Models for combining facilities and resources of renewable energy in the process of cogeneration

A A Alabugin, Z Liu, R Ji, T Wang

South Ural State University, 76, Lenina ave., Chelyabinsk, 454080, Russia

E-mail: pte2017pte@mail.ru

Abstract. The possibilities of the author's methodology for managing the integration of resources and the imbalance of the goals of technological development of complex systems for studying the processes of combining objects and cogeneration of several types of energy are revealed. The object of research is a set of objects using a combination of traditional and renewable energy resources, and the subject is a mechanism for controlling the combination of objects and resources under the conditions of cogeneration of several types of energy. On the basis of the economic and mathematical model, mathematical and methodological problems were solved, which confirmed the increase in controllability of energy and environmentally efficient processes and the synergistic effect of combining objects and resources for the cogeneration of several types of energy.

1. Introduction
The relevance of improving models and a mechanism of managing the combination of objects using traditional and renewable energy is determined by the needs of the post-industrial economy in solving environmental problems. The importance of techno-technological and economic factor-challenges of the environment and the competition of the developed countries of the world to increase the energy efficiency is growing. This is achieved in the processes of cogeneration of heat and electricity based on innovative methods of using renewable resources, including household waste. There is a need to take into account the different directions of interests of traditional energy facilities and new facilities that use renewable resources. In such highly innovative processes, we have established essentially non-linear cyclic processes of changes in the resulting functional property of controllability and efficiency of the processes of combination and cogeneration. This justifies the task of determining the zone of permissible variation of the indicator-property (CL) in the cycles of its dynamics according to the stages of the corresponding processes [1,2].

The analysis of statistics and the specified substantiations showed that at the beginning of the development of high-tech innovative methods of combining and cogeneration the level of controllability and cost-effectiveness of the systems development processes falls. Therefore, a research hypothesis is proposed, which consists in improving the quality of integration and inclusive management of the combination processes using special models and the control mechanism.

2. Models and methods of combination process management
To model and test the hypothesis, an economic-mathematical model of technological development controllability based on the Gibbs effect known in mathematics has been proposed [2,3]. It uses the
results of investigations of jump-like processes of S. V. Alyukov [2,4]. The model makes it possible to reveal the functional interrelationships of the indicator-properties CL from the time period t of the development and application of innovative technologies for combining resources and cogeneration of energy. Changes in the effective development zone of the system are cyclical, which defines two types of development processes during cycles 1 and 2. In the cycle and zone of evolutionary processes 1, advanced investment methods are used in research and development of methods for generating ETC objects of traditional and renewable energy [5,6]. In zone 2, modernization or energy production begins on the basis of the existing technical and technological base of separate production based on traditional energy sources. The controllability of energy saving processes is reduced due to the lag in the rate of increase in the levels of innovation receptivity and personnel competence from the requirements of a post-industrial knowledge economy. Zone 3 interprets the transition to a combination of resources and is characterized by an increase in investment costs for scientific research in the areas of developing energy-saving cogeneration processes and the formation of elements of the control mechanism when traditional and renewable energy facilities are included in the complex. The dynamics of investment processes occur in the negative zone of the indicator-properties -1 ... 0). Such CL estimates in cycle 1 can be interpreted by the widespread practice of not recognizing the uniqueness of a high-tech method of combining and cogeneration in domestic conditions of an excess of traditional energy resources at the initial stage. In cycle 2, which is distinguished by an abrupt increase in the levels of controllability of energy-saving development, this is ensured by the cumulative effect of the realization of the greatest volume of investments in the formation of the complex and combination control mechanism in comparison with their value in cycle 1. This allows structural transformations in zones 4 and 5 in the context of long-term cooperation forms of interaction between the spheres of education, science and the complex of traditional and renewable energy facilities. The dynamics of the indicator-properties in cycle 2 is explained in a similar way. Complementing the research hypothesis with quantitative assumptions, it can be assumed that the achievement and preservation of the compromise zone of the considered goals in the long term is possible with the balancing effects of the mechanism on the resulting property CL in the assessment interval (-1 ... 1) identified in the simulation by the minimum time criterion for achieving and maintaining the normative or effective values of the property index CL. The specificity of the considered processes determines the necessity of modeling them with mathematical functions of the step type [1,7].

The decomposition of the investigated function in a Fourier series has known drawbacks. For their elimination S.V. Alukov proposed to approximate the initial step function by a sequence of recursive periodic functions.

\[
\left\{ f_n(x) \right\} \quad f_n(x) = \sin\left(\left(\pi / 2\right) \cdot f_{n-1}(x)\right), \quad f_1(x) = \sin x; \quad n - 1 \in N \subseteq C^\infty[-\pi, \pi]. \tag{1}
\]

As can be seen, even with relatively small values n when using the iterative procedure, the graph of the approximating function approximates the original function quite well. At the same time, the approximating functions obtained using the proposed methods are free from the drawbacks of the expansion in Fourier series and the Gibbs effect.

3. Models of the management mechanism of processes of combination and cogeneration

The model is displayed by higher-order derivatives approximating the function of the efficiency of the processes for achieving the goals, the graphs of which were obtained by S.V. Alyukov [2]. Shown in Fig. 1 the graph of successive approximations of the second derivatives of the delta function is interpreting the effects of accelerators of the control mechanism. Accelerators interpreted by A.A. Alabugin [1] as regulators of the mechanism for controlling the processes of combination and cogeneration, used in accordance with the features of the innovative development stages discussed above. Stage 1 of the use of the Type 1 accelerator of the speed of evolutionary processes of increasing \( \dot{H}_t \) relates with controllability with equal integrating and disintegrating effects of basic and additional control functions on the dynamics of modernization processes. This type of accelerator models, as
established in an empirical study, symmetrical, multidirectional and strong impacts on the integration of resources at stage 1 (formation of a control mechanism) and 3 (preparation for creating a complex structure). Modeling on the basis of the first derivative of the approximation of the controllability function provides the possibilities of its evaluation for the subsequent regulation of the functions and indicators of the quality of management of the integration of resources [1,2,8].

![Figure 1. Approximation mappings of the second derivatives of the delta function for the interpretation of the processes of combination and cogeneration](image1.png)

![Figure 2. Approximation of the step function in the absence of a mechanism for managing energy-saving innovative development](image2.png)

Stage 2 of accelerator application consists of 2 speeds of efficiency increase with equal integrating and disintegrating effects of symmetric, multidirectional and average appearance on the results of accelerator functioning 1. Modeling based on the second derivative interprets acceleration of management quality improvement while ensuring compromise of goals based on the integration of diversified resources and inclusion of objects combining resources for the convergence of trajectory targets for manageability and eco cogeneration processes. Stage 3 of accelerator application consists of 3 speeds of efficiency increase with a significant predominance of integrating effects of asymmetrical,
multidirectional and strong types on accelerator 2 in all zones. Modeling on the basis of the third
derivative interprets the processes of evolutionary transformations of the structure of the complex when
the control mechanism is included in it to maintain the achieved level of controllability of development
at stage 2. Stage 4 of accelerator application consists of 4 speeds of efficiency increase with its
disintegrating control actions of asymmetric, multidirectional and weak types prevailing in all zones;
the effects of disintegration and divergence targets.

The peak height of the approximation (as the amplitude of the accelerator effects) can be determined
by differentiating the approximating functions of the sequence (2).

\[ H_0(x) = 0.5 \cdot (1 + f_0(x)) \]  

(2)

The operational model of the control mechanism develops the ideas of a number of authors [9] and
contains three component procedures and processes.

The procedures for preparing a database for modeling are based on the well-known provisions of
higher mathematics: determination of the rate of increase of the indicator-property with the number of
nested functions 9,10,11. They establish the range of the maximum effect of improving the quality of
control; calculation of derivatives of the directions of the vectors of these functions at the same time in
the ranges of the identified effect for the preparation of management decisions (- 0.15 ... 0 rad.) and their
implementation (0.15 ... 0 rad.). It allows identifying the direction of integrating or disintegrating the
effects of accelerators; determination of gradients of functions and construction of perpendiculars to
them with the number of investments 9,10,11 for assessing the symmetry and direction of effects on the
graphs of higher orders. This also helps identify the largest and zero growth accelerations of accelerators;
determination of bifurcation points of vector fields of the indicated functions for checking the criterion
for detecting the beginning of a leap (3):

\[ \tan \alpha_i = \frac{dH_i(x_i)}{dx_i} = 1 \]  

(3)

Practically, the criterion means the equality of the relative increments of the actual indicators of the
effectiveness and innovativeness of development at the time of their evaluation.

The processes of regulation of the control mechanism with the equality of relative increases in the
controllability of processes in the complex are carried out in the following sequence. The first is visual
assessment of graphs of approximations of derivatives and the study of functions for continuity,
differentiability, etc. (in terms of peak amplitudes and directional effects of accelerator types and
heterogeneous factors on the controllability of processes in assessing the closedness of fields of sets of
approximation functions of higher derivatives containing the four zones of the innovation cycle under
study). The next is application of the well-known methods of algebraic application of the well-known
methods of algebraic geometry based on approximations of the first, second, third and fourth derivatives
of the function according to equation (2), converted into the following field equations for accelerator
effects modeling. Third is determination of numerical restrictions on the domains of variables of the
studied functions of approximations of higher derivatives, interpreting the features of the effects of
accelerator types. The field equations can be considered as additional conditions for the function
approximations to belong to the four zones of the studied space; application of the specified elements of
the control mechanism in accordance with the specified parameters of restrictions. Procedures for
determining the results of improving the controllability of the processes of combination and
cogeneration (3) are shown further.

Approximation (1) is based on the use of trigonometric expressions, but not in the form of terms, as
in the Fourier series, but in the form of investments. In this case, the graphs of the step function and its
four successive approximations have the form to interpret the modeling of dynamic processes
controlling the effects of the mechanism in the organizational-mathematical model of the energy-saving
development of the complex, Fig. 2. At the same time, nested functions interpret an increase in the
number of additional functions for controlling the combination and cogeneration to five. This will
provide the necessary controllability in the transition from low- and medium-technology processes of
energy-saving development of facilities to high-tech, differing by the combination of resources and cogeneration of energy.

S.V. Alyukov [2] revealed that already at relatively small values $n$ the graph of the approximating function approximates the initial function quite well. The sinusoid stretches along the straight sections of the graph of the initial function; fluctuations in the approximating function in the framework of straight sections do not occur; no Gibbs effect; the convergence and error are such that the sequence of approximating functions $f_n(x)$ converges in norm to the original function $f_0(x)$. In this work, for the situation of disintegrating objects without combining resources at stages 3 and 4, it is possible to model the inclusion in the approximating procedure of the initial function of step functions with different gap lengths corresponding to positive and negative values of the initial step dependence. Using Alyukov's proposals as an initial function, we obtain a different sequence of functions (4):

$$f_1(x) = -0.7 + \sin(x).$$  \tag{4}

4. Method of verification of models

The numerical test of the proposed approximating procedure was carried out on the example of studying the dynamics of processes in regulating the control mechanism taking into account the real ranges of coefficient changes in the differential equation below. It was established above that weak links (for example, accelerators, which are characterized by insignificant influences at the stage of self-organization) can be excluded from the mechanism of regulation of the mechanism. Then the processes can be described by a significantly nonlinear second-order differential equation [2].

In order to verify the proposed approximating procedure, a numerical solution of a differential equation with signum and approximating functions was carried out for specific parameters of the development model and mechanism using the Runge-Kutta method. Phase trajectories on the phase plane depict a solution that determines the presence of two closed circuits as the limiting development cycles 1 and 2 (Fig. 2). The solid line shows the solution according to the model of the discontinuous sign-function, and the dotted line shows the analytical approximation. The thick line corresponds to a periodic solution. The presence of a zone of attraction of attractors and their stability with a focus at the origin of coordinates is revealed. On the external contour, the development efficiency decreases, this corresponds to the transition to the implementation of abrupt innovative energy-saving technologies and management methods. Evolutionary transitions are shown, corresponding to modernization within the framework of the existing phase portrait for the four nested approximation functions of increasing the effects of the corresponding number of types of resources or additional control functions. It is established that the error of the results is low, which indicates a good convergence of the proposed approximating procedures [1,2]. Moreover, the error of approximation can be reduced to an arbitrarily small value, increasing the number of nested functions.

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6. Scientific novelty
For the first time in the energy industry, economics methods are applied. These methods and possibilities of the author's methodology for managing the integration of resources and the imbalance of the goals of technological development of complex systems for studying the processes of combining objects and cogeneration of several types of energy are revealed.

7. Practical significance
On the basis of the economic and mathematical model, mathematical and methodological problems were solved, which confirmed the increase in controllability of energy and environmentally efficient processes and the synergistic effect of combining objects and resources for the cogeneration of several types of energy.

8. Conclusion
Thus, the following scientific and practical results are identified and disclosed in the article.

The results of a scientific study reflecting the use of the new methodology for managing the integration of traditional and renewable resources when they are combined according to the criteria for reducing the imbalance of the goals of manageability and economy and the convergence of their trajectories, are presented. The methodology provides a focus on improving the controllability of the processes of convergence of objects and methods in the integration of educational, research and production resources. The developed toolkit provides enhanced opportunities for quantitative assessment of the results of the transformation of a complex of objects based on mathematical modeling of evolutionary and abrupt processes using approximation methods of step functions that reflect the processes of high-tech energy-saving development.

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