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# Problems of Quantitative Estimation of the TPP' ACS TP Intelligence Level

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## Abstract

Actual problems of increasing the intelligence of TPP' (thermal power plant) automated control systems (ACS) built on the basis of modern PTC (program and technical complexes) are considered. It is shown that from the standpoint of the modern approach, complex technical control systems satisfy the definition of intelligent control systems as systems that act rationally and optimally. It is from these positions that the report considers the problems of increasing the intelligence of the TPP' automated control system based on the creation of a unified system for improving the quality of control and solving optimization problems at all hierarchical levels of technological and production processes control. As an estimation of the level of intelligence, it is proposed to use a conditional "intelligence coefficient", the essence of which is to determine the share of intelligent technologies in the total volume of performed functions of the automated control system on the considered task or control function. A method for determining the intelligence coefficient at hierarchical levels of control and the automated control system as a whole is proposed. An illustrative example of calculating this coefficient at all hierarchical levels of control in relation to TPPs with CCGT (combine circle gas turbine)) PGU-450 is provided. It is shown that for a significant increase in the level of intelligence of the ACS based on PTC, special attention should be paid to the intellectualization of optimization problems at the block and station levels of control.

***Keywords:*** *Intelligent System, Control, Rationality, Optimality, Intelligence Increasing, Intelligence Coefficient, Function Groups, Hierarchical Levels, Methodology, Illustrative Example*

## 1. Introduction

The current stage of evolution of the Russian and world energy sector is characterized by a high level of implementation of multifunctional automated control systems, due to intensive scientific and technical progress in various fields, including in the field of information and network technologies, improvement of control hardware. The main part of most modern ACS TP are multifunctional software and hardware complexes (PTC) that perform the functions of collecting, analyzing, displaying information of the automated object in real time, control the operation of all auxiliary and main equipment of the power unit. Although each automated control system based on the PTC is to some extent an intelligent system, the control algorithms currently used in modern automated control systems do not fully realize the potential of the software and information capabilities of the PTC, which leads to a significant proportion of operations performed by service personnel from the control panel or manually. Obviously, to reduce the influence of the human factor, facilitating the operator's work, improve the technical and economic parameters of automated systems work, improve the security and efficiency of electricity generation at thermal power plants, efforts should be made to increase the level of intelligence of modern ACS TP by development and introduction of new software and information functions, in some cases involving the possibility of artificial intelligence. This will allow us to solve a number of optimal control problems at all hierarchical levels of station control, which are not automated at the moment and can be implemented mainly with human participation [1-5].

The current situation with an insufficient level of control intellectualization, especially at the station level, is due, among other things, to the lack of third-party workable software that implements intelligent control in solving problems for optimal control of power generation, as well as station tasks, and the lack of instructions for implementing the interaction of these products with existing application software of various PTC; almost complete lack of experience, recommendations, and approaches for integrating third-party intelligent systems with existing proprietary PTC software..

## 2. Problems of TPP' ACS TP Intellectualization

It is known, that the creation of ACS TP requires huge intellectual and time resources, and the higher the degree of automation, the greater the cost of their development and implementation. On the other hand, it is obvious that the level of automation should correspond to the technical level of

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promising high-efficiency power plants. The higher the degree of development of technical controls, the higher the level of intelligence can be achieved due to the possibility of implementing optimal control algorithms both at the level of power units and at the level of power plants. Based on the analysis of technical accidents of the last few decades, it can be concluded that modern ACS TP are not able to fully ensure the adoption of adequate and optimal solutions in conditions of high uncertainty of the behavior of the control object and changes in its structure. As a result, there is a need to evaluate and improve the intelligence of ACS TP built on the basis of modern PTC. The optimal (appropriate) level of intellectualization (automation) of energy systems can be obtained only if all relevant aspects of the production process are taken into account and optimal levels are reached in terms of cost, productivity, quality and flexibility. As shown in [4], staff costs decrease in proportion to the increasing level of intellectualization. At first, cost-effective operations are automated first, so the cost of automation increases almost linearly. In addition, costs are rising in excessive proportion to the increasing complexity of the system. Therefore, achieving full intellectualization leads to the fact that the cost of automation increases exponentially, and the cost of personnel decreases only linearly, which indicates a higher overall cost. The authors believe that the optimal level of automation, at least at the moment, is 40-50%, and further growth of intellectualization will lead to economic instability of the system and, thus, will negatively affect the entire system as a whole. In principle, there is a reasonable question-what is the need for an assessment of the level of intelligence of the ACS TP? According to the authors, estimation of intelligence ACS TP on the basis of PTC is not suitable because it needs time (to implement the basic principles of "Industry 4"in the ACS), but also a practical necessity if: the comparison between the technical level of ACS TP on the basis of PTC different manufacturers; assessing the degree of functional possibilities of PTC, etc.

In addition, the method of estimation the degree of intelligence and its improvement will allow you to:

- evaluate the initial level of intelligence as an indicator of the perfection of the ACS TP and determine possible ways to improve it;
- evaluate the possibility and feasibility of implementing intelligent technologies in the ACS TP, including those built on the basis of modern PTC;
- compare the options for developing a new or upgrading an existing ACS TPs using PTC from different manufacturers;
- evaluate the feasibility of introducing new information technologies for the modernization of the ACS TP in general and on the basis of PTC, in particular.

Questions of the intelligence of complex technological objects ACS are debatable, and the estimation of the degree of intelligence is related to their complexity and diversity. There are four main areas of research on intelligent technologies-systems that: (1) think like people; (2) act like people; (3) think rationally; (4) act rationally and optimally in relation to technical systems. Of particular interest is the 4th definition [5, 6]. It is from these positions that this article considers the problems of increasing the intelligence of ACS TP based on the creation of a unified system for optimal control of technological and production processes in all operating modes of equipment, power units and the plant as a whole [7-9].

As a rule, modern hierarchically constructed TPP' ACS TP have the following control levels:

- lower (aggregate) level (control, alarm and protection level);
- block level that implements information, control and calculation tasks and archiving of data related to the power unit as a whole;
- the station level, which implements the functions common to all power units of the station, as well as control of general station systems.

The concept of a three-level hierarchy is implemented in the form of an "information pyramid" in which the maximum of information is processed at lower levels, and it is transmitted to higher levels in an aggregated form, which allows for optimal distribution of automation functions performed by the system [6, 7].

## 3. Methodology for Estimation of ACS TP' Intelligence Level

The following approach is proposed for a hierarchically constructed ACS TP, which includes the control system of a TPP: divide the entire ACS TP by hierarchical levels of the interconnected group, and the degree of intelligence of the ACS TP are to be regarded as the sum of the individual intelligent systems, interconnected process. This approach can be justified by the fact that, as we know, the requirements for the quality of control in a hierarchical control system are objectively different – the higher the level of control in a hierarchical system, the lower the quality of control and vice versa [2]. To assess the level of intelligence, we introduce the conditional term "intelligence coefficient", which is defined for each function or task as the ratio of intelligent technologies implemented at the considered time stage to the total number of possible intelligent technologies in relation to the considered function or task.

The algorithm for evaluating the ACS TP' intelligence contains the following steps:

1. All the functions of ACS TP and the optimization tasks proposed for implementation, no matter where solved each task (in the program complex of PTC or intellectual attachment to ACS TP) are distributed between the hierarchical levels of the ACS TP. Within each hierarchical control level the functions of the ACS and optimization tasks are divided into two groups:

1.1 tasks and functions of the ACS TP, which are aimed at improving the quality of process control and operation safety (regulation of technological processes, providing information support for the ACS TP, technological protection, etc);

1.2 optimal control problems, the solution of which directly leads to an economic or energy effect (reducing fuel consumption at constant electrical power due to optimal load distribution; increasing power at constant fuel consumption, reducing electricity consumption for their own needs, improving the reliability of equipment or station, etc.);

2. In each group, if necessary, subgroups can be allocated for a more reasonable estimation; for example, in group 1.1. as a subgroup, you can select the functions of the ACS that ensure the safety of operation, including technological protection and locks, diagnostics, etc.

3. In each group (subgroup) at each level of control, functions and tasks that are performed or can be performed by PTC tools without the use of intelligent add-ons or intelligence elements are allocated; similarly, a list of possible functions and optimization tasks that can be performed using intelligent technologies and algorithms is compiled; in accordance with this distribution, we will consider three varieties of the intelligence coefficient:

- internal, for each function and task within the group under consideration, and its value is less than or equal to one;

- group, as the sum of internal coefficients for this group, taking into account their weight coefficients, while the sum of the weight coefficients is equal to one, and the value of the group coefficient is less than or equal to one;

- hierarchical, as the sum of group coefficients taking into account their weight coefficients, while the sum of the weight coefficients is equal to one, and the coefficient value is less than or equal to the number of groups (in our case, two);

- total on ACS TP in general, as the amount of hierarchical indexes based on their weighting factors, the sum of the weighting factors is equal to one and the value of the coefficient is less than or equal to the number of groups ( in our case two).

The estimation of the intelligence coefficient ( $K_{ij0}^{I}$ ), for each group $j$ on the $i$-th hierarchical level, is proposed to determine by the expression:

$$K_{ij}^{I} = K_{ij0}^{I} + \Delta K_{ij}^{I}, \qquad (1)$$

where $i$ = 1, 2, 3 is the ordinal number of the hierarchical levels of control – lower, block and station; $j$ = 1, 2 – number groups in each hierarchical control level; $K_{ij0}^{I}$ – the coefficient of the initial ACS TP' intelligence level of the $j$-th group on the $i$-th level of control on the basis of PTC; $\Delta K_{ij}^{I}$ – increase of ACS TP' intelligence coefficient of the $j$-th group on the $i$-th level of control due to the increase of intelligence to be solved in process control functions or the application of new intelligent technologies.

The ACS TP' intelligence coefficient for the $i$-th hierarchical level of control is determined by the expression:

$$K_{i}^{I} = \sum_{j=1}^{2} (\beta_{ij0} K_{ij0}^{I} + \beta_{ij} \Delta K_{ij}^{I}), \qquad (2)$$

where β is the weight coefficient; $j$ is the index of weight coefficients reflecting the relative importance of the factors of the 1st and 2nd groups (their sum is equal to one) at the $i$-th level of control, $K_{ij0}^{I}$ - the estimate of the initial intelligence coefficient of the $j$-th group of the $i$-th level of control, calculated by the expression:

$$K_{ij0}^{I} = \sum_{m=1}^{m=M_i} \varphi_{mi} \phi_{mi} \Bigg/ \sum_{m=1}^{m=N} \varphi_{mi}, \qquad (3)$$

and $\Delta K_{ij}^{I}$ – increase in the value of the intelligence coefficient of the $j$-th group of the $i$-th level of control, calculated by the expression:

$$\Delta K_{ij}^{I} = \sum_{l=1}^{l=L_i} \delta_{li} \phi_{li} \Bigg/ \sum_{l=1}^{l=V} \delta_{li}, \qquad (4)$$

here $m$ = 1, 2,..., $M_i$, $l$ = 1, 2,...,. $L$ - the number of functions (tasks) in the $j$-th group of the $i$-th level of control of the ACS TP in the original and upgraded versions, which use intelligent technologies; $\phi_{mi}, \phi_{li}$ – the conditional coefficients of "internal" intelligence when implementing the $m$-th and $l$-th functions; $\varphi_{mi}, \delta_{li}$ -weighting factors of significance for this particular function, determined analytically or set by an expert, while, as indicated above,

$$\sum_{m=1}^{m=N_i} \varphi_{mi} = 1{,}0; \quad \sum_{l=1}^{l=V} \delta_{li} = 1{,}0.$$

The weights in (2) are set by an expert and depend on the hierarchical control level. For a more reasonable estimation, you can involve several expert specialists with subsequent averaging of the coefficient estimation. For an illustration, the results of a survey of a group of specialists in ACS TP of six people on the estimation of weight coefficients for $j$-groups at the $i$-th control level in relation to the PGU-450 power unit are presented in table.1.

**Table 1. Estimation of weight coefficients.**

| Group | Control level | | |
|---|---|---|---|
| | lower | block | station |
| 1.1 | 0,65 - 0,70 | 0,3 – 0,4 | 0,1 - 0,25 |
| 1.2 | 0,1 – 0,15 | 0,3 - 0,5 | 0,65 – 0,7 |

The intelligence coefficient of the ACS TP for the station as a whole is estimated by the expression:

$$K_{ACS\,TP}^{I} = \sum_{i=1}^{3} (K_{i0}^{I} + \Delta K_{i}^{I}) \alpha_i = \sum_{i=1}^{3} \alpha_i \left[ \left( \sum_{j=1}^{2} \beta_{j0} K_{j0}^{I} \right) + \left( \sum_{j=1}^{2} \beta_j \Delta K_i^{I} \right) \right], \qquad (5)$$

where $\alpha_i$ are the weighting coefficients of the significance of the $i$-th level of control in the station ACS, their numerical values depend on the purpose of the task. If the goal of the ACS intellectualization is to find ways to improve the economic efficiency of the ACS, then the priority is the station control level, since the main optimization tasks are solved at the station level and the following distribution can be recommended – station level - 0.6; block level - 0.3 and aggregate level - 0.1. If the goal when creating an intelligent ACS TP is to improve the quality of process control, then the lower and block levels become priority. Then we can recommend a different distribution: the station level - 0.2; the block level - 0.3 and the lower level - 0.5. If the goal is to assess the degree of perfection of the ACS as a whole, then we can recommend an even distribution across control levels.

Thus, the given calculation expressions allow us to assess the initial level of ACS intelligence and determine possible ways to improve it by using intelligent technologies and algorithms. At each of the control levels, a number of main tasks can be identified from the above-listed control system functions at hierarchical control levels, the solution of which with the use of intelligent settings will significantly increase the efficiency of the station and the intelligence of the control system:

**Aggregate level** - determination of current technical characteristics and technical condition of technological equipment based on the coefficient formed by evaluating a variety of diagnostic parameters; implementation of optimal control of flow, steam pressure and feed water, analysis and optimization of indicators such as: boiler efficiency, turbine efficiency, initial steam pressure, pressure in the condenser.

**Block level** - operational control of operating modes of the equipment; collection, processing and archiving of information; control and monitoring information; a calculation of current normative and technical and economic indicators (TEI), analysis and evaluation of compliance; participation in regulating power and frequency of the power system; monitoring the work of PTC; shutdown and automated startup from different thermal states at different variants of the composition of shutdown equipment; the adjustment of the timing of maintenance and repair work on the basis of the analyzed data, operational diagnosis.

**Station level** - selection of the composition of generating equipment, taking into account the possibility of redundancy, to enter the market of electricity and capacity with minimal fuel costs; solving the problem of optimal distribution of electrical and thermal loads between units, as well as automatic load redistribution when changing the dispatching schedule; development of automated diagnostics systems, setting the timing of repairs and maintenance at the station; calculation, analysis and management of the entire station TEI, as well as the necessary energy consumption to meet their own needs, etc.

## 4. Illustrative Example

Let's consider an illustrative example in relation to a virtual TPP with CCGT PGU-450 power units, whose ACS is based on a modern PTC. The task is to evaluate the value of the intelligence coefficient at the above 3 levels of control and the station as a whole in the initial state and after the implementation of certain technical and program measures aimed at improving the intelligence of the ACS. Set on condition that all the power units are identical in ACS TP hardware and software, and proposed measures to improve the degree of intelligence aggregation and block levels are implemented in all units, with the pre-application of these activities is techno-economically justified.

On the **aggregate level** (1st level of control $i = 1$) to simplify the calculations assume that the intelligence of the main functions of the ACS TP for group $j = 1.1.1$ (measurement of process parameters, costs, temperatures, pressures, verification of the measured parameters, regulation system, etc.) for cost effective volume in line with [4] achieved by the installation of smart sensors and control devices and does not require further improvement. For this group, to increase intelligence, consider the following algorithms

1.1.2 Determination of current resource characteristics of gas turbines, recovery boilers and steam turbines;

1.1.3 Determination of the technical condition of technological equipment based on the coefficient formed on the basis of parametric analysis;

1.1.4. Improving the quality of regulation using an all-time neural network controller.

For the aggregate level group $j = 1.2$, consider the following algorithms:

1.2.1. Selecting the optimal pressure in the steam turbine condenser;

1.2.2 Optimal distribution of the current GTU load between gas turbines;

1.2.3. Selection of the optimal sequence of unloading/loading of gas turbines when the GTU load changes.

Let's determine the estimation of the intelligence coefficient of group 1.1 of the aggregate control level with the following indicators of internal intelligence: 1.1.1 - 0,40; 1.1.2 - 0,2; 1.1.3 - 0,2; 1.1.4 - 0 and significance 1.1.1 - 0,8; 1.1.2 - 0,15; 1.1.3 - 0,05; 1.1.4 - 0

$$K_{1.1.0} = 0{,}40\times0{,}8 + 0{,}2\times0{,}15 + 0{,}2\times0{,}05 = 0{,}36.$$

The same is true for group 1.2 with indicators of: internal intelligence: 1.2.1 -0,2; 1.2.2 - 0,1; 1.2.3 -0,3 and significance 1.2.1 - 0,5; 1.2.2 - 0,4; 1.2.3 - 0,1

$$K_{1.2.0} = 0{,}2\times0{,}5 + 0{,}1\times0{,}4 + 0{,}3\times0{,}1=0{,}17.$$

Under these conditions, with significance coefficients 1.1 - 0.7 and 1.2 - 0.3, we obtain an estimate of intelligence for the initial state of the aggregate control level

$$K^{I}_{1.0} = 0{,}36\times0{,}7 + 0{,}17\times0{,}3 = 0{,}303.$$

Let's briefly consider the possibility of improving the intelligence of the aggregate level ACS for group 1.1. As indicated above, no additional measures are provided for in 1.1.1. On 1.1.2-1.1.3 current and resource characteristics of the technical condition of the equipment can be used in the selection of the generating equipment and the method of capacity reservation for gas and steam turbines and CCGT as a whole during the passage of the gaps of graphics power with the aim of ensuring maximum reliability . These tasks can be solved automatically, but this will require significant costs and new technological solutions, and at this stage we assume that they will be solved in an automated version. In this regard, the coefficient of internal intelligence is assumed at the level of 0.35. The introduction of an all-time neuro-network controller will significantly improve the quality of regulation at all loads and over time, and the internal intelligence coefficient will be equal to 0.6. With the significance of 1.1.2 and 1.1.3 at the level of 0.3 and 1.1.4 at the level of 0.7, the increase in intelligence for group 1.1 of the aggregate level will be

$$\Delta K^{I}_{1.1} = 0.35\times2\times0.3 + 0{,}6\times0{,}7 = 0.63.$$

Group 1.2 prior consultation with the developers of the PTC showed that feasibility of the optimization problems listed in 1.2.1-1.2.3 if you have the appropriate software in automatic mode is almost possible, but it will require major adjustments to the information security of ACS TP. When implementing them in automated mode with entering part of the information in manual mode, based on expert assessments, the following values of internal intelligence coefficients are accepted (the first number in brackets and the significance-the second number): 1.2.1 (0,35; 0,4); 1.2.2 (0,25; 0,3); 1.2.3 (0,15; 0,3). With these indicators, the increase for group 1.2 of the aggregate level will be:

$$\Delta K^{I}_{1.2} = 0{,}35\times0{,}4 + 0{,}25\times0{,}3 + 0{,}15\times0{,}3 = 0{,}260.$$

With the significance of 1.1 and 1.2, respectively, 0.6 and 0.4 for the growth of p.1. we get

$$\Delta K^{I}_{1} = 0{,}6\times0{,}63 + 0{,}4x0{,}26 = 0{,}482.$$

As a result for the aggregate level after the implementation of the proposed measures to modernize the ACS the degree of its intelligence will be

$$K^{I}_{1} = 0{,}303 + 0{,}482 = 0{,}785.$$

At the **block level** (second control level, $i = 2$), we will consider the following functions from a large number of ACS functions:

***- for group 2.1:***

2.1.1. Control the current operating modes of the equipment;

2.1.2. Control and monitoring of the current parameters and state of the equipment;

2.1.3. Calculation of current TEI for each unit of equipment and for the block as a whole;

2.1.4. Monitoring the work of the PTC.(self-diagnosis);

2.1.5. Participation in the normalized primary frequency regulation in the power system.

2.1.6. Automated launches from various thermal states.

***-for group 2.2:***

2.2.1. Selection of optimal current parameters of gas turbines and steam turbines;

2.2.2. Analysis of current and regulatory TEI for each unit of equipment and making adjustments to their operating modes;

2.2.3. Optimization of the current modes of gas turbines during unloading/loading of CCGT.

2.2.4. Optimal control at low loads, taking into account the outdoor temperature.

In the initial state, when control of technological processes using PTC functions listed in section 2.1 sufficient for the normal operation is automated, but does not exclude the participation of the operator in clauses 2.1.1, 2.1.3, 2.1.4, 2.1.6, for which internal coefficient of intelligence taken at 0.4, with an equal ratio of their significance 0,15; 2.1.2 and 2.1.5 completely automated with some elements of intelligence are, therefore, of intelligence coefficient was adopted at the level of 0.55 with a coefficient of significance of 0.2.

Under these conditions, the initial value of the intelligence coefficient for 2.1 will be:

$$K_{2.1.0} = 4\times 0{,}4\times 0{,}15 + 2\times 0{,}55\times 0{,}2 = 0{,}46.$$

A group of tasks according to 2.2.1-2.2.4 are not performed in full and the same value of internal intelligence and significance coefficients is accepted for them at the level of 0.3 and 0.25, respectively. Then

$$K_{2.2.0} = 4\times 0{,}3\times 0{,}25 = 0{,}3.$$

Thus, for the initial state for group $i$ = 2 with significance coefficients of 0.55 for group 2.1 and 0.45 for group 2.2, we obtain:

$$K^{I}_{2.0} = 0{,}46\times 0{,}55 + 0{,}3\times 0{,}45 = 0{,}288.$$

As can be seen from the data, the conditional intelligence coefficient for group 2.1 in the original version is at a fairly high level, so we assume that there is no urgent need to further increase the intelligence, i.e. $\Delta K^{I}_{2.1} = 0$ and $K^{I}_{2.1} = K_{2.1.0} = 0.46$.

A group of tasks according to 2.2.1-2.2.4 are optimization tasks, the implementation of which will require the development of intelligent technologies to account for fuzzy parameters (temperature and pressure of outdoor air, the presence of a large number of parametric and technological restrictions, the difference between the inertia characteristics of gas and steam turbines, etc.). Without going into details, we note that the implementation of the measures listed in [7] allows us to increase the internal intelligence coefficient to the following values: 2.2.1 - 0,55; 2.2.2 - 0,60; 2.2.3 - 0,55; 2.2.4 - 0,5. The above-mentioned group of experts assigned the following significance coefficients for these items: 0.15; 0.4; 0.2; 0.25.

At these values, the total increase in the intelligence coefficient for this group will be:

$$\Delta K^{I}_{2.2} = 0{,}55\times 0{,}15 + 0{,}60\times 0{,}4 + 0{,}55\times 0{,}2 + 0{,}5\times 0{,}2\ 5= 0{,}5575.$$

With the same significance coefficients:

$$\Delta K^{I}_{2} = 0{,}46\times 0{,}55 + 0{,}5575\times 0{,}45 = 0{,}504.$$

Then for the station level we get:

$$K^{I}_{2} = 0{,}288 + 0{,}504 = 0{,}792.$$

**Station level** (third control level $i$ = 3). As a rule, application software PTC different manufacturers, designed to control plant processes, has the following functions and algorithms: 1 - calculation of current normative and technical and economic indicators of station operation; 2 - the control for operation of power units; 3 - control over the implementation of dispatching schedule of loads; 4 - receipt and execution of dispatch instructions; 5 - optimal operational current distribution of load between units; 6-control of general station services.

You want to estimate the initial level of ACS TP intelligence coefficient and to determine the degree of its increase when implemented in ACS TP of a number of intelligent optimization algorithms.

Let's determine the estimated value of the intelligence coefficient for the initial state of the station level of the automated control system. Let's divide these functions into groups 3.1.1 and 3.1.2.

Group 3.1.1 - functions 2, 3, 4, and 6.

Group 3.1.2 - functions 1 and 5.

Let's assume that when performing the functions and tasks of group 3.1.1, the PTC uses intelligent technologies in limited volumes and their intelligence coefficient is 0.3. We assume that the expert estimations of the functions significance in group 3.1.1 is distributed as follows: 2 - 0,3; 3 - 0,2; 4 - 0,3 and 6 - 0.2., and in the group 1.2. 1 - 0.4 and 5 - 0.6.

$$K^{I}_{3.1.1.0} = 4\times 0,\ 3 = 0.12.$$

Let's assume that the estimates of internal intelligence coefficients are given by expert methods: for problem 1 - 0.55 and for task 5 - 0.50. And significance coefficients are 0.5 too. Then the initial values of the intelligence coefficient of the group of parameters 1.1 and 1.2 will be:

$$K^{I}_{3.1.2.0} = 0{,}55\times 0{,}5 + 0{,}5\times 0{,}5 = 0{,}525.$$

In accordance with Table 1, we take the coefficients of significance of the groups: $\beta_{3.1.1.0}$ = 0.25, $\beta_{3.1.2.0}$ = 0.75. Then the initial value of the intelligence coefficient of the ACS TP top-level will be:

$$K^{I}_{3.0} = 0.25.\times 0.12 + 0.75\times 0.525 = 0.424.$$

Review the list of optimization tasks that could be realized in the ACS station-level with the purpose of increase of efficiency of control system and solution which is possible with partial application of intelligent technologies (note that for greater efficiency of the proposed optimization problems should undergo the stage of evaluation of technical and economic feasibility of their implementation in the ACS). (The task significance values and internal intelligence coefficients are shown in parentheses).

1. Operational control of current TIP of power units and the station as a whole (0,15; 0,7);

2. Selection of the optimal composition of generating equipment at the stage of preparation of initial data for entering the power and capacity market of the station (0,2; 0,8);

3. Optimal distribution of the load predicted for the day ahead with a given composition of generating equipment (0.14; 0.8);

4. Selection of optimal operating modes of power units for passing the gap of daily energy consumption schedules (0.15; 0.85);

5. Further optimization of the current operating modes of power units for participation in the balancing electricity market (0,08; 0,8);

6. Improvement of the algorithm for optimal distribution of the current load between generating equipment using intelligent technologies (0,1; 0,6).

7. Choosing the optimal strategy for maintenance and repair, taking into account the results of solving problem 1 (0.18; 0.8).

As shown in [9], such a set of optimization tasks, when implemented in full, ensures the economic feasibility of implementing an ACS based on PTC. Based on the analysis of optimization algorithms and the results of calculating the economic impact for each optimization task, in parentheses, the name of the task specified rating their value (equal to the share of the economic effect of this problem of the total effect) and the ratio of "domestic" intelligence. Since all the listed tasks are part of group 3.1.2, the composition of the tasks in group 3.1.1 and the original intelligence coefficient remain unchanged. Under these conditions the coefficient of the parameter group 3.1.2 at the station level is estimated to be:

$$\Delta K^{I}_{3.1.2} = 0{,}15\times 0{,}7 + 0{,}2\times 0{,}8 + 0{,}14\times 0{,}8 + 0{,}15\times 0{,}85 + +0{,}08\times 0{,}8 + 0{,}18\times 0{,}8 = 0{,}679.$$

With the same significance coefficients, we get

$$\Delta K^{I}_{3} = 0{,}25\times 0{,}475 + 0{,}75\times 0{,}679 = 0{,}628.$$

We determine the value of the intelligence coefficient of the ACS station-level:

$$K^{I}_{3}= 0{,}424 + 0{,}628 = 1{,}052.$$

Thus, the implementation of optimization tasks at the station control level based on intelligent technologies under accepted conditions increases the intelligence coefficient of the ACS TP at the station level from 0.385 to 0.953.

Calculate the ratio of intelligence in the process control system in general, for two variants:

1. The primary purpose of enhancing intellectuality of ACS TP is to increase the energy efficiency of the ACS and production of energy, i.e. priority is given to optimal control problems, i.e., task groups the station level. For this option, the expert group of specialists assigned the following weight coefficients: 0.1; 0.3 and 0.6, respectively, for the aggregate, block and station control levels. For this option, the value of the intelligence coefficient will be

$$K_1 = 0{,}1\times 0{,}785 + 0{,}2\times 0{,}792 + 0{,}7\times 1{,}052 = 1{,}047$$

(52.35% of the $K_{max}$)

2. In the second variant, the priority is to improve the quality of control and safety of operation, i.e. tasks at the aggregate level with weights of 0.7; 0.2 and 0.1.

$$K_2 = 0.7\times 0{,}785 + 0{,}2\times 0{,}792 + 0{,}1\times 1{,}052 = 0.813$$

(40.65% of $K_{max}$).

Note, that the estimated values of the coefficients of internal intelligence and significance given in the calculations are illustrative and additional research is required to clarify them. Note, that the authors are well aware that the proposed simplified methodology for estimating the degree of intelligence and its improvement based on the introduction of intelligent technologies in process control contains many conventions and does not cover all the variety of functions of the ACS TP. At the same time, these calculations clearly show possible ways to modernize the automated control system for further intellectualization, while special attention should be paid to the intellectualization of optimization tasks at the block and station levels.

## 5. Conclusion

Simplified method for estimating the level of intelligence of the ACS TP based on PTC using a conditional "intelligence coefficient» is proposed.

Although a simplified estimating of the level of intelligence and its improvement on the basis of implementation of intelligent technologies in the control of technological processes in TPP contains a lot of conventions does not cover all the variety of functions of the ACS, the results of the calculations clearly show the possible ways of modernization of ACS for further intellectualization, special attention should be paid to the intellectualization of optimization problems block and station levels.


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