A Conceptual Database Model of Energy-Efficient Control over MIMO Process Systems

A. N. Gribkov[1], D. Yu. Muromtsev[2], V. N. Shamkin[3], I. V. Tyurin[4]
Tambov State Technical University
Tambov, Russia
[1]GribkovAlexey@yandex.ru, [2]Postmaster@nauka.tstu.ru,
[3]Shamkin-V@mail.ru, [4]TyrinIlja@yandex.ru

***Abstract*— Theoretical and practical aspects of constructing a conceptual database model for the system of energy-efficient control over MIMO-systems on a set of states of functioning are considered.**

Key words*— *energy-efficient control system; conceptual model; database; MIMO-system; set of states of functioning

I. Introduction

Energy-efficient control systems (EECSs) for complex technological objects are widely used in various industries. EECSs significantly reduce energy costs, but also increase the productivity of industrial processes and ensure the quality of products. In this regard, issues related to the development of such systems are quite relevant.

From the point of view of automation, practically all existing technological installations used in modern industry are complex MIMO-systems that have a lot of interrelated input and output variables [1]. The examples of such facilities are heat engineering devices (drying plants, industrial furnaces, boiler plants, etc.), which are not only widely distributed, but also belong to the most energy-intensive facilities in industrial production [2].

In most cases, the development of algorithmic support for EECSs ensuring the solution of problems of optimal control over MIMO-systems is “science intensive” research, since quite complex algorithms can be included in the algorithmic support of the system (identification of models, analysis and synthesis of optimal control on a set of states of functioning; simulation, decision-making under uncertainty, etc.), most of which run in real time.

Therefore, modern EECSs are powerful computing packages, one of the main components of which is complex software and information support, including a knowledge base and a database that provide the basic functionality of the system.

II. Database as a Key Component of the Energy-Efficient Control System

One of the most important stages in the development of software for EECS is its structuring, i.e. allocation of subsystems and modules. In the structure of the EECS for MIMO-systems, the following main components can be distinguished: knowledge management subsystem, interface subsystem and six basic program modules [3].

The knowledge management and data management subsystem includes: a knowledge base; the output machine; database and database management system. The subsystem of the interface consists of a module for input of initial data and a module of cognitive graphics [4], as well as an integrated development environment.

The software modules in the EECS are designed to perform the following functions: identification of the dynamics models of the control object; complete analysis of optimal control problems (OCPs); synthesis of optimal control actions; simulation modeling; identification of the current state of functioning; experiment planning. The considered structure of the EECS is sufficiently universal and invariant to various control objects.

The software modules and the EECS subsystems exchange data with each other using a database in which the results obtained by all modules of the system are saved, therefore the database is one of the key components to which all the subsystems and modules of the EECS address.

The specific structure and model of the database will in many respects be determined by the features of the EECS and the control object. In this case, it is also necessary to take into account that the architecture of the EECS software largely depends on which of the four classes in the set of operational states the considered EECS refers to [3]. This circumstance, in turn, is reflected in the structure of the database of the system.

Nevertheless, it is possible to identify a number of structural components of the database model that will be available in almost all EECSs for MIMO-systems. These components can be represented as a generalized structure of the database model.

III. A Generalaized Structure of Database Model for Energy-efficient Control System

One of the most popular standards used to represent the semantics of the described domain and develop a conceptual database model is the IDEF1X standard based on the models

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and methods proposed by Chen and Barker [5, 6] in combination with the concepts of E.F. Codd's relational theory [7]. It should be noted that relational databases are currently the most common storage environments structured information in automated information systems for various purposes (control, design etc.) [8].

The IDEF1X notation is a formalized language that is intended to describe data structures, the main components of which are entities, relations between entities, and attributes. An entity is a set of instances of objects that have common characteristics (attributes). Relations are the connections between two or more entities. At the same time, to ensure unambiguous identification of a particular entity instance, a certain set of attributes called a key is used.

The main entities in the generalized structure of the database model of the EECS are the following:

- "Source data" containing information about the control object, including the values of basic mode parameters and arrays of details of the EECS;
- "Results of the EECS analysis" containing results of a complete analysis of the EECS for a particular source data set [9];
- "Control algorithms" including the values of the components of the functioning state variable and the corresponding algorithms for synthesis of optimal control actions;
- "Results of the EECS functioning" providing storage of statistical data on the results of the EECS functioning.

The main attributes of the "Source data" entity that determines the arrays of the EECS details can be the dimension and the values of the parameters of the dynamics model; the boundaries of the time interval of control; the constraints imposed on the control actions at each point in time; the initial and final values of phase coordinates; the characteristics of disturbing effects acting through control and measurement channels; restrictions on the permissible energy limit, etc.

The main attributes of the "Results of the EECS analysis" entity include the calculated values of synthesizing variables and phase coordinates; the possibility of the existence of a solution for the given source data; the type and parameters of optimal control functions.

The main attributes of the "Results of the EECS functioning" entity are the values of the input and output variables of the control object. The input variables are control actions synthesized by the system based on the results of a full analysis of the EECS and simulation modeling (a direct selection of the synthesis algorithm is performed through the identified value of the functioning state variable). The output variables are measured by the corresponding sensors (temperature, pressure, humidity, etc.) and are fed into the system via the measuring channel. In addition, this value can also store the values of the minimized functional (for example, energy consumption or fuel consumption).

In addition to the entities considered, the database model can include entities that contain the results of identification of the dynamics models for various states of the system's functioning, simulation modeling of the EECS operation.

IV. A Practical Example of Constructing a Conceptual Model of Database

We consider a practical example of constructing a conceptual model of the EECS database for a group of complex heat engineering devices. The control objects are convective multi-sectional roller-belt dryers used for drying paste-like materials [10].

From the automation perspective, each dryer can be considered as a MIMO-system, in which the degree of opening of the steam supply valves in the air heaters is control actions, and the temperature values in each section of the device are phase coordinates. The influence of neighboring sections on each other can be considered as perturbing effects [11].

The EECS provides optimal control for a number of similar objects (drying plants), which are located in several workshops and differ from each other by process and design parameters (number of sections, types of air heaters installed in the sections, etc.). The considered EECS belongs to the third class of systems on the set of states of functioning [12], i.e. the value of the functioning state variable prior to the start of the control is known and it can change in the time interval of control, but at each instant of time it can be identified with high accuracy. The structural scheme of the EECS for a group of drying plants is shown in Fig. 1.

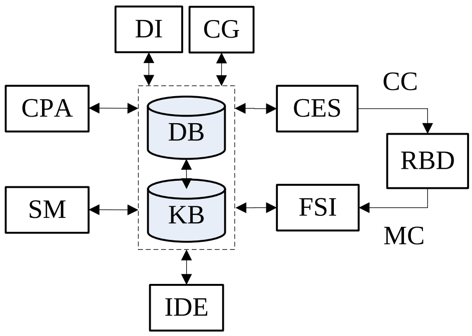

Fig. 1. Block diagram of EECS for drying plants

DB – database; KB – knowledge base; CPA – control problem analysis module; SM – simulation modeling; CES – optimal control effects synthesis module; FSI – current functioning state identification module ; DI – source data input module; CG – cognitive graphics module; IDE – integrated development environemnt; RBD – convective multi-sectional roller-belt dryers (control objects); CC – control channels; MC – measurement channels.

It should be noted that the above diagram is somewhat simplified, since it does not show such components of the EECS software as output machine, database management system, etc.

The EECS input receives the source data, which are set by the operator using the DI module or loaded from the database, from which the OCP data arrays are formed. Then, the OCP is analyzed in the CPA module and simulation in the SM module is carried, then the direct control of the drying plant is taken and the results are output via the CG module. The process of drying plant control is carried out in the following way: first, on the basis of data obtained from sensors, the current status of the drying plant is identified using the FSI module, then the most optimal algorithm for the synthesis of control actions is selected according to the results of the OCP analysis and simulation, which is implemented by the CES module. In this process, the main process parameters are continuously monitored and the resulting parameter values are transmitted back to the FSI module.

For each drying plant, depending on its current state of functioning, different OCPs are solved and various algorithms for the synthesis of optimal control actions are selected [13].

We consider a fragment of the database model for the EECS related to the operation of the program modules for input of source data, the OCP analysis, simulation and identification of the state of functioning (Fig. 2). The subject-significant entities include “Control objects”, “States of functioning”, “OCP data arrays”, "Results of OCP analysis”, “Simulation modeling”. Between the entities "OCP data arrays” and “Results of the OCP analysis”, a one-to-one relation is used, and one-to-many relations are used between the remaining entities.

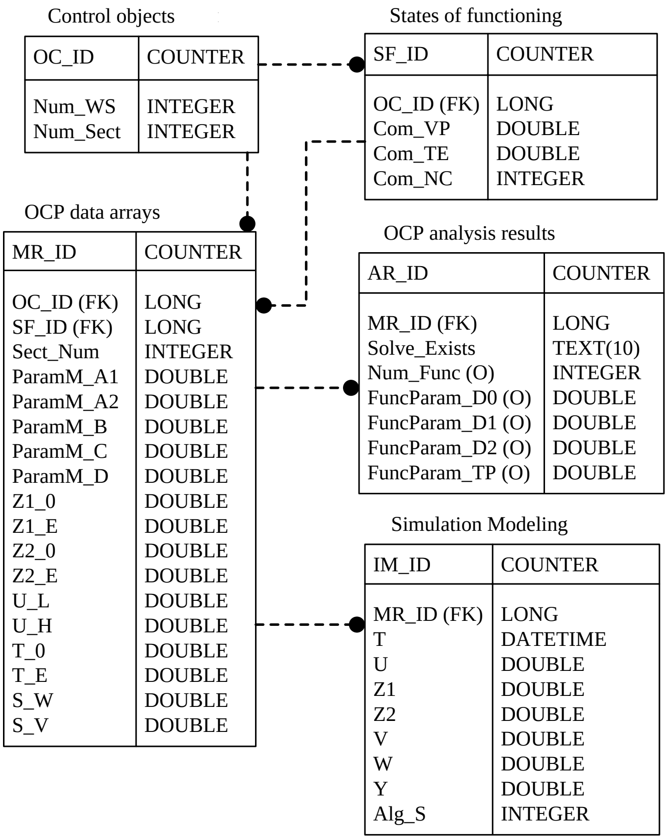

Fig. 2. Fragment of the conceptual model of the database

The attributes of the “Control objects” entity are: OC_ID is the object identifier (primary key); Num_WS is the number of the workshop in which the drying plant is located; Num_Sect is the number of sections of the drying plant.

In addition to the key identifier, the “State of functioning” entity also contains attributes related to the components of the state variable: Com_VP is vapor pressure; Com_TE is the ambient temperature; Com_NC is the presence of disturbances through the control and measurement channels.

The “OCP data arrays” entity includes the attributes containing the main components of the arrays of source data necessary for solving the OCP, where: Sect_Num is the number of the section of the drying plan for which the OCP is being solved; ParamM_A1, ParamM_A2, ParamM_B, ParamM_C, ParamM_D are parameters of the dynamics model in the form of a system of differential equations (in the example considered, the models of the double aperiodic link are used); Z1_0, Z1_E, Z2_0, Z2_E are initial and final values of phase coordinates; U_L, U_H are boundary values of the control action; T_0, T_E are initial and final values of the time interval of control; S_W, S_V is the intensity of disturbing effects through the control and measurement channels.

The attributes of the “Results of the OCP analysis” entity are as follows: Solve_Exists indicates the presence or absence of the OCP solution for the given source data; Num_Func is number of the optimal control function form; FuncParam_D0, FuncParam_D1, FuncParam_D2, FuncParam_TP are calculated values of the optimal control parameters function.

The attributes of the “Results of the OCP analysis” entity are as follows: Solve_Exists indicates the presence or absence of the decision of the LMS for the given source data; Num_Func is number of the form of the optimal control function; FuncParam_D0, FuncParam_D1, FuncParam_D2, FuncParam_TP are calculated values of the optimal control function parameters.

The “Simulation Modeling” entity contains the following attributes: T is current time value on the time interval of control; U is the magnitude of the control action; Z1, Z2 are values of phase coordinates; V, W are the values of the disturbing effects that were generated during the simulation; Y is the calculated value of the output variable; Alg_S is the number of the synthesis algorithm used to form the control values of U.

It should be noted that for the practical construction of database models CASE tools [14] are currently widely used that allow not only to create a conceptual model in IDEF1X notation, but also to automatically convert the obtained model into a data model for a particular database management system. An example of such a tool is AllFusion ERwin Data Modeler, which is used to design relational databases in IDEF1x, IE and Dimensional [15].

V. Conclusion

The theoretical and practical aspects of constructing a database conceptual model for MIMO-systems are studied. The structure of the EECS software is considered and the role of a database as a key element of the system with which all the software components of the EECS are interacting is shown. The generalized structure of the EECS database model on the basis of the IDEF1X standard is presented, and the main subject-significant entities and their attributes are identified.

A practical example of constructing a conceptual model of the database of the EECS for a group of heat engineering devices (roller-belt dryers) is considered.

References

[1] Goodwin G.C., Graebe S.F., Salgado M.E. Control system design. New Jersey. Prentice Hall, 2000. 908 p.

[2] Artemova S.V. Information system of optimal control of thermal technological devices: monograph. Moskow. St.Petersburg. Vienna. Hamburg. Publishing house IINC, 2011. 234 p. (In Russian).

[3] Gribkov A.N., Muromcev D.Yu., Shamkin V.N., Belousov O.A., Belyaev M.P. Software architecture for energy efficient control over process parameters of MIMO systems on a set of functioning states. *Materialy II Mezhdunarodnoj nauchno-tehnicheskoj konferencii "Problemy mashinovedenija"* [Proc. of the II Int. Sci. Conf. "Mechanical science and technology update"]. Omsk. 2018. pp. 190-194. (In Russian).

[4] Chernyshov N.G., Belousov O.A. Remote dynamic objects control system using the principles of cognitive graphics. *Avtomatizacija i sovremennye tehnologii* [Automation and modern technologies]. 2010. No. 7. pp. 28-33. (In Russian).

[5] Chen P.P-S. The Entity-Relationship model – toward a unified view of data. ACM Transactions on Database Systems. 1976. V.1. No.1. P. 9-36.

[6] Barker R. CASE method. Entity-Relationship modeling. N.Y.: Addition Wesley Publishing Company, 1991. 350 p.

[7] Codd E.F. A relational model of data for large shared data banks. Communications of the ACM. 1970. No.13(6). P. 377-387.

[8] Mokrozub V.G. *Grafovye struktury i reljacionnye bazy dannyh v avtomatizirovannyh intellektual'nyh informacionnyh sistemah* [Graph structures and relational databases in automated intelligent information systems]. Moskow. Izdatel'skij dom «Spektr». 2011. 108 p. (In Russian).

[9] Muromcev Ju.L., Pogonin V.A., Grebennikov R.V. Analysis of energy-saving control of multidimensional objects. *Vestnik Tambovskogo gosudarstvennogo tehnicheskogo universiteta* [Transactions of Tambov state technical university]. 2007. V.13, no. 4. pp. 838-846. (In Russian).

[10] Brjankin K.V., Degtjarev A.A., Bogachev D.A., Bel'kov A.I. Technological modes of drying temperature-pependent azo pigments in roller band dryer. *Vestnik Tambovskogo gosudarstvennogo tehnicheskogo universiteta* [Transactions of Tambov state technical university]. 2015, V.21, no. 4. pp. 615-623. (In Russian).

[11] Gribkov A.N. Information and control system by dynamic modes in multi-section drying plants. *Informatika i sistemy upravlenija* [Information science and control systems], 2009, no. 2(20). pp. 123-129. (In Russian).

[12] Muromcev Ju.L., Ljapin L.N., Popova O.V. *Modelirovanie i optimizacija slozhnyh sistem pri izmenenijah sostojanija funkcionirovanija* [Modeling and optimization of complex systems with changes in the state of operation]. Voronezh. Izd-vo VGU, 1992. 164 p. (In Russian).

[13] Muromcev D.Yu., Gribkov A.N., Shamkin V.N. Methodology for the selection of synthesis algorithm of control actions for the multidimensional technological object on the set of operation states. *Informatika i sistemy upravlenija* [Information science and control systems]. 2017. no. 3(53). pp. 109-118. (In Russian).

[14] Surkova N.E., Ostrouh A.V. *Metodologija strukturnogo proektirovanija informacionnyh sistem: monografija* [Methodology of structural design of information systems: monograph]. Krasnojarsk. Nauchno-innovacionnyj centr. 2014. 190 p. (In Russian).

[15] Tumanov V.E., Maklakov S.V. *Proektirovanie relyacionnyh hranilishch dannyh* [Designing relational data stores]. Moscow. Dialog-MIFI. 2007. 333 p. (In Russian).