Methodological bases of organization heat supply in conditions of different interests of subjects of relationships

Valery Stennikov[1], *Oleg* Khamisov[1], and *Andrey* Penkovskii[1, *]

[1]Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences (ESI SB RAS), 664033, Irkutsk, Lermontov str., 130,664033

Abstract. Heat supply is the most important area for the provision of energy services to a wide range of consumers. This industry determines the well-being of society, social stability and competitiveness of the economies of many countries of the world. The processes of energy liberalization initiated in the early 1990s led to the emergence of new forms of heat supply management based on market interaction among producers and consumers of heat energy. In market conditions, the problem of optimizing heat supply systems becomes much more complicated, and its structuring becomes multivariate depending on the characteristics of the industry organization. To solve the problems of optimal functioning and development of heat supply systems in changing conditions, along with existing optimization methods, it becomes necessary to use new approaches focused on solving problems in some specific uncertain situations characterized by conflicting interests of the parties, and often defined as conflict. The paper presents a comprehensive scientific and methodological approach based on mathematical modeling for solving problems of managing the development and functioning of heat supply systems in a market economy.

1 Introduction

The heat supply of Russia, most of which is located in a territory with a harsh climate, is the most important social sector of the economy, which largely determines the energy security of the country. Heat supply to consumers is carried out in heat supply systems (HSS), as a rule, in district systems based on cogeneration. The advantages of district heating are undeniable, these are fuel savings and the cost of its transportation, a significant increase in labor productivity in the heat and power industry, the possibility of effective improvement of the air basin of cities, etc. Currently, the Russian HSS includes about 50 thousand local systems [1], which serve more than 21 thousand enterprises. The volume of heat energy (HE) consumption is more than 2 billion Gcal per year, of which 1,300 billion Gcal is accounted for by district heating . The annual turnover from the sale of heat energy is estimated at 1.5 trillion. rub., or about 2.5% of the country's GDP.

* Corresponding author: penkoffsky@isem.irk.ru

Since the beginning of market reforms in the 1990s and liberalization processes in the Russian energy sector, many owners have appeared in the HSS, which has led to the formation of new economic relations among producers, suppliers and consumers of heat energy and the creation of a heat energy marketUse 170 x 250 mm paper size (W x H mm) and adjust the margins to those shown in the Table 1. The final printed area will be 130 x 210 mm. Do not add any page numbers.

2 Models and methods

The process of transformation of HSS, the formation of a new model of the heat market, motivation (interest) in technical and technological excellence, the feasibility of forming an effective infrastructure for heat generating capacity, heat networks have led to the fact that the issues of long-term development of HSS have become increasingly important.

In this regard, there is a need to create a methodological framework that allows the setting of problems and the implementation of solutions related to the development of HSS, ensuring their effective functioning and development in the conditions of a multitude of interests of participants in the process of heat supply to consumers.

In accordance with the foregoing, the choice of optimal directions for the development of HSS in market conditions develops into a major economic problem, especially within the framework of the heat supply reform being implemented in the Russian Federation. The main provisions of such scientific and methodological support are based on system research, which is understood as the direction of the methodology of cognition, which is based on the study of objects as systems [2].

The tool for systemic research of HSS in market conditions is mathematical modeling, taking into account their internal and external relations, i.e. consideration of HSS as a single technological complex, which includes various types of heat sources, heat networks and consumers. The mathematical models and methods of the theory of hydraulic circuits developed at the ISEM SB RAS serve as the basic scientific and methodological foundations for modeling HSS [3]. For HSS research in market conditions, various mathematical methods are used, in particular, game theory approaches [4], network flow models [5], bi-level programming [6], as well as elements of microeconomics [7]. The relationship among problems (development and functioning) and research methods for heat energy markets with various forms of their organization is shown in Fig.1.

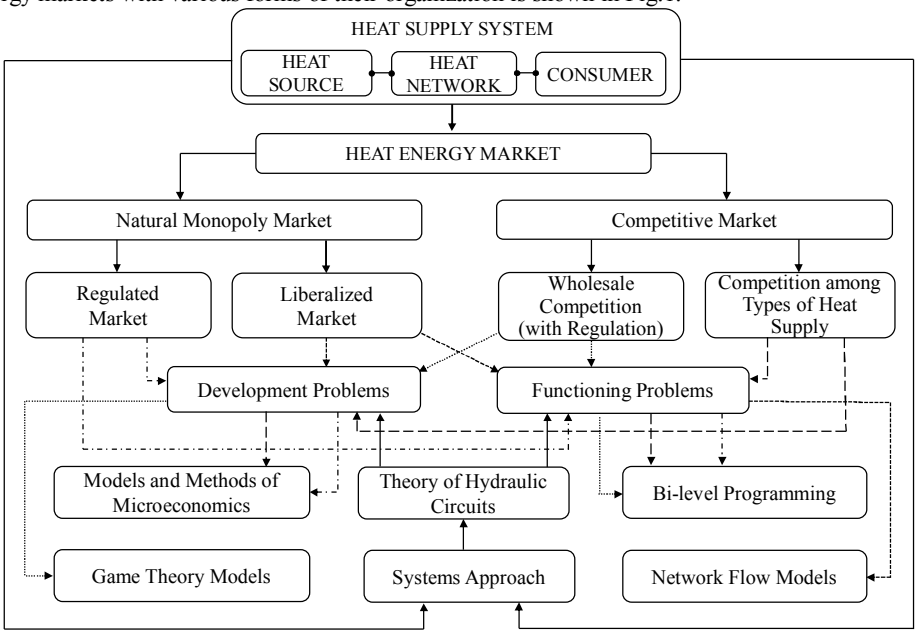

Fig. 1. Interrelation of problems and research methods of heat energy markets.

Fig. 1 shows that there are two main models for organizing the heat energy market, competitive and monopoly models, which in turn can manifest themselves in various forms depending on the specifics of the industry development. Depending on the task and forms of organization of the heat business, various approaches are used to solve them, while the basic models for their description and mathematical modeling are the theory of hydraulic circuits and system researches in energy. The developed scientific and methodological support is universal and allows you to calculate HSS of any scale, power and take into account not only different types of heat sources, but also their number [8-10].

3 Case study

With the help of the developed scientific and methodological support, practical studies were carried out on a real scheme of the heat supply system of the city of Angarsk (Fig. 2).

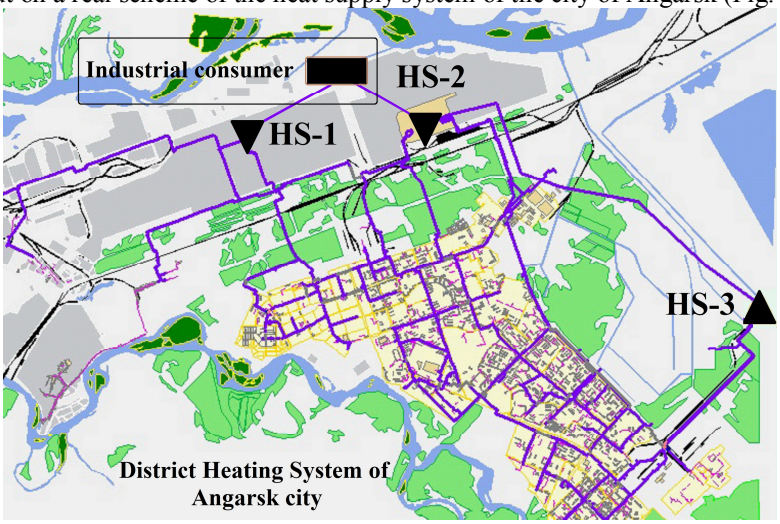

Fig. 2. Design scheme of heat supply system in Angarsk.

Calculations were carried out according to the following variants for the organization of heat supply to consumers: variant 1 - the “Single Buyer” model, a competitive market; variant 2 - the model "Unified Heat Supply Organization" (UHSO), free pricing (without regulation); variant 3 – UHSO model, regulation at the level of the minimum allowable tariff for heat energy; variant 4 - UHSO model, regulation of the tariff for household consumers at the level of average total costs; variant 5 - model of UHSO, regulation of the tariff for household consumers at the level of marginal costs; variant 6 - UHSO model, tariff regulation for household consumers based on the “alternative boiler house” method; variant 7 - UHSO model, minimum total costs in HSS.

Conducted practical studies of the HHS of Angarsk using the developed methodological apparatus and computational tools made it possible to determine the optimal directions for its development. They include the optimal capacities of thermal energy sources, taking into account their effective participation in covering thermal loads, distribution of heat sources coverage areas, flow distribution in the heat network, heat supply radii, costs required for the maintenance and development of the system, including sources and heat networks, prices for heat energy for consumers.

Conducted practical studies of the HHS of Angarsk using the developed methodological apparatus and computational tools made it possible to determine the optimal directions for its development. They include the optimal capacities of heat sources, taking into account

their effective participation in covering heat loads, distribution of heat sources coverage areas, flow distribution in the heat network, heat supply radii, costs required for the maintenance and development of the HSS, including heat sources and heat networks, heat energy prices for consumers.

The results obtained allow us to make a decision on the development of the heat supply system in Angarsk, the form of heat supply organization, as well as on the heat energyprices for consumers Fig.3.

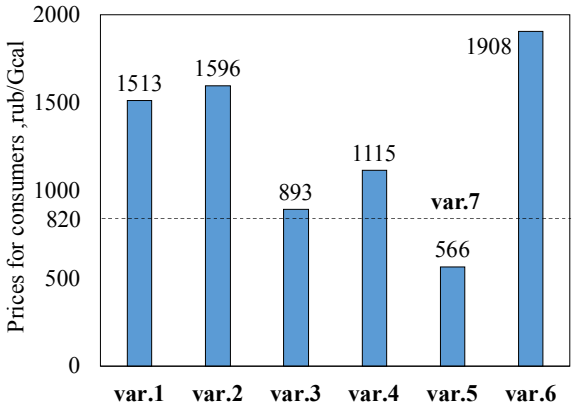

Fig.3. Comparative analysis of heat energy prices for consumers by variants.

Comparison of price levels for heat energy obtained by options 1-7 showed that the optimal for organizing heat supply to consumers in Angarsk is variant 4, in which the price for consumers is at the level of average unit costs for the UHS0, and the price for the "alternative boiler house" was the highest. At the same time, UHSO has a positive profit in both variants.

The high prices for heat energy under variant 7 are due to several factors: the alternative boiler house is a decentralized heat source and does not have economies of scale that work to reduce costs; the price includes an investment component, which should not be taken into account for existing HSS; the separate method of producing heat in a boiler house and electricity at a condensing heat power plant is objectively less efficient than the combined (cogeneration) method of their production, which also significantly increases costs.

4 Conclusion

The paper proposes a comprehensive scientific and methodological support that allows you to perform modeling and calculation of HSS for the conditions of a market economy. It includes mathematical models, methods and algorithms for calculating HSS for various forms of organization of heat energy markets. They are based on the main provisions of system research in energy, on models and methods of the theory of hydraulic circuits, mathematical modeling, energy economics, basic principles of microeconomics, game theory, bi-level modeling, network flow models. The use of these mathematical models and methods makes it possible to take into account the individual characteristics and technical and economic characteristics of heat sources and heat networks in a single integrated formulation, which should contribute to the mutual interests of producers and consumers of heat energy (increasing the income of the supplier and the willingness of the consumer to pay for the supplied heat), conduct research and perform calculations of technical and

economic indicators of HSS with several heat sources operating on unified heat networks, determine their optimal load levels and coverage areas, (services), optimal flow distribution in heat networks for dividing personal modes of operation of the HSS, as well as take into account various methods of tariff regulation for heatenergy for consumers. The developed methods, methods, models and algorithms for solving key problems of optimal functioning and development of HSS in market conditions meet modern requirements, have scientific and practical novelty, are unique in terms of their complexity and universality with respect to heat supply systems of any complexity and scale.

The research was carried out at the Meleniev Energy Systems Institute SB RAS within the framework of scientific projects FWEU-2021-0002, registration number AAAA-A21-121012090012-1 "Theoretical foundations, models and methods for managing the development and operation of intelligent pipeline systems in the energy sector" and FWEU-2021-0006, registration number AAAA-A21 -121012090034-3 "Equilibrium and dynamic models of intelligent energy systems: theory and numerical methods".

References

1. V.A. Stennikov, A.V. Penkovskii, EKO (2019) [in Russian]
2. L.A. Melentiev, *System Research in Energy. Elements of the theory. Development directions* (Nayka, Moskow, 1983) [in Russian]
3. A.P. Merenkov, V.Ya. Khasilev, *Theory of Hydraulic Circuits* (Nayka, Moscow, 1985) [In Russian]
4. H. Moulin, *Game theory with examples from mathematical economics* (Mir, Moscow, 1985) [In Russian]
5. J.L. Lagrange, *Analytical mechanics* (GONTI, Moscow, 1938) [In Russian]
6. S. Dempe. *Foundations of Bi-level Programming*, (Kluwer Academic Publishers Dordrecht, The Netherlands, 2002)
7. S.B. Avdasheva, N.M. Rozanova *Industrial Economics and Organisation* (Magistr, Moscow, Magistr, 1998) [in Russian]
8. A. Penkovskii, V. Stennikov. Mathematical modeling and optimization of the monopoly heating market. Int. J of En. Eco. and Pol, **10** (2020)
9. V. Stennikov, A. Penkovskii. The pricing methods on the monopoly district heating market. En. Rep. J, **6** (2020)
10. A. Penkovskii, V. Stennikov, E. Mednikova, I. Postnikov. Search for a market equilibrium of Cournot-Nash in the competitive heat market. En. J., **161** (2018)