Application of a multi-agent approach to solving problems of development of integrated energy systems

Valery Stennikov, *Evgeny* Barakhtenko, and *Gleb* Mayorov

Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences, Pipeline Systems Department of Energy No. 50, 664033, Irkutsk Region, Irkutsk, Lermontov St., 130, Russia

Abstract. Currently, when solving the problems of developing energy systems, it is necessary to take into account the profound changes associated with the transition from consideration of centralized planning and management to a new paradigm of a multilateral process of substantiating decisions and creating mechanisms for their implementation in conditions of uncertainty, multicriteria and a plurality of conflicting interests. The development of modern energy systems requires the use of innovative methods and technologies for their study, which assume the presence of many decision-making centers and take into account the complex structure of these systems. In this paper, to solve the problems of development of integrated energy systems, a multi-agent approach is used, in which solutions are obtained as a result of the interaction between a set of agents. Based on the proposed structure of the multi-agent system, a multi-agent model of an integrated energy system was developed in the AnyLogic software environment. A number of computational experiments were carried out, which made it possible to verify the developed principles of the interaction of objects in an integrated energy system when solving development problems.

1 Introduction

A promising direction in the field of energy research is the development of methods for the creation and operation of integrated energy systems (IES), which combine centralized and distributed energy sources into a single metasystem in order to increase their overall flexibility and efficiency [1-2]. Based on the research, as well as practical experience, it can be concluded that the integration and active participation of consumers are crucial for smart energy systems [3]. To achieve high efficiency in energy supply systems, it is important to optimally define design characteristics along with operational strategies corresponding to seasonal changes in energy demand [4-5]. It is necessary to take into account that energy needs have some uncertainty, and to develop optimal energy supply systems, taking into account distributed energy systems, which play an important role in the integration of renewable energy technologies [6].

This paper will consider the methodological principles and mechanisms for the interaction of objects in the IES in solving the problem of development. Their application is proposed to solve the following problems:

- Development of the structure of a multi-agent system for the interaction of objects in the IES in solving the problem of development.
- Development of a multi-agent IES model for implementing the principles and mechanisms of interaction between agents in solving the development problem.
- Carrying out a computational experiment to find the optimal solution for the development of IES and performing an analysis of the results with obtaining practical recommendations.

2 Principles of building integrated energy systems

Currently, the direction associated with the creation and development of models and methods for the study of IES is being widely developed all over the world, since this direction in the future can provide significant advantages in comparison with traditional energy systems. Intelligent IES combine multicomponent nature, intelligence, efficiency, reliability, controllability, flexible use of energy conversion, transport, and storage technologies and involve the participation of prosumers in the energy supply process (Fig. 1). With the growth in the number of renewable energy sources and the number of prosumers, new principles for the construction and management of energy systems are needed, taking into account the complex nature of the behavior and interaction of objects.

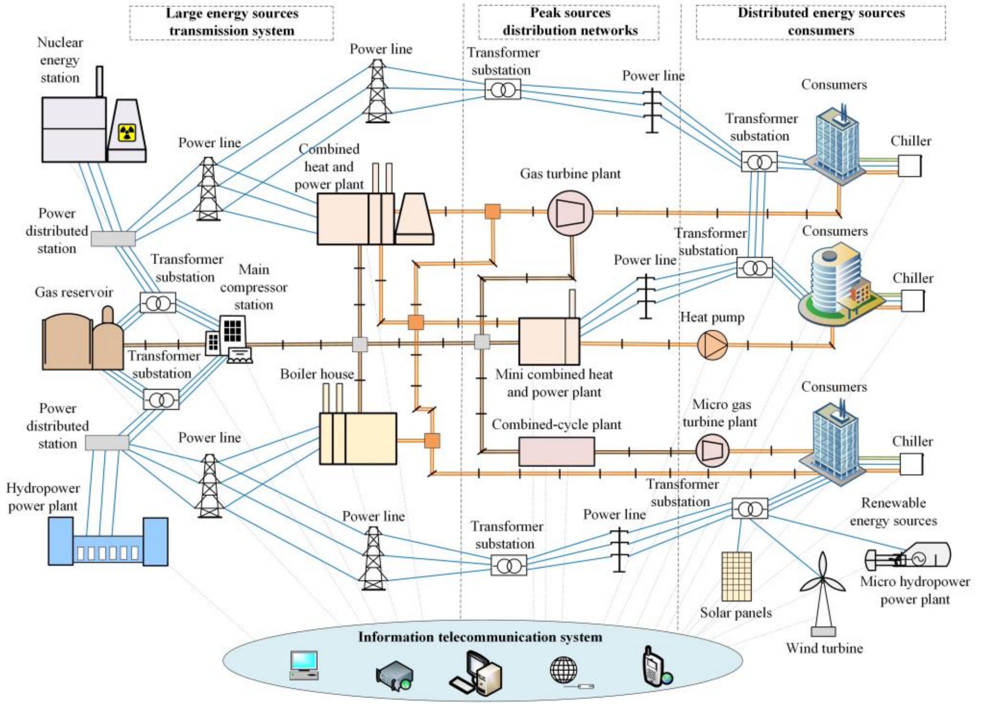

Fig. 1. Integrated energy system.

The main goals of technological integration and intellectualization of energy systems are to achieve a higher level of control in order to ensure a high level of comfort in residential, public and industrial buildings, ensure the efficiency of energy supply, and reduce the negative impact on the environment [7].

Basic principles of creating IES [1-2]:

- Transition from the functioning of several disparate systems to a common metasystem with a single control and a common information environment.
- Complex synergistic interaction of individual systems, the combined impact of which on the result significantly exceeds the effect of each system and exceeds the result of their simple summation.
- Emergence, expressed in the acquisition by the metasystem of new properties that are not inherent in its elements.
- Mutual redundancy of systems in the course of their operation, through energy conversion units.
- Transition from vertical-subordinate control to multi-agent control (from vertical to horizontal), when each system receives an impact from the external environment and reacts to this impact. Decisions are made and implemented by independent centres.
- Integration of IES mode control through network (distributed) coordination of monitoring.

3 The structure of a multi-agent system in solving the problem of development

The multi-agent approach is a relevant tool for modeling and researching IES, this approach is successfully used by scientists all over the world to solve problems of varying complexity and dimension. The multi-agent approach is widely used in such areas as distributed solution of complex problems, combined product design, building virtual enterprises, and simulation of integrated production systems [8-11]. Multi-agent technologies are aimed at obtaining a solution as a result of the interaction of many independent purposefully acting agents [12-13], and in this case, a distributed approach to solving a problem is applied, when a complex task is divided into many tasks of a smaller dimension, thus the search for a solution is carried out by several independent centers.

The enlarged structure of the multi-agent system, developed to study the interaction of objects in solving the problem of development in the IES, is shown in fig. 2.

All objects in the considered IES can be divided into three groups: consumers, networks and energy sources. Each object is represented by its own agent, which reflects its behavior in the system, links with other agents, characteristics, parameters, and individual restrictions. The hierarchy of interaction between agents is described by three levels. At the first level, the development level, there is a development agent and its auxiliary local agents: data analysis agent; database agent; schema generation agent. Development level agents prepare data for the calculation of the scheme, generate a redundant IES scheme and send the necessary data to the calculation level, then analyze the received data according to the found solution and form a solution for the development of the IES, they also display statistics to users in the form of graphs and diagrams. The second and third levels of functioning of objects are combined in the calculation level. At the second level there are coordinating agents: a network agent of a centralized system and network agents of distributed subsystems. The network agent of the centralized system coordinates and supervises the formation of a solution for centralized generation facilities. It exchanges information with the development agent and network agents of distributed subsystems. Distributed generation sources located at prosumers are coordinated and controlled by network agents of distributed subsystems. They, in turn, exchange data on the generated solution with the development agent and the network agent of the centralized system. If necessary, the network agent of the centralized system and the network agents of the distributed subsystems correct the obtained solutions. At the third level, there are consumer agents, network section agents, centralized generation agents and prosumer agents, they carry out the operation of IES objects and participate in the formation of a solution for their subsystems, exchanging data with the agents associated with them.

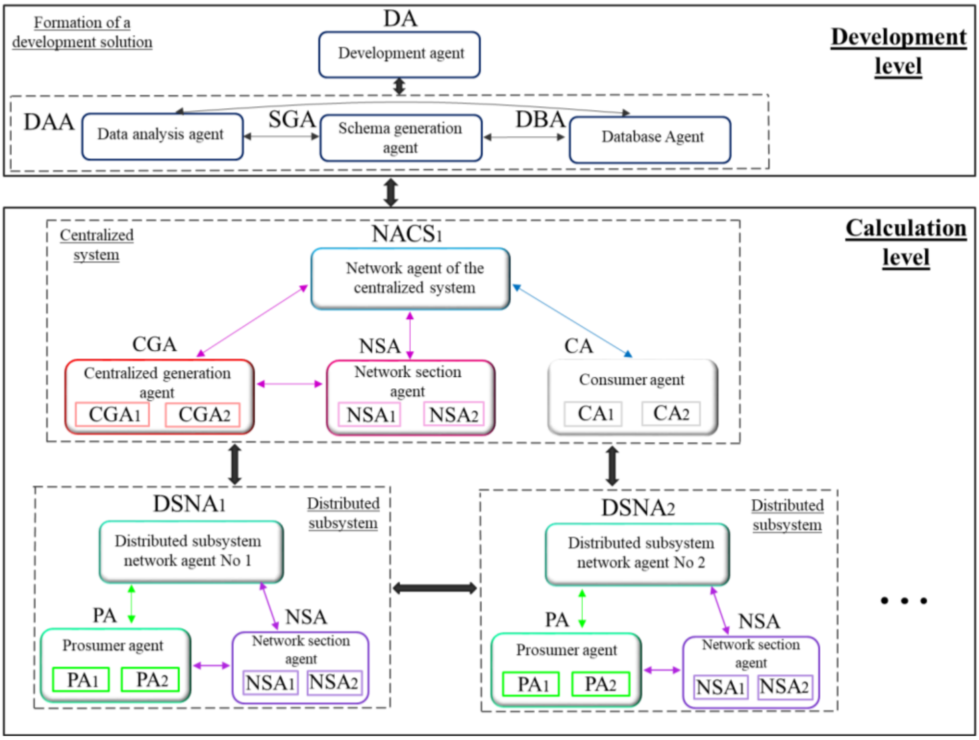

Fig. 2. The structure of a multi-agent system in solving the problem of development.

4 Development of a multi-agent model of an integrated energy system

To test the developed principles and mechanisms for the interaction of objects in the IES, a test scheme is used, shown in fig. 3. This scheme allows you to visualize the behavior of agents and the interaction between them when solving the problem of development in the IES. The considered test circuit of the IES includes the following objects: 5 consumers; 7 prosumers; 7 electric boilers for heat generation; 7 photovoltaic systems for generating electricity; 12 chillers for cooling; 29 power lines; 24 heat mains; 25 gas lines; source of combined heat and power generation - CHPP; sources of electricity - hydroelectric power plant (HPP) and condensing power plant (CPP); sources of heat two centralized boiler plants; gas distribution station for preparing gas of the required parameters and sending it to consumers. Centralized energy sources have zones of efficient operation of generating equipment. Electric boilers and photovoltaic systems are located at active prosumers, chiller installations are located both at prosumers and consumers.

Using this scheme, the developed algorithms for the interaction of objects in the IES will be tested and the analysis of the data obtained will be carried out. As a result of the calculation on this scheme, the most optimal IES configuration will be selected, reflecting the interests, preferences and capabilities of prosumers and the entire IES, taking into account system conditions and restrictions.

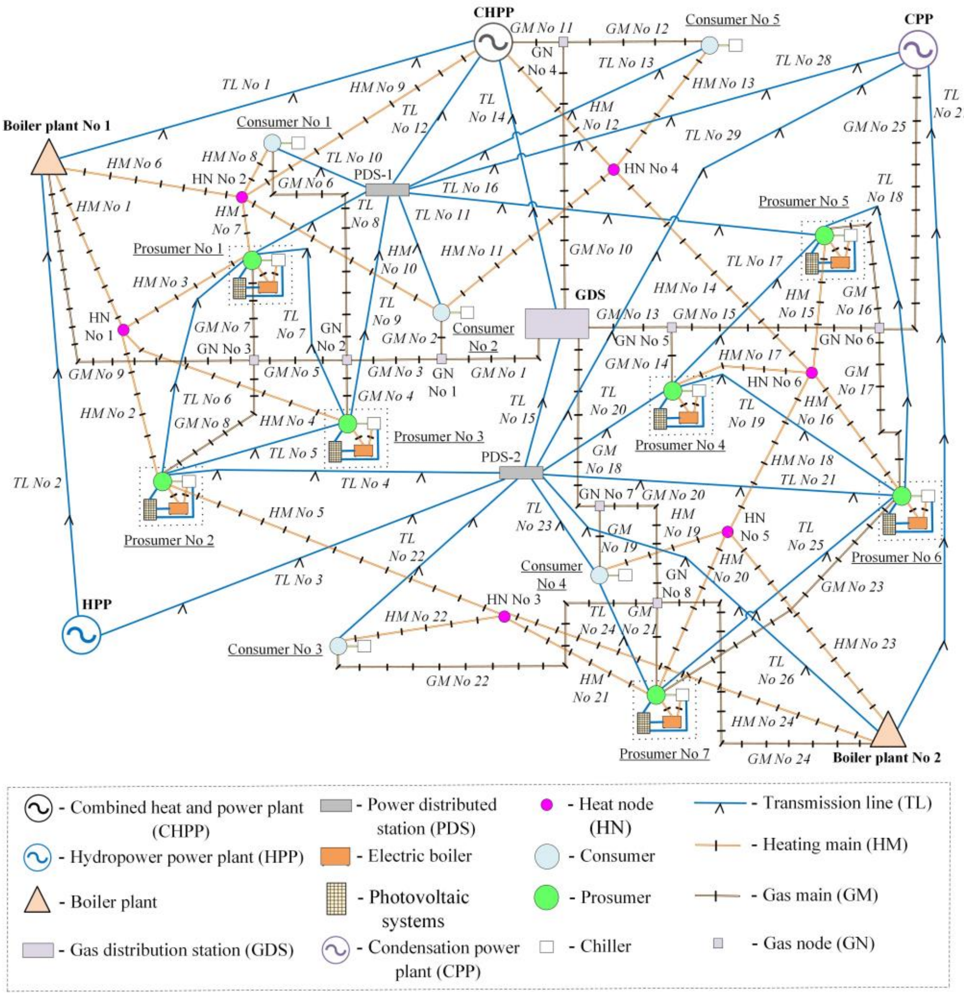

Fig. 3. Test scheme of the integrated energy system.

In the AnyLogic software environment, a multi-agent IES model (Fig. 4) was developed in accordance with the structure shown in Fig. 2. This model presents the elements of the heat, electric, gas and cold supply systems in the form of agents and describes the interaction of these agents with each other. Each element of the scheme is represented by its own agent, the agents in the model are highlighted in red (see Fig. 4). The description of the logic and behavior of agents in the developed multi-agent model is carried out through state diagrams. If an agent can have several states or behaviors that perform different actions when some events occur, then the behavior of such an object can be described in terms of a state diagram. State diagrams contain information about the various states an object can exist in and how it transitions from one state to another. Transitions from one state to another can be triggered as a result of an event specified as a condition: expiration of a specified time, receipt of a message, fulfillment of a specified logical condition, etc. [14-15].

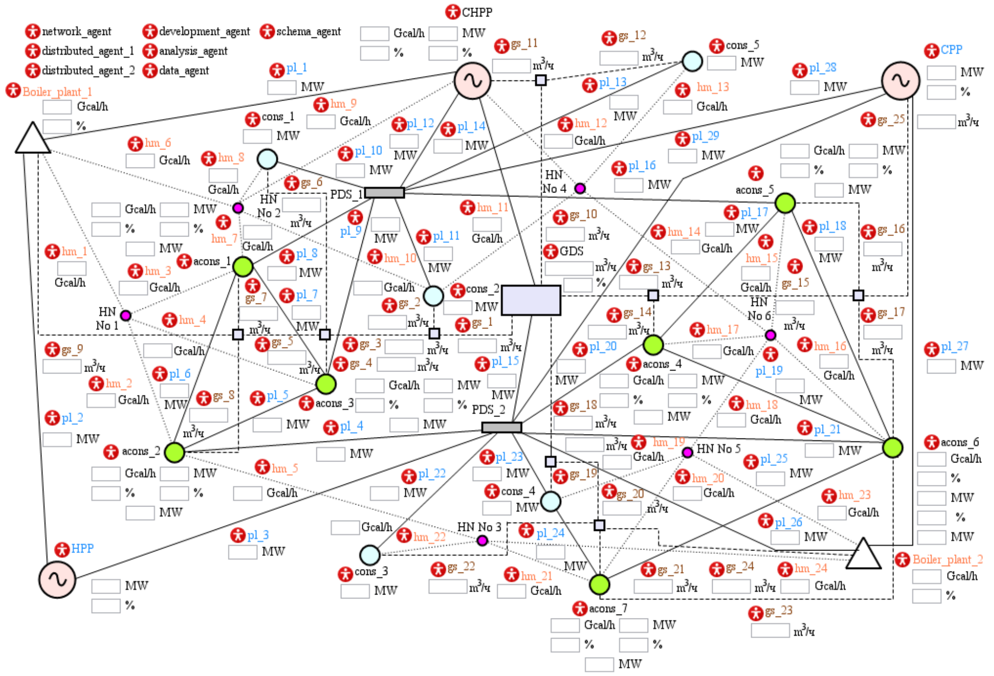

Fig. 4. Multi-agent model of an integrated energy system in the AnyLogic software environment.

5 Computational experiment

Using the developed multi-agent model in the AnyLogic software environment, a computational experiment on the development of IES was carried out. As a result of the interaction of agents and connected software components in the multi-agent model, an optimal solution was found, in accordance with which the necessary measures for the construction of network and generating equipment were formed and implemented. A visual representation of the obtained solution is shown in Fig. 5, the sections of the networks involved in the energy supply are highlighted in the appropriate color. As part of the given capital investments, the most economical and environmentally friendly energy sources were selected, taking into account the zones of effective operation of the equipment. Thus, in the scheme obtained, it can be seen that a 100% loaded CHPP and CPP in a centralized system were used to generate electricity, and a significant amount of electricity was taken from photovoltaic systems installed at prosumers, since such energy is the most economical and environmentally friendly. As a reserve to regulate the share of energy at night, when photovoltaic systems cannot produce electricity, it is planned to use the capacity of generating equipment of CPP, the electric reserve of which is 420 MW. To transfer the required amount of electricity to consumers, the corresponding transmission lines were built, selected from the possible options, and transmission lines No. 16 and No. 4 were built as backbone networks to redistribute energy between centralized and distributed sources. The HPP was not involved in the production of electricity, since its construction and the construction of extended transmission lines suitable for it, is beyond the specified capital investments.

For the generation of heat, a centralized boiler plant No. 1 and a CHPP were used, and distributed sources of heat were also involved in the form of electric boilers for prosumers. Boiler No. 1 acts as a reserve of heat, the total capacity reserve of which is 300 Gcal/h. Also, the most optimal pipelines for the delivery of heat to consumers from the presented list were selected, heat mains No. 5 and No. 14 act as connecting main networks between the

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subsystems. Chiller units were installed to generate cold at consumers and prosumers. The main consumers of gas are the boiler plant, CPP and CHPP, so the main gas pipelines from the gas distribution station with branches to consumers were laid to them. The total costs for the construction and energy supply of IES facilities amounted to 200.635 billion rubles.

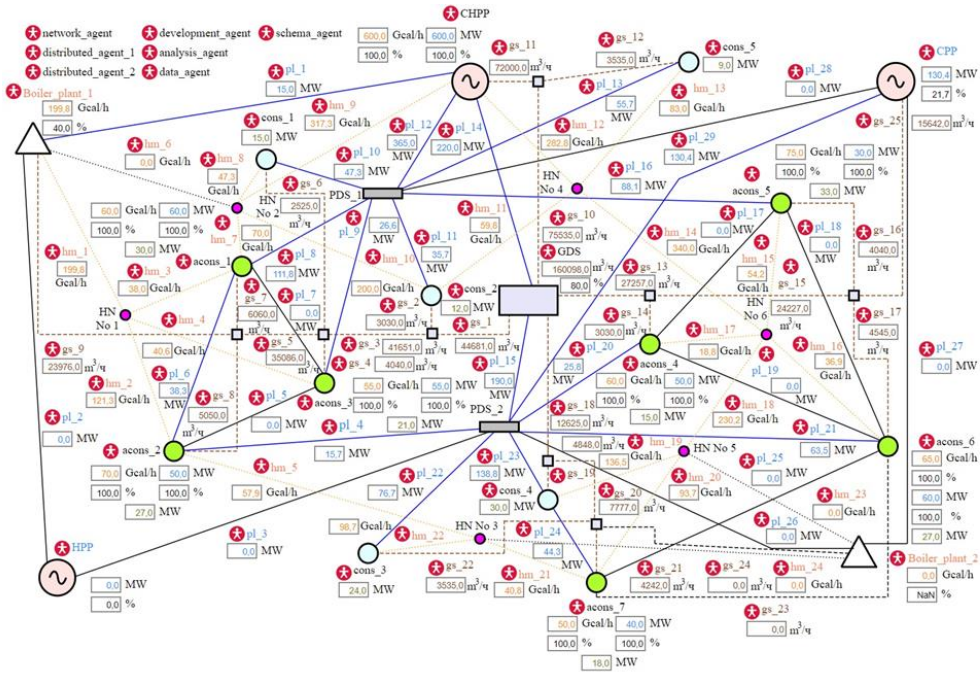

Fig. 5. Results of the calculation of the integrated energy system.

The conducted computational experiment shows the operability and efficiency of the proposed principles and mechanisms for solving the problem of development in the IES. As a result of the experiment performed on the developed multi-agent model, it was possible to form the optimal IES scheme for energy supply to consumers, taking into account system conditions and restrictions. Further development of this direction will simplify and speed up the process of developing IES schemes, taking into account the increasing influence of distributed generation and prosumers, which in turn will make it possible to create energy systems of a higher level, in which the shortcomings of current systems will be significantly reduced.

6 Conclusion

This paper discusses the basic principles of building IES and their advantages over traditional energy systems. The structure of interaction of agents for the study of the behavior of objects in the IES in solving the problem of development has been developed. To test the proposed principles and algorithms for the interaction of agents in solving the development problem, a test scheme of the IES was created. Based on this scheme, a multi-agent IES model was developed in the AnyLogic software environment in accordance with the proposed multi-agent structure. As a result of the computational experiment on this model, an optimal solution was found for choosing the most appropriate IES configuration that reflects the interests, preferences and capabilities of prosumers and the entire IES, taking into account system conditions and limitations. Analysis of the data obtained showed the efficiency of the proposed principles and mechanisms in solving the problem of development in the IES.

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