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Agents and Multi-agent Systems in the Management of Electric Energy Systems

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Abstract

Electric energy systems need constant modernization and updating to solve such problems as distributed management, self-sealing, improving the quality of electricity, demand management, and integration of renewable energy systems. Currently, energy systems need advanced and intelligent technologies to perform various system-level tasks. The purpose of this research is to analyze the existing control systems of electric energy systems, as well as to consider the possibility of using multi-agent systems to control electric energy systems. To achieve the aim of the research, the following scientific approaches were implemented: method of direct research, experimental method, questioning, comparative method, analysis method, and method of observation. The primary value of the research is in the novelty of the work and the fact, that functional components in multi-agent systems act as independent agents, which can interact with each other through a message communication system. This provides a simple connection between the components, which can benefit complex systems designed for an intelligent network. The intelligent network provides an efficient energy management system, and the modernization of the existing power system using a multi-agent system provides solutions to many problems. The best implementation of a multi-agent system can be achieved through the employment of fast and protected communication protocols. The authors of the research have conducted research and presented key statistical data on electricity usage in Kazakhstan over the past few years. The practical significance of the research is determined by the applied results, and their scientific significance, which is conditioned upon the use of deep, modern mathematical results and the development of an optimal control system. This research is a part of a universal model and optimal system of emergency quick response, conducting a quick preliminary prognosis as well as ensuring more lasting planning in electricity consumption.

Keywords

Communication protocol; Electricity consumption; Control system; Planning; System modeling.

Introduction

In the modern world, many forms of energy may be distinguished, among which electricity holds the most value to most of humanity. Electricity – is an integral part of everybody's everyday routine, while energy is a primary need for the development of every country. Possession of energy in one way or another is predefined by the geographical peculiarities of a country. Due to industrialization and modernization, energy consumption rates are growing, while Earth's reserves are dwindling substantially. Production and distribution of energy are dedicated to energy system development. It includes the production, transmission, distribution, and analysis of electricity. The main disadvantage of the existing energy system is inefficiency due to the lack of infrastructure (Zamora and Srivastava, 2010; Di Somma et al., 2018). Electric energy systems (EES) are high-risk systems, their analysis in various operating conditions in real-time is important for their smooth operation. Any information on an error may require a stoppage of the entire system operation. Implementation of complex control systems on all levels expedites the growth of efficiency and overall safety of the system. Detailed research on functioning, management, control, analytics, and intersystem connections (Akpojedje et al., 2018; Rajeswari and Janet, 2018; Hussain et al., 2018) is required. The energy system

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sustains a normal power level in the grid by adding or removing energy generation units from the network. Moreover, it ensures a balanced distribution of electricity to consumers at any time of day with a high degree of reliability. Currently, power grid networks are being developed to support the transmission of high-voltage alternating current, which increases the efficiency of the system and provides high quantitative loads (Koval et al., 2022; Yasinska, 2021). Moreover, a constant high-voltage electricity system is designed to decrease losses during transmission and lower the costs of cable work.

The introduction of a closed-circuit electric energy system network will increase its efficiency, as well as reduce the possibility of power outages. The rapidly growing needs in the structure of the energy system require the development of intelligent and self-sealing elements and control systems for the modernization of electric energy issues for the ever-growing global community. The scientific community is trying to create not only a new generation of calculation machinery but also to determine the need of developing newly created potential calculation machinery. These devices need to be smaller, quicker, and faster and must be able to quickly process the biggest amounts of data in the shortest time possible. To develop these machines and systems, it is necessary to include these factors: theories, which describe the artificial intellect, the ways of imprecise data processing, how it saves, restores memory, compares, collates, forms connections and outcomes, eliminates discrepancies; the small chip number technology for processing of a large amount of imprecise data over a short amount of time and with great precision; structures, which include new theories and technologies (Alsaif, 2017; Arcos-Aviles et al., 2017). Multi-agent systems (MAS) are connected to computers by intelligent programming. There are different definitions for an agent dependent on the conditions and characters of their employment. Mobility in all conditions and autonomous work is a primary distinctive quality of agent employment. Cooperative regulation and monitoring systems may be produced with the employment of intellectual regulators.

Agents are mostly interconnected between hardware and software components. They make decisions, based on data, acquired during the operational process. Multiagent systems are named after their effective operation in a system, where many agents are used. Principle attributes of the multiagents (MA) are constant, they only depend on environment localization. Thus, as a rule, the employment of the MA in the energy system in a sub-station and the control center is the same. Only the program differs, which runs on an MA and is allocated in dependence on the location. MA mechanism is connected to other MA systems, which, in turn, is connected to the network. During the independent operation, the real-time decision-making function is allocated to the MA, which is fulfilled on a basis of an analysis of current and prognosis data. MA information is saved and streamed alongside network usage to help organize connections in the multi-agent system (Avor and Janjic, 2016; Rasheed et al., 2016). The relevance of this research is defined by the changes in the energy market, objective changes in macroeconomic trends that lead to an increase in the cost of energy carriers, the cost of electricity produced, and foreign policy circumstances that dictate the need to reduce the energy dependence of the state from other countries. The issue of reducing energy costs in the economy, in general, is also important for the country.

The objective of the research is to analyze the existing control systems of electric energy systems. To achieve this objective, it is necessary to solve several tasks: to consider statistical data on the indicators of the electric energy industry of Kazakhstan for the last 4 years; to analyze methods and models of optimal management of electric energy systems; to investigate the issue of the use of multi-agent and agent systems.

Theoretical review

Industrial modernization of the current generation requires constant growth of electricity consumption. To satisfy the ever-growing electricity demand, different energy grids of various complexities are created. In modern conditions of the electricity industry of Kazakhstan, which is characterized by a substantial level of wearing and lack of intensive reconstruction processes, this question remains more difficult (Jacobson and Ycesan, 2008). In addition to the need to modernize Kazakhstan's electric energy industry, it is also needed to determine the efficiency of current innovative machinery employment and its functionality peculiarities. Electric energy systems, per their primary functions, ensure the work of industry, transport, and households of the population – all aspects of the country functioning in general. The energy system evolution process is following the path of large energy conjunctions creation. In some cases, they include whole continents, and many electricity generation installations and other energy installations are in these conjunctions. The growing tendency of converting transformers into resistive electricity usage to control power resistance parameters has caused a problem in ensuring electric power system stability (Gelig et al., 1978; Kalman, 1963). The combination of the abovementioned unfavorable conditions causes common discrepancies in the vibrational resistance of the polystyrene foam, which indicated a need and applied value of the solution for the set task. These conditions have caused the need for modernization of research methods and in-depth research of electric power system dynamic peculiarities. At the current stage, the efficient quantitative global asymptotic stability, T-controllability, applicability, and large-scale computational research task solution algorithm development is of great importance.

Electricity transmission systems are variable three-phase current systems. Unlike constant electricity systems, variable systems are far more favorable for production installations, transmission, and usage of electricity. On variable-current-based systems, a slight resistance conversion process is employed, which ensures flexibility in the usage of various current levels for energy transmission, generation, and consumption. To ensure a working state and energy transmission ability, it is necessary to keep energy transmission parameters high, even though on this level of energy consumption and manufacturing it is practically impossible to keep these current parameters. Moreover, machinery, based on variable electricity (generators and electric engines) is far more primitive and accessible in comparison to constant current machines. In the electric energy scheme, the generation and distribution of electricity are completed within a balanced system of three phases. Industrial consumers mainly utilize three-phase loads. Single-phase communal-household and productional grids are mostly equally distributed in phase one, which forms a harmonic three-phase system. An intelligent network creates an opportunity for effective control and management of the future energy system. A centralized network requires communication between a hardware and software protocol. Currently, the network can be automated by exchanging control signals and network status using a MAS that can use targeted automated process agents for monitoring and management. This is one of the reliable technologies for implementation into an existing network.

In this approach, several agents are interconnected to achieve the purpose of a multifaceted approach. MAS system modus operandi is to ensure autonomous effectiveness and optimal selection of output variants, while the network may be inaccessible or affected by an unforeseen operating condition. The main application of MAS is the efficient and manageable integration of renewable resources into the energy system. A system with a single agent implies that it interacts, in particular, with a single device for management and monitoring. However, this rarely expedites the implementation of the full system functioning concept. MAS has a large number of agents, which interact with each other to implement a cooperative strategy on basis of effective interaction, coordination, and cooperation between agents. In current electric power systems, effective connection and control are done with the use of a Supervisory Control and Data Acquisition (SCADA) system. SCADA does not allow for autonomous machinery production mode, instead, it sends control and order signals, which makes real-time mode impossible. A Multiagent system compensates for the downsides, relevant to active systems. It also allows the organization to have a distributed management control complex. Intellectual digital devices or special programs are used as control agents. It is also worth noting, that agents can perform a decision-making functionality following the environment state (Rahbar et al., 2015; Khan et al., 2015). Each agent sets goals to be completed in a certain amount of time. Concerning the functioning of the agent, they are divided into many categories, such as managing agents, distribution agents, monitoring agents, centralized control agents as well as databases.

Materials and methods

During the research, the task of managing the EES from the standpoint of optimization and automation of work is considered. The study analyzed the optimization process, its tasks, and steps to achieve the purpose. The optimization task is concluded in a search for an optimal variant in dependence on several parameters and within available means of optimization. Evaluation methods are standard operations, which ensure a search for an optimal malfunction resolution method in cases when they contain all required methods of these malfunction elimination concerning the specifics of the analyzed situation. Optimization algorithms are precise when they detect the best technical solution, or they may be heuristic, if the found solution may not be the most fitting. As for the electricity consumption optimization, the best outcome will be considered as an achievement of the best solution. However, in these regards, where a role of a human operator is more valuable, it is necessary to use heuristic methods to align results with requests or parameters, which the end user demands.

To achieve the abovementioned principles, it is necessary to 1) determine the subject of an issue; 2) determine and form the task; 3) research possible solution methods; 4) apply these methods; 5) find the most suitable solution methods and analyze their implementation method outcomes. Under their respective characteristics, multiagent systems are lately regarded as a promising heuristic method of complex approach to the various problems in different domains – distributed, complex by structure, and non-homogeneous. As such, most methods imply the achievement of success through a specific number of algorithms, the number of which depends on individual peculiarities. It is worth noting that, in its turn, the management of EES is characterized by the fact that it affects houses, buildings, and industrial installations with automated systems and regulation of lighting, heating, air conditioning, and ventilation. These factors need to be controlled as they are the determiners of the optimization task, and they influence each other's state. Optimization task requires a realization of set goal while meeting the requirements, related to such aspects, as ensuring ergonomics, reliability, interactiveness, rational consumption of energy, service and functional maintenance, and meeting normative regulations and current legislation in all regards. In addition to the multiagent systems, secondary recommendations on the integration of electricity consumption were added, such as linear programming (Amini et al., 2015; Wouters et al., 2015), prognosis-based mathematic models (Chen et al., 2017), decision models (Abushnaf et al., 2015; Gonzalez-Briones et al., 2018), integrated models (Khan et al., 2018), and gradient models (Su et al., 2015).

Existing EES supports centralized management, which leads to delays in operation, reduced reliability, and problems in the management and control of energy consumption. The use of renewable energy sources and energy management requires advanced technologies with autonomous management and operation (Amanbek et al., 2022). In addition, through the study, statistical data on the use of electricity consumption indicators over the past few years in Kazakhstan were collected and presented. A decent variation of methods, which allow the compilation of samples or search for data to commence necessary data analysis, are known. The three most important methods are direct research, experiment method, and questioning. The data representing electricity consumption indicators are considered quantitative data, which is expressed in numbers and summarized using statistics to obtain meaningful information. During the process of comparative analysis, positions, forms of analysis, opinions, and other factors, which may prove or deny one or another theory, are evaluated. It is necessary to ensure the availability of quantitative parameters, which allows to easily measure "statistical correctness". Quantitative parameters are gathered through closed form and closed content questions, such as employment of the Likert scale or multiple-choice questions. As soon as the research results will be distributed amongst the interested party members, all answers and answer variants will be easily countable.

In the case of collecting data on electricity consumption, an effective method is the use of observation. Due to the fact, that during the quantitative monitoring process, quantitative calculations are made, and data, acquired by this procedure, is more correct, than those, gathered through qualitative analysis methods, which cannot be evaluated. To ensure validity and integrity, it is necessary to determine the required sample size for the quantitative research. A sample should include a sufficient number of measuring instruments, indicators, and other things to make the overall observations, which indicate every available data. As such, the more reliable the combination of measurement of units is, the more integral the data will be, which a market researcher will be able to acquire from the analysis. Observed behavior is systematically categorized by the researcher into relevant categories. During the coding, it is possible to use numerical or symbolic information to denote attributes or to employ the evaluation system to determine the interaction intensity. Thus, the advantages of observation are:

1. Controlled research, which is conducted with a similar monitoring method, may be successfully continued and conducted with the following specialists. Consequently, it is possible to quickly determine the degree of integrity.
2. Results of structured measurements will be much easier and quicker to process, especially under their qualitative (numerical) format, which decreases the required amount of work, needed for this method, compared to the natural research.
3. Regular examinations are conducted comparably quickly, which is why it is possible to conduct a large number of observations in a small amount of time. This will allow the compilation of a large sample, the result of which will act as a representation and can be generalized to a large population.

After collecting the information, the data was processed using logical methods and presented in the form of tables. Within the statistical methods, many approaches are utilized, employment of which is caused by such factors, as the character of output parameters: qualitative and quantitative; the state of these parameters: explanatory and determinative; set of elements: one, two, or more, and character of conducted evaluation method: research (demonstrates primary notions) or stative (states the conclusions). As a result of data analysis, they may be transformed into a piece of integral information and, as such, acquire informative value, which leads to the evaluation of the parameter interaction. Data analysis — is a method of systemic nature, which is employed to describe data, demonstrate their peculiarities, sum up, generalize, or for other aspects and further statistical and logical expertise. Further examples of the use of various methods and means for managing the EES will be given. Object-oriented analysis (OOA) is a method of drawing analogies and identities for entities in the real world to describe their interaction to achieve a purpose. The primary definition of object-oriented analysis as a part of object-oriented programming (OOP) is not a sequence of interaction order analysis between system elements, but an evaluation of all elements, which form a system as a separate unit. Thus, each element is considered a separate object, and its work is evaluated depending on the result of certain actions. Moreover, such OOP components, as principles and mechanisms of inheritance, connections, polymorphism, types, and categories of methods, attributes, and processes, substantially expedite the replication and optimization of the developed solution. There are usually three main stages in object-oriented analysis:

- building an information model, represented as some sort of object model and attributes (characteristics) of objects;
- forming a mathematical basis for the creation of a state model for object process necessary format and expression of this base in form of schemes and intermediary tables; transfer of signals with objects is done through message transmission on one or another event;
- manufacturing operation scheme interaction compilation; Within the model, object functionality support events are distributed between fundamental and multifunctional cycles.

Equivalent models of complex electricity and electric-mechanical systems, for an imitational cycle of step-like formations, may be directly presented on examples of mathematical analysis of the physical process, which are observable in elements of these systems, or on a basis of equivalent schemes, which include principal (ideal) elements of electrical chains, as well as resistors, induction coils, capacitors, and power elements. If the transitional process analysis is in the discussion, then mathematical models are to consist of the combination of differential equations of the first order, which rely on Kirchhoff's circuit laws. Tensor analysis of networks is described in the paper (Kron, 1959). Instead of employing nodes and arcs in nodes to denote peculiarities of scheme topology, an improved presentation of the scheme with the employment of grid field edges was proposed. This principle was determined by topological prerequisites. The employment of effective quantitative methods to solve the issue of electromagnetic transitional processes in machines of various sizes and topologies is a current problem of modern science. Variable current systems are constant, while computer modeling is discrete. As such, the most important task of digital modeling remains the development of necessary instruments to solve differential and algebraic equations in discrete points. Fuzzy mathematics is accepted in all conventional mathematical fields, and the introduction of fuzzy mathematics and logic into the work of electric energy systems can show high results of an interaction. Fuzzy logic plays an important role in the engineering field, as well as in the commercial market since it provides a convenient approach for the consumer with complex management problems. A set of characteristics and perspective approaches to imprecise logic:

- a combination of technical and experimental-practical methods concepts;
- schemes for non-strict boundaries;
- the ability to model a variety of ambiguous tasks;
- solid fundamental mathematic structure, which allows performing operations with the abovementioned factors.

In the problems of energy systems, implicitness and inaccuracies manifest themselves in many ways, models with fuzzy logic can be used to solve this problem. Moreover, issues may arise in the knowledge of the system. Ways of ambiguity are determined by the abilities of the systems, while functions and set goals are formed during the creation and implementation of a solution strategy. Non-formed logical basis and database should be used in every sphere of energy system functioning, such as analysis of emergency conditions, diagnostics, and monitoring, process regulation in sales systems, workforce management, engine technical maintenance process planning, machinery status analysis, diagnostics and regulation of network parameters, load prognosis, load control, reserve power/capacity analysis as well as analysis of security system status. Uncertain combinations, based on a set of rules, are employed in energetic machinery, while probabilities meet every determining condition in the correction base. Particularly, the automated protected valve is activated in the distribution network during the chain overload. Two modeled uncertainties: "frequent" and "high", are easier to demonstrate as a form of ambiguity degree and non-formed multitude. A matrix modeling was conducted to determine quantitative changes, related to the low degree of integrity (Bitimanova and Abdildaeva, 2020).

Results

Presentation of statistical data

We will analyze statistical parameters of electricity consumption in Kazakhstan, where the interval of previous years in Kazakhstan was included. The data is presented by the official website of the Agency for Issues of National Stability of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (Bureau of National Statistics of the Agency…, 2021). The energy intensity of the economy is a particular indicator of the natural resource intensity. This indicator characterizes the sustainability of the energy sector and national development and is the basis of most systems of sustainability indicators. To determine the economic efficiency of the consumption of fuel and energy resources in the production of gross domestic product (GDP) nationwide in the Republic of Kazakhstan, the indicator of the energy intensity of GDP is calculated. This indicator is formed as a relation between fuel-energy resource gross expenditure on all manufacturing and non-manufacturing roles and tons of oil equivalent (TOE) and GDP value (Figure 1).

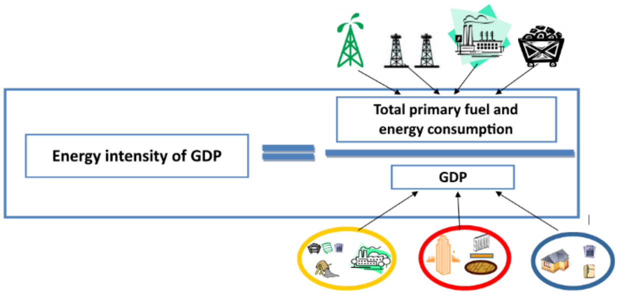

Fig. 1. Energy intensity of GDP

Table 1 demonstrated the characteristics of the GDP energy capacity of Kazakhstan changes from 2014 to 2020.

Table 2 shows the data on the number of heat supply sources and the number of accidents in Kazakhstan during 2020.

Table 3 shows data on the total primary consumption of fuel and energy and the energy intensity of Kazakhstan's GDP by individual sectors of the economy during 2015–2019.

The fuel and energy balance of the Republic of Kazakhstan for 2019 in the format of the International Energy Agency is presented in Table 4.

Multi-agent systems in the EES

Multi-agent systems — is a direction, which sources its knowledge from specific fields of science, mostly from the sphere of artificial intelligence and artificial reality (which is related to the research and modeling of systems, which simulate life, i.e., those, which possess the ability to multiply and adapt to external, unfavorable conditions). Multiagent systems require a set of interconnected and independent teams, which will have their position, their own set of skills, knowledge, and peculiarities as well as an original worldview, who will control their functioning with the employment of primitive algorithms. Decisions, which utilize agents, will allow replacing monolith, rigid and centralized mechanisms of management by those principles of work, which are based on distribution, which employ connections between people and expedite the formation of a "smart" management character. Notably, such systems demonstrate a high degree of autonomy and the possibility of reconfiguration without a fixed client-server structure. The development and implementation of multi-agent systems correlate with the current trend towards the creation of modular, intelligent, and distributed control systems that demonstrate innovative functions, such as rapid response to violations and dynamic configuration changes in real-time, that is, without the need to stop, reprogram, and restart the process (Yan et al., 2018).

From the point of view of management of energy facilities, multi-agent systems are quite effective, although along with their advantages they also have significant disadvantages. The positive points of multi-agent systems include distributed calculations, autonomy and scaling. However, for the successful functioning of multi-agent systems, there must be communication between all agents that would allow them to exchange data. Therefore, it is important to develop the system using the same programming language. Otherwise, the provided information will be lost between

Table 1
Dynamics of energy intensity of GDP during 2014–2020

	2014	2015	2016	2017	2018	2019	2020
Energy intensity of GDP, (tons of oil equivalent per thousand USD)	0.36	0.30	0.34	0.34	0.37	0.35	0.37

Note: United States dollar

Table 2
The number of heat supply sources and the number of accidents in 2020

	Quantity, units						Number of accidents at heat supply sources, steam and heating networks, units
	Heat supply sources	including capacity, Gcal/hr				Energy installations	
		up to 3	from 3.1 to 20	from 20.1 to 100	over 100.1		
Kazakhstan	2457	1613	574	152	118	5692	84
Akmola	520	430	73	13	4	1029	–
Akhtuba	247	162	51	29	5	557	–
Almaty	59	29	20	6	4	130	–
Atyrau	81	48	14	13	6	100	–
Batys Kazakhstan	113	51	31	6	25	288	–
Zhambyl	216	110	88	15	3	602	–
Karaganda	131	56	51	14	10	430	–
Kostanai	135	99	23	5	8	384	–
Kyzylorda	39	21	13	4	1	92	–
Mangystau	162	103	46	6	7	185	–
Pavlodar	179	138	24	3	14	388	71
Saltustik Kazakhstan	193	167	20	–	6	379	–
Turkistan	44	32	8	–	4	69	1
Shygys Kazakhstan	114	44	41	20	9	389	1
Nur-Sultan	25	8	13	2	2	88	–
Almaty	151	93	38	12	8	500	–
Shymkent kalasy	48	22	20	4	2	82	–

the agents, which will cause problems in the energy system as a whole. In the case of the energy system, an established management system plays one of the key roles. A multi-agent system should perform the following tasks for proper functioning: solving coordination tasks between subsystems; distribution of the calculation scheme of the electrical system into subsystems; aggregation of calculation results; assessment of the status of subsystems; ensuring the possibility of functioning of agents in the local network.

Systems involving many different agents must have specific concepts or scenarios. An agent script is a certain set of actions programmed by expert users, which are performed by agents at each stage of task execution. When a user creates a task, the order of agents with corresponding fixed actions is adjusted according to the received request. Depending on the task, you can choose the number of agents that will perform it. If one of the generation agents gets out of service, another agent makes a decision on ensuring a safe energy transmission on basis of the information, sourced to the end user during the current period of time (self-sealing). New technologies should be introduced in the EES to professionally manage the network. The energy system has a colossal network with a large risk coefficient in management and functioning (Xu and Xiang, 2022). These activity spheres require production control, tracking, malfunction resolution, overload and surplus energy production overcoming, and much more that requires more precise and intelligent work. Multi-agent systems can eliminate these high-risk factors without compromising the reliability of the system (Palma-Behnke et al., 2013; Jiang et al., 2013). To ensure the construction and development of agent modules, their behavior and the addition of artificial intelligence and neuron link creation ability to their functions should be developed. Some various structures and frameworks facilitate the development of proposals based on MAS:

- the JADE framework (Bellifemine et al., 1999; Bellifemine et al., 2007), an intermediate software, that has been used for more than ten years. This environment has a wide information-reference directive, which ensures the creation of agents via the most simplified way and is accessible by users, who have average knowledge of Java programming

Table 3
Total primary fuel and energy consumption and energy intensity of Kazakhstan's GDP by individual sectors of the economy

		Unit of measurement	2015	2016	2017	2018	2019
1	Total primary fuel and energy consumption, including by major sectors of the economy:	million TOE	78.1	81.6	85.0	75.2	73.1
1.1	Agriculture, forestry, and fisheries	million TOE	0.73	0.73	0.80	1.60	0.868
1.2	Industry	million TOE	20.90	22.88	21.57	15.50	17.209
1.3	Transport and logistics	million TOE	5.33	5.47	5.33	6.28	5.774
1.4	Accommodation and catering services	million TOE	4.31	4.30	4.91	5.28	4.599
2	Energy intensity of GDP	TOE/thousand USD in 2010 prices	0.42	0.42	0.42	0.37	0.34
		TOE/thousand USD in 2000 prices	1.53	1.54	1.53	1.36	1.25
	Energy intensity of GVA by industry:						
2.1	Agriculture, forestry, and fisheries	TOE/thousand USD in 2000 prices	0.09	0.09	0.09	0.17	0.09
2.2	Industry		0.40	0.44	0.38	0.26	0.28
2.3	Transport and logistics		0.32	0.32	0.30	0.33	0.29
2.4	Accommodation and catering services		2.46	2.43	2.68	2.82	2.38

Note: GVA – gross value added.

Table 4
Fuel and energy balance of the Republic of Kazakhstan for 2019 (in the format of the International Energy Agency)

Balance items	Coal	Oil	Gas	Hydro	Solar	Electricity	Universal
Production	44917	92172	28801	859	132		166941
Import	875	36	13910			166	15592
Export	–11044	–69940	–22572			–208	–108832
International bunkering							–164
International aviation bunkering							–475
Inventory changes	–275	461	–16				114
Total primary energy consumption	34473	22729	20122	859	132	–42	73176
Thousand tones of oil equivalent (1000 TOE)							

language. Java Agent Development Environment (JADE) benefits from the correspondence with The Foundation for Intelligent Physical Agents (FIPA) with these platform interactions, which allows the usage of it in conjunction with other MAS middleware that meets the requirements of FIPA. JADE has broad support and adoption in the research community and even in the industry;

- Python Agent Development Environment (PADE) is a structure for the MAC development and implementation, and, if necessary, for their control support in conditions of distributed calculation system functioning. This construction consists of MAS projection on Python programming language, which is object-oriented, supports transmission of FIPA-ACL standard signals, supports FIPA communication protocol, and is multiplatform, which allows it to be implemented and employed on internal hardware machinery under the management of various operating systems, such as Linux, Raspberry Pi, BeagleBone Black, and Windows;
- Open Agent Architecture, the OAA – is a backbone for the combination of elements into a unified structure of the various information agent environment into a single, organized environment (Cheyer and Martin, 2001). OOA is employed to create various complex systems, in which a large number of

complex non-homogeneous elements, require the principles of flexibility and scalability. In case, when a flexible system, which can be quickly expanded (or gradually), is needed, agent infrastructure, which works on delegation principles, opens up a new innovative model of solutions.

- Platform for Automatic Construction of Organisations of Intelligent Agents (PANGEA) is a MAS-based structure, which is concentrated on the development of virtual agent organization (Zato et al., 2013; Villarrubia et al., 2014). PANGEA, in comparison to other multiagent platforms, is mostly an optimal application, as it contains many operators, which support the implementation of the most basic tasks, such as information presentation, detecting services, and employment of algorithms, and it also supports the usual interagent interface protocols, such as FIPA-ACL. PANGEA foresees the employment of agents, which ensure safety on a system stage, opposite to other categories of systems, which require the creation of similar actions for complete processing and further analysis of acquired information (Briones et al., 2016).

Discussion

The employment of multiagent systems allows the support of the current demand for modern control systems in production spheres, which allows for achieving such characteristics, as flexibility, reliability, scalability capabilities, adaptiveness, reconfigurability, and efficiency. Multiagent systems are successfully employed in various spheres, especially in the sphere of digital trade, computer graphics (computer games and movies, for example), transportation, logistics, navigation, biorobotics, industry, communication, and energetics. Sources of these practices are usually employment of multiagent systems on manufacturing plants of Daimler Chrysler engines in Stuttgart (Schild and Bussmann, 2007), by the Tankers International company, which, currently, possesses and controls most oil tankers in the world (Himoff et al., 2005), by the Air Liquide America for the optimization of medical and industrial gases classification (Harper and Davis, 2008), and on the ships of The United States Navy (USA USN) to control heating, ventilation and air conditioning systems (HVAC) (McArthur et al., 2007). Investigation of the abovementioned employments of agent solutions allows to deduct following conclusions:

- currently, there is a possibility to employ a small number of agents in the industry, as the implemented programs are limited from the point of competency;
- solutions are management-oriented complexes of high-level or mostly applied software development systems (for example, in the sphere of digital trade);
- no required degree of activity both from the side of suppliers and from the side of manufacturing corporations.

Currently, in reliable sources, many reasons are already being analyzed, which explain the reasons, why such technology is not commonly used. Notably, these are the following main obstacles: the necessity for the starting capital, implementation of distributed approach thinking concept, interoperability on employment of various means, lack of standardization, real-time constraints, and insufficient maturity of technologies. As for networks and power plants, to become more "intellectual", faster, unrestrained, and organized, companies and developers actively search for programs and technology, which allow the implementation of complex, interconnected, and, in some conditions, competitive efficiency of the system. It is required to foresee the requirements of various tasks, such as electricity consumption control, stabilization of energy transmission, and ensuring automated systems function within the functional network system control. Information and parameters should be available for everyone, who needs these functions, while actions, aimed to perform one or another function, should not negatively influence the other functions, only if the unified decision by combining achieved results will be made. Several companies have confirmed their need to develop the standards and technologies to implement this method. The IntelliGrid EPRI (Electric Power Research Institute) architecture and the United States Department of Energy's GridWise architecture are two similar standardization projects supported by industry. These architectures are technology-independent and define the necessary functions of the intellectual network without offering operations. In general, both of those perspective structures must implement platforms, which will provide functional capabilities, scalability, and safety. Multi-agent systems are aimed at implementing those functions, which makes this technology a strong competitor for the implementation of the capabilities of intelligent networks. Interoperability through compliance with standards, additional ability through the implementation of new agents into the system, and reliability due to operator usage, which grants reserve capabilities, are recognized positive aspects of an agent-oriented system (Leturc and Bonnet, 2022). Currently, a large number of developers are working on the development of multiagent systems for the necessary intellectual network issues resolving, which is confirmed by recent widespread publications.

Despite the fact, that it is not the right moment for physical and service research of these systems, the quick rise of the agent technology popularity is expected as it is them, that can ensure the creation of flexible, scalable, and safe systems, required for the intellectual networks. Success in the implementation and service of similar agents in the manufacturing sphere indicates that agent and multiagent technology allows for the creation of reliable systems from self-sufficient components. However, several specific goals are still present in the sphere of energy for the common use of multiagent systems. They may be combined and used to ensure the required design system functionality regardless of a stated technical specification or described functionality. The initial question is usually how to develop a multiagent system. There are many methods (some of them are described in the research (McArthur et al., 2007)), even though a selected technology substantially influences the final design of the structure. Usually, those methods support the "from top to bottom" development method, engineering issues of which, such as technical state control or after-incident repairs, are divided into separate sub-tasks up to the moment, when they become acceptable for the functioning of the agent. This allows the formation of a structure with functionality, which satisfies the modern service variant, although it has insufficient scalability for any further modifications. Particularly, common capabilities of agents are restricted to the formation and receiving of the messages, required to perform a high-level task. Another development way is the "from bottom to top" method while keeping in mind, what functions and message transmission methods an agent should have in the environment. This approach is also applicable to the research object as it includes investing substantial resources into aspect development, which is not currently required to be employed to protect the system in the future yet may not be needed in the future altogether.

Conclusions

This research is a part of the creation of a universal model and an optimal system for rapid response to emergency situations, ensuring a short-term prognosis and electricity consumption plan on basis of retrospective information on electricity usage, as well as analysis and accounting of changes and other factors in real time. The scientific novelty of the work is determined by the creation of an optimal control system for electric energy systems that will be used in conditions of partial and incomplete observability and will provide effective assessments of the condition of the system in real-time. Moreover, the implementation of the project is important for the energy infrastructure of the Republic of Kazakhstan. Reliable and efficient control of the energy supply regime at all levels of dispatching control in the new, more complex economic and technical conditions of energy systems requires the creation of a fundamentally new system for collecting and processing a large amount of information, the development of automated modules to solve tasks of the complex process of operational dispatching control of heat and electricity in Kazakhstan. It is possible to solve this problem by using the concept of intelligent control systems developed in recent years and used in foreign energy companies.

It was concluded that little effort is being made to give an idea of multi-agent system applications from the standpoint of practice in the field of energy. In this research, a comprehensive review of the literature has been carried out, which examines the methods and means of managing EES in the world, as well as the direct application of multi-agent systems in the energy sector. The research shows that multi-agent systems are adaptable and applicable to various categories of energy. In conclusion, it is worth noting, that multiagent systems are constantly developing and, due to their multitude of characteristics, are especially interesting and perspective as an approach to system modeling in the sphere of electricity consumption optimization. They allow the modeling of various conditions in various contexts in uncontrolled environments. If modeling shows adequate results, it will be possible to develop full-scale multiagent systems, which will be able to control electric power systems and allow to move actions, taken during the modeling stage, into real-world context while keeping similar results. As part of the work in this area, the following have also been carried out: a universal mathematical and computer model for a complex electric energy system has been developed; analysis and assessment of significant factors affecting the functioning of electric power systems have been carried out.

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