Principles of Information Support for Intelligent Energy-Efficient Control Systems

D. Yu. Muromtsev[1], A. N. Gribkov[2], I.V. Tyurin[3], V.N. Shamkin[4]
Tambov State Technical University
Tambov, Russia
[1]mdjur@mail.ru, [2]GribkovAlexey@yandex.ru, [3]tyrinilja@yandex.ru, [4]shamkin-v@mail.ru

***Abstract*— The paper explores the approaches to the design of the information support for intelligent energy-efficient control system, the functional core of which is formed by an expert system. The information about the date stored in the database and data access models is given. The principles of representation of knowledge in the stratified frame-based knowledge base of a hierarchical structure are presented. The integrated graph of the generalized technology of intellectualization of synthesizing energy-efficient control actions for MIMO thermal systems in the mode of heating is presented.**

***Keywords*— energy saving; MIMO systems; database; knowledge base; expert system; control system; a set of states of functioning**

I. Introduction

Modern requirements for the environmentally friendly and economical use of industrial equipment imply extensive introduction of promising innovative methods to control energy-intensive facilities, such as intelligent and energy-efficient technologies. At present, in the vast majority of cases, only the costs of extracting mineral resources are taken into account in the manufacturing of products, therefore, the impact of solid and gaseous wastes that are a by-product of energy production are not included in the final price of the manufactured product. The industrialized countries use a huge amount of natural hydrocarbon raw materials for energy production, and in the foreseeable future, the world's oil and gas reserves will be depleted, thus the resource constraint factor also determines the need for wide application of energy-saving technologies. A feature of domestic industry is the inefficient use of fuel and energy resources. Many energy-intensive industrial facilities have a rather low efficiency, which leads to huge energy losses.

In the world practice to date, several basic approaches to reducing energy consumption have been developed. Firstly, it is the optimization of technological processes and the use of new materials and technical facilities. Secondly, alternative renewable energy sources, such as solar energy, geothermal energy, wind, tidal energy and others have been developed and used. Thirdly, it is necessary to develop energy-efficient technologies at the expense of optimal control of energy-intensive facilities.

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The most energy-intensive industrial equipment includes primarily thermal process units – various furnaces, dryers, vulcanizing heaters, boiler rooms and refrigeration units. Most of these devices are typical multiple input multiple output systems, in which each input signal affects a group of output signals and, accordingly, the output depends on several inputs.

II. Features of MIMO Systems as Objects of Control

The main features of MIMO systems as control objects are the following:

- significant energy costs;
- strict requirements for maintenance of process parameters;
- the importance of taking into account the processes occurring in the equipment and having mutual effect on each other;
- the presence of external and internal factors in the control and measurement channels;
- variation of parameters of MIMO systems in the course of actual operation.

The effectiveness of a MIMO system is determined by its fail-safe properties, operating modes, external effects and other destabilizing factors of deterministic, probabilistic or fuzzy nature. To take into account all these factors, in the aggregate, a set of operability states (SOS), a set of functioning states (SFS) and a fuzzy set (FS), forming a certain space, are introduced. Their schematic representation is shown in Fig. 1.

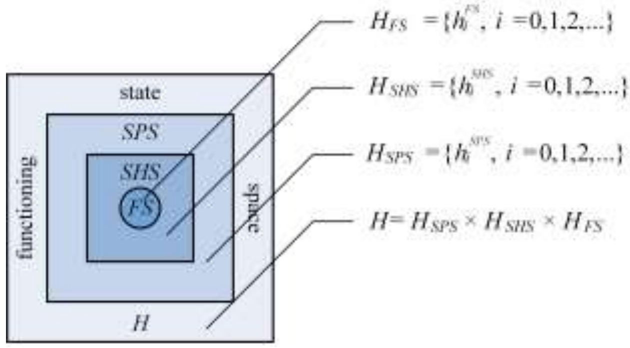

Fig. 1. Components of the functioning state space

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The following notations are introduced in Fig.1: H is functioning state space; H_{SPS} is a set of production situations; H_{SHS} is a set of operability states; H_{FS} is a discrete set obtained from fuzzy sets using a procedure analogous to the linguistic approximation.

The SOS makes it possible to analyze situations for which sufficient statistical data have been accumulated, for example, on equipment failures, information systems, personnel errors and other factors. The calculation of the probabilities of operability states (both stationary and non-stationary) is carried out using various methods [1, 2] based on the decomposition of the system, the construction of models of operability states of the components and the system as a whole, and then the solution of the systems of equations or the use of recurrence formulas.

However, knowledge of the operability states of the system and the probabilities of these states is in many cases insufficient to determine the risks and predict the performance indicators of the systems being designed in the course of actual operation. The possible states of functioning during the long-term operation of the system are presented by the SFS [1], in which, along with the working conditions, changes in operating modes associated with new production tasks, changes in the formulation of management tasks, the intensity of external effects, etc. are taken into account. The structure of the SFS is similar to the SOS, and practically the same methods are used to determine the probabilities of the functioning states.

At the same time, neither the SOS nor the SFS take into account the rapidly changing external environment. This may be due to changing consumer demand, energy prices, raw materials, as well as other factors, for which there is insufficient statistical material, and they can only be described at a qualitative level. The solution of this kind of situational problems associated with building models and optimizing under uncertainty in the operational decision-making leads to the need to use artificial intelligence methods. Inadequate theoretical training of users and insufficient use of experience and knowledge of experts in the relevant subject area also requires intellectualization of the system under development when it is actually used. Therefore, the development of the methodology for the design of an intelligent system that is invariant to various MIMO systems and that is able to synthesize energy-saving control actions in real time with regard to the features of these systems, is a sought-after task.

III. INFORMATION SUPPORT FOR INTELLIGENT ENERGY-EFFICIENT CONTROL SYSTEM

The basis of an intelligent energy-efficient control system is the expert system (ES), whose simplified structure is shown in Fig. 2 [3]. It implements a methodology for constructing hybrid expert systems designed to solve the problems of managing MIMO energy-intensive technological systems.

The database contains information on the results of the implementation of the intelligent energy-efficient control system, the effect obtained using the synthesized control algorithms, the different types of process models, the parameters and composition of models for MIMO systems, as well as the strategies used, the conditions for solving control problems, etc.

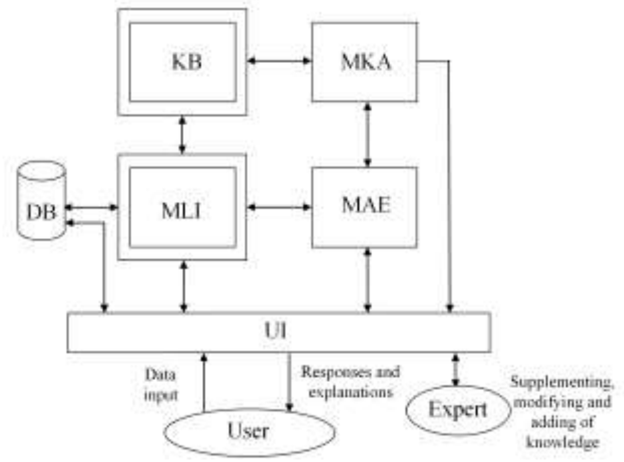

Fig. 2. Generalized block diagram of the expert system of an intelligent energy-efficient control system: KB is knowledge base; DB is database; MLI is mechanism of logical inferences; MKA is module for knowledge acquisition, MAE is module for advice and explanations; UI is user interface

The KB contains both general knowledge of mathematical methods of analysis and synthesis, as well as knowledge of applied nature, obtained from experts and used by developers of algorithmic support. Users and experts interact with the ES through a user interface. At the same time it is planned to replenish the KB with the results of actual operation of the facilities. The mechanism of logical inferences applies knowledge and information from the knowledge and data bases when solving practical problems. The knowledge acquisition module allows supplementing and modifying knowledge during the operation of the system, and the module of advice and explanations offers conclusions and necessary explanations to the user.

The KB has a stratified hierarchical structure in the form of a set of interrelated frames forming a single frame system in which declarative and procedural knowledge is combined, and principles inherent in the object-oriented approach, such as encapsulation, inheritance and polymorphism. Knowledge base frames have slots that contain not only a specific value, but also the names of procedures that allow you to calculate this value using a given algorithm. Some frames contain slots, the placeholders of which are the product rules used to determine a particular value.

As an example, Fig. 3 shows the integrated graph of the generalized technology of intellectualization of synthesis of energy-efficient control actions for MIMO thermal systems in the heating mode.

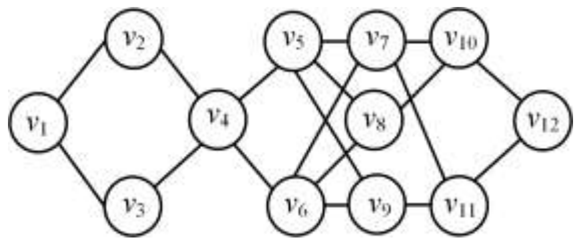

Fig. 3. Integrated graph of generalized technology of intellectualization of synthesis of energy-efficient control actions

The composition and description of the components shown in Fig. 3 graph is given in Table. 1.

TABLE I INTEGRATED GRAPH COMPONENTS

Stratum	Vertex	Description
modes	v_1	heating
control aims	v_2	energy-saving
	v_3	resource-saving
mathematical models	v_4	model of heating elements
features of control problems	v_5	energy saving
	v_6	fuel saving
strategies	v_7	program
	v_8	position
	v_9	combined
analysis and synthesis	v_{10}	control program
	v_{11}	synthesizing function
simulation	v_{12}	working areas heating models

The information intelligent environment of the designer of energy-saving control systems is a software package.

“Analysis and synthesis of optimal control” modules for the array of initial data of the optimal control problem of <*M*, *F*, *S*, *C*>, where *M* is type and parameters of the object model, *F* is type of minimized functional (energy consumption, fuel consumption, control time, etc.), *S* is implementation strategy of optimal control, *C* is conditions and limitations, make it possible to perform rapidly the following studies:

- determine the type of optimal control function implemented by the program or position strategy;
- calculate optimal control parameters;
- calculate the trajectories of the change in the phase coordinates and the control effect on the time interval of control;
- assess the effect of energy saving and improving the quality of products;
- evaluate the robustness of the optimal control algorithm when the initial data changes;
- develop software for microprocessor devices;
- solve inverse optimal control problems (to determine the values of the initial data to achieve the required results).

The original method of analysis and synthesis of optimal control makes it possible to display a generalized geometric image of a set of possible solutions for specific classes of mathematical models and initial data on the screen (Fig. 4)

The set of modules “Identification of the control object model” allows solving the following problems:

- carry out experiments and preliminary data processing;
- determine parameters of the object dynamics model;
- determine the distribution law of perturbations;
- visualize identification processes.

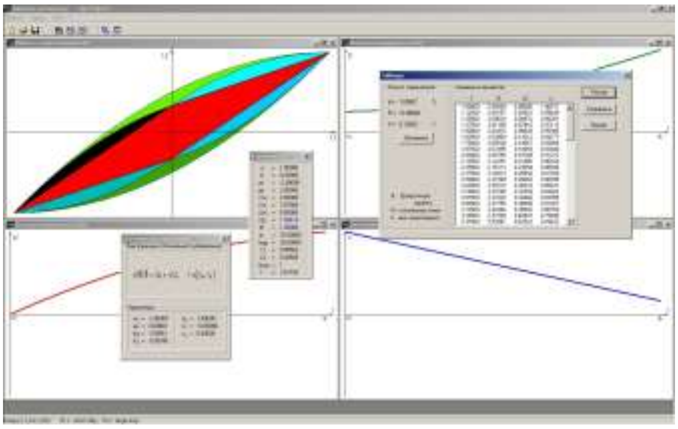

Fig. 4. Interface of the working environment of the module for analysis and synthesis of energy-efficient control

Fig. 5 shows a fragment of the interface of the working environment of the module.

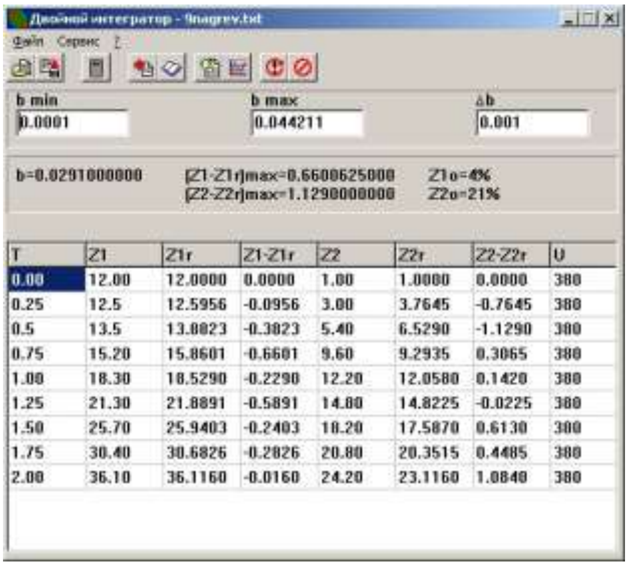

Fig. 5. Fragment of the interface of the identification module

The module “Making informed decisions” allows using a wide range of methods to rank alternative options, pair comparisons, Pareto optimization, Bayes-Laplace, game theory, etc., and also attract experts through the Internet. It should be noted that in the Internet there is a functioning module for Expert system of energy-efficient control designed for analysis and synthesis of optimal control, which can be viewed at http://crems.jesby.tstu.ru/di.

With the help of the created intelligent environment, algorithmic support and software of energy-efficient control systems for various industrial equipment (heat treatment plants for magnetic circuits, mixing machines for the production of polymer materials, vulcanizing units, chamber and multi-zone electric furnaces, multi-section rollers for dryers, electric motors, etc.) have been developed. [4, 5].

IV. CONCLUSION

A number of theoretical studies and the results of the practical implementation of energy-efficient control systems show that the use of the considered multifunctional intelligent information environment comprising all stages of designing such systems:

- reduces significantly the time frame for the development of resource-saving management systems;
- provides support for group design, including in remote access mode;
- uses the experience of previous developments (through the application of the principles of inheritance and the constant replenishment of the knowledge base);
- reduces the cost of design work.

At the same time, companies can upgrade their control systems of existing energy-intensive industrial facilities, improve the reliability of the equipment, ensure energy efficiency, environmental friendliness and cost-effectiveness of equipment, and reduce the cost of production and improve its quality.

The scope of application of the results obtained for energy-efficient control is quite extensive and is not limited only to multi-zone and electric furnace furnaces. The developed systems of control are universal, easy to operate, reliable, maintainable, adapted to harsh industrial conditions, have high noise immunity, which increases reliability in general. These systems are also scalable for different enterprise infrastructures based on specific needs.

The broadest possibilities appear when using remote access modes and managing spatially distributed objects. Remote access significantly increases the scope for large-scale process control. This is especially true for companies that have branches (subsidiaries) and can monitor and manage all the technological processes of their subsidiaries from the headquarters of the parent company.

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