Systemic issues of the power plants APCS development technology and performance paradigm

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Abstract. Current development of power engineering in Russia is characterized by deployment of power units with distributed multifunctional automatic process control systems (APCS) based on software and hardware systems (I&C) complex with hierarchical network structure. I&C is the backbone of this structure and APCS creates common information and technological environment of the power unit. Key issues of the multifunctional APCS are associated with lack of the technical efficiency of the I&C, usage of unproven control algorithms and immaturity of the system development technology. Overcoming the identified key issues in the development of the technology of creating I&C and APCS as a whole is associated with the formation of special functionality developed by I&C, their capabilities to use mathematical models of control objects and processes in real time (RT), assessing the information properties of controlled and uncontrolled parameters and generated signals. Performance paradigm (price/quality) of the APCS which answers on these questions can be received only after putting system in the operation and caring additional work on the assessment and optimization of information-functional and technical structures of APCS. The report discusses some new results in solving the indicated issues as part of improving the technology of modern APCS and prospects for their development as the main scientific direction of the Department of Automatic control Systems of ISPU.

1. Introduction

Current development of power engineering in Russia and in world is characterized by needs of powerplants working in wide range of loads and taking part in maintaining system-wide parameters in conditions of high non-uniformity of the daily schedule of electrical loads, variations of climatic factors, various technological limitations. Moreover, all power units deployed in power systems are equipped with multifunctional automated process control systems (APCS) based on software and hardware systems (I&C) with hierarchical network structure. I&C is the backbone of this structure and APCS creates common information and technological environment of the power unit¹[1].

Historically, technical means of automation (TMA) was considered as a necessary addition to the main power equipment, i.e. control and management systems (CMS) implemented on their basis were considered auxiliary equipment as part of an energy facility. TMA initially distributed over fairly autonomous technological zones of the energy facility in the form of control instruments, automatic control subsystems, emergency control (technological protections and interlocks), information and com-

¹ The essence of the functioning of an APCS is the interaction of two processes: the technological process that flows in the control object, and the information processing process in the control system.
puting systems, etc. With the replacement of local automation equipment with multifunctional I&C network hierarchical structure, the status of the control system has changed dramatically.

I&C APCS has become the backbone component of a large system, and APCS as a whole form a common information technology environment for a power unit and a power plant, the efficiency of APCS of an automated power facility substantially depends on the quality of its synthesis. The related issues of modern system-forming multifunctional APCS can be identified by three key factors [1,2,3]:

1) Power facility APCS technology development factor;
2) Technical level I&C factor (information technology and development process methodologies used);
3) Control algorithms and application software in the structure of multifunctional APCS factor.

Technology development factor of multifunctional APCS power facilities is determined by the significantly increasing science-intensive tasks of through/seamless design of a complex system, aimed at achieving a guaranteed result at the stage of its commissioning and subsequent efficient operation.

The essence of the issue of end-to-end/seamless design is related to the conceptual decisions made at the early stages of APCS creation: adequate structured distribution of the control object, theoretical justification of the necessary and sufficient information scale of APCS, with criteria for evaluating general system-wide decisions made, I&C requirements, and adequate synthesis of it design layout, etc.).

The relevance of the factor characterizing the technical level2 of the software and hardware complex (I&C) used in the APCS structure [4,5] is determined, firstly, by the development of modern information technologies and their intensive integration into I&C and APCS, and secondly, by the transition from a limited circle components with certain supported software versions and a number of protocols to a distributed hardware structure with dynamically developed functionality.

The essence of the issue lies in the significant mutual influence of I&C components on each other in the process of their development and system organization (system synthesis), including information security during subsequent operation at an energy facility. Typical for modern IT systems, periodic software updates for I&C APCS (real-time mode) should be completely excluded or fit, at least during periods of equipment maintenance.

The factor of control algorithms and applied software (AS) in the structure of multifunctional APCS is characterized by the problems of obtaining the necessary and sufficient information about technological processes, the accuracy of the conversion of generated signals and the creation of a representative/adequate APCS archive that is accessible to all its subsystems, structural synthesis -stable (meeting the survivability criterion) local control algorithms for the fundamental/basic/"lower" level of APCS.

Overcoming the identified key issues in the development of the technology of creating I&C and APCS as a whole is associated with the formation of special functionality developed by I&C, their capabilities to use mathematical models of control objects and processes in real time (RT), assessing the information properties of controlled and uncontrolled parameters and generated signals. As a result, with an assessment of the required level of technical and software of I&C and its components, including third-party/integrated into APCS subsystems of integrated supplies of thermomechanical (TM) and electrical (ET) equipment.

At the same time, the paradigm of the APCS overall/system effectiveness problem is that the answer to the above issues and key factors can be obtained only after the system is put into operation and additional work is carried out to assess the compliance of the obtained quality with the information-functional and algorithmic structures APCS, the possibilities of its development/maintenance throughout the life cycle of an automated generating facility as a whole.

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2 Going beyond the typical functions of TMA and ICS in the direction of creating intelligent APCS, it should be recognized that the capabilities of modern I&C are very limited.
2. Challenges of the initial stage of end-to-end / seamless APCS creation technology

At the initial stage of APCS creation technology, the main tasks are [1]:
- determination of the technical appearance of APCS (development of a concept, substantiation of the information scale of APCS, etc.);
- development of I&C requirements and decision-making on the selection of an I&C supplier company;
- economic evaluation of the cost of creating a system (function of the information scale of the system).

The technical appearance of the created APCS is formed as a concept and technical requirements. In particular, the technological boundaries of the subsystems are determined, the APCS functions (including the composition of the necessary and sufficient local automation - automatic regulators, technological protections, etc.), respectively, the number and types of sensors, execution devices, etc.

The informational scale of APCS has, as a rule, a pilot commercial origin. Its rigorous/theoretical justification (as a result, estimation of the real cost of the system) is one of the high-tech tasks of the early stages of APCS design related to creating an adequate database of the field zone. To solve the problem of assessing the information scale of APCS, the authors apply the methodology of a generalized thermodynamic analysis of an energy facility [1,6,7,8].

At the stage of development of technical specifications, requirements for APCS are detailed:
- a database of sensors and actuators is formed;
- the requirements to the composition and characteristics of applied functions are specified;
- the general requirements for the system (reliability, performance, accuracy) are defined;
- requirements for I&C as the main system-forming component of APCS (requirements for hardware, system and tool software, technical documentation for I&C etc.) are formed.

The technical level of the software and hardware complex (I&C) used in the APCS structure is determined, as noted above, by the transition to a distributed hardware structure with dynamically developed functionality that allows timely detection and elimination of various types of software defects during development [9,10].

The challenge of the I&C functional development process is the significant mutual influence of I&C components, which places high demands on its development methodology, including diagnostics of the impact of the current code change on the development process of software components (fig.1).

Figure 1. The process of developing and implementing I&C in terms of the mutual influence of components (X is the vector of initial requirements for I&C. Y - vector of compliance/non-compliance of the characteristics declared in the technical/commercial proposal (TCP) with the actual).
For example, at the initial stage, the technical requirements are formalized, which is transferred to the development of the hardware and software parts of the PLC, as well as the SCADA system. Each of the components affects each other and makes its own adjustments to the development process. As a result, a version of the product is released, which is transferred to develop an applied software. Obtaining extreme Y is associated with the testing of the I&C functional at the stage of its development.

I&C testing differs from software testing in the presence of hardware devices and the distribution of the system.

The essence of the testing is to structure the system by including additional links between each of the development stages (red dashed lines) so that the developer can assess the impact of his change on the final product. For this, the testing system should provide: scalability of the components used, the ability to change the complexity of the mathematical model inside the tests and their frequency of exposure to the system, work with real application projects or generate them with a specific set of elements, prepare factory polygons in various configurations, etc.

The decision on the selection of I&C supplier companies, as a rule, responsible for the creation of APCS as a whole, is currently made through a tender, during which, according to the customer's technical requirements, the participating companies form their own technical and commercial proposals (TCP). At the same time, there are problems on the solution of which both the competitiveness of the automated object and its effectiveness throughout the entire life cycle depend.

1. During most tenders, the technical audit stage is artificially excluded, which is carried out by a group of independent customer experts at the I&C and APCS implementation facility and the results of tenders are summarized according to formal (cost/market) criteria.

As a result, the customer makes a decision on the declared indicators declared in the TCP of companies without an objective verification of their compliance with the actual values of the standards and technical requirements, assessment of the technical level of the proposed solutions, features/development technologies of I&C, etc.

2. Technological equipment of power units (for example, boilers coal pulverization systems, gas turbines, etc.), supplied complete with "built-in" ACS, are implemented at I&C, which usage is not always justified. As a result, several heterogeneous, informationally incompatible I&C are operating simultaneously on some new power units APCS.

As a result of the additional difficulties of their integration and the formation of a single information technology environment, problems arise in the ability to achieve the required level of efficient operation of an energy facility for the entire period of its life cycle.

3. There is a contradiction between the target functions of the investor and the customer (generating companies and their branches), incompetent/uncivilized interference of competitive commissions in technical policy, etc.

Under these conditions, the most important in the end-to-end technology for creating a complex system are the stages of the initial phase (the so-called preliminary design): the formation of the concept and technical requirements for I&C and APCS, justification of the informational scale of the system, objective examination of technical and commercial proposals training (preparation) of investor and customer’s specialists on APCS technology based on the I&C hierarchical network structure and technical audit of the proposed technical and commercial proposals, including I&C and APCS development technology.

Compliance with the usefulness of events and participation in the work of a group of independent experts (technical "lawyers" of the customer) allows, as a rule, to promptly (in the early stages of design) avoid fundamentally erroneous technical solutions for creating a complex technical system.

3. Challenges of designing APCS's functional-algorithmic and application software

At the stage of functional design, the technical structure of APCS is formed, algorithms for the implementation of APCS functions are determined (including circuit solutions for automatic regulation), application software is developed (software for controllers; software for workstations, including an operator interface and an operational database). The main part of work at this stage is associated with
the development of algorithms for the implementation of the most complex APCS functions (automatic regulation, functional-group logical control, etc.), which forms the basis of the technical project.

*At the design stage,* working documentation of the technical structure project is developed (circuit diagrams, installation drawings, cable journals, etc.) mainly in the part of APCS “field” equipment. At the same time, design solutions for connecting process parameters sensors and actuators to I&C are implemented on the basis of the corresponding standard schemes. In general, the amount of design engineering of APCS based on I&C is significantly reduced compared to traditional CMS in connection with the implementation of functional tasks in the form of an AS system.

*At the commissioning stage* (technological design), I&C polygon tests are carried out and APCS commissioning is being carried out. At the same time, I&C field tests include an analysis of the layout of its hardware, loading of proprietary (tool) software, and testing the operability of software and hardware as a whole. As a rule, the verification of the adequacy of the functioning of the control and management algorithms implemented by the AS system is not performed.

According to modern estimates, the main bottleneck in the creation of APCS seems to be an insufficient level of sophistication of the control algorithms and the corresponding applied software at the time of the input of the energy facility, as well as *the inability to guarantee the absence of errors in a large amount of documentation and defects in application software.*

One of the proven ways to eliminate errors in the design documentation for APCS technical support seems to be the transition to its predominantly automatic formation using intelligent CAD. For example, specialized CAD AutomaticS-ADT, which implements aggregate decomposition technology [11].

The main direction of solving the problem of developing high-quality control algorithms is associated with usage of high-precision mathematical models of heat and power equipment (polymodal complexes) [1,3-8].

At the same time, the technology for creating APCS should be expanded by including additional steps involving the development and widespread use of mathematical models of heat power equipment at the next stages of creating APCS:

– at the stage of functional design in the form of a universal "computer" model used to test algorithms for automatic control by APCS developers;

– at the commissioning stage (technological design) in the form of a real-time model informationally compatible with I&C (for example, implemented by I&C tools) and used to develop application software for the main APCS functional tasks.

Real-time models, information-compatible with I&C, have a multi-purpose purpose.

They can be used: for training specialists in new technology and operational management tasks; to develop application software for APCS functional tasks at the appropriate training ground; for the synthesis of ACS with a reference model in the control loop, etc.

Pre-acceptance of APCS in the test site eliminates the risk of damaging equipment that occurs when debugging APCS at a real facility.

In general, the following requirements should be imposed on mathematical models of technological subjects of control (TSC):

– should be feasible both with the help of universal simulation systems for complex dynamic systems (computer models), and with I&C APCS (real-time models);

– should have an open modular structure with the transition from simplified structures to more complete ones, taking into account the specific features of specific installations and external disturbances, have the ability to control intermediate values of the parameters of technological processes (factors - observability, controllability);

– should be highly accurate, versatile, and oriented towards solving a wide class of TSC control and diagnosis problems;

– should provide the possibility to check their adequacy taking into account the results of the functioning of a real TSC (identifiability).
According to these requirements, the most effective way is to use an analytical approach that involves the construction of a nonlinear mathematical model based on fundamental physical conservation laws in the form of systems of differential equations with lumped parameters at the stage of functional design; and at the stage of entering the system and its operation - an experimental approach involving the solution of identification problems with obtaining appropriate interval estimates of the adequacy of the results in the time and frequency domains in linear approximations by input-output models [12].

To improve the technology of creating APCS, it seems rational to use mainly analytical models with their subsequent correction at the stage of putting the system into operation, i.e. if it is possible to identify the TSC and the random operational disturbances acting on it. At the same time, an important direction in the application of experimental input-output models is the assessment of the adequacy of the initial analytical models. In addition, when building APCS by coordinating TSC and a control system, usage of analytical models of heat and power equipment developed for computer training complexes is also promising.

The considered elements of improving the APCS technology of TPP power units in the last decade have been developed and are used in the scientific and educational process of the university in the following main areas:

- APCS test site deployment. The technical structure of polygons is basically identical to industrial APCS with the addition of an application software design zone. The functional structure includes a subsystem of real-time TSC models along with the main control system;
- development of analytical models of heat power equipment, initially oriented to real-time operation as part of APCS based on I&C network organization;
- development of TSC identification methods and means (including according to the APCS archive) with the determination of interval estimates of frequency characteristics as a measure of the adequacy of the resulting models. Based on the results of experimental studies, a continuously updated information of the database “Fund of Experimental Dynamic Characteristics” was created;
- improvement of automation tools designing the technical structure of APCS based on ADT technology;
- examination of technical solutions for APCS, including verification of compliance of the volume of the solved functional tasks with the requirements of regulatory documents, assessment of the operability of control algorithms, etc.;
- development of new functional calculation and diagnostic tasks of APCS, including: analysis of quality indicators of automatic regulation, diagnosis of regulatory bodies, etc.

In practical terms, the development of the methodology and the improvement of the end-to-end design technology of control systems allows eliminating the contradictions between the investor and the customer at the early stages of creating a complex system, thereby avoiding fundamentally erroneous decisions, increasing the competitiveness, cost-effectiveness and availability of APCS at the time of its commissioning minimize operating costs.

In the scientific aspect - the results achieved allow us to concentrate our efforts on developing the methodological foundations for creating advanced I&C and intelligent APCS technology.

4. Conclusions

1. It is shown that the efficiency of modern system-forming multifunctional APCS based on I&C network hierarchical structure is determined by factors of the development of high-tech elements of APCS creation technology, features of the I&C functional development process under conditions of significant mutual influence of I&C components and the level of readiness of control algorithms and application software at the stage of deployment of power unit.

2. A set of high-tech measures is considered to ensure the elimination of fundamental technical errors when choosing I&C for APCS, the minimum required readiness of complex functional tasks and control algorithms at the stage of object commissioning, and the efficiency of a complex system as a whole throughout the life cycle of an automated object.
In particular, have been identified: the procedures of independent scientific and technical examination and technical audit of the proposed TCP; development and usage of multi-purpose APCS polygons based on modern I&C with the inclusion in their structure of an additional subsystem of MOD-ELS of technological equipment in real time, which provide promising development of control systems.

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