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INTELLIGENT DATA MAINTENANCE FOR AUTOMATIZED CONTROL SYSTEM OPERATORS OF A THERMAL POWER PLANT

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Представлені результати розробки структури та інформаційного забезпечення системи інтелектуальної підтримки операторів для прийняття рішень при управлінні технологічними процесами на теплоенергетичному підприємстві.

Ключові слова: *обслуговування даних, інтелектуальне, система управління, теплова електростанція.*

Представлены результаты разработки структуры и информационного обеспечения системы интеллектуальной поддержки операторов для принятия решений при управлении технологическими процессами на теплоэнергетическом предприятии.

Ключевые слова: *обслуживание данных, интеллектуальное, система управления, тепловая электростанция.*

INTRODUCTION

Modern automatized control system of a technological process is multi-level man-machine control system. Solved problems and functions of these automatized systems were increased under improvement of technical and hardware/software means. Functions of a man (operator/manager) provided ordered execution of technological processes were also changed during this evolution. A manager in multi-level automatized control system of a technological process receives data from computer monitor and acts on significantly distant objects via telecommunication systems, controllers, intelligent actuators. A manager is the main person at the control of a technological process. Thermal power technological processes are potentially dangerous; so, the number of registered accidents is doubled for near every ten years. It is known that in complex power systems the following relationships between constituents of errors for steady regimes takes place because of inaccuracy: 1) of initial data – 82-84%; 2) of model – 14-15%; 3) of method – 2-3% [1, p.119].

Error in calculation of target function appears because of such significant part of initial data error. It results in large zone of uncertainty at the choice of optimal system operability regime. So it follows that the design of methods taking into account uncertainty of initial data under multi-level control of technological processes is needed. Decision making under conditions characterized by significant errors of initial data caused by inaccuracies of both data estimation and defects of operation and rejections of data measuring and transmitting devices are discussed in some publications [1-5].

FUNCTIONAL TASKS OF A MAINTENANCE SYSTEM FOR DECISION MAKING AND REALIZATION OF MANAGED CONTROL

Transfer of manager functions on data analysis, forecast of situations and appropriate decision-making on components of intelligent systems for maintenance of decision making and realization (SMDMR) is the actual problem now under the design of automatized control systems [6, 7]. The concept of the SMDMR covers a set of means joined by the general purpose: to promote making and realization of rational and effective control decisions. SMDMR is dialogue-automatized system that is as intelligent mediator maintaining natural interface of a user and SCADA-system. It uses rules of decision-making and appropriate models with knowledge bases. SMDMR organizes dialog of SCADA-system and a user/manager presenting needed data being suitable for an operator. In addition SMDMR realizes function of automatic accompaniment of a manager at stages of data analysis, recognition and forecast of situations. Basic structural constituents of the suggested SMDMR are knowledge base and the mechanism of logic conclusion. The knowledge base is aimed to the storage of a set of facts, laws, relationships (knowledge) describing a problematic area and rules describing expedient forms of structurization, formalization and transformation of knowledge in this area. Mechanism of logic conclusion represents a set of ways for application of conclusion rules. Sequence of rules is received using current or intermediate initial data (facts) and knowledge from the knowledge base. These rules being applied to initial data (facts) received from SCADA-system as a result of monitoring of the state of a technological process, result in solution of a task of diagnostics, forecast and regulation of parameters of a technological process. Flexible open structure of SMDMR gives ability to increase functional abilities of the system and the number of problems solved at its exploitation. It increases constantly also accuracy of analysis, forecast, planning, organization, coordination and monitoring of made decisions at the expense of experience accumulated in the knowledge base.

APPLICATION OF SCADA-TECHNOLOGIES

Application of SCADA-technologies allows achieving high degree of automatization at the design of systems on the level of control algorithms and also of algorithms for data sampling, processing, transmission, storage and imaging. SCADA is now the basic and mostly perspective method for automatized control of complex dynamic systems [7, p.151]. Among basic functions of SCADA-systems are: data sampling on a technological process, provision of interface for an operator, storage of process history, directly automatic control on a needed level.

However some drawbacks of existent SCADA-systems results in the fact that testing of highly effective and complex control algorithms providing optimal control of objects with changeable coefficients, and also testing of the whole system in order to check correct operation in situations of temporal change of parameters and accidents is forced to be done on the final stage of ordered works directly at a controlled object. Such works need deviation of operation of automatized control system from its normal regime and often full stop of a process. Forced stoppage of technological equipment results in increase of a project's price and of its introduction time and in some other difficulties.

Therefore on the design stage there is a need to have mathematical models of technological processes. Using them it is possible to solve problems of situational simulation of processes in order to tune algorithms of monitoring, control and intelligent maintenance of operators at the stage of decision-making. These problems are especially topical at thermal power plants where processes in components of technological systems have casual, non-stationary character. Sampling of thermal power by consumers depending on environment temperature, on operation time of a plant and also on parameters of a boiler (burning quality of a fuel mixture in a furnace, content of salt in boiler water, operation regimes of basic and auxiliary equipment, etc.) are among these processes.

CHOICE OF CRITERION AND STRUCTURE OF OPTIMAL CONTROL SYSTEM

Objects that function within automatized technological processes are subjected to the influence of assigning and disturbing actions that have random character. So realization of control strategy is needed that takes into account probabilistic characteristics of measured values.

Operation quality of any control system is determined by a value of the error that is equal to the difference between assigned $g(t)$ and current $x(t)$ values of regulated value

$$e(t) = g(t) - x(t). \quad (1)$$

Error of the system determined by the formula (1) is also random value. In similar systems control accuracy is characterized by mathematical expectation of error's square [8, p. 243]. Condition of system optimality is

$$h = M\left[e^2(t)\right] = \min . \quad (2)$$

Value h as initial second-order moment of system error may be expressed by mathematical expectation and dispersion of the error. Generalization of the criterion (2) is the criterion of extreme for an assigned function of mathematical expectation and dispersion of the error [8, p. 244]:

$$f(M(e), D(e)) = \text{extremum} \quad (3)$$

In systems for stabilization of parameters there is a need to provide regulation by minimum value of mathematical expectation and dispersion of the error. So, there is needed to provide minimum value of the function (3). In this case mathematical expectation of the error may be presented so:

$$\begin{aligned} M[e(t)] &= M[g'(t) - x(t)] = \\ &= M[g(t) + z\,(t)] - M[x(t)] = \\ &= g(t) - M[x(t)] = M_{\text{a}}(t) - M_{\text{c}}(t) \end{aligned} \qquad (4)$$

where $z\,(t)$ is stationary disturbance with zero value of mathematical expectation; $g(t) = \text{const}$; $M_{\text{a}}(t)$ and $M_{\text{c}}(t)$ are assigned and current values of mathematical expectation for a regulated parameter.

Expression (4) is the shift of regulated parameter by mathematical expectation that should tend to minimally permissible value:

$$e_{\text{m}}(t) = M_{\text{a}}(t) - M_{\text{c}}(t) \to \min \qquad (5)$$

Shift of regulated parameter by dispersion is determined by the following formula:

$$e_{s^2}(t) = s_{\text{a}}^2(t) - s_{\text{c}}^2(t) \to \min \qquad (6)$$

where $s_{\text{a}}^2(t)$ and $s_{\text{c}}^2(t)$ are assigned and current values for dispersion of a regulated parameter.

Taking into account ability of quality estimation by the shift value of mathematical expectation $e_{\text{m}}(t)$ and dispersion $e_{s^2}(t)$ providing assigned quality items for a controlled process (value of overregulation, time of regulation, decaying coefficient) the following functional will be minimized [8, p. 244]:

$$J = \frac{1}{N}\sum_{i=1}^{N}\left(e_{\text{m}_i}^2 + e_{s_i^2}\right) \to \min \qquad (7)$$

Formulated quality criterion provides ability for structural synthesis of control system. Using it automatic parameters' tuning of regulators operating under the influence of random disturbances is possible to realize. The problem for structural synthesis of a control system is formulated so: to find control $u(t) = f(x(t),\ g(t), V(t))$ as function of assigned value *g*(*t*), regulated value *x*(*t*) and disturbance *V*(*t*) providing movement of a closed system according to the quality criterion for an object assigned by its appropriate mathematical model.

In any moment a controlled object is described by the vector of unknown values of parameters $x \in q$ that influence on dynamic behavior of the object. Besides dynamic behavior of an object is influenced by measured disturbances $r = r(t)$, non-measured disturbances $j = j\,(t)$ and controlling action $u = u(t)$.

In this algorithm measured values are used and for any $x \in q$ achievement of an assigned control purpose is provided. Control problem implies provision of quantities for a regulated value with an assigned accuracy according to (5) and (6).

Suggested structure of control system is related to the class of adaptive self-tuned systems. Contour of self-tuning is closed. Self-tuning is done by measurement results of regulated value *x*(*t*), auxiliary regulated value *z*(*t*), disturbing factor *r*(*t*) and setting action *g*(*t*) (Fig. 1).

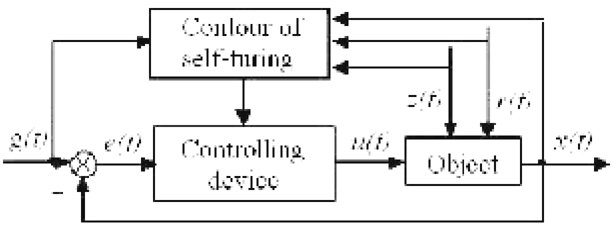

Fig. 1. General structure of control system

Introduction of the auxiliary value $z(t)$ is caused by features of the technological process for production of steam. Data on auxiliary regulated values is used in some control contours of a steam boiler. So, for example flow of supplied water $G_{\text{sw}}(t)$ serves as such value in the system for regulation of level in the drum of a boiler. System for regulation of overheated steam temperature may serve as the second example. Temperature of steam after steam cooler is the auxiliary regulated value.

Controlling device contains regulator that provides purpose of the control at known value $x \in q$. Contour of self-tuning tunes vector parameters of the regulator under change of a situation in a controlled object at unknown disturbances of this object's parameters.

Self-tuning is realized by analysis of real control process and search of extreme value for the quality item (7).

APPLICATION OF FUZZY LOGIC METHODS FOR DATA MAINTENANCE OF OPERATORS

Increasing complexity of monitoring operation of control systems' objects at various regimes and situations resulted in the need to suggest new approaches at realization of strategies for decision-making by operators of automatized control systems [7, p.154]. These strategies foresee the need to divide all the process of decision-making under control realization into such number of levels that solution of optimization problem at each of them would be not complicated. But new problem for coordination of decisions made at all levels appeared after the rise of multi-level hierarchic control systems.

New approach is suggested in the paper that foresees coordination in making optimal (for the set of control quality items) control decisions, control decisions in two-level system. This approach is the following. Components of control subsystems transfer a set of basic data items of their operation into the center. These items characterize vector of a controlled object state. This data represents a vector item of a component admissible from the point of view of its local restrictions. On the base of received variants the center forms plan for realization of control strategy that is optimal for operation of the whole system. Then this plan is transferred to components of control system and is detailed by them.

Problem of decision-making at fuzzy conditions is interpreted as complex influence of fuzzy target *G* and fuzzy restriction *C* on the choice of alternatives. It is characterized by crossing $G \cap C$ that determines fuzzy set of solutions *D* that is

$$D = G \cap C \quad (8)$$

Membership function for a set of solutions is determined by the following relationship:

$$m_D(x) = m_G(x) \wedge m_C(x) \quad (9)$$

In general case if there are *n* fuzzy targets and *m* fuzzy restrictions then resulting solution is determined by crossing of all the set targets and restrictions that is

$$D = G_1 \cap \mathbf{K} \cap G_n \cap C_1 \cap \mathbf{K} \cap C_m \quad (10)$$

and correspondingly:

$$m_D(x) = m_{G_1}(x) \wedge \mathbf{K} \wedge m_{G_n}(x) \wedge m_{C_1}(x) \wedge \mathbf{L}$$
$$\mathbf{K} \wedge m_{C_m}(x) \quad (11)$$

Fuzzy targets and fuzzy restrictions are presented within the expression *D* quite similarly. Such presentation of the solution as fuzzy set in the space of alternatives may seem to be some artificial. It is really quite natural because fuzzy solution may be considered as an “instruction” whose non-formal character is sequence of inaccuracy at formulation of assigned targets and restrictions.

In many cases it is worth to choose such alternatives that have maximal degree of membership to *D*. If there are several such elements then they determine usual set that is called optimal solution while every element of this set is called maximizing solution.

Structure of control system as hierarchic one for a thermal power plant is suggested in the paper in order to relate new and traditional control problems.

Structure of the system for decision-making support of district heating plant is shown in Fig. 2. It allows to a dispatcher of a heating plant to realize control of heat-supply of a district. Technical state, needed productivity of thermal power sources are calculated in the unit for estimation of situations depending on a season, time of a day, day of a week and also environment characteristics. Such approach allows to solve problems of fuel economy due to district heating, to increase loading degree of basic equipment, to exploit boilers in regimes with optimal efficiencies [3, p.72]. Task for needed productivity of a district heating plant is designed in the unit for estimation of situations based on outer factors (temperature of outer air, speed of wind, a season, time of a day, day of a week, own needs, steam consumption by industrial plants). Rules contained in the unit are based on temperature diagram of loading, experience of operators controlling boiler aggregates, dependence of power consumption on air temperature, a season, a day of a week. Task for every boiler (regime and loading) taking into account technical condition of every boiler (from six boilers) and data from the unit for estimation of a situation is designed by the unit for assigning regimes and loadings of boilers. Power characteristics of steam generators and of a district heating plant as a whole relating to the dependence of received heat on supplied fuel are needed to know in order to determine optimal loading of a district heating plant. Solution of the problem is realized by check-up of correspondence between heat power production and loadings that is by planning change of loading and decrease of losses under transfer of thermal power.

Model of the unit for assigning regimes and loading of boilers using MATLAB – SIMULINK was designed (Fig. 3) in order to check operability of fuzzy approach at the solution of the problem for estimation of a situation. Such structure was built on the base of theoretical data described.

Model of the control system in MATLAB 6.5 using means of Simulink was designed in order to check operation efficiency of the suggested approach under solution of the task of water level regulation in a steam boiler of a district heating plant. It was done modeling of control system with ordinary PI and PID regulators, fuzzy regulators and also a neuroregulator. Efficiency of two fuzzy regulators’ structures was studied. Algorithm for fuzzy control was modeled in one of them where a set of controlling rules [7, p.152]

$$P_i : if\ V_i, then\ U_i,\ i = \overline{1,n} \qquad (12)$$

was taken into account. These rules describe control process where V_i is combined expression setting linguistic values of input constituents, U_i is simple expression setting one of terms for output linguistic constituent as controlling action.

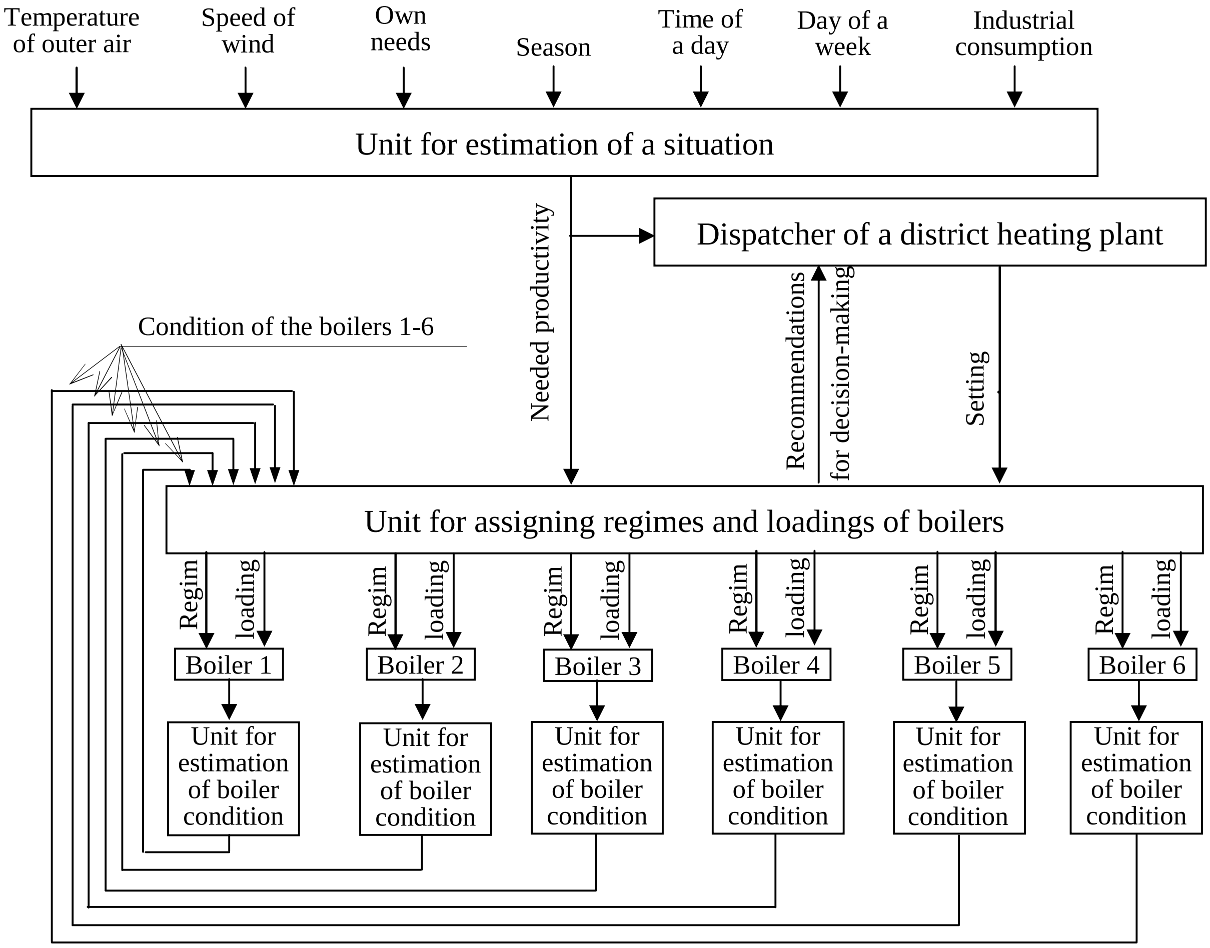

Fig. 2. Structure of the system for decision-making support of district heating plant

Neurocontroller "Model Reference Control" presented in the library of MATLAB was applied for comparative quality estimation of different structures of regulators. This unit allowed to model supervising operation regime of multilayer neuronet within the system with a dynamic object described by equations of the state. The controller represents the structure that contains two multiplayer neuronets for control and identification. Each net of the unit contains one concealed layer where quantity of neurons is chosen depending on the complexity of a control problem [6, p.383]. Modeling results of the studied system for the marked above structures of regulators under disturbance by steam flow are shown in Fig. 4.

Analysis of diagrams (Fig. 4) showed that in the system with fuzzy regulator and five rules (curve 6) aperiodic transient process takes place under disturbance of a controlled object by removal of steam. Lowest value of regulation time t_s = 200 s is provided in this case. Transient process in control system with single-pulse regulator realizing fuzzy algorithm for tuning of coefficients (curve 3) is oscillation one. Decaying coefficient of transient characteristic k_d = 0,77 and regulation time t_r = 600 s. In regulation scheme with single-pulse PID-regulator transient process is oscillating one with regulation time t_r = 1200 s. Three-pulse PID-regulators (classic and with the algorithm for fuzzy tuning of coefficients) provide equal aperiodic transient process with regulation time t_r = 1200 s. Control quality is generallyControl quality is generally worse in schemes with three-pulse regulators. It is explained by transient and transfer delays between channels of water flow and steam flow. Some conclusions may be done by the results of modeling. Operation quality of automatic control system (curve 7) with neurocontroller is higher as compared with other structures of regulators.

Note that significant time for education of neurocontroller is needed and its realization is rather complicated. Transient process with single-pulse PID-regulators is oscillating one. Regulation time is less if algorithm for fuzzy tuning of coefficients in single-pulse regulator is used. Aperiodic transient process takes place in control systems with three-pulse PID-regulators Regulation time is also less in this case under fuzzy tuning of the regulator's coefficients.

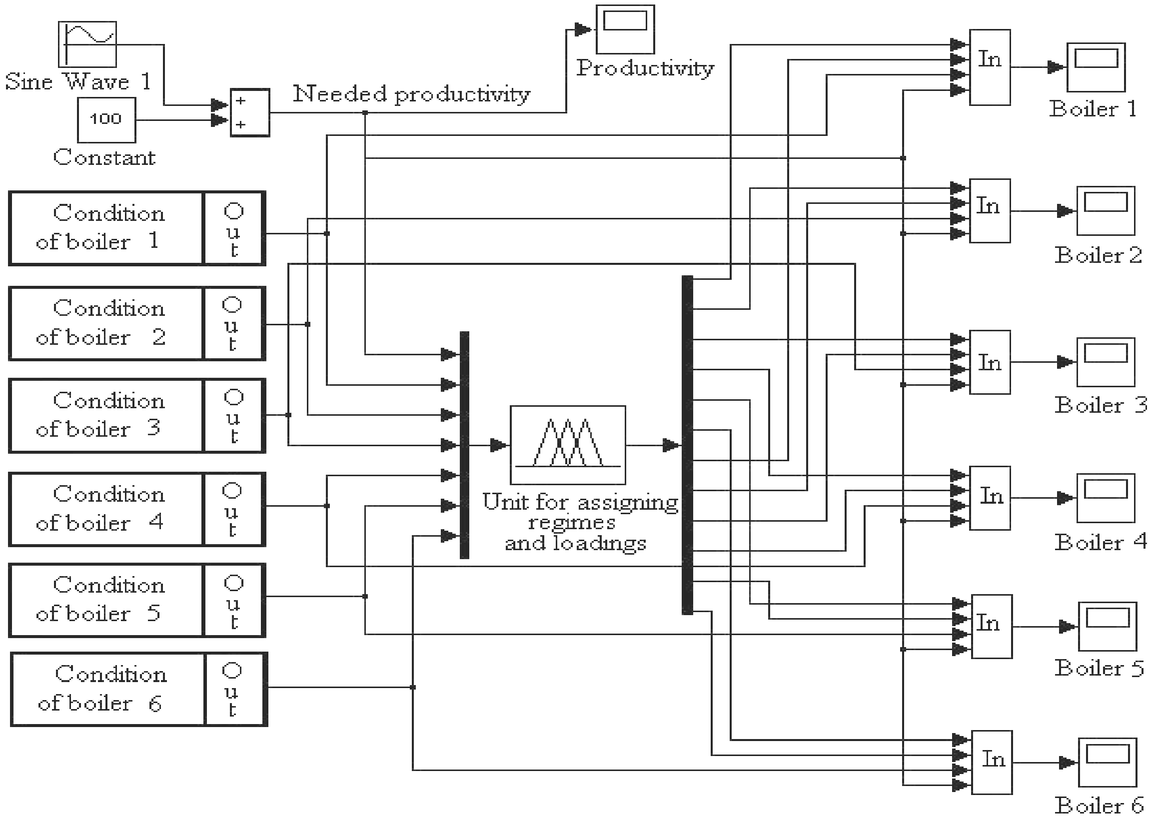

Fig. 3. Model for the unit of assigning of regimes and filling in of boilers

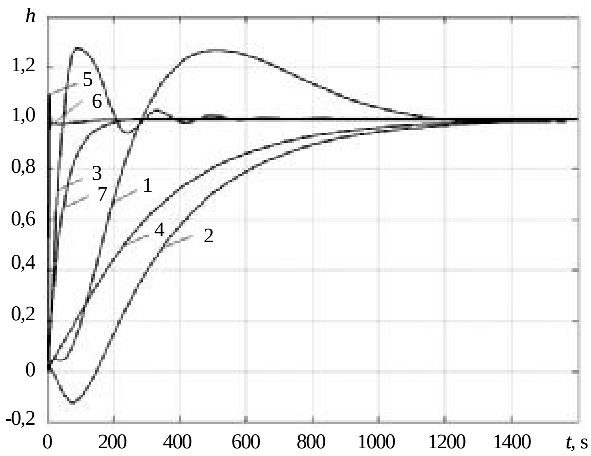

Fig. 4. Temporal diagrams for the change of water level under disturbance by steam flow for different structures of regulators:

1 – single-pulse PID-regulator;
2 – three-pulse PID-regulator;
3 – single-pulse PID-regulator with fuzzy tuning of coefficients;
4 – fuzzy three-pulse PID-regulator;
5 – fuzzy single-pulse regulator with three rules;
6 – fuzzy two-pulse regulator with five rules;
7 – neurocontroller

Algorithms of fuzzy control are suggested in the paper under solution of the problem of local control. These algorithms tune transfer regulators coefficients of continuous control in accordance with values set by local optimizers. These set values are realized in accordance with set criteria of control quality.

At the same level algorithms of situational control are curried out. They realize control actions in the class “situation-strategy-action”.

CONCLUSION

New approach covering coordination for optimal decision-making of assigned control quality items is suggested. Proposed structure of control system for a thermal power plant is presented as hierarchical one in order to determine relationship between traditional and new control problems. Realization of control problems at basic functional levels is foreseen in this structure: local regulation, local optimization, coordination of local optimization systems, operative control and decision-making by an operator/dispatcher. In the paper are presented results received at simulation of control objects on a thermal power plant. These results give ability to provide intelligent data maintenance for operators of automatized control system for boilers of district heating plant “Severnaya” and also of automatized system for managed monitoring and control by central heating points and pumping stations of the city Murmansk of Russia.

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