Information Operator Support Systems of Nuclear Power Plants and a Flexible Modeling Complex

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Abstract—In the paper, there are considered functional abilities of information operator support systems (IOSS) of power units of nuclear power plants (NPP) and their place within the an unit-level system of automated process control systems (APCS) of NPP. The purpose of implementation of NPP IOSS is preventing or decreasing the frequency and heaviness of human-operator errors appearing during transients and non-regular situations, when human-operators perform under the conditions of the time deficit, fast changes of the current plant status, and huge volumes of information, conditioning thus the excessively high work load. Within the frameworks of the NPP IOSS, issues of creating flexible modeling complexes are considered, enabling one to turn the system to an NPP power unit of a given type.

Index Terms—Operator support system, upper unit-level system, NPP, normal operation, flexible modeling complex.

I. INTRODUCTION

At present, the nuclear power engineering puts forward increased requirements to the reliable and safe operation of power units of nuclear power plants (NPP). An aspect of this implies a requirement of creating information operator support systems (IOSS) of NPP, which are to provide personnel of the main control room (MCR) generalized information on parameters of the NPP power unit.

The need in the NPP IOSS helping human-operators to understand a situation correctly has appeared on the background of common interest to the artificial intelligence technology, especially, to expert systems. V.A. Trapeznikov Institute of Control Sciences (ICS RAS) was standing by the development of scientific foundations of the NPP IOSS [1-9]. Issues of creating the NPP IOSS have not lost their vitality up to the current time [10-20]. At present, developing specialized NPP IOSS is considered as a main direction of solving the problem of qualitative improving the safety, reliability, and efficiency of the operation of power units of NPP.

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The main principles of constructing the NPP IOSS are the following [6, 8]:

- NPP IOSS is intended to operative performance during the working shift at the MCR of a power unit of an NPP as a supplementary tool of monitoring, analysis, and prediction of the technological process.
- NPP IOSS does not substitute regular MCR tools, but as supplement to them provides human-operators with a number of new, non-traditional functions of monitoring, increasing the reliability of the performance of the human-operators.
- NPP IOSS requires minimal interference in its performance of shift operators.
- NPP IOSS input is connected with persistently updated plant data base.
- NPP IOSS possesses the ability to provide human-operators with a guaranteed time reserve to make a decision.

II. FUNCTIONAL ABILITIES OF THE NPP IOSS AND UPPER UNIT-LEVEL SYSTEM

Implementation of principles of constructing the NPP IOSS enables one to equip the system with the following functional abilities that, in turn, are divided on the two main groups. The first group is concerned with improving and detailing monitoring of the power unit status, implemented under human-operator call. The second group is concerned with the information support based on implementing predicting calculations on-line and off-line.

The first group of functional abilities of the NPP IOSS involves:

- Operative text messages on the time and cause of actuating controlled elements of the power unit, performance of automatic systems, passing various commands, actuating emergence protections, bars, and blockings;
- Displaying fields of parameters of the reactor core and their dynamics under moving control rods;
- Displaying magnitudes of technological parameters, status of controlled elements and control systems in comfortable for perception mimic panels and tables, united in a hierarchical structure, with providing an
efficient access to any branch and level of the hierarchy;

- Displaying information on trends of parameters in the form of conventional dynamic plots, emulation of logger performance;
- Elements of imaginary information displaying, such as displaying a “working point” trend in the field of parameters with indicated bounds of set-ups, displaying fields of parameters as two- and three-dimensional structures, displaying distributions of parameters in the form of dynamic histograms, displaying the dynamics of elements and systems of the power unit in the form of controlled animation.

Within the second group of functional abilities of the NPP IOSS, in the operative mode (on-line) there are implemented:

- Predicting the technological process behavior under performance of the regular system of automatic control of the power unit without interference of human-operators;
- Predicting technological process behavior under interference of human-operators in the performance of the regular control system, and implementation by them of optimal program of actions on the power unit control, consisting in acting the plant by organs of manual control, changing turnings and set-ups of actuating automatic regulators;
- Predicting technological process behavior under selection by human-operators a program of actions on control of the power unit;
- Predicting consequences of violations revealed in the equipment status and technological process behavior, confirmation of the initial diagnosis by use of corresponding calculations;
- Using results of the prediction jointly with control performance index to solve the problem of stabilization of the plant parameters with respect strategically optimal trajectories;
- Using equations of predicting models jointly with results of measurements to solve the problem of operative estimation of truth magnitudes of measured parameters.

In turn, in the non-operative mode (off-line) the NPP IOSS solves the following problems on predicting the technological process behavior:

- calculating modes of the power unit performance under various violations in the equipment and technological process behavior in order to form a base of modes, which then is processed in a special manner [28, 29];
- using predicting model jointly with control performance index to calculate strategically optimal trajectories of behavior of power unit parameters under its performance in transients, involving maneuvers by power in accordance to the dispatch load schedule, load following modes, participation in emergence regulating the frequency and power of a power grid, planned starts and stops, actuating regular emergence protections.

Meanwhile, the result of processing the base of modes is creating a base of images of the progress of technological processes under different initial events (violations, anomalies, accidents). Besides this, the predicting model is used to optimize the control under power unit operation after the pointed out initial events.

Particular meaning the NPP IOSS acquire under transfer to the symptom-oriented approach to detection and removing non-regular and emergence situations. From another hand side, sharply grown abilities of the computer engineering enables one effectively implements complex mathematical models of technological systems, quickly implement analysis of predicted and current information on the plant.

A main direction in providing the safety, reliability, and efficiency of the operation of power units of NPP of the next generation lays in inclusion in the make-up of regular control systems of these power units (namely, in the make-up of the upper unit-level system of APCS) of intelligent systems of information support of operators. At present, it is commonly recognized that effective implementation of such systems sharply increases the reliability of the performance of MCR operators as a key link of the human-machine control system.

At present, ICS RAS implements works on modernization and design of the software for the upper unit-level control system (ULCS) of the APCS of the “Kudankulam” NPP (India) and “Bushehr” NPP (Iran) in accordance to the life-cycle [21-27]. Original particularities of the software enable one a possibility not to put forward high requirements to corresponding hardware tools on the capacity and memory, what provides a possibility of installation of the software on hardware tools from mobile devices to supercomputers, and enables one to apply typical solutions for localized subsystems, separate power units, and multi-unit NPP.

The ULCS is intended to monitor and control the power unit under normal operation modes and modes with violation of the normal operation, involving design basis emergence modes of the NPP power unit performance, but without violations of the limits and conditions of the safe operation.

The ULCS provides integration in unique system of all APCS subsystems. The ULCS is an open, distributed, extendable information-and-control system providing the developer a possibility to introduce functions “step by step” and add new applications. Implementing the ULCS functions is provided by solving information, control, and auxiliary tasks, involving the NPP IOSS.

III. MAIN GUIDELINES ON CREATING FLEXIBLE MODELING COMPLEX

The NPP IOSS is an intelligent system, whose kernel are a block of dynamic modeling of parameters of the controlled
system (long-term and short-term predictions) and expert-logic block of the analysis of predicted and current information on the system. Information on current and predicted system status is presented to the personnel in maximally comfortable for perception form in specialized screen formats.

Main requirements, which the structure and properties of the NPP IOSS are to meet to:

- High detailing of description of power unit properties and ability of achieving the speed of modeling, exceeding the speed of run of real processes.
- Using effective high-performing algorithms in the junction of powerful computer tools (for instance, hardware with parallel architecture or unifying hardware in high-performance networks).
- The modeling dynamic complex is to be flexible, in other words, it should contain a set of models of a different degree of complexity, applied in the dependence of a specific modeled power unit and type of predicted process.
- As initial data for the complex, information on operation parameters of the power unit, obtained directly from regular monitoring systems, is used.
- An integral part of the complex is effective high-performance software applications of visualization of predicting results in the form of easily accessible for human-operator perception videograms.

One of the most important properties of the flexible modeling complex (FMC) is its flexibility that enables one to turn the system to already existing, updated, or designed NPP power unit on the basis of a dialog system of selecting a specific set of modules from a library of modules. The result of performance of such a system is a computer software application implemented a plant assigned.

The FMC make-up involves models of various degree of complexity and detailing, what enables one to implement predicting calculations at a power unit without essential loss of the accuracy.

The dynamic complex implementing the tasks of predicting the technological process behavior in the dependence on a type of modeled performance mode for a specific prediction task (operative or non-operative) uses three types of predicting models enabling one to reach the speed of modeling, exceeding the real speed of running technological processes in tens times:

1-st type – model constructed in accordance to the module principle, under which each block (module) describes corresponding aggregate or element of the technological equipment. Each of the blocks is implemented in several modifications differing with the detailing degree and, hence, computational time, but possessing the same inputs-outputs coinciding with inputs/outputs of a real plant. Such a model enables one, assembling various configurations of the blocks, to reach optimal compromise between the time of obtaining a prediction and details of the plant description.

2-nd type – model constructed in accordance to a principle, when a special subsystem implements search a mode that is mostly closed to a current one and modeled in advance, while modeling results were kept in a special base. Such a model enables one to reach quite high speed of obtaining a prediction.

3-rd type – model constructed in accordance to a principle, when differential equations describing the dynamics of power unit parameters are written for all nodes of the computational scheme (their number may vary from several tens to several tens thousands in the dependence of a modeled process type). Then each time step solving the system thus formed is implemented.

IV. FLEXIBLE MODELING COMPLEX AND OBJECT OF CONTROL

Since there are not two identical power units of NPP, a problem of creating such a flexible modeling complex appears, which might be operatively turned to any existing, updated, or designed power unit, and which might operatively response to any change in the technological equipment or control system of an NPP power unit, that is might account any particularities of a modeled plant.

Organization and implementation of polygon tests of software and hardware tools of APCS for existing, updated, and designed NPP of the new generation are to be arranged with accounting of the following factors:

- Toughening requirements to the safety and reliability of existing NPP.
- Requirement of creating designs of power units of NPP of the new generation with qualitatively more high level of the safety and reliability.
- Requirements of main regulation documents, concerning the development in the make-up of a design of an APCS of a power unit of systems of information support of operative personnel, implementing the prediction and diagnostics of the technological process behavior of an NPP.

The requirements listed lead to the necessity of reconsidering the existing technology of design and polygon tests of APCS and creating an instrument enabling one: firstly, operatively to implement engineering and organizational solutions oriented to increasing the safety and reliability of an NPP before including them in the design (for newly designed NPP) or before put in operation at power units (for existing NPP); secondly, providing training and support of high level of readiness of the operative personnel. Such an instrument, being the flexible modeling complex, is to involve two main components:

- Tools of design and implementation of algorithms of the upper level of APCS, enabling flexibly integrate developments of different collectives in the unique software complex;
- Tools of computer modeling technological processes of a power unit, enabling operatively implement turning the complex to any specific power unit design.
and necessary corrections in the course of development of the project.

Design tools are to be a universal platform for developing software, in particular for:

- Developing operator support systems;
- Implementing typical algorithms of the upper level of APCS;
- Developing systems of technical and regime diagnostics;
- Operator interface for functional simulators;
- User interfaces with computer models of different intention.

Tools of computer modeling technological processes are to provide creating, updating, and maintaining neutron/physical and thermo/hydraulic models of various intention for power units with different technological specifics.

Tools of design and modeling united in the make-up of the FMS have functional structure, scheme of which is presented in fig. 1.

Developed by the ICS RAS upper unit-level system is intended to control power units of NPP with reactors of the VVER-1000 type, whose principal heat scheme is presented in fig. 2. In fig. 3, a structure scheme of FMC performance in the part of modeling power unit parameters is presented.

Under consideration of problems of NPP power units control (when the speech is about a “fuzzy” control of technological processes), it becomes evident, that a human-operator may control a complex technological process more effectively, than an automatic system. Even under maximal richness of a modern NPP with tools of automatics, evaluation of critical situation remains a priority of human-operators, who analyze the situation and make decisions on the basis of their experience and heuristic logics [28-30]. If a human-operator faces difficulties under this process, the difficulties may be explained by insufficient speed or imperfect way of displaying information, or by absence of analysis that is needed to make decisions corresponding to the situation. Such a problem appeared may be solved in the following manner:

- Improving the form and contents of procedures, implemented by human-operator under normal operation, in an emergence situation, and after an accident;
- Providing human-operators with generalized exhaustive information that is processed in a corresponding manner.

The technology developed is oriented to creating tools of diagnostic information support of human-operators and enables one to construct systems of information support of human-operators in the make-up of existing, updated, and designed APCS of power units of NPP.
The technology is based on the notions of the common field of data and knowledge [31, 32] about an object of diagnostics and instrumental tools of non-constantly attended area, intended to creating and verifying data bases, knowledge bases, and operator interface, as well as constantly attended area (operative circuit), intended to solve problems of intelligent information on-line support of human-operators.

Data bases are divided on operative, containing measured variables, characterizing current status of object and diagnostics; and normative, involving normative description of the status of the technological equipment of an NPP power unit for various technological modes.

Data bases are implemented by a model of a semiotic type and are divided on non-operative, containing text descriptions of diagnostic models of knowledge for each diagnosed equipment element, and operative, which involve binary diagnostic models of knowledge for operative diagnosing equipment elements. Data bases are a hierarchy of models of knowledge, corresponding to the hierarchy of equipment in a specific NPP power unit (see fig. 4).

![Diagram of the hierarchical structure of power unit](image)

**Hierarchical structure of power unit:**

- **Technological installations**
  - Diagnostic models of technological installations
- **Technological systems**
  - Diagnostic models of technological systems
- **Technological groups**
  - Diagnostic models of technological groups

**Process of diagnosing power unit status:**

Since there are no two identical power units of NPP, there has appeared a necessity of creating a flexible modeling complex that might be operatively tuned to any existing, updated, or designed power unit, and which might operatively response to any change in technological equipment or control system of an NPP power unit.

For purposes of preventing incorrect control decisions by human-operators of NPP power units, the NPP IOSS is intended. The NPP IOSS provides not only NPP personnel operative information on power unit performance, but also enables one to implement engineering and organizational activities to economize power sources.

Under developing NPP IOSS software, involving the flexible modeling complex, there were used unified approaches and solutions, being analogous to the software of the upper unit-level system in the part of:

- Unification of software with using the module principle of constructing algorithms and typification of algorithmic modules;
- Algorithmic modules;
- Unification of functional structure and modules involved in it;
- Ways of implementation of system functions and unique operator interface in the system;
- Using methods of structure programming, module principle of constructing software components and typification of communications between software modules on the basis of unique software interfaces;
- Using unique ways of structuring data and constructing data bases, managing data bases, access to data bases and methods of linking computer software applications and data.

**REFERENCES**


