RESEARCH ON CONTROL SYSTEMS OF COMPLEX DYNAMIC PLANTS BASED ON QUANTUM ALGORITHMS

Yakubova Noilakhon Sobirjonovna
Tashkent State Technical University
Sadikova Shahnozakhon Shukurillayevna
Tashkent State Technical University
Ubaydulloyev Farrux Barakayevich
Tashkent State Technical University
E-mail: noila.yakubova@gmail.ru
Tel: +998946853505

Abstract. Ensuring accuracy and stability of control processes is one of the key scientific and practical challenges in the automation of thermal power engineering plants. Most thermal energy systems are complex, multi-parameter, and nonlinear in nature, which requires the use of control algorithms with high computational efficiency. From this perspective, the application of quantum algorithms represents an effective approach for solving complex control problems. In this study, a control model based on quantum algorithms is proposed for a steam superheater, which is an essential component of thermal power systems. The proposed approach is based on the mathematical representation of quantum states and the parallel formation of control decisions. The control task focuses on maintaining the outlet steam temperature at 480 °C under operating pressures of 13-15 MPa and load variations of up to ±10 %. The performance of the quantum-algorithm-based control system was evaluated through simulation and computational experiments. The obtained results demonstrate that the proposed quantum-based approach ensures stability and improved regulation quality in the control of the steam superheater.

Keywords: quantum algorithms; steam superheater; thermal power systems; complex objects; control systems; quantum computing

Annotatsiya. Issiqlik energetik obyektlarini avtomatlashtirishda boshqaruv jarayonining aniqligi va barqarorligini ta’minlash muhim ilmiy-amaliy masalalardan biri hisoblanadi. Ko‘pchilik issiqlik energetik qurilmalar murakkab, ko‘p parametrli va nolinear xususiyatga ega bo‘lib, ularni boshqarishda yuqori hisoblash samaradorligiga ega algoritmlardan foydalanish talab etiladi. Shu nuqtai nazardan, kvant algoritmlarini qo‘llash murakkab boshqaruv masalalarini yechishda samarali yondashuv hisoblanadi. Mazkur tadqiqotda issiqlik energetik tizimining muhim elementi bo‘lgan bug‘ qizdirgichni boshqarish uchun kvant algoritmlariga asoslangan boshqaruv modeli taklif etildi. Taklif etilgan yondashuv kvant holatlarning matematik ifodalanishi va boshqaruv qarorlarini parallel shakllantirish tamoyillariga asoslanadi. Boshqaruv jarayoni chiqishdagi bug‘

ISSN 3030-3907

haroratini 480 °C darajada ushlab turish masalasi doirasida, 13-15 MPa ish bosimi va ±10 % yuklama o‘zgarishlari sharoitida tadqiq etildi. Kvant-algoritmli boshqaruv tizimining ishlash samaradorligi imitatsion modellashtirish asosida baholanib, hisoblash tajribalari o‘tkazildi. Olingan natijalar taklif etilgan kvant algoritmlariga asoslangan yondashuv bug‘ qizdirgichni boshqarish jarayonida barqarorlik va rostlash sifatini ta’minlash imkonini berishini ko‘rsatdi.

Kalit so‘zlar: kvant algoritmlari; bug‘ qizdirgich; issiqlik energetik tizimlar; murakkab obyektlar; boshqaruv tizimlari; kvant hisoblash.

Аннотация. Обеспечение точности и устойчивости процессов управления является одной из важнейших научно-практических задач в автоматизации теплоэнергетических объектов. Большинство теплоэнергетических установок характеризуются сложной, многопараметрической и нелинейной динамикой, что требует применения алгоритмов управления с высокой вычислительной эффективностью. С этой точки зрения использование квантовых алгоритмов представляет собой эффективный подход к решению сложных задач управления. В данной работе предложена модель управления на основе квантовых алгоритмов для пароперегревателя, являющегося важным элементом теплоэнергетических систем. Предложенный подход основан на математическом представлении квантовых состояний и параллельном формировании управляющих решений. Задача управления заключается в поддержании температуры перегретого пара на выходе на уровне 480 °C при рабочем давлении 13-15 МПа и изменениях нагрузки до ±10 %. Эффективность квантово-алгоритмической системы управления оценивалась на основе имитационного моделирования и вычислительных экспериментов. Полученные результаты показали, что предложенный подход на основе квантовых алгоритмов обеспечивает устойчивость и повышение качества регулирования в процессе управления пароперегревателем.

Ключевые слова: квантовые алгоритмы; пароперегреватель; теплоэнергетические системы; сложные объекты; системы управления; квантовые вычисления

INTRODUCTION.

The rapid development of thermal power engineering and industrial automation has significantly increased the complexity of control tasks associated with modern energy systems. Thermal power objects such as steam superheaters operate under highly nonlinear, multivariable, and dynamically changing conditions. Strong coupling between temperature and pressure variables, large thermal inertia, and sensitivity to load disturbances complicate the design of control systems that ensure stable and accurate regulation. As a result, achieving high

ISSN 3030-3907

control performance under varying operating conditions remains a challenging scientific and engineering problem [1,2].

Traditional control algorithms often rely on sequential data processing and deterministic decision-making mechanisms, which limits their effectiveness when applied to complex dynamic objects with high-dimensional state spaces. In such systems, the ability to process multiple control scenarios simultaneously and to rapidly adapt to changing conditions becomes critically important. These requirements have motivated the exploration of alternative computational paradigms capable of overcoming the inherent limitations of classical control approaches[3,4].

Quantum algorithms provide a fundamentally different framework for information processing by exploiting quantum principles such as superposition and parallel state evaluation. These properties allow quantum-based methods to efficiently analyze multiple control trajectories and optimization alternatives within a single computational process. As a result, quantum algorithms have attracted growing attention in control engineering, particularly for applications involving complex, nonlinear, and multi-parameter systems [5].

In thermal power systems, the steam superheater plays a key role in ensuring the required steam temperature and pressure before entering the turbine. Deviations in superheated steam temperature directly affect turbine efficiency, operational safety, and overall energy performance. Therefore, the development of advanced control strategies capable of maintaining the outlet steam temperature within strict operational limits is of critical importance [6].

This study focuses on the development and investigation of a control system for a steam superheater based on quantum algorithms. The proposed approach utilizes the mathematical representation of quantum states and the parallel formation of control decisions to improve regulation quality under variable operating conditions. The control objective is to maintain the outlet steam temperature at 480 °C within a pressure range of 13–15 MPa under load variations of up to ±10 %. The effectiveness of the proposed quantum-algorithm-based control system is evaluated through simulation and computational experiments, providing insight into its applicability for controlling complex dynamic objects in thermal power engineering [7].

RESEARCH METHODS AND THE RECEIVED RESULTS

During the fermentation process, maintaining the temperature of the apparatus within the specified operational limits is a critical requirement. The dynamic behavior of the process was analyzed to design an automated control system for temperature regulation. In parallel, the dynamic characteristics of the

ISSN 3030-3907

actuator and the controlled variable channel were identified. These dynamic properties of the control channel served as the basis for selecting an appropriate control algorithm and for determining its optimal parameters [8,9]: The dynamics equation of the object under study has the following form:

$$\dot{X} = F(X,U,W),\ X(t) = X^0,\ Y = \Psi(X,U,W)$$

where: $X = \{x_1, x_2, \ldots, x_n, y\}^0$ - generalized vector of phase coordinates; $N = \sum_{i=1}^{n} n_i + n_0$ - dimensional output variables; $U = \{u_1, u_2, \ldots u_n\}$ - control vector; $W = \{w_1, w_2, \ldots w_n\}$ - disturbance vector; $Y = \{y_1, y_2, \ldots, y_n\}$ - output coordinate vector.

These variables are influenced by multiple disturbances and exhibit probabilistic behavior. Under such conditions, the development of effective control systems necessitates the application of intelligent control approaches supported by modern information technologies [10]. Accordingly, the selection of an appropriate mathematical framework becomes a crucial requirement. The sigmoid membership function looks like this:

$$f_{z_3}(x,a,b) = \frac{1}{1+e^{a(x-b)}};\ a = \frac{2\ln\frac{\Delta}{1-\Delta}}{x_2 - x_1};\ b = \frac{x_1 + x_2}{2},$$

$$\begin{cases} \frac{1}{1+e^{-a(x_1-b)}} = \Delta, \\ \frac{1}{1+e^{-a(x_2-b)}} = \Delta \end{cases} \Rightarrow \begin{cases} a = \frac{2\ln\frac{\Delta}{1-\Delta}}{x_2 - x_1}, \\ b = \frac{x_1 + x_2}{2} \end{cases}$$

where: a, b - parameters of the sigmoid function. Based on these connections, the parameters of the proposal function are determined for each layer of the neural network [11,12]. Then the defuzzification operation is performed and the control signal is found in the form:

$$U = \frac{az_1 + bz_2}{a+b}$$

here: $z_{i+1} = z_i + \nu(y - y_{бер})$ - calculated at each stage of training; ν- is the learning rate.

It is necessary to increase the number of hidden layers and the number of neurons in them to ensure the suitability of the selected neural network for the real process and increase its accuracy [13].

The formulation of technological processes using the proposed method allows us to express control models for dynamic objects operating under conditions of uncertainty based on a unified mathematical apparatus [14].

ISSN 3030-3907

In a quantum computing scheme, these two states $|0\rangle$ and $\langle 1|$ can be in a superposition state, that is, the most general state of a quantum bit can be written as:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

here: α and β are complex numbers.

To write two states of qubits, bra $\langle\ |$ and ket $|\ \rangle$, Dirac notation is used. Vectors of the form $|\ \rangle$ are called ket-vectors, and vectors of the form $\langle\ |$ are called bra-vectors. The ket vectors and unit state of the qubit will look like this [15]:

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \text{ and } |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$

The actions of the Adamar operator on qubits are determined by the following mathematical relations:

$$H|\Psi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} \alpha+\beta \\ \alpha-\beta \end{pmatrix} = \frac{\alpha+\beta}{\sqrt{2}}|0\rangle + \frac{\alpha-\beta}{\sqrt{2}}|1\rangle$$

Based on this approach, an algorithm for generating quantum superposition was developed to determine the optimal control actions for the steam superheater [16]. At present, conventional control systems used in thermal power plants are primarily designed to maintain the outlet steam temperature within a predefined range using classical regulation principles [17]. However, such control strategies are insufficient to ensure high operational efficiency, since local automatic control systems are unable to comprehensively account for the nonlinear dynamics of the process, the strong coupling between temperature and pressure variables, and the uncertainty of operating conditions [18].

As a result, the development of advanced control systems based on intelligent technologies that explicitly consider uncertainties and complex interdependencies inherent in steam superheating processes remains a pressing research challenge. Addressing these issues requires the formulation of new methods and algorithms grounded in intelligent and quantum-based computational paradigms for the control of thermal power engineering objects.

To evaluate the effectiveness of the developed fuzzy-quantum temperature control algorithms for a steam superheater operating under various uncertainties, a computer model of the fuzzy-quantum control system was implemented in the MATLAB environment. A series of computational experiments was conducted under external disturbances and variable operating conditions. In this process, the transfer functions of the steam superheater were identified by approximating

ISSN 3030-3907

experimental and simulation data. Based on the above, an algorithm for the synthesis of a quantum controller for steam superheater control was developed as follows [19]:

1. The input and output variables of the quantum controller are defined (e.g., fuel flow rate and attemperation water flow rate as inputs, and outlet steam temperature and pressure as outputs);
2. The normalization (scaling) coefficients of the quantum controller are determined to ensure compatibility between physical variables and the fuzzy inference domain;
3. Corrective parameters are selected to reduce steady-state error and to improve tracking accuracy under operating disturbances.

The proposed synthesis procedure for a fuzzy–quantum controller differs from conventional approaches by its computational simplicity and practical convenience, enabling the use of standard membership function families and compact rule bases while preserving control effectiveness [20]. A software implementation based on the proposed algorithm makes it possible to compute optimal control actions for the steam superheater under variable operating conditions, including load variations and pressure disturbances, and to evaluate the transient and steady-state characteristics of the controlled variables.

The results of simulation and computational experiments conducted on the quantum fuzzy control system for the evaporation process show significant improvements in process efficiency, stability, and product quality. Figure.1 depicts the temporal characteristics of the output parameters, which show the temperature changes over time. The quantum controller effectively maintained the reactor temperature within the optimal range and demonstrated high stability despite external disturbances. Figure 4 depicts the output signal of the quantum controller during temperature control, which highlights its fast response and adaptability to changing process conditions.

ISSN 3030-3907

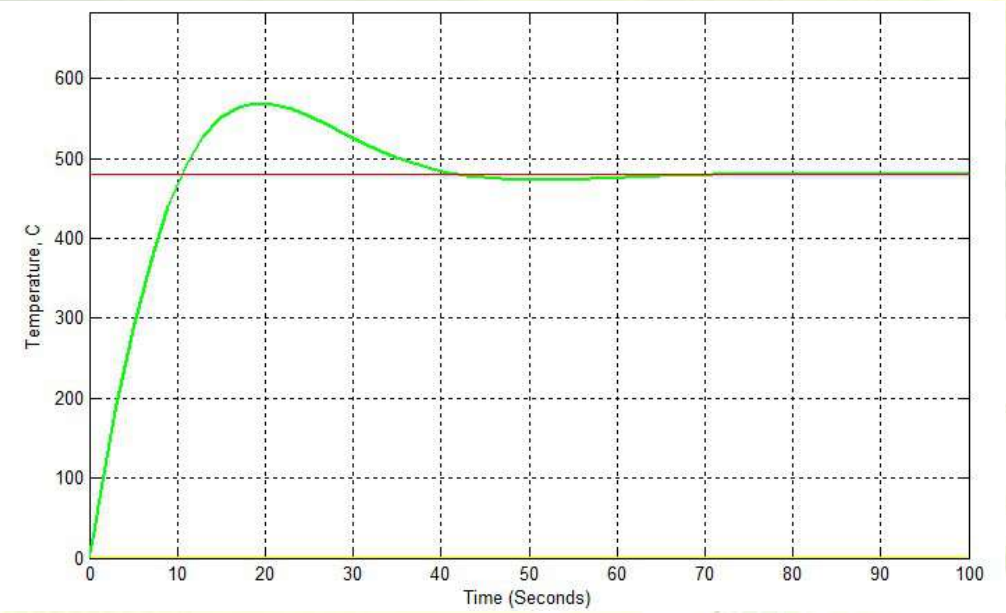


Figure 1. Heater temperature control

Figure 1. shows the outlet steam temperature response of the steam superheater under quantum-based control. The red horizontal line represents the reference temperature of 480 °C, while the green curve indicates the controlled temperature. A moderate overshoot is observed during the initial transient, demonstrating the fast dynamic response of the controller. The temperature then smoothly converges to the setpoint within approximately 40–50 s, indicating stable operation and effective real-time adaptation of the quantum control algorithm.

CONCLUSION

This study presented a quantum-based fuzzy control approach for the regulation of a steam superheater as a complex thermal power engineering object. Using a multivariable dynamic model with time delays, the proposed controller was designed to maintain the outlet steam temperature at 480 °C under operating pressures of 13-15 MPa and load variations of up to ±10 %. Simulation results showed fast transient response, limited overshoot, and stable convergence to the setpoint, confirming effective real-time adaptation of the control algorithm. The obtained results demonstrate that quantum-based fuzzy control provides reliable and robust temperature regulation for steam superheaters, indicating its potential for application in advanced thermal power plant automation.

REFERENCES:

1. Litvintseva L. V., Ulyanov I.S., Ulyanov S. V., Ulyanov S. S. Quantum fuzzy inference for knowledge base design in robust intelligent controllers // Computer and Systems Sciences Intern. – 2007. – Vol. 46. – № 6. – Pp. 908-961.

2. Litvintseva L.V., Ulyanov S.S., Takahashi K. et all. Intelligent robust control design based on new types of computation. Pt 1 // New soft computing technology

ISSN 3030-3907

of KB-design of smart control simulation for nonlinear dynamic systems. – Milan: Note del Polo (Ricerca), Universita degli Studi di Milano, 2004. – Vol. 60..
3. Usmanov, K., Eshbobaev, J., & Yakubova, N. (2023). Modeling and Optimization of the Ammonium Solution Extraction Process. Engineering Proceedings, 56(1), 198..
4. Frank Tabakin, Bruno Juliб-Dнaz, ”QCMPI: A parallel environment for quantum computing”, Computer Physics Communications №180, p. 948. 2009.
5. Сидиков, И. Х., Усманов, К. И., Якубова, Н. С., & Казахбаев, С. А. (2020). НЕЧЕТКОЕ СИНЕРГЕТИЧЕСКОЕ УПРАВЛЕНИЕ НЕЛИНЕЙНЫХ СИСТЕМ. Journal of Advances in Engineering Technology, (2), 16-19.
6. L.Lace. Enlarging gap between quantum and deterministic query complexities. Proceedings of Baltic DB&IS 2004, vol. 2, Riga, Latvia, pp. 81.-91. .
7. Sidikov, I. K., Usmanov, K. I., Yakubova, N. S., & Kazakhbaev, S. A. (2020). Fuzzy synergetic control of nonlinear systems. Journal of Advances in Engineering Technology,(2), 16-19.
8. Усманов, К. И., Сарболаев, Ф. Н., Исломова, Ф. К., & Якубова, Н. С. (2020). Адаптивно нечеткое синергетическое управление многомерных нелинейных динамических объектов. Universum: технические науки, (3-1 (72)), 24-28.
9. Yakubova, N. S., & Abdurasulova, G. E. (2023). Study of fuzzy controllers in intelligent control systems based on quantum computing. Universum: technical sciences: electron. scientific magazine.
10. Venegas-Andraca S. E. Quantum Walks for Computer Scientists. Synthesis Lectures on Quantum Computing, Morgan Claypool, 2008, 133 p.
11. Metodi T. S., Faruque A. I., Chong F. T. Quantum Computing for Computer Architects. Synthesis Lectures on Computer Architecture, Morgan Clay-pool, 2011, 203 p.
12. Yakubova, N. S. (2023). Synthesis of the control system of complex dynamic objects based on quantum computing methods. Descendants of Muhammad al-Khorazmi. Scientific-practical and information-analytical journal.(2023-y.).
13. Cirac J.I., Zoller P., “Goals and opportunities in quantum simulation”, Nature Physics, 8 (2010), 264–266.
14. Yakubova, N. S. (2023). Application of quantum algorithms in the synthesis of dynamic objects. Chemical Technology. Control and Management, 6, 61-67.
15. S. Rastegar, R. Araújo, J. Sadati, and J. Mendes, “A novel robust control scheme for LTV systems using output integral discrete-time synergetic control theory,” Eur. J. Control, vol. 34, pp. 39–48, 2017, doi: 10.1016/j.ejcon.2016.12.006.

ISSN 3030-3907

16. Якубова, Н. С., & Абдурасулова, Г. Э. (2023). Исследование нечетких регуляторов в системах интеллектуального управления на основе квантовых вычислений. Universum: технические науки, (3-1 (108)), 22-25.
17. Usmanov, K. I. (2022). SYNERGISTIC INTELLIGENT CONTROL OF NONLINEAR DYNAMIC OBJECTS. Journal of Advances in Engineering Technology, (1), 10-13.
18. Sidikov, I. X., Usmanov, K. I., Yakubova, N. S., & Kazaxbayev, S. A. (2020). Nechetkoye sinergeticheskoye upravleniye neli-neynix sistem. Journal of Advances in Engineering Technology, 2.
19. Ablayev F., Ablayev M. On the concept of cryptographic quantum hashing. Laser Phys. Lett., 2015, vol. 12, no. 12, art. 125204, pp. 1–5. doi: 10.1088/1612-2011/12/12/125204.
20. Usmanov, K. I., Islamova, F. K., & Yakubova, N. S. (2023). DEVELOPMENT OF A MATHEMATICAL MODEL OF THE DIESEL FUEL HYDROTREATMENT PROCESS. Universum: technical sciences: electron. scientific journal, 2, 107.

ISSN 3030-3907