The problems of intelligence improving of power plants process control system

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Abstract. Trends in the development of modern control systems of technological processes (ACS TP) on the basis of program and technical complexes (PTC) are aimed at creating a unified control system of the power unit in all modes of its operation, capable in addition to directly controlling the power unit, blocking operator errors, using intelligent control strategies. At the same time, improving the quality of technological processes based on new hardware and software and the achievements of the modern theory of automatic control occurs mainly at the level of power unit equipment and to a much lesser extent – at the level of the power plant. It is obvious that the level of intelligence of ACS TP should correspond to the technical level of promising high-efficiency power plants. Under these conditions, the problem of increasing the degree of intelligence of energy production management systems in power plants through the development and implementation of new innovative technologies, algorithms and systems for optimal control of the operation of equipment of power plants and power plants in general is extremely urgent. At the same time, a set of technical solutions and technologies should provide, in addition to high efficiency, such "sparing" modes of operation, which allow to reduce the rate of exhaustion of the resource characteristics of the equipment and thereby prolong its service life. This shows the necessity and expediency of developing intelligent high-performance control systems for the entire cycle of energy production in power plants, by expanding the functionality of the PTC in terms of optimal control of technological and production processes of the block and station levels.

1. Introduction

Modern ACS TP of power plants are built on the basis of PTC, network hierarchical structure and technical means of field level and have powerful information support. At the same time, the main system-forming element of the information management system was, is and remains PTC. This objectively led to the fact that the PTC is now considered as the main technical means of control and management of any power facility under construction or being modernized and is selected at the stage of purchase of basic equipment. The number of thermal power plants and nuclear power plants with partial or complete modernization of individual units and power units based on PTC is growing every year. At the same time, improving the quality of technological processes, based on new hardware and software and the achievements of the modern theory of automatic control, occurs mainly at the level of power unit equipment and to a much lesser extent – at the station level. It is known that domestic PTC inferior to foreign counterparts in terms of the capabilities of application software (AS), and therefore
the integration of optimization algorithms in their AS to solve production problems of block and station levels will ensure their competitiveness in the automation market. It is known that the competitiveness of each unit of thermal power plant (TPP) generating equipment in the electricity and capacity market is determined by the value of the fuel component in the cost of electricity generation, so the presence in the PTC of control algorithms for the economic factor (the optimization algorithms proposed for use in the AS PTC are mainly aimed at reducing fuel costs) will allow the station to enter each sector of the market (wholesale, spot, balancing, system services) with a minimum fuel component. The target model of the wholesale market provides for the transition from the establishment of tariffs by regulatory authorities for market community members to the establishment of marginal tariffs and free competitive pricing for wholesale market participants. All of the above shows the need, feasibility and timeliness of the development and implementation of intelligent process control systems by expanding the functionality of the application software PTC in terms of optimal control of technological and production processes of block and station levels. The complex solution of the designated scientific problem in relation to thermal power plants on organic fuel and nuclear power plants is proposed to be carried out by significantly increasing the intelligence of production management systems (PMS) through the development, scientific justification and testing of a complex of new intelligent energy-saving and resource-saving innovative technologies and software products of optimal management based on modern information technologies with the possibility of their integration into the software of the PTC.

Innovation in the proposed approach to the problem of increasing the intelligence of the new generation of automated process control systems on the basis of domestic software and hardware by integrating into its software modern methods of optimization and decision-making is an integrated approach to the management of technological and production processes of energy production at thermal power plants and nuclear power plants on the criteria of energy and technical efficiency. In contrast to the existing approaches of separate solution of optimization problems of aggregate, block and station levels, leading in most cases to conflicting results, the solution of these problems in the complex allows in the course of solving problems on a hierarchical approach “unit-block-station” to use the results at the lower levels of the hierarchy in solving problems at the upper levels [1-3].

2. Optimal control problems

In this report, some problems of optimal control of technological processes of energy production at thermal power plants, the implementation of which at the PTC will significantly increase the intelligence and, accordingly, the efficiency of ACS TP, are briefly considered.

2.1. Optimal control of power equipment operation modes is a solution of two interrelated tasks relevant for modern power engineering: selection of generating equipment composition and optimal distribution of a given thermal and electrical load between generating equipment taking into account its current state. At present, various methods and software systems for in-station optimization of equipment operation modes have been developed. Unfortunately, they have not found wide application in the operation. The reason for the complexity of their use in operation is a significant proportion of manual input of the initial data to select the optimal mode for each change in the job. This is due to the lack of interfaces between software systems and automation systems installed in power plants. The purpose of these studies is to improve the methodological, technical and information support of ACS TP on the basis of modern PTC for the practical implementation in automated mode of the task of operational control modes of power plant equipment. At the same time, the optimization criterion, in addition to achieving the minimum fuel consumption (or total fuel costs, maximum profit of the station, etc.) for the station as a whole, is the most efficient use of the remaining life of the equipment. This can be achieved if, when choosing the composition of generating equipment, especially when solving the problems of passing the gaps of energy consumption schedules, in addition to the criteria of efficiency and reliability, also take into account the factor characterizing the overall reduction in the life of generating equipment, both in the short and long term intervals.

As a rule, the task is solved in an hour interval of load change as a static task. However, it is known that in the absence of a technique and algorithm of the choice of the sequence and pace of unload or
loading time during the night of the loads gap, i.e. in the periods of the evening decline and morning set load thermal power plants in each power unit occurs advanced or delayed load change, which leads to additional losses of fuel, the variance for the distribution of power and electricity than that required by the dispatch schedule the load. The complexity of the solution of this dynamic problem lies in the fact that, in contrast to the methods used, based on fuel consumption, calculated by the flow characteristics of each power unit, it is required to take into account also unaccounted for these characteristics additional dynamic fuel losses due to transient and non-stationary processes in the equipment of the unit and associated with these processes unstable and suboptimal operation of control systems. According to [1], these losses range from 0.5 to 1.0% of the annual fuel consumption for gas-fuel oil units and from 1.5 to 3.0% for solid fuel units.

This problem is particularly relevant in the periods of the morning load set due to the significant duration of the power units output to the calculated loads due to the presence of restrictions on the loading speed.

As a criterion of choice of optimal strategy of loading units of the possible criteria (maximum marginal station, the minimum total losses of fuel, minimum total fuel consumption) the use of minimum fuel consumption during loading stations, due to the complexity of the above-mentioned additional dynamic losses of fuel in the calculation of the marginal stations and total losses of the fuel at the loading station. In addition, when choosing the composition of generating equipment and optimal load distribution with a known composition of generating equipment according to the criterion of maximum margin profit, one of the main determining factors is the price of electricity in the electricity and capacity market. It is known that the price of electricity when passing the night gap is significantly different from the price when passing the morning maximum load of the system.

The set dynamic problem of optimal control has a number of significant differences from the traditional problems of optimal load distribution of the station, including: the distribution between generating units is not the current load, and power generation in the process of changing the load of the station; the need for simultaneous provision of two balances – on the final power of the station; the need to take into account the previously obtained optimal loading rates of power units in the calculation of dynamic losses as a function of the type of fuel burned and the magnitude of the load change, etc.

One of the proposed methodological approaches in solving the problems of optimal control of equipment operation modes is a multi-criteria approach with consideration of criteria for efficiency, reliability and ecology, with an additional important factor, which in similar tasks is considered for the first time – it is the current real economic and technical condition of the equipment under consideration. The exclusion of this factor from consideration in the previously proposed solutions led to low efficiency, and in most cases – to the impossibility of practical application of the results. The peculiarity and difference of the proposed research in this direction is also the fact that thermal power plants with a complex composition of equipment, including heating units and units, as well as steam and gas installations will be considered.

The complexity of the implementation of the tasks of optimal control of thermal power plant modes at existing power plants is due to the following factors:
- the transition of energy to market relations and the operation of power plants in the electricity and capacity market has radically changed the established methodological approaches to the selection of optimal modes of operation of power plant equipment; instead of the criterion of minimum fuel consumption or fuel costs, it is necessary to operate the criterion of maximum profit of the station with its participation in the electricity and capacity market; under the terms of the rules of participation of power plants in the market, the related tasks of choosing the composition of generating equipment and optimal load distribution are spaced in time; the market of electricity and power working group points of delivery and consumption of electricity and, in the cases when the station simultaneously services multiple points of delivery, the above tasks is much more complicated because of the need for the simultaneous implementation of balance sheet ratios and numerous restrictions to individual insights, and the station in general;
- despite numerous attempts to implement software systems to select the composition of generating equipment and optimal load distribution, the solution of these problems has not found a noticeable
shift in operating conditions. In many ways, this situation was due to the fact that the lack of automated process control systems or their limited ability to provide information for these tasks required manual input of a large number of parameters, which led to a loss of efficiency and accuracy of solving problems.

2.2. Generally speaking, the existing algorithms for technical economic indicators (TEI) restricted by the fixing of the values of TEP with a significant error due to the uncertainty of the initial information and lack of information, backward and forward balances among themselves. For the first time it is proposed to use an intelligent algorithm for solving the problem of obtaining estimates of the values of technological parameters based on the results of measurements using a system of equations of material and thermal balance relations of units and sections and the entire station to improve the reliability of the initial information. The proposed approach provides the necessary reliability of all the basic parameters necessary for the information of thermal and energy balances for each unit and for the station as a whole, the calculation of TEI and all the necessary calculations for optimal control of technological processes and modes of operation of power equipment both at the power plant level and at the level of power units. An indicator of the reliability of the estimates in the proposed algorithm using neural technologies is the implementation of material and energy balances for the algorithm embedded in the technological scheme of the production complex with a minimum amount of deviations within the normalized errors of the measuring channels of the uncertainty ranges of the desired estimates from the measured values of technological parameters. The presence of reliable indicators of the current TEI allows you to set and solve the problem of TEI management. On the basis of the obtained reliable indicators, TEI is calculated for each production unit in the current and basic (normative or agreed with the operation) modes, the root cause of the deviation of the weaving index from the basic one is revealed and recommendations for its maximum reduction are developed. According to the results of preliminary calculations, it can be expected that the proposed approach to the management of TEI allows to reduce the specific fuel consumption for the generation of electric energy in the condensation cycle by 2-3%.

2.3. The problem of passing the gaps of power consumption schedules has always been one of the difficult tasks of operation, but in modern conditions it has become even more complicated due to the fact that in the absence of highly maneuverable power units, the backup modes available for operation do not always ensure the fulfillment of system requirements for maneuverability and reliability, so the unloading of power units within the adjusting range does not always provide the required depth of unloading (especially when working on solid fuel), and the shutdown with the subsequent start-up is associated with both large losses of fuel and with a high risk due to the high probability of emergency situations during the start-up, which can lead to the failure of the dispatching schedule and the corresponding penalties from the System operator.

3. Capacity reserving

Development and implementation of a "gentle" technology, redundant power, with the passage of the power consumption load gaps on the basis of automated motor mode (synchronous compensator) will: significantly improve the efficiency, reliability and flexibility, reduce thermal stress condition of metal equipment when they are redundant with the passage of the gaps of the graphs of energy consumption, and thus reduce the wear of equipment; The basis of this technology can be previously conducted large-scale studies conducted with the participation of many organizations [2], but not widely implemented on a number of technical problems. The availability of modern software and hardware systems with their wide software and technical capabilities will allow to raise to the modern level this technical solution by automating the transfer of the turbine to the motor mode and back, as well as to fully control and manage the temperature condition of the turbine flow during its operation in this mode. The advantage of the mode is not only to ensure high maneuverability, reliability and efficiency of power redundancy, but also the fact that the generator operating in the motor (motor) mode is converted into a powerful source of reactive power, which allows to optimize the operation of the electrical networks of the power system in terms of maintaining voltage and reducing electrical losses. The implementation of automated motor mode will allow to reduce losses of fuel on the reservation by 20-30%, reduce the time of the start of the turbine after an
overnight stop at 40-50%, with a simultaneous increase of the reliability of redundant equipment with the passage of the load gaps.

The study of maneuverable characteristics of steam-gas installations (CSGT) of high power taking into account the climatic conditions of the region of the station location and ways to expand the boundaries of the regulatory range, including by converting the CCGT steam turbine into the motor mode, will bring the maneuverability of gas and steam turbines of CSGT [2]. In the framework of these studies will be proposed and investigated the installation and method of regulating the high pressure steam temperature at the outlet of the recovery boiler, characterized by autonomy of the installation (in relation to the recovery boiler) and the ability to regulate the temperature of the steam in the entire range of the load of the CSGT. In the framework of these studies, a method is also proposed for unloading the steam turbine with a decrease in the load of the CSGT by transferring part of the high-pressure cylinder (HPC) of the steam turbine to the mode with the cessation of high-pressure steam supply to the HPC of the steam turbine using it in the part of the turbine operating in the generation mode. The results of comprehensive studies of CSGT operation at low loads and in power reserve modes will be used to optimize the operation modes of thermal power plants with complex equipment, including CSGT.

4. **The use of fuzzy information**

The purpose of research on the development and implementation of an intelligent automated system for diagnosing the current technical condition of the main equipment and its resource characteristics is to develop a methodology for the analysis and use of fuzzy information in the identification of the state and parameters of power plants. In real conditions of the assessment of efficiency of power installations of TPP performed on the basis of diagnostics of their condition for the purpose of determination of readiness for work and increase of duration of work and operation, the analysis of defects, recognition and the prevention of malfunctions, it is necessary to use and process the most various information. Much of this information can be of very poor quality, i.e. uncertain, given ambiguously, unclear, incomplete. The uncertainty of such information is caused by significant errors of the measured values of the parameters, inevitable and significant errors of the state estimates, errors of the decisions made, i.e. their variances. In this case, the level of uncertainty for different information will be different, as well as dependent on the operating conditions of the power plant. Taking into account these factors will allow in the management of operating modes, the development of fuzzy identification models for forecasting and control of the power plant, the study of the effectiveness of such models for use in the expert system, the use of poorly formalized fuzzy knowledge for diagnosing the state of functioning power plants, creating a system of intelligent diagnostic control, state analysis and optimization, improve the efficiency and quality of maintenance of power plants. As a result, it will save significant energy resources and will have a significant economic effect by increasing the availability of equipment, additional generation of electricity and heat and reducing the cost of additional repairs. The peculiarity of the development of such methodology is the formalization and use of heuristic, linguistic, expert and stochastic information to obtain hybrid (clear and fuzzy) knowledge, contributing to the increase of intelligence of maintenance management systems.

5. **Enterprise asset management**

One of the important functions of intelligent control systems can be effective management of production assets, including the task of managing the life cycle of technological equipment in order to ensure optimal operating conditions. This problem can be decomposed into a single concept based on three components: determination of the optimal strategy for the management of the lifecycle of technological equipment; identification of the status of the process equipment efficiency and reliability, and forecast of situation development; formation and implementation of optimal repair programs of technological equipment at a given planning interval. The formalization and implementation of these components involves the use of both traditional system and mathematical methods, and the use of artificial intelligence methodology. This approach is due to the presence of
poorly formalized processes, poorly structured objects, accumulated quality information and expertise to identify the state and forecast, the subjectivity of decisions. Thus, the task can be formulated as follows – the creation of methodology and algorithms for intelligent life cycle management of process equipment of thermal power systems in order to optimize reliability and efficiency at all stages of the life cycle. The object of the study is the life cycle of technological equipment as a single production system with a hierarchical structure with traditional levels of nesting – a system, a subsystem, an element with an unlimited number of links.

6. Restrictions

The above-mentioned basic, but not complete set of control tasks aimed at increasing the level of intelligence of power plant control systems is based on calculations, according to the assessment of the technical and economic feasibility of the ACS TP of condensation-type power units with a capacity of 200 and 300 MW on the basis of the domestic PTC "KVINT" [4, 5], which showed that the economic effect of the introduction of a full-scale ACS TP with the solution of a set of tasks of block and station levels is distributed among its components as follows: - by improving the quality of regulation of technological processes of the equipment and partial optimization of their parameters - 15-20%; - due to optimal control of the equipment operation modes (including automated starts from different thermal conditions) – 15-20%; - by solving problems to ensure the optimal strategy of participation of the power unit in the electricity and power market – 30-35%. - by improving the reliability of the equipment and reducing operating costs by optimizing the timing and volume of repairs and maintenance - 30-35%.

One of the factors limiting the ability to integrate various algorithms into the application software (AS) of PTC is the high workload of PTC controllers by processing a large number of signals. To overcome this limitation, finds the widespread introduction of geographically and functionally distributed control system on the basis of the PTC using the peripheral (field) controllers. This principle is currently implemented by many companies developers PTC. Within the framework of this principle, an algorithm for optimal functional distribution of the above and a number of other optimization tasks and their information support between the peripheral, block and station level controllers according to the criterion of maximum speed can be developed. In accordance with this approach, it will be necessary to develop recommendations of the technical, organizational and programmatic nature of the modernization of AS PTC for the management of technological and production processes of energy production.

It is obvious that increasing the intelligence of the process control system will require large computing power and a powerful methodological and algorithmic base necessary for the calculation in the mode as close as possible to real time. The lack of necessary information, the difficulties in ensuring the reliability of the equipment and the inexpediency of embedding control optimization algorithms in the system of ACS TP suggests the complexity of the implementation of operational management at this level. At the same time, despite the full satisfaction of the needs for computing power, the implementation of operational management is impossible at the MES level due to the lack of the necessary amount of initial information. A mandatory requirement for the system of operational control of equipment operation modes is the presence of multiple I/O interfaces for data exchange. It is necessary to provide the possibility of connecting large computing power for calculations in real time. The modularity of the system will allow to avoid high maintenance costs, allow flexible configuration, provide interfaces for creating your own modules for advanced users and third-party developers. In addition, the solution of station level problems will require the development of general provisions of the theory of proactive (predictive) management of complex technical objects in relation to thermal power facilities.

7. Conclusions

The problems and possible approaches to increasing the intelligence of the process control systems of thermal power plants, built on the basis of PTC, by expanding the application software PTC to solve optimization problems of block and station levels. This will significantly improve the reliability and efficiency of power plants.
The use of the developed methods and algorithms will improve the intellectual level of control systems and accelerate the creation of intelligent equipment and intelligent power plants.

8. References

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