Formation of a power-technological complex of renewable energy objects in the conditions of combination of sources

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Abstract. New possibilities of combining conventional and renewable energy sources under conditions of a power-technological complex of objects are identified. Sustainable development is substantiated by a theoretical model of an integration-balancing methodology for regulating the processes of combining energy sources in the cycle of formation and development of the complex. A mathematical model for the representation of evolutionary and abrupt processes of increasing energy efficiency has been adapted for simulation based on the approximation of step and generalized functions. A decrease in the imbalance of goals of the objects of conventional and renewable power industry in the formed complex is revealed over the period of four stages of the source integration and combination cycle. The simulation is implemented using the Data Science method. This provides an increase in the depth of analysis and quality of control based on the criteria of reducing the imbalance of the goals and increasing the efficiency of development processes. The possibilities of increasing the controllability of abrupt transition processes of objects to the conditions of combining energy sources and integrating with research and educational resources in the formed complex are substantiated

1. Introduction
The significance of the formation of power-technological complexes is proved by the need to improve the control quality of the interaction between power engineering and industrial objects. The interconnectedness of producers of various types of energy, the complexity of objects increase with the expansion of resource composition and combination of conventional and renewable energy sources to increase the cogeneration of products. Such increase in the complexity of relationships determined the use of the method of Big Data databases. Since 2015, the share of renewable energy objects in global energy supply has exceeded that of conventional energy. A similar dynamics appeared in the Arab countries of the Middle East [1, 2]. This is due to their energy policy of enhanced compliance with global trends and opportunities for the use of solar energy resources. In the period from 2020 to 2030, it is necessary to leapfrog to an industry that meets the challenges of the Fourth Industrial Revolution and the post-industrial knowledge economy. It has been found that the existing analysis and regulation tools ensure only evolutionary development processes leading to a decrease in the indicators of economic and environmental efficiency of separately functioning objects. Opportunities of "green" energy are overestimated, which leads to underutilization of the capacity of hydroelectric power plants and existing conventional energy objects. The absence of an integrated balancing methodology does not provide a sufficient planning horizon for a strategy for the joint development of objects in the power-technological complex. The methodology substantiates methods for simulating
cyclic processes of transition to the technology of combining resources and cogeneration of products. Taking into account the cyclical nature of processes expands the possibilities of long-term planning. In the Arab countries of the Middle East, these terms do not yet exceed 10 years, causing insufficient economic efficiency of projects. Technologies with a medium level of innovation, for example, using existing types of solar cells, are mainly implemented [2]. In more developed countries, the planning time and the scale of application of high technologies are longer (in Europe – 30 years, in China and the United States – more than 50 years [3,4]). Such technologies involve a wider diversification of resources, including hydrogen energy, bioresources, etc. The difficulties in implementing the technology for combining resources in a complex of conventional and renewable energy objects increase with the transition to the local use of liquefied and shale gas. At the same time, the increase in the energy efficiency of distributed-type complexes in remote regions of the countries reduces the scale of the use of expensive heat and power networks. The spread of innovative technologies, for example, heat pipes and electrical conductors with special insulation, special section and lower energy losses, is also on the upside. In order to solve the considered problems, the goal is to improve the comprehensive control quality of the combination of different energy sources based on the results of simulating the regulation processes of imbalance of the objects’ goals.

2. Models and methods of improving the control quality under conditions of a complex of conventional and renewable energy objects

In order to improve the quality of control under conditions of a complex of conventional and renewable energy objects, new models and methods of business analytics are needed. Industry needs are growing for radical methods of improving quality to ensure the effectiveness of the post-industrial knowledge economy. Such an economy is more focused on the use of intellectual research and educational resources. In addition, with cogeneration of more types of energy, the requirements for waste-free high-tech production increase. This necessitates the processes of combining the expanded composition and the integration of energy and intellectual resources in the complexes. A significant contribution to improving the quality of development control by the knowledge economy methods was made by R.R. Azizis et al. [5]. However, they proposed an insufficient set of organizational tools, which do not provide an accurate analysis of complex socio-technical systems such as the complex being formed. M. Hoegland A. Schulze [6] concretized the initial stages, and P.L. Liu et al. [7] developed approaches to empirical estimates of the relationships between objects under conditions of uncertainty.

A significant increase in the complexity of the interconnections between a complex of objects led to the development of a combined approach to the analysis and regulation of thermodynamic processes using a neural network. The possibilities of a comprehensive assessment of energy efficiency to increase the controllability of resource combination processes are investigated using the example of regulating the parameters of a number of power generating units. The adaptation of standard developments in the study led to a reduction in the cost of implementing the Data Science method. The absence of design stages for deep, or multilayer neural networks, the development of unique software provided a significant reduction in the cycle time. An increase in the efficiency of decision making in real time was achieved while reducing the cost of training specialists, developing special tools for mathematical simulation and algorithmizing actions to solve problems of combining resources. The possibilities of multivariate and multicriteria analysis of thermodynamic processes have been expanded, since in the proposed combined approach to their analysis and regulation, control is carried out without primary filtering of the initial data. The new digital approach enhances the depth and longevity of business analytics in the cycle of research and projects implemented through a series of management decisions.

Considerable attention to the issues of automatic control of power-technological complexes of objects has been given in the publications of Z.G. Salikhov [9,10]. The simplest control methods using neural networks in relation to rotary kilns have been studied in detail in [11,12]. It has been found that in many cases, an increase in the energy, environmental and economic efficiency of these processes is
achievable in the processes of cogeneration of products and the combination of resources in the complex when organizing a cycle of evolutionary and abrupt changes. At the same time, the need for new theoretical models and methods has been identified. Organization of project development and improvement of computer programs based on the results of simulation and algorithmization of processes, examination of projects and the results of their implementation is in the technology of artificial neural networks. To organize joint planned or design actions of the objects of combining resources in the complex, a special model and integrated balancing methodology of regulation are required.

3. Theoretical model of the integrated balancing management of the formation of power-technological complex

The theoretical basis of this study is the previously developed methodology of integrated balancing management [13,14] and mathematical models of the approximation of step and generalized functions [15,16]. This makes it possible to simulate cycles, technological and thermodynamic processes of increasing the energy efficiency of power plants in the concept of the 4W theoretical model. The model is aimed at the spatial-temporal coordination of the development processes of conventional and renewable energy objects based on the criterion of reducing the imbalance of their goals and increasing the energy efficiency of the processes. W1 and W2 stand for "where" and "when", respectively, and reflect space-time factors of efficiency. The W3 (what) and W4 (why) factors take into account the orientation of the regulatory impact of control functions towards the change of the cause-and-effect relationships of objects in the complex.

The proposed approach to improving the methods of enhancing the control quality substantiates the four stages of the transformation cycle shown by the arrows in Figure 1. Insufficient control quality is explained by two reasons. Firstly, there is no combination of resources and integration of objects in the complex at the beginning of the cycle, when there are no joint projects or cooperation with research and educational objects. Secondly, only the basic management functions existing at independently functioning objects are used. This achieves the minimum energy efficiency (H1) shown by the W1 and W2 zones of the Theoretical Model 1. With the transition to new technologies for high-tech combination of resources and cogeneration of main and secondary products, a controlled directivity of changes appears in the new network structure of the complex (W3 and W4 zones of the model). At this stage of the cycle, it is necessary to use additional management functions, methods of combining resources and their integration. The increased efficiency of high-tech development processes is achieved based on the criterion of compromise on the goals towards achieving efficiency of conventional and renewable energy objects of the complex.

4. Scientific novelty

The simulation of processes in the cycle is carried out by choosing the optimal number of used nested functions that display their analytical approximations. We propose to interpret the number of integrated resources and additional functions for regulating the interconnections of objects of the complex as the number of functions. To simulate the processes, we differentiate the approximating functions of the studied property of energy efficiency. We use the approximation to the Heaviside step function, which describes stepwise processes by a sequence of functions of the form

\[ H_n(x) = 0.5(1 + f_n(x)) \]

for a different number of nested functions [11] (1):

\[
\frac{dH_n(x)}{dx} = \frac{\pi^{n-1}}{2^n} \prod_{k=1}^{n-1} \cos \left( \frac{\pi}{2} f_n(x) \right) \cdot \cos x 
\]  

(1)

By inserting \( x = 0 \) into the resulting expression for the derivatives, we find the maximum corrected value of the function \( H_n(x) = A_n \) for the zones W2 and W3, corresponding to the optimal control quality indicator (2):
The necessary and sufficient range of the number of approximations of nested functions \((n = 1 \ldots 18)\) for organizing the stages of the cycle is justified by the indicated stages of improving the control technology and technological infrastructure of objects. The sufficiency of nested functions is determined in the range of \((1 \ldots 4)\). They simulate the regulatory impact of basic control functions that provide only low-tech development in the W1 and W2 zones. At these stages, negative effects of resource disintegration and separate production of energy products without the use of secondary resources are revealed. With the long duration of the operation of objects outside the complex, an imbalance in the goals of conventional and renewable energy objects appears and grows. The low quality of control with the use of only basic functions or with the self-organization of processes makes possible only low- or medium-technology development.

The control quality, providing a radical increase in energy efficiency, is achieved in the W3 and W4 zones when using the optimal number of 9–11 functions (basic and additional) and resources (primary and secondary). The assessment of the high dynamics of high-tech processes of combining resources and the transition of objects to a new structure of the power-technological complex is carried out by the corresponding derivatives \((\frac{dH}{dx}(x))\). They are shown in the range of stepwise development of \(x\) of conventional units as at the stage of the integration of combined resources and high-tech cogeneration of an expanded composition of products.

Such stages correspond to the development and implementation of methods for modernizing the existing technology, increasing its level in the evolutionary processes of increasing innovation. Methods of self-organization and development of strategies or projects are used. Next, a hopping transition to high technologies is implemented in the new structure of the energy technology complex.

![Figure 1. Theoretical model of the methodology of integrated balancing regulation of combination processes](image)

The increase in the integration space of possible resources necessitates the estimator parameters for jump-transition singularity. They assess the possibility of reducing the influence of zero-length paradoxes of transition time and the unpredictability of the behaviour of open-loop systems. This led to the development of mathematically justified methods of “extending the time interval” for the implementation of short-term technological and organizational solutions of a jump type. A tangible extension value is achieved by approximating a growing number of nested functions in the range \(A = (9,10,11)\). The planar representation of the effect of space–time expansion is given in cycle 1 of medium-tech processes during the jump-to-cycle to cycle 2 and high-tech processes.

The thickness of the lines in the figure increases as the number of investments of approximating functions increases, interpreting the increase in the integration of objects and the degree of
combination of resources to increase the $H_i$ by the factors of innovation $x$. The graph illustrates the jump process in the range of ±0.1 radians. The number of nested functions that provide the zone with the optimal values of the indicator of the LE should correspond to the number of combined resources or additional control functions displayed on the graph. The change in the stability of the system under study ($H$) over time ($x$) in cycle 2 vs. cycle 1 is also displayed. It can be determined by the ratio of the areas of the interaction zone of complex objects bounded by dashed lines. Moreover, cycle 1 corresponds to zone 1 of the implementation of low- and medium-tech processes based on the use of evolutionarily added control functions, and cycle 2 corresponds to the zone 2 jumps to the high-tech level and zone 3 of evolutionary changes in the structures of the complex.

5. Practical significance
Possibilities of modeling the effect of the expansion of the process space with an increasing degree of combining resources and the time of making managerial decisions based on a theoretical model of the “4W” of economic sustainability of a multipurpose ETC-type system are mathematically substantiated. We propose to implement in the methodology verification methods and verification of the results of regulation of economic stability according to static, dynamic and probabilistic criteria for ensuring the efficiency and stability of the processes of combining resources. Providing a stability zone in cycle 1 is simulated by the estimated dynamics of the levels of sustainability and efficiency of the processes of combining resources and organization in the formation cycle of a multipurpose energy technology complex model. This is possible by using additional control functions displayed by the system in cycles 1 and 2, implemented using the methods of the theoretical model “4W”. Verification is an analysis of the results of a real project, corresponding to the experience and directions of development of energy and resource conservation for use of products in the formed (ETC) of solid, household and other waste [15, 16]. The result of the project may be the reduction of losses from the insufficient quality of energy-saving control processes, expressed in the underutilization of the results: replacement of traditional energy resources; more types of energy products in terms of cogeneration, trigeneration and, in general, their polygeneration; diversification of energy production methods, increasing the reliability of energy supply in remote areas; increased processing to solve environmental problems; sale of waste to other countries.

6. Conclusion
The formation of the power-technological complex of objects contributes to the transition to high-tech processes of increasing energy efficiency based on the combination of an expanded composition of resources. The required quality of projects and the adoption of operational management decisions is ensured by the results of mathematical simulation of the processes of formation and development of the complex. For this, the set of tools of nested functions has been adapted in the representation of analytical approximation of generalized functions of singular form. The organizational interpretation of the nested functions is implemented by expanding the composition of the basic and additional control functions and resources of conventional and renewable energy objects of the complex. This made it possible to increase the controllability of the processes of a stepwise transition to a greater degree of combination of diversified resources and cogeneration of various products. Recommendations for the creation of a power technology cluster of objects have been given. The cluster solves the problems of the coordinated development of objects more effectively based on the criterion of the balance of their interests in assessing the compromise on the goals when achieving energy and environmental efficiency for formation of a power-technological complex.

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