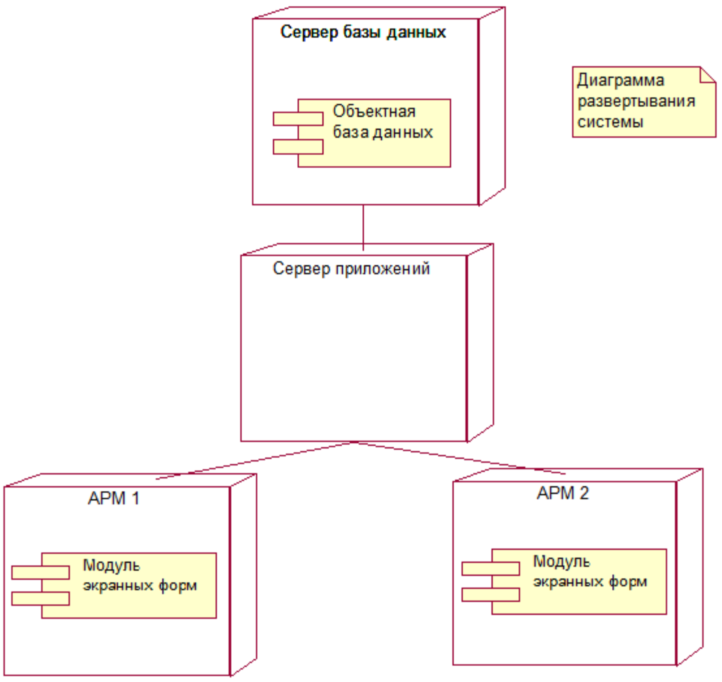

Figure 1 - IP Deployment Diagram

Conclusion. The paper deals with the problems of optimal control of a nonlinear system of ordinary differential equations in two different cases. The model under study, in particular, describes the control processes in electric power systems.

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Под редакцией М.Н. Калимолдаева

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