Experience and features of innovative training of specialists in the field of automation at the proving ground of power plant APCS

Yu S Tverskoy, E S Tselishchev, A V Golubev, I K Muravev and A N Nikonorov

1 Ivanovo State Power Engineering University
Russia, 153003 Ivanovo, Rabfakovskaya, 34

kafsu@su.ispu.ru

Abstract. Power units and power plants as automation and control objects are characterized by high dimension and redefinition, the presence of the uncertainty factor of most characteristics of a generally non-linear non-stationary system, as well as the action of random, as a rule, uncontrolled disturbances and a significant number of parameters inaccessible for direct measurement. The complexity of the technical system determines the appropriate level of requirements for the training of engineering and operational personnel in the field of modern automation and control systems, and at the same time requires the creation of adequate training tools and methodology by integrating fundamental engineering education and modern achievements in the field of information management technologies. The article summarizes the experience of 20 years of use and development of the educational and research complex «The proving ground of power plants APCS» for training specialists on the problems of modern technology of automation of energy facilities, advanced training of personnel of power plants, energy associations and engineering companies.

1. Introduction

In the age of rapid development of information technologies, modern energy-dependent civilization imposes high requirements for the quality of energy produced by energy facilities (TPP, NPP, hydroelectric power stations) and transferred to the final consumer.

The problem of efficient (technical, ecological, economic) functioning of complex power equipment in a wide range of loads in the mode of high-precision stabilization of frequency and voltage on the buses of the final consumer can be solved only with the corresponding operation of multifunctional APCS of power units and power plants [1].

Modern APCS have ceased to be auxiliary means of the production process and serve as a structure that forms a single information and technological environment of automated energy facilities. In other words, they serve as the main system-forming equipment.

APCS are complex digital control systems, which are built on the basis of design-built software and technical complexes (STC), have a large (of the order of 2000–3000 technological parameters) information scale, various kinds of restrictions and features of adequate implementation of digital control and diagnostics algorithms.

The problem of creating this class of systems affects many well-known scientific areas in the field of system analysis, the theory of hierarchical and multicriterial control systems, and generalized thermodynamic analysis. The problem is complicated by the high dimension and redefinition of...
multidimensional multi-link control objects, the presence of the uncertainty factor of most characteristics of a generally nonlinear non-stationary system, as well as the action of random, usually uncontrolled disturbances and a significant number of parameters not available for direct measurement.

Under these conditions, the level of requirements for interdisciplinary training of engineering and operational personnel in the field of modern automation and control systems is determined, as it is not difficult to see, by a complex of a number of objective factors. In this regard, the creation and improvement of adequate tools and methodologies for training in automation technology and management problems through the integration of basic engineering education and modern developments in management information technology is crucial.

The educational and laboratory base existing in higher technical educational institutions in many respects does not correspond to the modern level of industrial systems and is not sufficient to provide the required level of interdisciplinary training of specialists. At the same time, on the one hand, a large number of computer textbooks on the theory of automatic control and APCS technology are disconnected from the practice of creating industrial control systems and do not close the niche of the scientific and experimental laboratory base. On the other hand, standard computer simulators of power units and industrial retraining centers are created for specific equipment, mainly perform operational control functions and cannot perform the main task – basic interdisciplinary training of specialists in the field of automation [2-4].

This article summarizes the experience of 20 years of regular operation of the educational and research complex «The proving ground of power plants APCS» (hereinafter – The Proving Ground) in the scientific and educational process of ISPU in order to show the effectiveness of an innovative approach to the training of professional specialists and the implementation of scientific research.

2. The proving ground of power plants APCS

The main distinguishing feature of The Proving Ground is the possibility of performing on its basis all the main works on end-to-end design, adjustment of control systems and commissioning of APCS, as well as the implementation of all functions of educational and training complexes with simulation models of technological equipment of power plants operating in real time.

The technical and functional structure of The Proving Ground as a whole corresponds to the structure of real APCS, which traditionally distinguish the actual control system and controlled technological equipment (control object), during normal (standard) operation of those functioning as a single complex, in which mathematical models of the control object and the control system have a joint solution.

The control system is implemented by means of STC and is performed as identical as possible to the real APCS, and the control object is replaced by its adequate simulation model operating in real time. Sensors, actuation mechanisms, controllers and gateways can be both real and virtual (implemented software). This depends on the scale of the system and the tasks being solved at The Proving Ground.

This structure makes it possible to consider The Proving Ground as a multifunctional software and technical tool, which can be used not only for the training (retraining) of specialists, including operational and non-operational personnel of power plants, designers and system setters, but also for debugging algorithms and expertise (checking the correctness) of control systems.

In general, The Proving Ground allows you to solve three classes of problems: educational (training complex); practical (test bench); scientific (research facility).

The main purpose of The Proving Ground as a training complex is the training of various categories of specialists involved in the process of creating and operating APCS thermal and nuclear power plants. The categories of trained specialists include not only the operational and repair personnel of the power plants themselves, but also employees of the main contracting organizations (engineering, commissioning and design organizations).
The use of The Proving Ground as a test bench is primarily related to the development of technology and methodology for the formation of local control algorithms, as well as a comprehensive expert assessment of the functioning of APCS subsystems.

The use of The Proving Ground as a test bench allows you to close the technological niche of testing complex control algorithms (for example, equipment launches and shutdowns, deep unloads to the idling level, etc.) at the early stages of design. This significantly reduces the risks of damage to process equipment during debugging on live equipment, allows you to increase the level of automation and its efficiency in accident-free operation.

As a research facility, The Proving Ground allows you to carry out research work on the development and improvement of complex knowledge-intensive functions of control and diagnostic systems, including aimed at upgrading APCS at the life cycle stages of aging power plants.

3. Training and research APCS as a basis for job training
The technical and functional structure of «The proving ground of power plants APCS», its mathematical and software make it possible to create fully functioning in real time training and research APCS of power units.

Training and research APCS is a system that differs from the main (industrial) prototype by a smaller information scale (the volume of simulated process equipment and actuation mechanisms) and some given restrictions on operation modes (Figure 1).

![Figure 1. Typical structure of training and research APCS](image-url)
The features of the typical structure of training and research APCS are connections between real and virtual controllers, which provide inter-controller information exchange characteristic of APCS STC. For example, processed signals from real sensors can be transmitted for further use to algorithms implemented in virtual controllers.

The methodology for the construction of training and research APCS includes five main stages. **Stage 1.** Development of the concept and requirements for the training and research APCS of the energy facility:

- definition of purpose and objectives of APCS creation;
- creation of requirements for automatic control tasks;
- creation of requirements for mathematical and simulation models of the control object;
- substantiation of basic STC selection.

**Stage 2.** Development of mathematical model of control object (modeling complex) [5-7].

It is the most knowledge-intensive stage and includes:

- decomposition of complex control object into process zones and subsystems;
- development of mathematical model for each component of the control object;
- definition of parameters of mathematical models;
- development of simulation model of the control object;
- formation of interaction of simulation model of control object with basic STC;
- complex testing and debugging of the simulation model of the control object.

A current example is the technology of developing a multi-model complex of thermal and mechanical equipment of power units with steam-gas plants with an electric capacity of 160–800 MW [6, 7].

**Stage 3.** Development of the control subsystem.

Input for development:

- P&I-diagrams of process equipment, which form requirements for the scope of control and information scale of the system;
- end-to-end information and functional structures of control systems as a reflection of the minimum required amount of automation in accordance with regulatory and technical documents and industry standards.

Result of development:

- synthesis of structural-stable automatic control systems;
- parametric optimization of automatic control systems;
- filling of APCS operational database;
- development and implementation of algorithms for solving functional problems in STC controllers;
- development of operator interface in real APCS environment.

**Stage 4.** Commissioning and testing of training and research APCS:

- launch of the model of the control object in real time;
- loading of technological programs into real and virtual controllers;
- testing and debugging of control subsystem algorithms;
- comprehensive tests of training and research APCS.

**Stage 5.** Creation of working and accompanying field area operational documentation (supported by a special computer-aided design complex) [8]:

- development of field area design model;
- generation of sensors database in accordance with metrological requirements;
- generation of database of actuation mechanisms of required power and speed;
- development of schematic and electrical diagrams (installation and switching diagrams, end-to-end diagrams, specifications, etc.).
The methodology for the development of training and research APCS largely repeats the technology for creating and commissioning system-forming multifunctional APCS power units and is distinguished by the presence of a knowledge-intensive stage associated with modeling a technological control object and ensuring the operation of a polymodel complex in real time.

4. Training modes at The Proving Ground

Training and research APCS provide operation both in the operational mode and in the design and adjustment mode. In this way, they provide an opportunity to implement an integrated approach to the study of all stages of APCS creation and operation based on them.

In design mode, The Proving Ground allows you to study:
- instrumentation of STC controllers and workstations;
- design of human-machine (operator) interface of APCS.

When designing the operator interface of APCS, it is possible to master: the main methods of working with the editor of the SCADA system; order of image design; technology of development of videograms.

At the controller level, The Proving Ground allows you to study: the virtual structure and content of the algorithm library; algorithmic diagrams of typical APCS tasks (input and processing of information, interface with actuation mechanisms, tasks of automatic regulation, etc.).

The developed algorithmic control schemes can be tested as part of the training and research APCS of power units.

In the STC adjustment mode, The Proving Ground allows to master:
- hardware of modern STC, composition and layout of microprocessor controllers (modules of basic and design and layout sets);
- peculiarities of installation both of STC itself and its interfacing with sensors and actuation mechanisms;
- testing of controllers and I/O modules using signal simulators and calibrators of I/O modules;
- check of power supply and grounding of cabinets;
- physical start of controllers.

In addition, it is possible to study the information and computing complex (configuration and execution of workstations), network tools (system network, gateways, switches, hubs), and basic software.

In the mode of adjustment of functions The Proving Ground provides:
- study and testing of control of actuation mechanisms and process equipment using operator interface;
- testing of standard and development of new control algorithms;
- study of operation of archival, engineering, operator and other APCS stations;
- study of manual adjustment of control system algorithms from engineering station level;
- mastering the technology of quality control of automatic control and automated adjustment of control systems, as well as the possibility of scientific and technical examination of key parameters and standard algorithms declared by STC suppliers.

The solution of such problems requires the construction of high-precision models of specific equipment, with an assessment of the measure of adequacy of the developed models of technological control objects [1, 5-7].

In the normal operation mode, The Proving Ground functions as a training complex of an automated energy facility. At the same time trainees get the opportunity to:
- study the means of operator interface (structure of operator station screen, types of images, hierarchy of videograms, display of trends of process parameters signals, etc.);
- acquire the skills of remote control of the mode by influencing actuation mechanisms;
- master interaction with individual functional tasks of APCS, etc.
In addition, since The Proving Ground is a multi-mode software and hardware complex, it is possible to master the operation with the system not only in standard modes, but also in case of various malfunctions of its functioning. For example, a group of watch personnel in real time can conduct emergency training, practice standard and abnormal situations at the power unit.

5. Prospects for the use of the educational and research complex «The proving ground of power plants APCS»

The educational and research complex «The proving ground of power plants APCS» is involved in the educational process of training bachelors, masters and graduate students mainly in the direction «Management in technical systems», as well as in the educational process of the Institute for advanced training of specialists of energy enterprises and engineering companies.

The Proving Ground foundation contains mathematical models of the basic elements of thermal and mechanical equipment of power units, computer simulators, as well as complex multi-model complexes of gas-fuel-oil, dust-coal, gas-turbine and steam-gas power units.

The scientific and technical level of The Proving Ground as a means of supporting and improving the new technology for creating APCS on the basis of the STC network hierarchical structure is determined by a complex of performed scientific research protected by patents for inventions, master's, candidate and doctoral dissertations.

6. Conclusions

1. The modern interdisciplinary training of professional specialists in the problems of automation and control technology of energy equipment requires the integration of basic engineering training with production experience and scientific achievements by using advanced, including simulation modeling tools, industrial software and hardware management tools and innovative training methodology in the scientific and educational base.

2. The Proving Ground and its educational and methodological support can serve as an adequate scientific and technical means of solving problems (including upgrade) of efficient (technical, ecological, economic) functioning of complex automated energy equipment operating in a wide range of loads in the mode of regulation of system parameters, at the entire life cycle of APCS power plants.

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