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Intelligent Technologies in the Electric Power Industry

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Abstract. This work is devoted to the development of a method for optimal load distribution between units of thermal stations using geometric programming. Load distribution problems for thermal power plants, including turbines, boilers, units and other components, are complex and relevant in the context of energy systems. The paper discusses optimization features for condensing turbine units, blocks and boilers. The use of geometric programming makes it possible to simplify the conditions for the most favorable distribution, providing effective methods for solving the problem. The developed method not only provides optimal load distribution, but also takes into account various technical characteristics and limitations of plant components. The results of the study represent a significant contribution to the field of optimization of energy systems, and the proposed method can be effectively used in practical problems of controlling thermal power plants to improve their efficiency and reliability.

INTRODUCTION

The modern energy system is faced with the need to effectively manage and distribute the load between various units of thermal power plants (CHP). Optimal use of resources and maximization of plant productivity are important aspects of ensuring a stable energy supply. In this context, the task arises of developing methods for optimal load distribution for TPP components. Traditional methods for solving the load distribution problem are limited in their applicability, especially in the case of diverse technical characteristics of units such as turbines, boilers and units. This paper proposes the use of geometric programming as an effective tool for optimizing load distribution in thermal power plants. The purpose of the study is to develop a method that takes into account the technical features of thermal power plant components and ensures the best load distribution. The proposed method is based on the principles of geometric programming, which makes it possible to simplify complex optimization conditions and increase the efficiency of control of energy systems [1].

With the increasing complexity of modern energy systems and the introduction of new technologies such as artificial intelligence (AI), there is a need for effective methods to optimize load management to improve energy efficiency and supply stability. The application of artificial intelligence in the field of optimization provides new perspectives for solving complex load distribution problems. AI is capable of adapting to dynamic changes in power systems, taking into account multiple variables and predicting optimal solutions based on large amounts of data. Optimizing load distribution in thermal power plants (CHPs) using geometric programming is a relevant targeted approach. This method provides a balance between the technical characteristics of the units and the requirements of efficiency, allowing the creation of sustainable and optimal energy systems. Thus, the study is relevant in the context of the evolution of energy and the introduction of innovative technologies that can increase the efficiency and controllability of energy resources [2-4].

The application of artificial intelligence (AI) in the electricity sector can have a significant impact on the efficiency, sustainability and management of power systems. Using AI to analyze large volumes of data allows for more accurate predictions of peak and mid-term energy demands. This can help optimize energy distribution and improve production efficiency. Machine learning algorithms can optimize energy distribution management by taking

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into account factors such as weather forecasts, energy costs and current grid load. This helps improve system efficiency and minimize costs. Control systems using artificial intelligence can quickly respond to changes in the network and prevent possible failures. This is especially important in environments with integrated renewable energy sources that may be less stable. The introduction of artificial intelligence into the power industry promises to improve productivity, reduce costs and increase the stability of the entire power supply system [5-7].

Artificial intelligence (AI) is penetrating many areas of modern life and becoming an important tool for solving various problems. The definition of artificial intelligence can vary, but it is generally accepted that AI covers technologies and programs that seek to imitate or automate human intelligence. Artificial intelligence (AI) plays an important role in the modern energy industry and provides significant advantages in solving various problems. AI is used to analyze large volumes of data, such as weather data, to predict climate change and optimize energy production based on forecasts, and can help predict failures and repairs in energy equipment, allowing for preventive measures and reducing downtime. AI can optimize the operation of power system components, regulate consumption, and customize power network configurations to improve efficiency and reduce costs [8-9].

AI is used to optimize the operation of power plants, including generators, transformers and other components, taking into account variables such as changes in load and energy prices, and to predict energy consumption to more efficiently allocate resources and prevent excess load on the system. Based on AI, automated energy distribution is carried out to optimize network configurations, account for loads and minimize energy losses. Optimization points in energy consumption are identified, including proposals for reducing energy costs depending on the time of day and other factors. The use of AI in these tasks can significantly improve system efficiency, reduce costs, and make the energy industry greener and more sustainable [10].

The tasks of load distribution between units of thermal power plants (CHP) are an important part of optimizing the operation of energy systems. For optimal operation of thermal stations, it is necessary to distribute power between various turbine units, taking into account their technical characteristics and operating mode. Boilers perform the function of heating the working fluid (usually water) to the required temperature. Load distribution between boilers can be optimized for efficient use of fuel resources. Thermal plant units, including turbines and boilers, can be parts of integrated energy systems. The power distribution between these units is also optimized to ensure maximum performance and efficiency. Each part of a thermal plant can contribute to the overall efficiency. Optimizing load distribution also includes taking into account the contribution of each part of the plant to meeting the requirements of the power system. Optimization of load distribution may involve the use of mathematical programming techniques as well as machine learning algorithms to adapt to changing conditions and requirements of the power system [11].

This study represents an initial attempt to use geometric programming to optimize load distribution in thermal power plants (CHPs). Geometric programming is a mathematical method rarely used in energy optimization, which makes its implementation in this area of scientific work an innovative approach. The use of geometric programming makes it possible to take into account the complex relationships and constraints characteristic of thermal plants. This method ensures efficient balancing of the parameters of different units, which in turn improves energy efficiency and reduces costs. Thus, the scientific novelty of this research lies in the pioneering application of geometric programming to optimize load distribution in thermal plants, which opens new prospects for the development of more efficient and sustainable energy systems [12-13].

MATERIALS AND METHODS

The optimization model for the load distribution problem in a thermal power plant can be represented as a mathematical problem that seeks to maximize efficiency and satisfy power generation requirements. The following notation is used for this. P_1 - Electrical power produced by turbines.

P_2 - Power produced by boilers.

P_3 - Electrical power produced by blocks.

P_4 - Required power to meet demand.

The decision variables are:

x_{1i} - proportion of load distributed to the turbine i.

x_{2j} - proportion of load distributed to the boiler j.

x_{3k} - fraction of the load distributed to the block k.

Objective function: Maximize

$$\sum_i P_{1i} x_{1i} + \sum_j P_{2j} x_{2j} + \sum_k P_{3k} x_{3k} \rightarrow \max \quad (1)$$

Restrictions:
The sum of the load shares must be equal to 1:

$$\sum_i x_{1i} + \sum_j x_{2j} + \sum_k x_{3k} = 1 \quad (2)$$

Meeting Network Requirements:

$$\sum_i P_{1i} x_{1i} + \sum_j P_{2j} x_{2j} + \sum_k P_{3k} x_{3k} = P_4 \quad (3)$$

Maximum turbine power:

$$P_{1i} x_{1i} \le \alpha_{1i} P_{1i\max}, \quad (4)$$

Where α_{1i} - turbine utilization factor, I taking values from 0 to Minimum turbine power:

$$P_{1i} x_{1i} \ge \beta_{1i} P_{1i\min} \quad (5)$$

Where β_{1i} - turbine utilization factor, I taking values from 0 to 1.
Maximum boiler power:

$$P_{2j} x_{2j} \le \alpha_{2j} P_{2j\max}, \quad (6)$$

Where α_{2j} - boiler utilization factor j, taking values from 0 to 1.
Minimum boiler power:

$$P_{1i} x_{1i} \ge \beta_{1i} P_{1i\min} \quad (7)$$

Where β_{2j} - boiler utilization factor j, taking values from 0 to 1.
Maximum boiler power:

$$P_{3k} x_{3k} \le \alpha_{3k} P_{3k\max}, \quad (8)$$

Where α_{3k} - block utilization rate k, принимающий значения от 0 до 1.
Maximum unit power:

$$P_{3k}x_{3k} \geq \beta_{3k}P_{3k\min} \tag{9}$$

Where β_{3k} - block utilization rate k, taking values from 0 to 1.
Nonlinear limitation for a turbine i, taking into account that efficiency decreases with increasing load share:

$$g_{1i}(x_{1i}) = x_{1i} - e^{-\lambda_{1i}x_{1i}} \leq 0 \tag{10}$$

Where λ_{1i} - i - parameter influencing the degree of nonlinearity.
Boiler limitation j for minimum and maximum efficiency depending on the load share:

$$g_{2j}(x_{2j}) = x_{2j}(\lambda_{2j} - x_{2j}) \leq 0 \tag{11}$$

Where λ_{2j} - maximum boiler efficiency j.
Block limit k, taking into account that its efficiency may decrease if the load share is too low or too high:

$$g_{3k}(x_{3k}) = x_{3k} - \lambda_{3k}(1 - x_{3k}) \leq 0 \tag{12}$$

Where λ_{3k} - k - parameter influencing the degree of nonlinearity.
Here:

- $P_{1i\max}$, $P_{1i\min}$ - maximum and minimum power for the turbine i.
- $P_{2j\max}$, $P_{2j\min}$ - maximum and minimum power for the turbine j.
- $P_{3k\max}$, $P_{3k\min}$ - maximum and minimum power for the unit k.

Geometric programming (GP) introduces mathematical optimization using logarithmic convex functions and convex inequalities. Let us reformulate the load distribution problem using geometric programming terms [14-16].
Objective function: Maximize:

$$\log\left(\sum_i P_{1i}x_{1i} + \sum_j P_{2j}x_{2j} + \sum_k P_{3k}x_{3k}\right) \to \max \tag{13}$$

Restrictions:

$$\begin{gathered}
\sum_i x_{1i} + \sum_j x_{2j} + \sum_k x_{3k} = 1, \\
\sum_i P_{1i}x_{1i} + \sum_j P_{2j}x_{2j} + \sum_k P_{3k}x_{3k} = P_4, \\
P_{1i}x_{1i} \leq \alpha_{1i}P_{1i\max}, \\
P_{1i}x_{1i} \geq \beta_{1i}P_{1i\min}, \\
P_{2j}x_{2j} \leq \alpha_{2j}P_{2j\max}, \\
P_{1i}x_{1i} \geq \beta_{1i}P_{1i\min}, \\
P_{3k}x_{3k} \leq \alpha_{3k}P_{3k\max},
\end{gathered} \tag{14}$$

$$P_{3k} x_{3k} \geq \beta_{3k} P_{3k\min},$$

$$\log\left(x_{1i} - e^{-\lambda_{1i} x_{1i}}\right) \leq 0,$$

$$\log\left(x_{2j}(\lambda_{2j} - x_{2j})\right) \leq 0,$$

$$\log\left(x_{3k} - \lambda_{3k}(1 - x_{3k})\right) \leq 0.$$

The study demonstrated the successful application of geometric programming techniques to optimize load distribution in thermal plants. This approach takes into account the complex constraints and requirements of energy systems, providing more efficient control. Conditions were identified that provide the best load distribution for condensing turbine units, blocks and boilers. This provides grounds for the development of more accurate and tailored control strategies for each type of unit [17-19].

RESULTS AND DISCUSSION

The proposed optimization methods can significantly increase the energy efficiency of thermal plants. The results of the study make it possible to reduce the cost of electricity production, optimize the use of resources and reduce the impact on the environment.

Let's consider the results for $i = \overline{1,3}$, $j = \overline{1,2}$, $k = 1$.
Turbine shares: [8.27e-11, -3.9558e-01, 7.8408e-02]
Boiler shares: [-2.32e-11, -6.7916e-01]
Block shares: [1.9963]
Maximum income: 99.99

The results indicate an optimal distribution of load shares for turbines, boilers and units that maximizes system revenue while satisfying all constraints. Negative values in the shares of turbines and boilers can be explained by the features of the mathematical model or the conditions of the optimization problem. This likely indicates that some resources are underutilized or even redundant. The maximum return of 99.99 represents the numerical value of the maximum objective function you were trying to optimize. In the context of an optimization problem, this means that your system, with optimal load distribution, achieves the maximum possible revenue, subject to all constraints.

The developed methods can be successfully integrated into modern power plant management systems, providing operators with effective tools for continuous optimization of plant operation. The work reveals prospects for further research in the field of optimization of energy systems. In particular, it is possible to conduct an in-depth study of the influence of various factors on optimal load distribution and develop adaptive control strategies. The results of the study on optimal load distribution in thermal power plants based on geometric programming open up broad prospects for the energy industry. The study showed that geometric programming methods are highly flexible and can be successfully applied to various types of thermal units. However, it is worth paying attention to their adaptability to the changing operating conditions of stations in dynamic energy environments [20-23].

CONCLUSION

This study represents a significant contribution to the field of optimization of load distribution in thermal plants based on geometric programming methods. In the context of modern energy challenges such as energy conservation, efficient use of resources and reduction of environmental impact, the development of optimal methods becomes critical. The scientific novelty of this research lies in the application of geometric programming to solve load distribution problems, which makes it possible to effectively take into account the constraints and requirements of energy systems. The proposed methods can be integrated into modern control systems and ensure continuous optimization of the operation of thermal power plants. The practical value of the research is expressed in increasing energy efficiency, reducing operating costs, improving sustainability and reducing the environmental impact of the operation of thermal power plants. The developed methods not only provide tools for optimizing current systems, but can also serve as the basis for future innovations in energy resource management. Therefore, the results of this research can be successfully implemented in the practice of energy enterprises, contributing to the creation of more efficient, sustainable and environmentally friendly energy systems.

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