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OPTIMIZATION OF OPERATING MODES OF POWER UNITS OF NUCLEAR POWER PLANTS

The materials of the article consider the main methodological provisions of calculations and optimization of NPP power unit equipment parameters using mathematical modeling methods. For the effective implementation of tasks related to determining the optimal parameters and structures of NPP power unit equipment using mathematical modeling and well-developed multifactor optimization methods, it is necessary to fulfill a number of requirements at their productions. Practice shows that it is impractical to optimize with the help of a single mathematical (simulation) model the entire set of parameters characterizing a given power unit, because with such a formulation, the optimization tasks are often mutually incorrect due to a significant discrepancy in the accuracy of various source information, unequal influence of parameters on the target function, specific differences in the mathematical description of various units and elements of the power unit. In order to effectively optimize the parameters of NPP power units, it is necessary to create a system of interconnected mathematical models, which include: a group of detailed mathematical models of individual units and elements of power unit equipment; more generalized mathematical models for the main equipment of power units built on their basis; complete mathematical model of power units.

Keywords: installation of NPP power units, methods of mathematical modeling .

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ОПТИМІЗАЦІЯ РЕЖИМІВ РОБОТИ ЕНЕРГОБЛОКІВ АТОМНИХ ЕЛЕКТРОСТАНЦІЙ

У матеріалах статті розглянуті Основні методичні положення розрахунків та оптимізації параметрів устаткування енергоблоків АЕС методами математичного моделювання Для ефективної реалізації задач, пов'язаних з визначенням оптимальних параметрів і конструкцій устаткування енергоблоків АЕС за допомогою математичного моделювання й добре розроблених методів багатофакторної оптимізації, необхідно виконання ряду вимог при їх постановці. Практика показує, що недоцільно оптимізувати за допомогою однієї математичної (імітаційної) моделі весь комплекс параметрів, що характеризують даний енергоблок, оскільки за такої постановки задачі оптимізації часто бувають взаємно некоректні внаслідок значної невідповідності в точності різної вихідної інформації, нерівнозначності впливу параметрів на цільову функцію, специфічних відмінностей математичного опису різних вузлів і елементів енергоблоку. Для ефективної оптимізації параметрів енергоблоків АЕС необхідно створення системи взаємопов'язаних математичних моделей, що включають до себе: групу докладних математичних моделей окремих вузлів і елементів устаткування енергоблоків; побудовані на їх основі більш узагальнені математичні моделі для основного устаткування енергоблоків; повну математичну модель енергоблоків.

Ключові слова: устаткування енергоблоків АЕС, методи математичного моделювання.

I. Introduction.

The basis of energy in many countries of the world, which determines the pace of their economic development, is nuclear power plants. At the same time, they, as complex technological systems, are objects of increased man-made danger. Therefore, methods of increasing the reliability, safety and efficiency of NPP power equipment have already been developed and continue to be developed, which are largely based on diagnostic procedures [1].

One of the principles of the practical implementation of the world energy policy in nuclear energy, the impact of which on climate change is significantly less than that of thermal energy, is to minimize the probability of nuclear incidents and accidents at NPP power units while simultaneously increasing their thermal efficiency. This principle can be implemented due to a number of factors, including improvement and optimization of thermal schemes and parameters of technological processes of NPP power units with reactors of various types, optimal selection of modern and promising coolants and construction materials of active zones of nuclear reactors and steam generators, optimization of operating modes of NPP power units based on modern methods of mathematical modeling.

Modern NPP power units are complex technical systems. They include a lot of interconnected equipment of various technological purposes, which ensures that the power units perform the complex function of producing electric energy and heat of the specified quality and according to the specified load schedule (Table 1).

Table 1. Mathematical models for solving the main thermal and hydraulic optimization tasks parameters of NPP power units with reactors cooled by water under pressure.

№	Mathematical models of equipment
1	Reactor
2	Steam generator
3	Turbine
4	System of external separation and intermediate steam
5	Regeneration system
6	«Condenser-water cooler» system.

Such systems are characterized by multiparameters, a complex structural and functional connection of parameters, the presence of restrictions on changing parameters and connections, functioning under the influence of random factors, and a variety of physicochemical processes occurring in them.

In this regard, complete mathematical models of the functional state of steam turbine power units of nuclear power plants are characterized by a large number of nonlinear (in many cases transcendental) relationships and contain implicit functions. This complicates their wide application to solve the problems of system analysis of the quality of operation of power units [1–3;7].

One of the most important and urgent problems of nuclear energy is the task of optimizing the planning and organization of repair work on power units of power plants and calculating their availability coefficients based on the results of diagnostics of the technical condition of the equipment (Table 2).

Table 2. Classification-identification of some research components.

№	Hierarchy of study components.
1	The object of research is power units of nuclear power plants.
2	The relevance of the problem is the task of optimizing the planning and organization of repair work on power units of power plants and calculating their availability coefficients based on the results of diagnostics of the technical condition of the equipment.
3	The purpose of the research is to optimize the parameters and characteristics of the equipment of NPP power units.
4	Research methods – optimization of individual parameters and characteristics of NPP power unit equipment is closely related to their design and construction processes. The initial data for conducting the first preliminary optimization calculations in the design process are structural designs of the equipment.
5	Stages of research. At the stage of optimization calculations, analytical methods of optimization are the most effective.
6	Stages of research. In the mathematical modeling of NPP power units, idealization methods are used: - dismemberment into simpler technological subsystems (decomposition method); - selection of the most significant properties and effects on them in a parametric form (macromodeling method); - linearization of non-linear models in some area of change of variables (linearization method); - bringing the system with distributed parameters to the system with concentrated parameters; - contempt for the dynamic properties of technological processes.
7	Stages of research. At the stages of the final optimization studies, the most effective optimization method is the simulation modeling method, which allows you to achieve the required degree of accuracy in the description of the object being optimized, and to use special mathematical methods for finding the optimum when solving multifactor and multicriteria problems.
8	Mathematical models include: - a group of detailed mathematical models of individual units and elements of power unit equipment; - more generalized mathematical models for the main equipment of power units built on their basis; - a complete mathematical model of power units.
9	The solution to the problem of optimizing the parameters of NPP power units includes the following stages: - selection of optimality criteria (objective functions); - development of a system of interconnected mathematical models in accordance with the necessary hierarchical level of optimization studies; - selection of computational methods and optimization algorithms.
10	Conclusions: - for reasons of reliability and economy, reactors are usually designed on the basis of designs of standard heat-emitting elements (fuel elements) that have fixed geometric characteristics and a certain thermal power; - energy release in the active zone of the reactor depends on the geometric dimensions of the zone itself; - it is expedient to optimize the parameters of NPP power units at a constant thermal power of the reactor; - bringing to an equal energy effect should be carried out by taking into account the change in the electric power of the power unit, that is, the introduction of the so-called substitute electric power in the power system.

Timely and effective solution of these problems in the practice of operation of NPP power units allows to increase the economic efficiency of repair work and to determine the optimal power reserve of the power system, necessary to compensate for the underproduction of electricity due to the downtime of power units during repairs, thus ensuring the stability of power system operation.

II. The goal of the work.

Optimization of individual parameters and characteristics of NPP power unit equipment is closely related to their design and construction processes. The initial data for conducting the first preliminary optimization calculations in the design process are structural designs of the equipment. The results of the preliminary optimization, taking into account the change of the initial data in the permissible range of values, serve as the basis for new optimization calculations of the parameters and designs of the equipment, taking into account the specifics of its operating conditions. Optimizing the parameters and characteristics of the equipment of NPP power units is a complex iterative process, and each stage of optimization research during the creation and improvement of the equipment is characterized by its own methods and means.

III. Main part.

At the first stage of optimization, the amount of information about the object being optimized is minimal, and the output data has a significant error. Therefore, it is often impossible to accurately describe how the parameters are interconnected and how they determine the type of the objective function. In this regard, analytical methods of optimization are the most effective at the first stage of optimization calculations. They make it possible to visually detect the influence of correlations between the initial data, to obtain with minimal time expenditure general dependencies for determining optimal parameters for various combinations of technical and economic factors.

In the following stages, the amount of information about the optimization object increases significantly. New thermodynamic, structural, regime factors and necessary technical limitations are revealed. Since these stages are already directly related to the creation of the equipment, it is necessary to more accurately and fully take into account all the factors that determine the criterion of optimality, and this significantly increases the number of parameters to be optimized. At the same time, the relationship between the parameters becomes more complex, and it is possible to obtain an analytical solution only with a significant simplification (idealization) of real dependencies.

The following idealization methods are used in the mathematical modeling of NPP power units: dismemberment into simpler technological subsystems (decomposition method);

- selection of the most significant properties and effects on them in a parametric form (macromodeling method);
- linearization of non-linear models in some area of change of variables (linearization method);
- bringing the system with distributed parameters to the system with concentrated parameters;
- contempt for the dynamic properties of technological processes.

At the stages of final optimization studies, the most effective optimization method is the simulation modeling method, which allows you to achieve the required degree of accuracy in the description of the object being optimized, and to use special mathematical methods for finding the optimum when solving multifactorial and multicriteria problems.

For the effective implementation of tasks related to the determination of optimal parameters and designs of NPP power unit equipment using mathematical modeling and well-developed methods of multifactor optimization, it is necessary to fulfill a number of requirements when setting them up. Practice shows that it is impractical to optimize with the help of a single mathematical (simulation) model the entire set of parameters characterizing a given power unit, because with such a formulation, the optimization tasks are often mutually incorrect due to a significant discrepancy in the accuracy of various source information, unequal influence of parameters on the target function, specific differences in the mathematical description of various units and elements of the power unit.

In order to effectively optimize the parameters of NPP power units, it is necessary to create a system of interconnected mathematical models, which include:

- a group of detailed mathematical models of individual units and elements of power unit equipment; more generalized mathematical models for the main equipment of power units built on their basis;
- complete mathematical model of power units.

In accordance with the above, it is advisable to optimize the parameters of NPP power units using a system of mathematical models of the main equipment: reactor, steam generator, turbine. The main equipment, in turn, should be divided into characteristic nodes. Such a division allows rationally, taking into account the specific features of the functional dependencies between the parameters of each node, to create their mathematical models and carry out optimization of both individual nodes and the main equipment of NPP power units through successive refinement [5].

The parameters of each node can be divided into two groups: external parameters that determine the relationship between nodes, and internal parameters that characterize only this node, the values of which depend mainly on external connecting parameters.

If the number of external parameters for a given node is small, then the optimization of its internal parameters can be carried out in the zone of their expected optimum separately from other nodes with fixed external parameters, and then, taking into account the optimal values of internal parameters, optimization of external parameters can be carried out. Thus, the NPP steam generator is related to the turbine installation by the following parameters: thermal power, pressures, consumption and temperatures of the generated steam and feed water. Since the number of these binding parameters is relatively small, the internal parameters of the steam generator, such as, for example, the speed of water in the tubes of the heat exchange surface, the length of the tubes, their outer and inner diameters, and others, can be optimized separately from the turbine unit according to the values of the generated steam parameters, and feed water, presented in the form of restrictions. According to the same value, the internal parameters of the turbo installation are optimized separately from the steam generator. Then the parameters of the steam generated and the feed water connecting the steam generator and the turbine are optimized using appropriate mathematical methods [6].

If the number of connecting parameters between nodes is large, then these nodes should be optimized together in a single model. For example, together with the main thermal and hydraulic parameters of the thermal circuit of NPP power units with WWER reactors, it is necessary to optimize the internal parameters of their external separation and intermediate steam superheating systems, since they are related to the separation pressure of the heated steam, the flow rates, pressures and temperatures of the steam, that heats up, and the heated steam at the entrance and exit of the superheater stages, pressure losses of the heated steam in the superheater stages and others.

Thus, the solution to the problem of optimizing the parameters of NPP power units includes the following stages:

- selection of optimality criteria (objective functions);
- development of a system of interconnected mathematical models in accordance with the necessary hierarchical level of optimization studies;
- selection of computational methods and optimization algorithms.

When optimizing the parameters of NPP power units, it is very important to determine under which given limitations it is advisable to carry out the optimization: at a constant electric power of the NPP power unit or at a constant thermal power of the reactor of the NPP power unit. If optimization is carried out at a given constant electric power of the NPP power unit, then it is necessary to create a mathematical model that describes the functioning of the entire equipment of the NPP power unit, and at the same time take into account the continuous change in the thermal power of the reactor [2;7].

Conclusions.

In the nuclear power industry, for reasons of reliability and economy, reactors are usually designed based on the designs of standard heat-emitting elements (fuel elements) that have fixed geometric characteristics and a certain thermal power. The total thermal power of the reactor changes discretely by changing the number of operating fuel rods, and, importantly, not proportionally to their number. This unevenness is due to the fact that the energy release in the active zone of the reactor also depends on the geometric dimensions of the zone itself. In this regard, it is very difficult to take into account the continuous change in the thermal power of the reactor in the process of parameter optimization under the conditions of the given constant electric power of the NPP power unit. Therefore, it is advisable to optimize the parameters of NPP power units at a constant thermal power of the reactor, and to bring the variants to equal energy effect by taking into account the change in the electric power of the power unit, i.e., the introduction of the so-called substitute electric power in the power system. Under such a setting, in order to solve the tasks of optimizing the main thermal and hydraulic parameters of NPP power units with reactors cooled by water under pressure, mathematical models of such equipment are necessary: a reactor, a steam generator, a turbine, a system of external separation and intermediate steam overheating, a regeneration system and a "condenser-water cooler".

The depth of detail of the mathematical modeling of this equipment should be based on the principle of equal accuracy, that is, in each model it is necessary to take into account parameters that have one order of influence on the target function.

Taking into account the methodological provisions and approaches outlined above increases the effectiveness of the application of mathematical modeling to solve the problems of calculations and optimization of the parameters of NPP power units.

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ОПТИМІЗАЦІЯ РЕЖИМІВ РОБОТИ ЕНЕРГОБЛОКІВ АТОМНИХ ЕЛЕКТРОСТАНЦІЙ

У матеріалах статті розглянуті Основні методичні положення розрахунків та оптимізації параметрів устаткування енергоблоків АЕС методами математичного моделювання Для ефективної реалізації задач, пов'язаних з визначенням оптимальних параметрів і конструкцій устаткування енергоблоків АЕС за допомогою математичного моделювання й добре розроблених методів багатофакторної оптимізації, необхідно виконання ряду вимог при їх постановці. Практика показує, що недоцільно оптимізувати за допомогою однієї математичної (імітаційної) моделі весь комплекс параметрів, що характеризують даний енергоблок, оскільки за такої постановки задачі оптимізації часто бувають взаємно некоректні внаслідок значної невідповідності в точності різної вихідної інформації, нерівнозначності впливу параметрів на цільову функцію, специфічних відмінностей математичного опису різних вузлів і елементів енергоблоку. Для ефективної оптимізації параметрів енергоблоків АЕС необхідно створення системи взаємопов'язаних математичних моделей, що включають до себе: групу докладних математичних моделей окремих вузлів і елементів устаткування енергоблоків; побудовані на їх основі більш узагальнені математичні моделі для основного устаткування енергоблоків; повну математичну модель енергоблоків.

Ключові слова: устаткування енергоблоків АЕС, методи математичного моделювання.

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ОПТИМИЗАЦИЯ РЕЖИМОВ РАБОТЫ ЭНЕРГОБЛОКОВ АТОМНЫХ ЭЛЕКТРОСТАНЦИЙ

Основные методические положения расчетов и оптимизации параметров оборудования энергоблоков АЭС методами математического моделирования Для эффективной реализации задач, связанных с определением оптимальных параметров и конструкций оборудования энергоблоков АЭС с помощью математического моделирования и хорошо разработанных методов многофакторной оптимизации, необходимо выполнение ряда требований их постановке. Практика показывает, что нецелесообразно оптимизировать с помощью одной математической (имитационной) модели весь комплекс параметров, характеризующих данный энергоблок, поскольку при такой постановке задачи оптимизации часто бывают взаимно некорректны вследствие значительного несоответствия в точности различной исходной информации, неравнозначности влияния параметров на целевую функцию. отличий математического описания различных узлов и элементов энергоблока. Для эффективной оптимизации параметров энергоблоков АЭС необходимо создание системы взаимосвязанных математических моделей, включающих: группу подробных математических моделей отдельных узлов и элементов оборудования энергоблоков; построены на их основе более обобщенные математические модели для основного оборудования энергоблоков; полную математическую модель энергоблоков.

Ключевые слова: оборудование энергоблоков АЭС, методы математического моделирования.