Information Operator Support Systems and Providing Normal Operation of Nuclear Power Plants

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Abstract—In the paper, principles of constructing systems of information support of human-operators (IOSS) of power units of nuclear power plants (NPP) and their place within the system of upper unit-level of automated process control systems (APCS) of NPP. The purpose of implementation of the NPP IOSS is preventing or decreasing the frequency and heaviness of operator errors appearing under transients and non-regular situations, when human-operators perform under the conditions of lack of the time, fast change of the actual status, and huge volumes of information, conditioning the excessively high work load.

Index Terms—Operator support system, upper unit-level system, NPP, normal operation, diagnostics.

I. INTRODUCTION

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

An serious interest to NPP IOSS has appeared in the middle of 1980s and was motivated by accidents at the “Three Mile Island” NPP in USA in 1979, and at the Chernobyl NPP in USSR in 1986, as well as by a number of critical incidents and breakdowns at NPP in different countries. The need of NPP IOSS helping operators to understand properly a situation has appeared on the background of the general interest to the artificial intelligence technologies, in particular, to the expert systems. The V.A. Trapesnikov Institute of Control Sciences of the Russian Academy of Sciences (ICS RAS) was a scientific organization that laid the development of scientific grounds of the NPP IOSS [1-9]. Issues of creating NPP IOSS have so far not lost their vitality at present [10-20]. At present, developing problem oriented NPP IOSS is a basic directions of solving the problem of qualitative improving the safety, reliability, and efficiency of NPP power unit operation.

Only efficient NPP IOSS are able to provide qualitative increasing the reliability of performance of the “key link”, human-operators, what just conditions the indirect (through the human-operator) action of the NPP IOSS on the common increasing the quality of NPP power unit operation, and, what is of particular importance, on decreasing the risk of heavy accidents due to the reason of actions of human operators, which are inadequate to a current technological situation. Meanwhile, creating the NPP IOSS does not assume a substitution of available regular tools of monitoring and analysis, but supplements them, providing the personnel a possibility to implement a number of new, non-traditional functions of monitoring and, due to this, to achieve a new control quality in a whole.

Under creating the NPP IOSS, there should be envisioned autonomous tools providing the registration and storage of information needed for investigating accidents and breakdown situations. These tools are to be protected of unauthorized access and keep the workability under normal operation, as well as under violations of the normal operation, including design basis accidents and non-design ones.

One of the most informative indicators of the NPP IOSS classification is separation in accordance to a functional intention. In [10, 12], the classification of NPP IOSS functions is associated with a model of human-operator actions, consisting of four phases: monitoring and detection; situation evaluation; planning response actions; implementing these actions. Using this model, one may emphasize systems of support of processes of detecting a situation, evaluating a situation, planning actions, and implementing the actions. The NPP IOSS model is of course not a uniquely possible.

The NPP IOSS should not substitute the human-operator and implement its work instead of him. Its purpose is to augment the human-operator abilities in those actions that the he implements better then a computerized system. Sometimes, such augmenting is achieved due to the NPP IOSS accents the human-operator attention to a one of numerous valuable indicators. In other case, it is achieved by monitoring actions of human-operator in the part of implementing a sequence of operations in accordance to regulations. In other words, frequently it is necessary “to support” not a whole task, but certain its phase only. Revealing such critical and vulnerable phase is implied by an analysis of errors made by human-operators at a simulator or in the process of operation, or by use of an expert analysis. Introducing the classification of systems in accordance to their orientation to the support of a certain phase of implementing a task gives an instrumentation...
II. PRINCIPLES OF CONSTRUCTING THE NPP IOSS AND THE UPPER UNIT-LEVEL SYSTEM

Main principles of constructing the NPP IOSS are as following [6, 8]:

- NPP IOSS is intended to operative performance during working shift at the MCR of an NPP power unit as a supplement tool of monitoring, analysis, and prediction of the technological process behavior.
- NPP IOSS does not substitute existing regular tools of the MCR, but additionally provides operators with a number of new, non-traditional functions of monitoring, increasing the reliability of human-operator performance.
- NPP IOSS requires minimal interference in its performance of shift operators, in other words, the implemented conception of the information support does not assume long-term diverting MCR human-operators of implementing their regular duties.
- NPP IOSS is input connected with the persistently updated plant data base. The plant connection enables one to implement two main modes of the NPP IOSS performance АЭС: improved and detailed monitoring of technological power unit systems simultaneously with the speed of updating information (sensors signals processed) in the power unit data base; and the mode concerned with implementing non-traditional functions of the information support based on the operative predicting calculations of the dynamics of technological parameters.
- NPP IOSS acquires its most important property to provide human-operators with a guaranteed reserve of the time to make decisions.

Implementing these principles will enable one to provide the NPP IOSS with the following functional abilities that, in turn, are separated on two groups. The first group involves improving and detailing monitoring of the power unit status, implemented in accordance to a human-operator's call. The second group involves the information support on the basis of implementing predicting calculations in the operative and non-operative modes.

The NPP IOSS purpose is preventing or decreasing the frequency and heaviness of errors of human-operator, which appear in the process of transients and non-regular situations, when human-operators perform under the conditions of time deficit, fast change of the current technological status, and huge volumes of information, leading to excessively high work load. Such a purpose is achieved due to implementation by the system of the following functions of the human-operator support:

- Proving information on the status of the technological process, equipment, and possible risks;
- Simplifying the evaluation of a situation and interpretation of the status of the equipment or NPP in a whole;
- Assisting correct panning of actions and priorities of control in accordance to changing conditions;
- Promoting to prevent errors under implementing actions and monitoring their efficiency.

The basis of the NPP IOSS construction is the idea of harmonic use and combination of main particularities of the human and computer. From one hand side, there is maximally activated and used the unique human ability practically instantly to accept and recognize complex color images, to analyze a situation as a complex, to make (within legalized bounds) effective non-standard decisions under the conditions of uncertainty and time deficit [21-23]. At present, it is commonly recognized that effective implementation of such systems sharply increases the reliability of personnel performance of NPP power units. The personnel really become the key link of the human-machine control system. A particular importance of the NPP IOSS arises under the transfer to the symptom-oriented approach to detecting and removing non-regular and accident situations. From another hand side, the sharply increased abilities of the computer engineering enable one effectively to implement complex mathematical models of technological systems, to implement fast analysis of predicting and current information on the plant.

Control systems of power units of NPP, performing in power grids, have no regular NPP IOSS in their make-up. However, a number of collectives-developers undertake efforts to work in practice at the MCR of existing power units of separate subsystems implementing certain functions of the NPP IOSS. Up to the present time, the relation of developers of control systems of updated and newly designed power units of NPP to the NPP IOSS is manifested quite clear. In the corresponding design documentation, there are introduced special sections from which it follows that of directions of providing the planned safety, reliability, and efficiency of operation of power units of NPP of the new generation is inclusion in the make-up of regular tools of control systems of these power units (namely, in the make-up of the upper unit-level system of the power unit APCS) of intelligent systems of information support of human-operators. At present, it is commonly recognized that effective implementation of such systems sharply increases the reliability of performance of MCR operators as a key link of a human-machine control system. The NPP IOSS, being a subsystem of the upper unit-level of NPP APCS, is to be manifested as an experienced and highly-qualified consultant under the search of initial causes of a violation of the normal operation of the technological plant, especially under non-regular and accident situations, when human-operators of the NPP power unit are not in position to response operatively to the avalanche-like flow of emergence signals.
At present, the V.A. Trapeznikov Institute of Control Sciences of the Russian Academy of Sciences 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 [24-30]. 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 NPP APCS ULCS [24, 25, 28] developed by the ICS RAS is one of the first control systems, in which under the design a profound level of protection of unauthorized access is incorporated. So, the system architecture and integrated protection tools provide the sustainability of the systems to cyber-attacks, possibility of detecting violations in the protection before these lead to the fault in functions implemented in the system.

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 is intended to perform at:

- MCR that in its composition and information flows is separated on the constantly attended circuit, non-constantly attended circuit, supervisor control circuit;
- Emergence control room (ECR);
- Shop of heat automatics and measurements.

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 TYPES OF THE OPERATORS SUPPORT

Two types of the human-operators support are emphasized: intelligent and information ones. In the branch of the intelligent support, at present in the world three sustainable classes of systems have been composed, achieved the level of industrial operation: systems of processing and displaying signaling/alarm; system of displaying critical safety functions; and the system of computerized procedures. As an explicit indicator of such a composition, three standards serve: IEC 62241 [32] – Alarm functions and presentation; IEC 60960 [33] – Functional design criteria for a safety parameter display system for nuclear power stations; IEC 62646 [34] – Computer-based procedures.

Systems of processing and displaying signaling/alarm are intended to decrease the volume of signals in critical situations and to effective control of human-operators attention. In accordance to IEC 62241, this is achieved by three ways: dynamic changing of priorities of signals, their filtering (suppressing), and hierarchical organization. The hierarchical organization usually is introducing three levels: overview level, system level, and individual messages level. Decreasing the priority takes place in the cases, when a signal reflect an event-consequence, does not require immediate human-operator reaction, is redundant for a current operation mode, points out less heavy violations in the same equipment, etc. As methods and algorithms of the analysis, logical trees of events are applied, but a thinner analytical processing of signaling/alarm is possible, involving the correlation and frequency analyses [31].

Systems of displaying safety parameters implement calculating and displaying safety indicators, causes of their degradation, and ways of restoring. Requirements to these systems are described in IEC 60960.

Systems of computerized procedures are intended to juxtapose observed symptoms with input symptoms of available procedures, selecting and step-by-step representation of a suitable procedure, and monitoring its execution. Main guidelines are presented in IEC 62646, however their implementation requires solving two scientific problems:

- Developing methods of identification of a situation and selecting most suitable procedure with using various relevance indexes [11];
- Developing approaches to automatic generation of the procedure in the case of its absence with application, for instance, semantic networks [35].

Advanced trends of extension of the intelligent support are directed to the branch of systems of risk evaluation, predicting, displaying paths of running of accidents and control of accidents (involving heavy ones), as well as systems based on knowledge and models, and intended to the complex diagnostics of the power unit and monitoring the correctness of running operation modes.

The following classification of methods for such a diagnostics is considered [36-38]: methods based on models, when current behavior of NPP is compared with nominal, represented in the form of a mathematical model; methods based on data, when NPP behavior is analyzed from the point of view of dependencies obtained in the result of processing historical data by use of multivariate statistical methods; methods based on signals, when current values of signals or technological parameters are compared with corresponding nominal values.

IV. DIAGNOSTICS OF TECHNOLOGICAL PROCESSES AND THE NPP IOSS

Real-time diagnostic methods may be conditionally divided on algorithmic and knowledge-based ones. In the basis of algorithmic diagnostic methods to search system faults, there lay theories of estimation, filtering, parameter and structure identification. In contrast to them, the diagnostics in knowledge-based systems resembles the style of solving a problem by human-operator.
A structure scheme of an expert system for NPP IOSS of a
power unit is presented in fig. 1. This expert system is one of
main parts of the NPP IOSS.

The hierarchical structure in the diagnostic and predicting
processes is a result of decomposition of the technological
process on certain intelligent levels. The process diagnostics
starts with the very top level (system level, for instance: NPP
power unit) (see fig. 2), then: level of technological system,
and so on to the lower level: to the level of technological group
or elementary equipment.

In a complex technological system, disturbances, appearing
as a result of violation of performance of elementary units of
the equipment, then are expanded to other subsystems of the
plant, what leads to emergence stop of the whole system, if the
human-operator will not undertake measures to compensate the
disturbance and removing the violation. Determining a cause of
the violation consists of several stages:

- Detecting deviations from nominal running technological process;
- Locating the violation cause to the level of an element
  of control object;
- Detecting contradictions between measured and
calculated parameters;
- Revealing possible violations.

Availability of information on parameters important for the
NPP safety enables one to evaluate quickly a situation, to
predict the progress of a technological process and operatively
react on various non-standard situations under operation. This
task may be solved by introducing critical functions and safety
parameters in the make-up of displaying information within the
NPP IOSS and by generation of symptom-oriented
instructions.

The human-operator ability to solve control problems in
transient modes depends on not only his qualification, but also
on information load during the control process. There are not
rare situations with appearance of overlapping accompanying
faults of equipment, regulators, or with false actuating of
blocks and protections, when the human-operator is to hold in
the field of view changes of considerable number of main
technological parameters to make a decision. Since a human-
operator is not in position to implement an analysis of
information entering the MCR within a short time period due
to large number of parameters and spatial distribution of
instruments to monitor the parameters, a problem of complex
representation of information in a single information field
arises, as well as creating a system of displaying critical
functions and safety parameters, which will enable one to
generalize information on main parameters of the technological
process and, thus, to provide the operative personnel with
information on the status of power unit performance from the
point of view of the safety.

In a real accident situation, a large number of signals is
activated, indicating to deviation from nominal magnitudes of
variables, what complicates revealing a one-to-one connection
between non-correctly performing system components and
signals from measurement systems. In this connection, it is
necessary a complex representation of displaying parameters
important for the power unit safety, so as the representation
obtained would enable one unambiguously to judge on a status
of both individual subsystems and the power unit as a whole.

V. PROVIDING NORMAL NPP OPERATION

Under developing documents on information tasks of NPP
APCS, a problem of their embedding in the general system of
measures of providing the safety on revealing vulnerabilities of
the technological process arises. An analysis and evaluation of
risk of normal NPP operation are not possible without
understanding all totality of NPP systems, involving such elements as hardware tools, software, ergonomics, human factor, as well as the NPP IOSS. The integrity of this system is the fact that its properties may not be reduced to the simple sum of subsystems composing it, and elimination of a one of them leads to a violation of the system performance.

A risk may be defined as a potential prejudice involving non safe actions and/or conditions that may end with particular situations of any classification. The risk is a concretizing notion of the danger and is considered as a degree of danger of an event and the frequency of appearance of the event. Determining risks with regard to the normal NPP operation is the initial stage of the risk management, at which the identification of dangers and their analysis are implemented.

For instance, in the part of the information task of “Calculating technical and economical indexes” ("IT-TEI") in the result of unauthenticity of input parameter “Flow at output collector of heat exchangers of intermediate circuit of normal operation” 21 output parameters (30.29% of the total number of output parameters) are not calculated, subject to output to videomonitors of workstations of the senior engineer on reactor control, senior engineer on turbine control, and power unit shift supervisor. One should point out, that, meanwhile, a number of video frames, with the exception of the power level of the unit, do not contain authentic parameters (see fig. 3) characterizing the power unit performance. Human-operators, who do not possess all nuances of running the technological processes and specifics of information tasks, such a situation may be recognized as critical. The considered inauthentic signal is not related to the parameters important for the NPP safety, but its unauthenticity leads to impossibility of obtaining information on the efficiency of the power unit performance and may lead to incorrect control decisions, which in indirect manner will influence the normal power unit operation.

VI. CONCLUSIONS

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

Under development of the NPP IOSS software, unified approaches and solutions were used, being analogous to the software of the upper unit-level system in the part of:

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

REFERENCES


[34] IEC 62646:2016, Nuclear power plants – Control rooms – Computer-based procedures.


