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Calculating Technical and Economical Indexes and Providing Normal NPP Operation

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Abstract: In the nuclear power engineering, methods of detecting faults and diagnostics play increasing role, as well as systems of information operator support in order of increasing the safety and operation reliability. One of problems solved within the information support system, there is the task of calculating technical and economical indexes and its connection with providing the model of normal nuclear power plant operation.

Keywords: nuclear power plants, upper-level control system, information task, technical and economical indexes, normal operation

1. INTRODUCTION

The process of the automation development of complex industrial plants, whose violation of performance leads to large economical, ecological losses, threats to the human health, is characterized by the tendency of design of automated process control systems (APCS) implementing considerably more complicated algorithms of control and data analysis by use of complex software and hardware tools (Byvaikov et al., 2006).

Under development of systems for power engineering, where the operation period of the main equipment is dozens of years, one should apply such solutions in the APCS, which would enable one to operate, repair, and update the installed equipment without stopping the technological process. Besides this requirement, providing high reliability, survivorship, and safety are the key requirements (Jharko, 2014).

The nuclear power engineering is increasingly interested in applying techniques of fault detection and diagnostics to increase the safety and reliability of nuclear power plants (NPP) (Hashemian, 2006; Hashemian and Feltus, 2006; Ma and Jiang, 2011).

At present, there has been sharply revealed the tendency of solving the NPP control within the statement conditioning the necessity of implementation at the upper APCS level of a system providing a powerful information support of human-operator activity. Properly, the information support involves:

- Providing a possibility of fast analysis of current situation, based on which the human-operator makes a decision on different control strategies;
- Initiating (in the form of advices) actions needed for correct maintaining the technological process;
- Monitoring actions of the human-operator themselves.

2. UPPER-LEVEL CONTROL SYSTEM

At present, the V.A. Trapeznikov Institute of Control Sciences of the Russian Academy of Sciences (ICS RAS) is implementing works in accordance to the life-cycle of the software of the upper (unit) level control system (ULCS) of the APCS of "Kudankulam" NPP (India) and "Bushehr" NPP (Iran) (Byvaikov et al., 2006; Jharko, 2008, 2010, 2011, 2013, 2014; Mengazetdinov et al., 2014; Poletykin et al., 2006; Zharko, 2006). Original features of the software provide a possibility not to put forth strict requirements imposed on hardware tools with regard to the performance and memory size, what ensures a possibility of installation of the software to hardware tools relating both to mobile devices and supercomputers, and enables one to apply typical solutions for localized subsystems, individual power units, and multiunit NPP.

The NPP ULCS developed by the ICS RAS is one of the first control systems, in which a profound level of the protection of unauthorized access was installed under the design. So, the system architecture and integrated protection tools provide the sustainability of the system to cyber-attacks, possibility of revealing violations in the protection before they will lead to a fault in functions implemented by the system.

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

The ULCS is intended for performing at:

- Unit control room, in which its integration and information flows are separated on the operative control loop (circuit), loop (circuit) of non-operative control (non-constantly attended area), and supervisor control loop (circuit);
- Emergence control room;

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- Automatic equipment repair and maintenance shop.

The ULCS provides the integration in a unique system of all APCS subsystems. The ULCS is an open, distributed, extendable information and control system providing the developer with a possibility to insert functions “step-by-step” and to add new applications.

The ULCS is a system for automatic sampling, storage, display of information on the current status of technological control objects (TCO), and automated remote forming commands of TCO mechanisms control by the APCS algorithms for:

- Economically efficient manufacturing of the electric power;
- Meeting operation limits;
- Meeting limits and conditions of safe equipment operation;
- Improving characteristics of technological processes and technological equipment performance;
- Decreasing the manufacturing content of the equipment, improving the hardware maintainability, decreasing the strength of service personnel, improving consumer characteristics of APCS elements;
- Improving the labor conditions of the personnel and decreasing the number and diminishing consequences of mistaken human-operator actions.

The ULCS is a complex hardware and software tool, supported by an automated process design and adjustment system, intended to unite in a unique system of all APCS subsystems. The ULCS implements information, control, service, and auxiliary functions of the APCS. The information task “Calculating technical and economical indexes” (“IT-TEI”) is a computation application and is involved in the make-up of the application software of the upper (unit) level control system (ULCS) of NPP APCS developed by the ICS RAS (Jharko, 2015a, 2015b). The task of “IT-TEI” is performed in the automatic mode.

Since there are not existing two equivalent power units of an NPP, the problem of creating software oriented to specifics of a particular power unit of an NPP appears, both in the part of hardware and taking into account points of monitoring technological parameters. Calculating the TEI is a technological basis of automated information revealing, characterizing the heat efficiency of the power unit and the equipment involved in its make-up. Meanwhile, as the heat efficiency (hereinafter, simply the “efficiency”), it is understood using the heat produced in the reactor by the nuclear fuel to manufacture the electric power.

3. OBJECT OF THE CONTROL AND THE INFORMATION TASK OF “IT-TEI”

The upper (unit) level control system is intended to control power units of NPP with reactors of the VVER-1000 type, whose schematic heat circuit is displayed in Figure 1. The schematic heat circuit of an NPP power unit with the VVER-1000 type reactor has two circuits.

The primary circuit is radioactive. It involves the VVER-1000 type reactor and circulation cooling loops. Each loop contains the main circulation pump, steamgenerator, and two main shutoff gate valves. To one of circulation loops of the primary circuit, the pressure compensator is joined, by use of which the set water pressure is maintained; meanwhile the water is simultaneously coolant and neutron moderator. At a power unit with VVER-1000 reactor, there are four circulation loops.

The secondary circuit is non-radioactive. It involves steamgenerators, steam pipelines, steam turbines, separators-steamsuperheaters, feed pumps and pipelines, deaerators and regenarative heaters. The steamgenerator is a common equipment for the primary and secondary circuits. In it, the heat energy elaborated in the reactor is transmitted from the primary circuit to the secondary circuit via the heat exchange tubes. The saturated steam elaborated in the steamgenerator via the pipeline comes to the turbine that makes in rotating the generator elaborating the electric current.

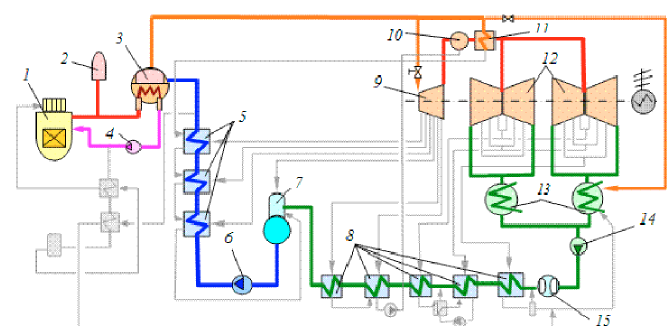

Fig. 1. The schematic heat circuit of the power unit of an NPP with the VVER-1000 reactor:
1 – reactor; 2 – volume compensator; 3 – steamgenerator; 4 – main circulation pump; 5 – high pressure heaters; 6 – feed pump; 7 – deaerator; 8 – low pressure heaters; 9 – stages of the high turbine pressure; 10 – separator; 11 – steam superheater; 12 – stages of the lower turbine pressure; 13 – condensers; 14 – condensate pump; 15 – ejectors.

The prospect of having performance measures that are useful in gauging the economic and financial success of business enterprises is certainly not new. It is well recognized that there are a plethora of commonly used standard measures that have been successfully employed by the business and financial community, as well as by electric utilities, throughout the world for a very long time. Clearly, when it comes to the safety and reliability of nuclear power plants, there is no question as to the industry’s achievements in developing and implementing superlative nuclear performance indicators and the processes to engage them, on a worldwide basis. Over the years, the world nuclear industry’s development and application of the World Association of Nuclear Operators and Power Reactor Information System performance indicators have contributed significantly to substantial improvements in the operating and safety performance of nuclear power plants. Although many

NPP have traditionally embraced simple economic measures of resource utilization and budget performance, little has been achieved to date to standardize and implement economic and financial performance measures that help to assure economic competitiveness and financial success at the nuclear plant generating level. Theoretically, the performance associated with any aspect of constructing or operating a nuclear power plant affords some degree of economic consequence (Technical Report, 2006).

The purpose of the TEI calculation is to provide information for the most efficient use of the equipment, prediction its maintenance and repair, as well as to form reports on the power unit efficiency.

The information task of "IT-TEI" is implemented for two groups of the NPP equipment: 1st – the main equipment influencing the power unit efficiency; and 2nd – equipment, whose status defines the power unit performance mode.

The make-up of the first group involves equipment, whose status/state is estimated on the basis of results of a whole complex of tasks. The first group covers the turbine equipment, involving the turbine itself, high pressure heaters, low pressure heaters, separator-steamsuperheater, condenser, deaerator, and so on.

The make-up of the second group involves the equipment (pumps, valves), in the dependence on the status of which the performance mode of the technological systems of the primary and secondary circuits is changed, and, accordingly, the algorithm of the TEI calculation is changed. This equipment involves the feed and condensate pumps, valves at feed and condensate lines, main circulation pumps, etc.

The output information of "IT-TEI" is outputted to the automated workstations of the senior engineer on reactor control, senior engineer on turbine control, and power unit shift supervisor.

4. IMPLEMENTATION OF THE INFORMATION TASK OF "IT-TEI"

The software of the information task of "IT-TEI" in accordance to the type of solved problems is subdivided and consists of the following main parts:

- Providing the calculation itself, analysis and displaying at automated workstations of results of the TEI calculation (performing in the real-time mode);
- Providing formation of forms of reports (performing in the interactive mode);
- Providing service functions (performing in the interactive mode).

The TEI calculation is implemented by use of coordinated mutually performed a complex of tasks, which involves:

- Preliminary calculations over the operative interval;
- TEI calculation over the operative interval;
- Sorting information over different time intervals;
- TEI calculation over different intervals;
- Output of results of the TEI calculation.

All calculated technical and economical indexes are divided on three main groups:

- Actual indexes that characterize the level of the equipment efficiency under the operation conditions;
- Normative indexes that characterize the rated level of the equipment efficiency;
- Indexes of changing the power unit efficiency due to deviation of actual indexes from the normative ones.

In Figure 2, the cycle of the information task of "IT-TEI" is displayed.

The initial time interval (discretization (sampling) period) is a segment of the time between beginning two following one after another cycles of sensors sampling. The duration of the discretization period is taken unique (identical) with other functions of the APCS. To calculate the TEI, the most rational duration of the discretization period is 1 minute.

To calculate the TEI, the following time intervals, over which the calculation is implemented, are provided:

- Operative interval taken to be equal to 15 minutes;
- Shift, the interval with the duration being equal to one working shift;
- Day, time interval being equal to 24 hours;
- Month, interval being equal to the number of hours in a calendar month.

In the dependence of interval, at which indexes were calculated, these are referred accordingly operative, shift, day, and month ones. Besides these indexes, obtaining integral indexes in the progressive total mode from the month beginning till the request time instant within the current month is provided.

Separating the indexes characterizing the life cycle of the power unit performance of an NPP on four groups enables one to collect and store data corresponding to different groups of the indexes under a necessity in different data bases that may be stored at individual servers, what, in turn, enables one to implement the search and processing of required for calculations data more effectively, what leads to decreasing the calculation time amd increasing the results accuracy.

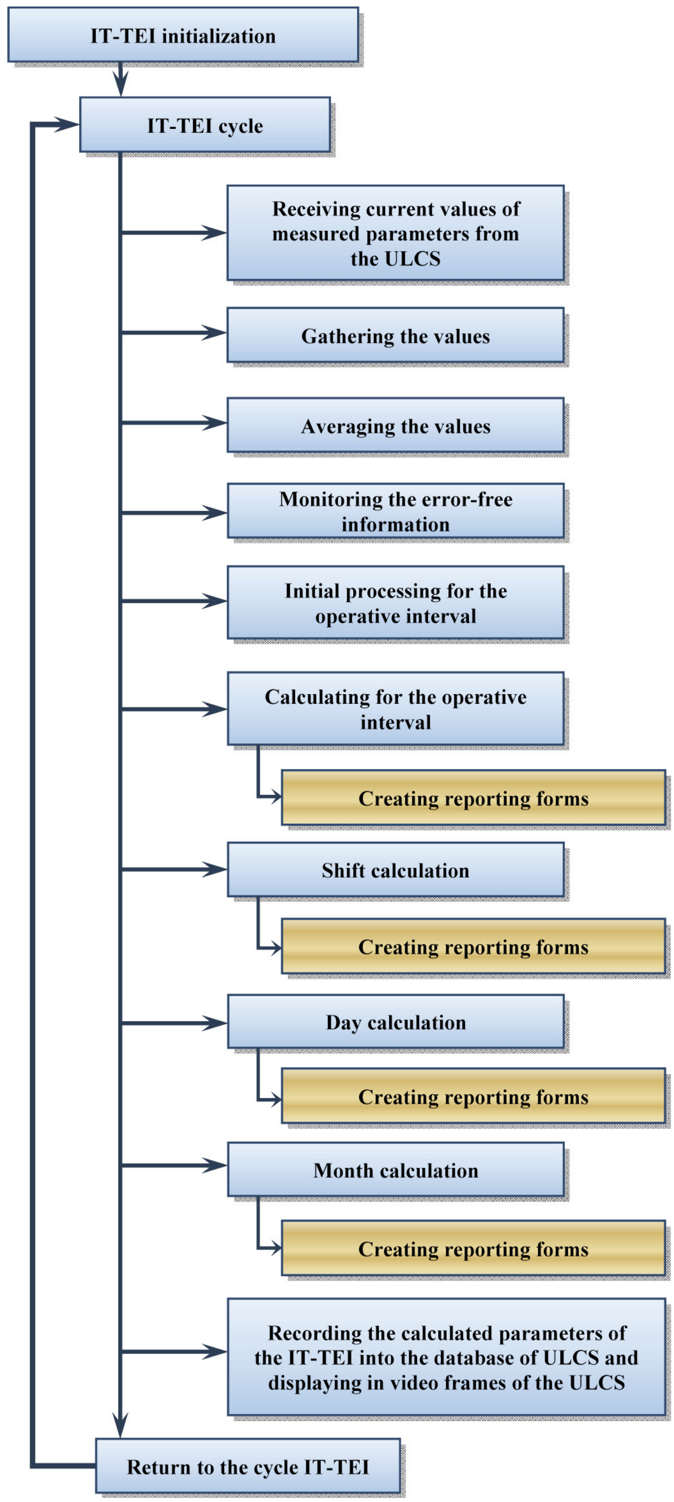

Fig. 2. The cycle of the information task of “IT-TEI”.

After completion of the calculation of the technical and economical indexes, in accordance to templates forms of reports are generated (where xxx is an interval indicator: 01 is the operative interval indicator; 02 is the shift report; 03 is the day report; 04 is the month report):

- TEI01_xx General characteristics;
- TEI02_xx NSSS;
- TEI03_xx Steam Parameters and HPC seal conditions;
- TEI04_xx NSSS parameters;
- TEI05_xx SRH Parameters Analysis;
- TEI06_xx HPR Analysis;
- TEI07_xx LPR Analysis;
- TEI08_xx Turbine condenser analysis;
- TEI09_xx Feedwater pump analysis;
- TEI10_xx General Operation parameters of the power unit;
- TEI11_xx Turbine parameters;
- TEI12_xx Efficiency analysis of the Unit;
- TEI13_xx Unit performance during the month.

5. PROBLEMS OF IMPLEMENTING THE “IT-TEI” TASK

For the “IT-TEI” task more than 400 analog and discrete signals are parameters, and in the event if at least one of these signals is inauthentic, then it becomes impossible to obtain an authentic calculation of technical and economical parameters of the power unit in the full volume, and outputting operative information on the task to monitors of automated workplaces of shift engineers on reactor and turbine control is not the case. But in the course of the start and adjustment works, a necessity of at least partial outputting information on the task has appeared in order:

- Diagnosing both the equipment fault and non-conformity of the equipment to the ranges of change of analog signals;
- Determining the efficiency operating the equipment.

Thus a problem of implementing a decomposition of the task over input signals and revealing the influence of these signals on output parameters has appeared (see Figure 3). As a result, there will be calculated and outputted to monitors those output parameters only, for which a full set of required authentic input signals is available. The task of calculating technical and economical indexes is strongly connected, and individual input signals (both discrete and analog ones) participate in calculating of large enough number of output parameters, and their unauthenticity (for instance, flow of chemical distilled water in turbine condensers) may lead to exclusion from the calculations of up to 30% of output task parameters connected with this inauthentic signal. In Figures 4 and 5, examples of output to the video frames of results of non-full calculation (fields, colored with magenta, show filed of values to calculate which full set of authentic input parameters was not available) are displayed.

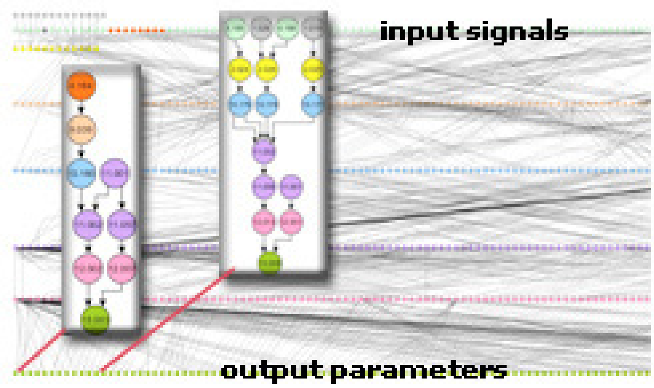

Fig. 3. An example of the calculation decomposition.

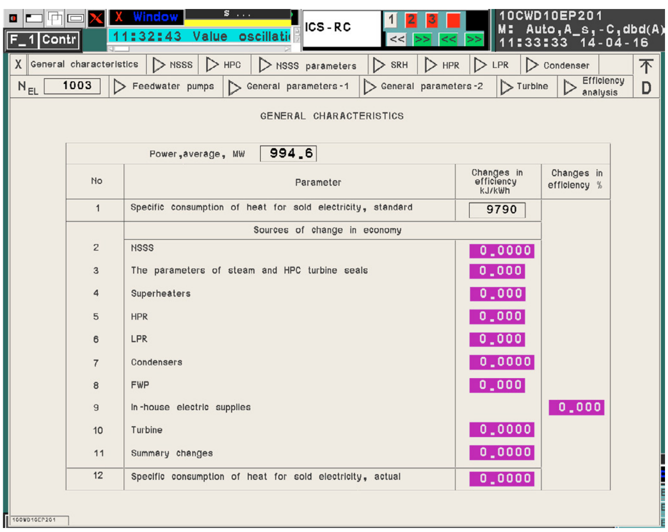

Fig. 4. An example of output of an incomplete calculation of the task of "IT-TEI" to the video frame "General characteristics".

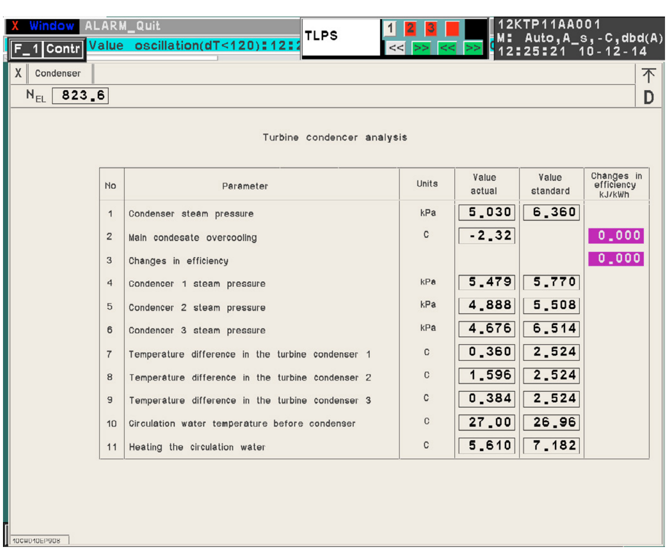

Fig. 5. An example of output of an incomplete calculation of the task of "IT-TEI" to the video frame "Turbine condenser analysis".

6. PROVIDING NORMAL NPP OPERATION

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

A risk may be defined as a potential damage, involving non-safe actions and/or conditions that may lead to specific situations of any classification. The risk is a specifying notion of a danger and is considered as a degree of an event danger and 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 identification of dangers and their analysis are implemented.

For instance, as a result of unauthenticity of the input parameter of "Flow at output collector of heatexchangers of intermediate circuit of normal operation" 21 output parameters (30.29% of the total number of output parameters) subject to output to video monitors of workstations of the senior engineer on reactor control, senior engineer on turbine control, and power unit shift supervisor, are not calculated. One should note that, meanwhile, a number of video frames, with the exception of the unit power level, do not contain authentic parameters (see Figure 4) characterizing the power unit performance. Operators, who do not possess all particularities of running technological processes and features of information tasks, may recognize such a situation as critical. The considered inauthentic signal does not relate to parameters important for the NPP safety, but its unauthenticity in the course of long time period leads to impossibility to obtain information about the power unit efficiency and may lead to incorrect human-operators control decisions that indirectly will influence the normal power unit operation.

7. CONCLUSIONS

Under developing the software of the information task of "IT-TEI", unique approaches and solutions were used, being analogous to the software of the upper (unit) level control system in the part of:

- Unification of components of software with applying the module principle of constructing algorithms and typification of algorithmic modules;
- Algorithmic modules;
- Unification of the functional structure and modules involved in it;
- Ways of implementing system functions and unique operator interface in the system;

- Applying methods of structured programming, module principle of constructing software components, and typification of connections between software modules on the basis of unique software interfaces;
- Using unique ways of structuring data and constructing data bases, data base control, access to data bases, and methods of conjugation of computer codes and data.

The information task of "IT-TEI" is solved for the main equipment influencing the power unit efficiency, as well as for the equipment, whose position/state/status is defined by the power unit operation mode. The information task of "IT-TEI" is implemented in the volume of the organizational structure, design solutions of tools of automation of equipment of power units of NPP with the reactor of the VVER-1000 type, providing with a given sampling period entering information in the ULCS. Calculating the technical and economical indexes of the power unit of NPP is implemented with high accuracy, quantitatively expressed in the accuracy of calculating reactor heat power. The accuracy of the estimate of the efficiency of performance of individual equipment is defined by the accuracy of regular measurement channels of technological parameters.

The information task of "IT-TEI" provides not only the administrative personnel of an NPP with operative information on the power unit performance, but also permits to implement organizational and technical actions to economize power sources.

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