The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS for operational and maintenance personnel of nuclear power plant units with WWER.

The integrated programming environment Microsoft Visual Studios was used. The structure of the program block for the parameter diagnostics of the equipment of nuclear power units is presented. The general structure of the software package for the analysis of the performance and parameter diagnostics of NPP units with WWER has been developed. When creating the software package, the integrated programming environment Microsoft Visual Studios was used. The structure of the program block for the parameter diagnostics of nuclear power units is presented.

Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and equipment, including obtaining operational (energy) characteristics of power unit systems and equipment, optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

Computer-integrated components, automated decision-making support system, nuclear power plant units with WWER, software package, simulation model, parameter diagnostics.

**Keywords:** computer-integrated components, automated decision-making support system, nuclear power plant units with WWER, software package, simulation model, parameter diagnostics.

**O. V. Eфимов, T. O. Есипенко, T. A. Гаркуша, B. L. Каверцев, T. I. Беркутова**

**Computer-Integrated Components of the Automated Decision-Making Support System for Operational and Maintenance Personnel of Nuclear Power Plant Units with WWER**

The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS for operational and maintenance personnel of NPP units according to the criterion of technical and economic efficiency, taking into account the diagnostics of the technical equipment state based on the simulation model describing by means of up-to-date mathematical methods the technological processes in the main and auxiliary equipment of power units using up-to-date mathematical methods at the level of detailing, corresponding to their principle and deployed thermal schemes. The results of studies aimed at the development of computer-integrated components of the automated decision-making support system (ADMS) for operational and maintenance personnel of NPP units by the criterion of technical and economic efficiency, taking into account the diagnostics of the state of the power unit equipment, are presented. The general structure of the software package interaction for the analysis of the performance and parameter diagnostics of NPP units with WWER has been developed. When creating the software package, the integrated programming environment Microsoft Visual Studios was used. The structure of the program block for the parameter diagnostics of the equipment of nuclear power units is presented. The main types of problems arising during the operation of NPP units with WWER, that can be solved with the help of the developed ADMS are considered, and a form for presenting the results to the operational and maintenance personnel of power units is proposed. Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and equipment, including obtaining operational (energy) characteristics of power unit systems and equipment, optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

Keywords: computer-integrated components, automated decision-making support system, nuclear power plant units with WWER, software package, simulation model, parameter diagnostics.

**O. V. Ефимов, T. O. Есипенко, T. A. Гаркуша, B. L. Каверцев, T. I. Беркутова**

**Computer-Integrated Components of the Automated Decision-Making Support System for Operational and Maintenance Personnel of Nuclear Power Plant Units with WWER**

The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS for operational and maintenance personnel of NPP units according to the criterion of technical and economic efficiency, taking into account the diagnostics of the technical equipment state based on the simulation model describing by means of up-to-date mathematical methods the technological processes in the main and auxiliary equipment of power units using up-to-date mathematical methods at the level of detailing, corresponding to their principle and deployed thermal schemes. The results of studies aimed at the development of computer-integrated components of the automated decision-making support system (ADMS) for operational and maintenance personnel of NPP units by the criterion of technical and economic efficiency, taking into account the diagnostics of the state of the power unit equipment, are presented. The general structure of the software package interaction for the analysis of the performance and parameter diagnostics of NPP units with WWER has been developed. When creating the software package, the integrated programming environment Microsoft Visual Studios was used. The structure of the program block for the parameter diagnostics of the equipment of nuclear power units is presented. The main types of problems arising during the operation of NPP units with WWER, that can be solved with the help of the developed ADMS are considered, and a form for presenting the results to the operational and maintenance personnel of power units is proposed. Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and equipment, including obtaining operational (energy) characteristics of power unit systems and equipment, optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

Keywords: computer-integrated components, automated decision-making support system, nuclear power plant units with WWER, software package, simulation model, parameter diagnostics.

**O. V. Ефимов, T. O. Есипенко, T. A. Гаркуша, B. L. Каверцев, T. I. Беркутова**

**Computer-Integrated Components of the Automated Decision-Making Support System for Operational and Maintenance Personnel of Nuclear Power Plant Units with WWER**

The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS for operational and maintenance personnel of NPP units according to the criterion of technical and economic efficiency, taking into account the diagnostics of the technical equipment state based on the simulation model describing by means of up-to-date mathematical methods the technological processes in the main and auxiliary equipment of power units using up-to-date mathematical methods at the level of detailing, corresponding to their principle and deployed thermal schemes. The results of studies aimed at the development of computer-integrated components of the automated decision-making support system (ADMS) for operational and maintenance personnel of NPP units by the criterion of technical and economic efficiency, taking into account the diagnostics of the state of the power unit equipment, are presented. The general structure of the software package interaction for the analysis of the performance and parameter diagnostics of NPP units with WWER has been developed. When creating the software package, the integrated programming environment Microsoft Visual Studios was used. The structure of the program block for the parameter diagnostics of the equipment of nuclear power units is presented. The main types of problems arising during the operation of NPP units with WWER, that can be solved with the help of the developed ADMS are considered, and a form for presenting the results to the operational and maintenance personnel of power units is proposed. Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and equipment, including obtaining operational (energy) characteristics of power unit systems and equipment, optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

Keywords: computer-integrated components, automated decision-making support system, nuclear power plant units with WWER, software package, simulation model, parameter diagnostics.

**O. V. Ефимов, T. O. Есипенко, T. A. Гаркуша, B. L. Каверцев, T. I. Беркутова**

**Computer-Integrated Components of the Automated Decision-Making Support System for Operational and Maintenance Personnel of Nuclear Power Plant Units with WWER**

The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS for operational and maintenance personnel of NPP units according to the criterion of technical and economic efficiency, taking into account the diagnostics of the technical equipment state based on the simulation model describing by means of up-to-date mathematical methods the technological processes in the main and auxiliary equipment of power units using up-to-date mathematical methods at the level of detailing, corresponding to their principle and deployed thermal schemes. The results of studies aimed at the development of computer-integrated components of the automated decision-making support system (ADMS) for operational and maintenance personnel of NPP units by the criterion of technical and economic efficiency, taking into account the diagnostics of the state of the power unit equipment, are presented. The general structure of the software package interaction for the analysis of the performance and parameter diagnostics of NPP units with WWER has been developed. When creating the software package, the integrated programming environment Microsoft Visual Studios was used. The structure of the program block for the parameter diagnostics of the equipment of nuclear power units is presented. The main types of problems arising during the operation of NPP units with WWER, that can be solved with the help of the developed ADMS are considered, and a form for presenting the results to the operational and maintenance personnel of power units is proposed. Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and equipment, including obtaining operational (energy) characteristics of power unit systems and equipment, optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

Keywords: computer-integrated components, automated decision-making support system, nuclear power plant units with WWER, software package, simulation model, parameter diagnostics.
Introduction. Nuclear power plant units, which are complex technical systems, are characterized by a large number of parameters, multifunctional links between them, a variety of equipment for various technological purposes and physic-chemical processes occurring in it, as well as operation under the influence of external random processes, etc. To study the parameters, characteristics and performance of NPP units as complex technical systems, methods of mathematical modeling using computer-integrated technologies for their implementation are now widely used. They make it possible to simulate the set of functional states of both systems and equipment of power units in a simulation experiment [1–26].

It should also be noted that the technological processes occurring in the equipment of NPP power units under various modes of their operation, including dynamic (transient) ones, are generally described by complex systems of nonlinear differential equations in partial derivatives. To describe the technological processes in steady-state (quasi-stationary) modes of the power unit operation, nonlinear equations with their own characteristics are used. To solve them, the use of numerous methods in the process of simulation modeling, and in some cases their linearization, makes it possible to obtain an approximate solution with the accuracy, which is sufficient for engineering practice [1, 2, 3].

The purpose and objectives of the research. The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS variants for operational and maintenance personnel of NPP units according to the criterion of technical and economic efficiency, taking into account the diagnostics of the technical equipment state based on the simulation model describing by means of up-to-date mathematical methods the technological processes in the main and auxiliary equipment of power units using up-to-date mathematical methods at the level of detailing, corresponding to their principle and deployed thermal schemes. This simulation model, methods and approaches to its creation based on the graph theory are described in sufficient detail in [1, 3–6] and several others.

The main components of the approaches presented in these works are the simulation model that adequately describes the technological processes, both in individual elements and in the power unit as a whole, and its computer implementation in the form of an automated set of programs. The listed computer-integrated components can be considered as the basis for the creation of an automated decision-making support system (ADMS) for operational and maintenance personnel of NPP units, which allows to perform:

- calculation of the parameters of technological processes in the elements, nodes and systems of the power unit;
- parameter diagnostics of the technical state of the power unit equipment;
- calculation of the reliability and safety indicators of the systems and equipment of the power unit;
- calculation of the projected electricity and heat generated by the power unit in a given period of operation;
- calculation of the technical and economic indicators of the unit efficiency;
- calculation of the performance indicators of repair work (repair cycles) at the power unit.

The effectiveness of using such ADMSS in the process of operation of NPP units as parts of their APCS, the accuracy and number of decision-making options offered by the system significantly depend on the level of the unit simulation model detailing and the accuracy of the mathematical methods used in the computer programs of the above-mentioned calculations to describe the technological processes in the equipment of the units.

Computer-Integrated Components of ADMSS. Based on the simulation model of the NPP power unit with WWER-1000 (Fig. 1), computer-integrated components of ADMSS were developed as a set of computer programs for analyzing technical and economic efficiency of operation and parameter diagnosing the technical state of two-loop cycle NPP unit equipment.

These components are used for a new, more advanced version of the automated complex of programs for analyzing the operation of two-loop cycle NPP units [6], expanded by developing programs for computing diagnostic parameters of the main and auxiliary equipment of power units.
The structure of individual components (blocks) of the automated computer program complex for analyzing technical and economic efficiency of operation and parameter diagnosing NPP power units with WWER is shown in Fig. 2. When creating it we used the Microsoft Visual Studio 6 development environment and the algorithmic language Fortran 95 as integrated programming environment, as in [6], which proved to be quite good as software tools when creating software packages for computing the parameters of technological processes in complex technical systems.

This set of programs, which is controlled by the MAIN file (Fig. 2), can be divided into two parts: conservative and operational, which is quite typical for automated decision-making support systems for operational personnel of power facilities as complex technical systems [6].

The conservative part of the program complex, which provides the adequate description of the technological processes in the systems and equipment of the NPP power unit at different operation modes, includes:

- a database operation block which is used to store the information accumulating during the operation of the power unit (Fig. 2);
- a block for processing information about the values of the parameters and characteristics of technological processes in the power equipment received from the instrumentation of the power unit (Fig. 2);
- a block for identifying the simulation model with the actual technical state of the power unit equipment (Fig. 2);
- a block of the modification of the structure and parameters of thermal power unit scheme (TS) that provides for connecting, disconnecting, switching, replacing, eliminating and including equipment into the TS, as well as entering and correcting the initial data necessary to compute the parameters of the technological processes in the power unit equipment (Fig. 2).

The operational part of the program complex, which provides the computation of parameters in the power unit systems and equipment, contains the following program blocks:

- a block of programs for computing parameters, characteristics and indicators in the reactor plant equipment by means of the corresponding algorithms given in [2, 3], including programs for computing thermal and hydraulic parameters and characteristics of the heating agent in the primary loop equipment, in particular, in main circulation pumps, as well as working substance in steam generators;

![Fig. 2 The structure of the interaction of components (blocks) of the automated system performance analysis and parameter diagnostics of NPP power units with WWER](image-url)
- blocks of programs for computing the parameters, characteristics and indicators of the turbine installation by means of the corresponding algorithms given in [2, 3], including: a block of programs for computing the parameters, characteristics and indicators in the flow sections of the main turbine and the turbo drive of the feed pump;
- blocks of programs for computing the parameters, characteristics and indicators in the systems of condensation and regenerative heating of the main condensate and feed water;
- a block of programs for computing the parameters, characteristics and indicators in the system for heating the network water (heating system);
- a block of programs for the parameter diagnostics of the main and auxiliary equipment in the power unit, created on the basis of the approaches, methods and models described in detail in [1, 2, 3].

The structure of the parameter diagnostics program block is presented in Fig. 3.

The factors causing the deviation of diagnostic parameters (functions) from standard values for various dimensions of the power equipment of NPP power units with WWER are summarized, systematized and entered into the database of the program complex.

The operational part of the program package for analyzing the quality of the operation of NPP units also includes a block of programs for controlling simulation experiments (Fig. 2).

The presented computer-integrated components in the form of a program complex allow to solve the following types of problems arising during the operation of NPP power units with WWER:
- problems of analyzing the influence of the equipment parameters, the structure of thermal schemes and external operating conditions on the performance of power units:
  \[ \Omega(\chi) = f(\chi, G^T, \Lambda, B, Y); \]  
- problems of structural and parameter optimization of the performance indicators of power units:

![Diagram showing the block diagram of the program complex for parameter diagnostics of NPP power unit equipment with WWER](image-url)
The form of presenting information in the ADNSS about the values of parameters, characteristics and technical and economic indicators of the operation modes and diagnostic results of WWER NPP units, their individual systems and equipment obtained using the developed set of programs is shown in tabl. 1–3 as a fragment of the output information about the values of parameters, characteristics and indicators of the NPP power unit with WWER-1000, PGV-1000 steam generator and K-1000-60-1500/2 (K-1000-5.9/25) turbo-installation at nominal mode operation. This form of presenting information may be modified in accordance with the specific requirements of the ADNSS users at nuclear power plants.

The analysis of the results of computing a number of specific problems of the above-mentioned types using the described complex of programs showed that their values in terms of the initial data error, caused by errors in measuring technological process parameters by means of standard instrumentation, as well as errors in formula which were used in the computation algorithms, do not exceed the limits acceptable for assessing technical and economic efficiency, reliability and safety of NPP power units.

**Conclusions.** Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

### Table 1 – Main indicators of power unit operation

| Electric power $N$ (kW) | Specific heat consumption $q$ (kJ/(kWh)) | Efficiency |
|-------------------------|------------------------------------------|------------|
| net                     | 1077247,91                              | 9992,9     | 31,99       |
| gross                   | 1103572,93                              | 10237,1    | 32,76       |

| Total consumption of generated steam $G$ (kg/h) | Pressure of generated steam $P$ (atm) | Temperature of generated steam $T$ (°C) | The degree of dryness of the generated steam $X$ | Feedwater temperature at the inlet to steam generator $T$ pit (°C) |
|-----------------------------------------------|--------------------------------------|----------------------------------------|-----------------------------------------------|-------------------------------------------------|
| 6430000,0                                    | 61,98                                | 274,20                                  | 0,995                                | 224,74                                          |

### Table 2 – Reactor plant heating agent parameters

| Sitename                                      | Heating agent temperature $T$ (°C) | Heating agent pressure $P$ (atm) | Specific volume of heating agent $I$ (m$^3$/kg) | Heating agent enthalpy $I$ (kJ/kg) |
|-----------------------------------------------|------------------------------------|---------------------------------|---------------------------------------------|---------------------------------|
| At the inlet to steam generator               | 319,93                             | 158,87                          | 0,0014698                                   | 1452,52                         |
| At the outlet of steam generator              | 289,81                             | 157,66                          | 0,0013391                                   | 1282,77                         |
| At the inlet to reactor core                  | 290,45                             | 162,16                          | 0,0013399                                   | 1285,99                         |
| At the outlet of the reactor core             | 319,97                             | 159,06                          | 0,0014696                                   | 1452,73                         |
Table 3 – Turbo-mount computation of the process of steam expansion in turbine

| Names of the elements of turbine flow part | Steam consumption G (kg/h) | Vapor pressure P (atm) | Steam temperature T(°C) | Degree of steam dryness X | Steam enthalpy I (kJ/kg) | Specific volume of steam V (m³) | Power compartment (kW) |
|------------------------------------------|---------------------------|------------------------|-------------------------|--------------------------|------------------------|-----------------------------|------------------------|
| High pressure turbine inlet             |                           |                        |                         |                          |                        |                             |                        |
|                                          | 6157865,01                | 58,3646                | 272,53                  | 0,9954                   | 2775,12                | 0,0340                      | 169844,00               |
| Compartment 1                           | 5651553,03                | 30,5538                | 233,81                  | 0,9291                   | 2675,88                | 0,0620                      | 98398,71                |
| Compartment 2                           | 5359023,02                | 19,8102                | 210,94                  | 0,9041                   | 2613,24                | 0,0927                      | 87456,32                |
| High pressure turbine Outlet            |                           |                        |                         |                          |                        |                             |                        |
|                                          | 5077590,02                | 12,6117                | 189,32                  | 0,8849                   | 2554,49                | 0,1404                      | 0,00                    |
| Low pressure turbine inlet              |                           |                        |                         |                          |                        |                             |                        |
|                                          | 4347883,04                | 11,7201                | 250,01                  | 1,0000                   | 2935,99                | 0,2011                      | 126963,10               |
| Compartment 3                           | 4158750,03                | 6,6920                 | 192,51                  | 1,0000                   | 2830,94                | 0,3151                      | 117642,80               |
| Compartment 4                           | 3846209,05                | 3,5678                 | 139,13                  | 1,0000                   | 2729,14                | 0,5244                      | 210826,90               |
| Compartment 5                           | 3606599,07                | 0,9673                 | 98,24                   | 0,9393                   | 2532,41                | 1,6715                      | 166163,30               |
| Compartment 6                           | 3404928,01                | 0,2580                 | 65,31                   | 0,8940                   | 2366,64                | 5,4855                      | 126817,80               |
| Low pressure turbine Outlet             |                           | 0,0410                 | 29,12                   | 0,8700                   | 2232,62                | 30,1089                     | 0,00                    |

Pressure in the condenser $P = 0.03983$ atm

References

1. Палагин А. А., Ефимов А. В., Меньшкова Е. Д. Моделирование функционального состояния и диагностика турбиностроения. Киев: Наук. думка, 1991. 192 с.
2. Ефимов А. В., Гончаренко Л. В., Потанина Т. В., Каверцов В. Л., Меньшкова Е. Д., Гончаренко А. Л., Гаркуша Т. А., Есипенко Т. А., Моль Л. С., аль-Тувайни А. М. Совершенствование и оптимизация моделей, процессов, конструкций и режимов работы энергетического оборудования АЭС. ГЭС и отопительных котельных. Харьков: НТУ «ХПІ», 2017. 376 с.
3. Ефимов О. В., Пилипенко М. М., Потанина Т. В., Каверцов В. Л., Гаркуша Т. А. Радиаторы и парогенераторы энергообъектов АЭС: схемы, процессы, материалы, конструкция, модели. Харьков: ТОВ «В справа», 2017. 420 с.
4. Потанина Т. В., Ефимов А. В. Разработка имитационной модели энергообъекта АЭС с ВЭР-1000 для решения задач анализа, управления и диагностики. Зб. праць конф. «Моделирование–2006». Київ: Інститут проблем моделювання в енергетиці ім. Пухова НАН України, 2006. С. 217–220.
5. Потанина Т., Ефимов А. Симуляційне моделювання функціонування енергооб'єктів електричної та атомної енергетики з реактором ВВЕР-1000. Наук. дослід. Презенція. 2009. № 2 (14). С. 59–69.
6. Ефимов А. В., Кухтин Д. И., Потанина Т. В., Гаркуша Т. А., Каверцов В. Л. Автоматизированная система поддержания принятия решений эксплуатационным персоналом энергообъектов АЭС по критерию технико-экономической эффективности с учетом показателей надежности. Ядерна та радіоактивна безпека. 2018. № 2 (78). С. 3–11.
7. Анюхин А. Н. Адаптивный человеческо-машинный интерфейс для операторов атомных станций. Зб. наук. праць CHSU/ЕМПУ, 2013. № 2 (46). С. 16–24.
8. Marcus G. H., Levin A. E. New designs for nuclear renaissance. Physics Today. 2002. Vol. 55, no. 4. P. 54–60.
9. Hoffman J. M. Nuclear new are Machine Design. 2001. Vol. 73, no. 18. P. 93–98.
10. A technical roadmap for generation IV nuclear systems: Technical roadmap report. Washington: NERAC, 2002. 112 p.
11. Generation IV roadmap: Crosscutting fuels and materials R&D scope report. Issued by the Nuclear energy research advisory committee and the generation IV international forum. 2002. 76 p.
12. Gardzliewicz A., Jefimow A. The heat and flow diagnostic procedure leading to a steam turbine repair Plan. Proc. 10th Conf. on Steam and Gas Turbines for Power and Cogeneration Plants. Karlovy Vary (Czech. Rep.), 1994. P. 87–93.
13. Gardzliewicz A., Jefimow A. Thermal Diagnostics of Thermal Cycle Components on an Example of a Regenerative Heat Exchanger Rep. IFFM-PAS 256, Gdansk (Poland), 1994. P. 34–40.
14. Glicz J., Gardzłewicz A. The analysis of performance of the turbine condenser with the prognosis of repair: Proc. of the International Joint Power Generation Conf. Baltimore (23–26 August 1998 p., Maryland USA). 1998. Vol. 2. P. 179–190.
15. Dudek G. Экономический расчет возобновляемых агрегатов в АЭС. Разработка и оптимизация моделей, процессов, конструкций и режимов работы энергетического оборудования АЭС. ГЭС и отопительных котельных. Харьков: НТУ «ХПІ», 2017. 376 с.
3. Yefimov O. V., Pylypenko M. M., Potanina T. V., Kavertssev V. L., Harkusha T. A. Reactors and paragenerators: Models, materials, methods. [Reactors and steam generators of NPP units: circuits, processes, materials, designs, models]. Kharkiv, TOV "V sparvi" Publ., 2017, 420 p.

4. Potanina T. V., Efimov A. V., Razzbokta imitation models of a reactor VVER-1000 for solving problems of analysis, control and diagnostics. Zb pracz konf. Modelirovanie-2006. [Collection of scientific papers of the Conf. Modelirovanie-2006]. Kyiv: Institut problem modelirovannya v energetyci im. Puxova NAN Ukrainy Publ., 2006, pp. 217–220.

5. Potanina T., Yefimov A. Symulacijne modelowanie funkcjonowania energoblokow atomowej z reaktorem VVER-1000 [Simulation of the operation of the power unit of the nuclear power plant VVER-1000]. Nauka i studia. Przemyśl. 2009, no. 2 (14), pp. 59–69.

6. Efimov A. V., Kukhlin D. I., Potanina T. V., Garkusha T. A., Kavertssev V. L. Avtomatizirovannaya sistema podderzhki primyatyia resheniy ekspluatatsionnym personalom energoblokov AES po krityiyu tekhniko-ekonomicheskoy efektivnosti s uchetom pokazateley nadezhnosti [Automated decision-making support system for operational personnel of NPP units by the criterion of technical and economic efficiency, taking into account reliability indicators]. Yaderna ta radiatsionnya bezopasnost., 2018, no. 2 (78), pp. 3–11.

7. Anokhin A. N. Adaptivnyy cheloveko-mashinnyy interfeys dlja operatorov atomnykh stanisii [Adaptive man-machine interface for nuclear power station operators]. Zh. nauk. pracz SNUYaELa [Collection of scientific papers]. 2013, no. 2 (46), pp. 16–24.

8. Marcus G. H., Levin A. E. New designs for nuclear renaissance. Nauka i studia. Przemyśl. 2000, pp. 112–116.

9. Hoffman J. M. Nuclear new are Machine Design. 2001, vol. 73, no. 18, pp. 93–98.

10. A technical roadmap for generation IV nuclear systems: Technical roadmap report. Washington,NERAC Publ., 2002. 112 p.

11. Generation IV roadmap: Crosscutting fuels and materials R&D scope report. Issued by the Nuclear energy research advisory committee and the generation IV international forum. 2002, 76 p.

12. Gardzilewicz A., Jefimow A. The heat and flow diagnostic procedure leading to a steam turbine repair Plan. Proc. 10th Conf. on Steam and Gas Turbines for Power and Cogeneration Plants. Karlovy Vary (Czech. Rep.). 2002, pp. 87–93.

13. Gardzilewicz A., Jefimow A. Thermal Diagnostics of Thermal Cycle Components on an Example of a Regenerative Heat Exchanger Rep. IFPM.PAS 256/94. Gdansk (Poland), 1994, pp. 34–40.

14. Gluch J., Gardzilewicz A. The analysis of performance of the turbine condenser with the prognosis of repair. Proc. of the International Joint Power Generation Conf. Baltimore (23-26 August 1998 p., Maryland USA). 1998, vol. 2, pp. 179–190.

15. Dudek G. Ekonomiczny rozdział obcięć z zastosowaniem algorytmów ewolucyjnych: Rozprawa doktourska. T. I. [Economic load distribution using evolutionary algorithms Dr. eng. Sci. diss. Vol. 1]. Czestochowa, 2002. 199 p.

16. Da Costa G., Costa C., De Souza A. Comparative Studies of Optimization Methods for the Optimal Power Flow Problem. Electric Power Systems Research. 2000, vol. 56, pp. 249–254.

17. Wei H. An Interior Point Nonlinear Programming for Optimal Power Flow Problems With A Novel Data Structure. IEEE Trans on Power Systems. 1998, vol. 13, no. 3, pp. 870–877.

18. Miranda V., Srinivasan D., Proenca L. Evolutionary Computation in Power Systems. Electrical Power and Energy Systems. 1998, vol. 20, no. 2, pp. 89–98.

19. Dudek G. Algorytm genetyczny jako metoda optymalizacji doboru składu jednostek wytwórczych w systemie elektroenergetycznym [The genetic algorithm as a method of optimizing the selection of the composition of generating units in the power system]. Materiały konferencyjne: "Algorytmy Ewolucyjne i Optymalizacja Globalna" [Conference materials: "Evolutionary Algorithm and Global Optimization"]. Warszawa, Ładzek Zdzisław. Wydawnictwo Politechniki Warszawskiej Publ., 2000, pp. 51–58.

20. Shi L., Xu G. Self-Adaptive Evolutionary Programming and Its Applications to Multi-Objective Optimal Operation of Power Systems. Electric Power Systems Research. 2001, vol. 57, p. 181–187.

21. Kozl W. M. A. Conceptual foundations for building an integrated power plant control system. Energies and Electricity. 2007, no. 8, pp. 16–24.

22. Pešik S. N. Baskakov V. C., Tsisek'skaya T. V. Kompleksnyy krityerii efektivnosti algoritma manevoirovaniya mochnost'yu reaktora VVER-1000 v pervom rezhime [A complex criterion of the efficiency of the algorithm for maneuvering with the power of a VVER-1000 reactor in a variable mode]. Publizhatyi Odesko ho politekhinchnoho univertyetu [Publications of Odessa Polytechnic University]. 2009, vol. 2 (32), pp. 53–58.

23. Potanina T., Efimov A. Problem of optimal load distribution between power units on the power stations. MOTROL. Lublin. 2009, vol. 11A, pp. 25–30.

24. Kukhlin D. I., Efimov A. V., Potanina T. V., Garkusha T. A. Matematicheskie modeli sistem i oborudovaniya energoblokov elektrostantsiy dlya avtomatizirovannogo upravleniya rezhimi i eksploataciyi [Mathematical models of systems and equipment of power generating units for automated control of their operation modes]. Bulletin of the National Technical University "KhPI". Series: Hydralic machines and hydraulic units. Kharkiv, NTU "KhPI" Publ., 2015, no. 45 (1154), pp. 96–104.

Received 20.04.2019

Відомості про авторів / Сведение об авторах / About the Authors

Сфімов Олександр В'ячеславович (Ефимов Алексей Вячеславович, Yefimov Alexander Vyacheslavovich) – доктор технічних наук, професор, Національний технічний університет "Харківський політехнічний інститут", доцент кафедри "Іноземні мови". ORCID: http://orcid.org/0000-0003-3300-7447; e-mail: AVEfimov@kpi.kharkov.ua

Єсипенко Тетяна Олексіївна (ЕФімов Олексій, Yefimov Oleksandr) – науковий співробітник кафедри "Іноземні мови". ORCID: http://orcid.org/0000-0003-3300-7447; e-mail: teta@kpi.kharkov.ua

Гаркуша Тетяна Анатоліївна (Гаркуша Татьяна Анатольевна, Harkusha Tetyana Anatoliivna) – Національний технічний університет "Харківський політехнічний інститут", доцент кафедри "Іноземні мови". ORCID: http://orcid.org/0000-0003-3300-7447; e-mail: harkusha@gmail.com

Каверцев Валерій Леонідович (Каверцев Валерий, Kavertsev Valeriy Leonidovich) – кандидат технічних наук, доцент, Національний технічний університет "Харківський політехнічний інститут", доцент кафедри "Іноземні мови". ORCID: http://orcid.org/0000-0001-6513-2088; e-mail: kavertsef@gmail.com

Беркутова Харківська (Беркутова Харківська, Berkutchova Harkivska) – Національний технічний університет "Харківський політехнічний інститут", доцент кафедри "Іноземні мови". ORCID: http://orcid.org/0000-0002-3221-1086; e-mail: tberk77777.ukr.net

Bulletin of the National Technical University "KhPI". Series: Hydraulic machines and hydraulic units, № 1’2019