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FEATURES OF INTEGRATED ENERGY ASSESSMENT OF THE ACTUAL ENVIRONMENTAL PERFORMANCE OF ENERGY FACILITIES

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This paper deals with the design of methodology for integrated energy assessment of the actual environmental performance of energy facilities. It reveals structural problems of existed and planed heat and power plants and provides a complex stage solution. Methodology implementation consist of nine stages which were shown on the example of water heating boiler by means of creating automatic monitoring and control system. The latter will ensure high level of ecological-energy plant efficiency through the algorithm of comparison of actual power plant parameters and passport data. In addition monitoring system will storage information about previous plant's operational conditions that allows one to predict it future state on different operation mode and provide operative recommendations to personnel for safe and reliable operation of the equipment.

Key words: ecological-energy performance, energy facility, actual characteristics, coefficient of energy and environmental efficiency, real state, operation reliability, state prediction.

ОСОБЛИВОСТІ КОМПЛЕКСНОЇ ОЦІНКИ ФАКТИЧНИХ ЕНЕРГО-ЕКОЛОГІЧНИХ ПОКАЗНИКІВ РОБОТИ ЕНЕРГЕТИЧНОГО УСТАТКУВАННЯ

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Робота присвячена розробці комплексної параметричної діагностики фактичних енерго-екологічних показників роботи енергетичних пристроїв. Показано основні структурні проблеми збудованих енергооб'єктів, а також тих, що знаходяться на стадії проектування, та запропоновано комплексне пошагове рішення проблеми. Реалізація методології складається з дев'яти етапів, які були показані на прикладі створення автоматичної системи контролю й управління водогрійного котла. За допомогою використання цієї системи можливе досягнення високих енерго-екологічних показників експлуатації енергообладнання. Крім того, система моніторингу буде створювати базу даних, що включатиме в себе інформацію про попередні стани енергооб'єкта. Це дозволить прогнозувати його характеристики при роботі на інших режимах та давати оперативні рекомендації персоналу для забезпечення зручності й надійності роботи обладнання.

Ключові слова: екологічна безпека, енергооб'єкт, реальні характеристики, коефіцієнт енерго-екологічної ефективності, стан енергооб'єктів, експлуатаційна надійність, передбачення стану.

PROBLEM STATEMENT. On the one hand, constant increase in the consumption and cost of energy resources for energy production forces power producers to expand and deepen the analysis of operating system parameters and operating characteristics of gas-pumping installations (GPI) and boilers equipment, which are a part of energy facilities.

On the other hand, rapid development of modern computer and microprocessor technologies allows one to design and implement complex computer algorithms and systems for monitoring, analysis and research of complex energy processes that affects efficiency of the equipment and operational safety for the forecast period.

Systematic analysis of existing methods and positive experience of their application should be the background for development, improvement, modernization and implementation of new methods, technologies and devices to ensure efficient use of energy resources and energy conversion processes.

At the same time, it becomes a high-priority task for the systems of energy production that requires ensuring reliable technological conditions and optimum loading of equipment that thermal power complexes include.

Analysis of existing research in this area

Nowadays one of the most important life-support system for people is heating system. The latter delivers heating and hot water to end-user. Two main types of heating systems are used for heating industrial, civil and residential buildings. They are centralized and decentralized heating systems [1].

The main sources of centralized heating are heat power plants (HPP), industrial and utility boilers. Boilers and ancillary devices are main elements providing conversion of chemical energy of fuels into the thermal energy. Indicators of energy and environmental conditions of their operation are low. Therefore these objects require new approaches for improving above mentioned indicators. The level of equipment automation in the operation of these facilities does not meet modern requirements and applicable standards. Two ways for solving this problem can be suggested.

The first one consists in carrying out a complete reconstruction of energy facility by means of replacement boilers with new environmental energy-efficient installations. But this way requires huge investments.

The second one connected to carrying out technical re-equipment and modernization of the existing heat-generating boilers by means of the latest technologies and is cost-effective. It is based on gradual replacement of the equipment and allows one to improve energy efficiency and environmental safety of boilers operation due to fast payback projects and technologies. The latter do not require substantial initial costs.

In this work it was developed and suggested a new methodology for the implementation of the second way for integrated assessment of actual energy and environmental performance of energy facility and parametric identification of the actual characteristics of the operation of energy facilities.

Analysis of existing research in this area

There are numerous of scientific works [2–5] related to the need of increasing environmental safety level and energy efficiency of energy facility in the world as well as in Ukraine.

In particular, there are well-known fundamental researches [4–5] related to the analysis of energy saving technologies in thermal energy production and distribution solving problems of energy efficiency and environmental safety in the fuel and energy complex (FEC).

However, it should be noted that thermal engineering requires solving the problems causing of low energy and environmental efficiency of energy conversion. These are listed below:

– the use of out-of-date technologies of energy conversion;

– the lack of an unique methodology for assessing real quality efficiency level of environmental safety and power equipment reliability;

– lack of permanent monitoring of the main parameters and characteristics in real time, which describes the operational efficiencies and allows one to prevent accidents and predict future work with the possibility of extending the service life;

– lack of objective effective mechanism of governmental control for enterprises emissions and the environment in densely populated areas.

The developed methodology of complex parametric identification of the actual parameters and the environmental and power performance of power facility operation enables solving some of the abovementioned problems and improve the qualitative indicators of the equipment and the object itself.

Methodology use

Today it is crucial to improve quality and reliability of energy to ensure high levels of environmental and technological safety. At the same time high level of energy efficiency should be provided. Our methodology suggests ways for solving the abovementioned problem.

The relevance and role of our scientific work related to limitations of the existing theoretical and experimental researches on the introduction of new techniques and methodologies. The latter consider quality changes in the technical condition of the technological equipment of thermal power facilities such as heat energy station (HES), heat cogeneration station (HTC), regional boiler station (RBS).

The methodology is aiming at hypothesis confirmation about low-quality assessment of the real state of the complex power equipment by existing systems for monitoring process parameters in the energy equipment.

This methodology is based on the implementation of new approaches to the assessment and verification of the quality of sensors and devices; they show the importance of determining technological parameters and values of different processes. The latter occur in plants of energy transfer and transformation.

Accuracy and objectivity of parameters in certain processes define control solutions in a single element or unit as well as the whole thermal power plant or system.

This scientific work is aiming at developing the methodology of an accurate determination of quantities and characteristics of the actual state of thermal power facility for making objective decisions for ensuring stability of steady energy production with controlled operation mode and high environmental performance and energy use.

Research object: performance parameters, the size and characteristics of ecological purity, energy efficiency, safety and security, equipment, facilities and systems for heat and electricity production.

Research subject: units, installations, objects, systems and processes of energy production at HES, HTC and RBS.

Research methods: system-oriented scientifically grounded analysis, theoretical and experimental studies, mathematical and statistical modelling, universal and modular programming, scientific research in the software environments.

The idea of the work lies in the implementation of integrated solutions. They will enable elimination or consideration of system random and systematic error in the determination of the real condition of the equipment in the process of operation and in the forecast analysis and planning.

Practical implementation of the methodology ensures reliable operation of power facility and can be implemented both in individual boiler units and in complete thermal power facility.

Methodology purpose

The methodology is developed for solving the problem of raising environmental cleanliness level and energy efficiency for supplying energy consumers with heat and electricity.

The hypothesis suggested for solving the problem of determining actual performance characteristics of equipment condition and complex thermal power plants lies in the implementation of multi-level quality checks. They determine parameters and variables for providing the feedback. Modern computer technologies enable implementation of the most complex analytical algorithms as well as creation software and computing systems.

Various monitoring parameters of the heat and power facilities represent an important feature of this solution. These systems are used in the methodology as information source for determining actual values of the parameters, values and characteristics of the plant operation. Herewith computing systems created on the basis of the methodology don’t affect the primary performance measurement of sensors and devices. It is due to their connection in parallel to the existing monitoring systems and use information about the measured parameters and values that already exists in the database. Software and computing systems can't change values of initial measurement, because they are already collected by monitoring system, processed and recorded to data base. They can be extracted from the latter for purposes of analysis in the mentioned complexes.

The powerful mathematical tool with complex algorithm of checks and feedbacks is used in the methodology for determining actual values of the quantities and characteristics of the operation of the facility.

The methodology allows one to create a system of comprehensive assessment of the actual state of power facility and can be applied to existing facilities with standard equipment, sensors and instrumentation. It can be applied for modernization of separated units, assemblies, equipment, and entire facility as a whole by means of low-cost and cost-effective technologies, creating automatic systems of on-line monitoring and control (AMC) for the entire unit with prediction of its future state.

EXPERIMENTAL PART AND RESULTS OBTAINED. The methodology is implemented based on the examples of complex parametric identification of the actual characteristics of the operating gas pipeline pumping unit and water heating boiler. The implementation is based on developing a universal method for parametric identification of the actual characteristics of the units that make up the energy facility.

Methodology implementation on the example of water heating boiler is carried out according to the following algorithm (Fig. 1).

The first stage: to determine the basic quantities that characterizes boiler's technical condition and efficiency.

The second stage: to define the list of parameters fixed by standard devices and sensors and associated with basic values. They are:

– heating water consumption;
– heating water temperature and pressure inlet the boiler;
– heating water temperature and pressure outlet the boiler;
– air temperature;
– flue gases temperature;
– air pressure before burners;
– negative pressure in the combustion chamber;
– excess air coefficient;
– gas flow rate;
– gas pressure after control valve;
– gas pressure at each operating burner.

The third stage: definition of operating and environmental parameters. These are:

– concentration of dihydric and polyhydric components in the flue gases O_2, NO_X, CO;
– the temperature of the flame, the flame length, etc.

The fourth stage: the development of mathematical base parameter identification with the definition of mathematical relationships between quantities that characterize technical conditions and energy and environmental efficiency of water heating boiler combining the main and additional parameters, values and characteristics.

The following basic quantities characterizing the technical condition and the effectiveness of boiler's operation are defined for a particular type of boiler:

1) heating power (Gcal / h);
2) coefficient of performance (COP);
3) heat loss from the flue gases (%);
4) heat loss from the chemical underburning (%);
5) heat loss from the cooling external surfaces (%);
6) instant (hour) fuel flow (m^3 / h, m^3 / min, m^3 / s);
7) specific consumption of equivalent fuel for generation of 1 Gcal of heat (kg eqv. fuel / Gcal);
8) mass concentration of oxides of nitrogen (mg / m^3);
9) mass concentration of carbon oxides (mg / m^3);
10) specific environmental performance of operation mode (power emissions, emissions per unit of heat, index of emissions harmfulness);
11) total emissions of danger;
12) coefficient of energy and environmental efficiency (CEEE) of operation mode.

Determination of the above mentioned quantities and characteristics is carried out on the existing regulatory procedures [6–13] with the addition of certain mathematical relationships, which reveal specific energy-environmental indicators and ratios, which are universal for boilers and GPI.

1) Boiler heating power:

$$Q_B = D_{HW}(T''_{HW} - T'_{HW}), \quad \frac{kcal}{h}, \tag{1}$$

where D_{HW} is heating water consumption, ton/h; T''_{HW} is heating water temperature outlet the boiler, ^{o}C; T'_{HW} is heating water temperature inlet the boiler, ^{o}C.

2) Boilers COP, determined by indirect heat balance:

$$\eta = 100 - \sum q, \ \%, \tag{2}$$

where $\sum q$ is the sum of heat losses, which calculated by formulas of paragraph 3–5.

3) Heat loss from the flue gases in case of natural gas combustion can be determined as follow:

$$q_2 = (3,53\alpha + 0,6)(t_{out} - \frac{\alpha}{\alpha + 0,18} t_0) \times \times (0,9805 + 0,00013 t_{out}) 10^{-2}, \ \%, \tag{3}$$

where t_0 is air temperature, ^{o}C; t_{out} is flue gases temperature, after the last heating boiler surface, ^{o}C; α is excess air coefficient in the flue gases after the last heating boiler surface measured by flue-gas analysing apparatus.

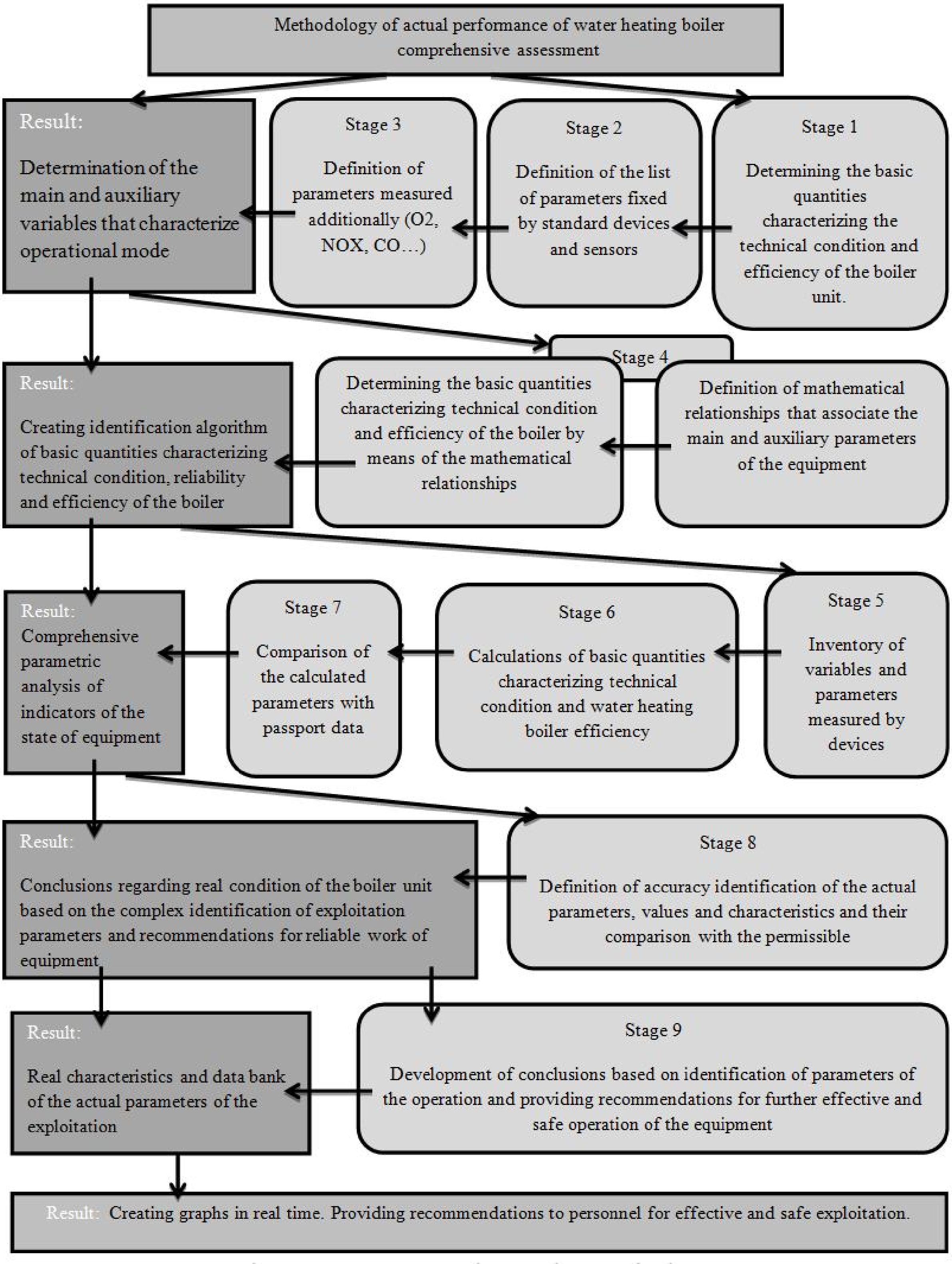

Figure 1 – Algorithm for the comprehensive assessment of the actual characteristics of water heating boiler

4) Heat loss from the chemical underburning in case of methane absence in combustion products can be determined as follow:

$$q_3 = \frac{35CO}{CO + CO_2}, \% , \qquad (4)$$

where CO is carbon monoxide concentration in flue gases, after the last heating boiler surface, %. Measured by flue-gas analysing apparatus; CO_2 is carbon dioxide concentration in flue gases, after the last heating boiler surface, %, measured by flue-gas analysing apparatus.

5) Heat loss from cooling of the boiler's external surface q_5 is equal to 0.05 % throughout the load range.

6) Instant (hour) fuel flow, determined by indirect heat balance:

$$B = \frac{Q_B}{E\eta}, \ \frac{m^3}{h}, \tag{5}$$

where E is low heat value (LHV), $\frac{\text{kcal}}{m^3}$.

7) Specific consumption of equivalent fuel for generation of 1 Gcal of heat:

$$b = \frac{10^6}{7000\eta}, \ \frac{kg\ eqv.fuel}{kcal}, \tag{6}$$

where 7000 is equivalent fuel LHV, $\frac{\text{kcal}}{kg}$.

8) Mass concentration of nitrogen oxides (carbon monoxide) in flue gases in case of excess air coefficient equal unity can be determined as follow:

$$C_{\alpha=1} = Ch, \ \frac{mg}{m^3}, \tag{7}$$

where C is measured mass concentration of nitrogen oxides NO_X (carbon monoxide CO), mg/m^3; h is dilution coefficient of combustion products, %;

– specific emissions of nitrogen oxides (carbon monoxide) can be determined as follow:

$$b_i = \frac{3.6C_{\alpha=1}(100-q_4)}{L\eta}, \ \frac{mg}{kWh}, \tag{8}$$

where i are nitrogen oxides (NO_x) or carbon monoxides (CO), %; q_4 are carbon losses; L is LHV on dry fuel basis, MJ/m^3.

9) Coefficient of energy and environmental efficiency (CEEE) of operation mode.

Power plants (energy facility) CEEE reflect unit's efficiency and environmental safety level. This coefficient was suggested by authors.

$$\varepsilon = \frac{\eta}{A}, \tag{9}$$

where A are general flue gases aggressiveness.

The fifth stage: accounting and analysis of parameters and values measured by the instrument.

The sixth stage: according to the above listed mathematical expressions which constitute the mathematical basis of identification basic quantities calculations characterizing technical conditions and efficiency of the unit are carried out.

The seventh step: performing comprehensive parametric analysis and comparison of the real condition of the equipment's and its passport identification data and actual database operation of the unit. To do this, each basic parameter is compared with passport and actual values from the database.

In case of rejection in quantities that characterize operating mode of the unit, from the passport data or from database values of previous similar operation mode to the amount of allowable values, the system carries out automatically comprehensive analysis and verification of the relevant parameters measured with sensors and measuring instruments.

The eighth step: the definition of the accuracy of actual parameters, values and characteristics identification and compare it with the permissible. All values and data by means of mathematical calculations on the developed algorithms are analyzed for the magnitude and causes of deviations. All calculated values and disclosures are explained to personnel.

The ninth stage: the conclusions about the real condition of the boiler based on our identification of parameters of operation and providing recommendations to personnel for future safe and reliable operation of the equipment.

Based on the developed methodology the identification of the actual characteristics of the boiler as well as the possibility of planning further effective and reliable operation of the equipment is implemented. The timing of scheduled and unscheduled repairs, modernization of equipment also was implemented. All of these measures will be used to reduce the costs of maintaining the equipment in working condition, optimize the formation of scheduled and unscheduled repairs, the implementation of the renovation and modernization of the equipment.

Advantages of the methodology were demonstrated in the results of comprehensive researches and tests when methodology is regarded as a component of software and computer complexes (SCC) that are connected to the monitoring system for operating parameters of gas pumping unit on the pipe [20] as well as a part of a power boiler.

Therefore, we consider the introduction of SCC in thermal units (steam and hot water boilers, heat generators, combustion gas turbines) will be efficient and profitable.

The methodology is developed for integrated environmental and energy assessment of the actual conditions of the existing and new SCC of energy objects that are designed and are ready to be used after construction.

Besides, the methodology enables creation and implementation of the new algorithms of comprehensive analysis and evaluations of the quality of implementation and use of the latest technologies, methods, techniques, cycles and systems for improving technical and economic indicators of environmental and energy facilities. The above listed reflects mobility and efficiency of the methodology in the implementation.

The implementation of such SCC in real power facilities enables:

– developing innovation approaches for raising ecological and energy efficiency and reliability of power supply for the consumers;

– creating effective systems for control and monitoring and alerting operational staff about the beginning or undesirable trends and changes in the equipment and operation modes of the equipment and installations;

– receiving and accumulating information data about complex parameters for recording and analyzing technical, economic and environmental energetic performance based on them;

– receiving new generalizing dependences and criteria for assessment of the actual level of ecological and energy efficiency of energy transformations on power facilities;

– developing new approaches to the implementation of ecological and energy management of power facilities using advanced innovation energy technologies;

– defining acceptable limits, scientifically proven criteria for complete optimization of the equipment and energy facility operation modes as a whole.

New approaches developed by means of the methodology are also vital for companies working in other sectors of the economy. They can be implemented in the specific facilities and power supply systems in agriculture, livestock, tourism, and other facilities for increasing environmental cleanliness, comfort, reliability and security of energy production, profitability of medium and small enterprises.

The possibility of predicting energy conditions of power and environmental background for the future, reducing the unit cost of energy in systems of energy production with the implementation of new approaches and technologies is an important feature of the implementation of the SCC at power facilities.

SCC implementation on the existing power facilities is based on the methodology of integrated identification of the actual characteristics of equipment operation. They enable estimation of the value and minimization of harmful effects on the health of today's and future generations of harmful by-products of energy production for ensuring leveling effects of cumulative concentrations of toxic substances in the atmosphere, soil and water pools. They eliminate the risk of unpredictable occurrence of critical situations affecting the environment.

Methodology application allows making qualitative evaluation of energy production systems, assessing adequately safety, environmental and economic feasibility of using existing schemes, systems, and technologies of energy and introduction of new ones.

CONCLUSIONS. 1. The foundation for improving system quality and reliability is laid by the methodology of complex parametric identification of equipment actual performance during its implementation at a power plant. It is set basing on the comprehensive analysis of the main technological parameters and technical and economic characteristics.

2. On the basis of analytical studies and mathematical apparatus parameters identification PC software can be created. The latter will be connected to existing boiler monitoring system. Such computing systems implemented on the basis of the methodology will provide operational analysis of the real conditions of the equipment, energy efficiency level and cost effectiveness enabling costs minimization of the fuel and energy resources.

3. The universal approach for solving all types of above mentioned problems in the heat energy station and units of various types is highlighted as an important feature of the methodology. For example, the methodology implemented according to the same algorithm is suitable for heat boilers and gas compressor units for gas transportation system.

4. Software and computing systems created on the basis of the methodology are mobile; a slight composition change of energy equipment or modernization of the program of computing units and checks on the measurement adequacy is easily changed due to the introducing of additional mathematical relationships in the software system.

5. In the economic terms, the methodology implementation on the energy facility allows monitoring the actual condition of processes and plants, as well as alerting operational staff about emerging uncontrolled changes in control system over complex and multivariable processes that can prevent accidents.

In addition, the timeliness of repairs and renovations based on the actual values of the units and installations characteristics allows making realistic graph for their implementation, saving funds on operations and replacement of some parts of units meeting the necessary requirements. All of the mentioned leads to increasing the profitability of energy production.

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ОСОБЕННОСТИ КОМПЛЕКСНОЙ ОЦЕНКИ ФАКТИЧЕСКИХ ЭНЕРГО-ЭКОЛОГИЧЕСКИХ ПОКАЗАТЕЛЕЙ РАБОТЫ ЭНЕРГЕТИЧЕСКИХ УСТАНОВОК

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Работа посвящена разработке комплексной параметрической диагностики фактических энерго-экологических показателей работы энергетических устройств. Показаны основные структурные проблемы построенных, а также энергообъектов, находящихся на стадии проектирования, и предложено комплексное пошаговое решение проблемы. Реализация методологии состоит из девяти этапов, которые были показаны на примере создания автоматической системы контроля и управления водогрейного котла. С помощью использования данной системы возможно достижение высоких энерго-экологических показателей эксплуатации энергооборудования. Кроме того, система мониторинга будет создавать базы данных, содержащих информацию о предыдущих состояниях энергообъекта. Это позволит прогнозировать его характеристики при работе на других режимах и давать оперативные рекомендации персоналу для обеспечения удобства и надежности работы оборудования.

Ключевые слова: экологическая безопасность, энергообъект, реальные характеристики, коэффициент энерго-экологической эффективности, состояние энергообъекта, эксплуатационная надежность, прогнозирование состояния.

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