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INFORMATION SUPPORT OF STAKEHOLDERS IN THE MANAGEMENT OF ENERGY SYSTEMS: DEVELOPMENT AND IMPLEMENTATION OF INTERFACES

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The object of this study is the process of providing informational support to stakeholders of the life cycle of energy to ensure strategic management of energy systems with renewable energy sources. The task to improve and develop information technologies applied to the management of complex energy systems and the issue of their socialization and perception by people were tackled. Considerable attention was paid to the task of data visualization in order to improve the perception of information by users. An important aspect of the interaction of energy life cycle stakeholders during the management of energy systems was explored and the need to ensure their involvement and trust in information technology was emphasized. The research considers the development and implementation of interfaces for a decision support system in the management of energy microgrids using renewable energy sources such as solar panels and wind generators. The results include web application architecture design, user role assignment, user action modeling, and data visualization. Approaches to the distribution of stakeholder authority, database access, interface design and data visualization for full client support were proposed. It is noted that the proposed interface solutions are designed for a decision support system in the management of microgrids with different types of renewable energy sources, such as solar panels and wind generators. Summarizing the results, the relevance of the task to devise methods of information support and interfaces for strategic management of energy systems has been emphasized. The conclusions imply the effectiveness of the proposed solutions for the strategic management of microgrids

Keywords: sustainable development, information support, data visualization, decision support system

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1. Introduction

The modern development of society is connected with the development of technologies. Technologies, which are constantly developing and improving, aim to ensure sustainable development. In 2015, the UN agreed on the Sustainable Development Goals (SDGs). The UN declared its determination to take bold and transformative steps to urgently put the world on a sustainable path. Very often sustainability and sustainability are considered in three key aspects – ecological, economic, and social. Accordingly, the development of all technologies without exception must be considered in these aspects.

Several SDGs relate to energy development. Energy supply affects all processes of the economy, society, health, and comfort of people. At the challenge of modernity, energy systems are becoming complex cyber-technical systems, which can only be managed through information technologies. Information technologies ensure the proactivity of such systems and simultaneously bring them closer and further away from the person. Along with issues of automation of processes, data integration, intellectualization of solutions, there are issues of socialization of energy management systems. Scientific studies of how people perceive information technologies and how much they trust intelligent cyber-technical systems are becoming very important.

Research results that make informational support available to stakeholders are needed in practice. This is due to the fact that, at the moment, stakeholders do not have the means and tools through which it is possible to influence the energy management process and ensure the achievement of strategic goals, such as SDGs.

Thus, an urgent scientific and practical task is to devise appropriate solutions and means of stakeholder involvement, their informational support, the formation of accessibility for perception and trust in intelligent information technologies.

2. Literature review and problem statement

Among the SDGs outlined in [1] is affordable and green energy. Conceptual foundations of sustainable development are considered by the authors of work [2], where the influence of the human factor on system management is emphasized. This also applies to energy systems. The life cycle of energy in microgrids is under the control of different types of stakeholders, from electricity service providers to end consumers. The analysis of the involvement of the main stakeholders of the energy life cycle conducted in [3] showed that there is a significant gap between the business level and the information level. The entire business logic of power system management is performed at the information level, while the main activities of stakeholders do not seep into the information level but are focused exclusively on the business level. Part of the data from stakeholders is involved in analytical processes. Part of the data on processes in the energy cycle is provided to stakeholders in the form of reports, such as bills for the payment of consumed electricity.

To prevent user frustration, energy microgrids must become smarter. In work [4], the authors see prospects in the intellectualization of energy systems. This aims to overcome the vulnerability of such systems, the aspects of which are described in study [5]. At the same time, users expect that microgrids should become more economical and ecological. To solve these problems, researchers are developing different approaches based on the use of information technologies. One such approach is the use of Smart Grid technologies.

Smart Grid is a network that uses information technology to manage electricity distribution [6]. A further development of the Smart Grid concept is the use of decision support systems (DSSs) as a superstructure over the energy supply management system. DSSs help users make decisions by using expert knowledge. DSSs can be used to manage energy systems with renewable energy sources (RES) to ensure a balance between electricity generation and consumption. They make it possible to make the management process more intelligent and, accordingly, to overcome the problem of uncertainty characteristic of energy microgrids with RES.

Information support for energy management processes in microgrids can help reduce energy consumption and costs, as well as improve reliability and sustainability. Such approaches use real-time data from RES facilities and smart home appliances to optimize energy use.

In [7], the authors claim that the use of expert knowledge is particularly important for smart networks because their management requires a high level of work experience. As more and more countries and regions implement smart grids, and RES microgrids are of particular interest in this context, there is a growing need to formalize expert knowledge on various aspects of power system operation. The authors of [7] defined three dimensions of experts' competencies (perception, judgment, and decision making), which provide a basis for understanding the knowledge transfer process.

In study [8], the authors propose a new dynamic smart home energy management system with a one-week forecasting model for the PV/GES system, dynamic electricity pricing, smart appliance control, and energy storage charge status forecasting. But the article does not provide a real implementation of the proposed system, and the simulation study is based on a simplified model of a smart house and power grid.

In general, DSSs can play an important role in supporting the provision of services by energy microgrids. They can be used for automation, monitoring and control, visualization, and analytics [9].

Several research projects have explored the possibility of using web-based systems to support energy microgrids. For example, study [10] developed a web application for monitoring and managing a microgrid in a university campus. The application provided real-time data on the microgrid's energy production and consumption, as well as the status of its equipment. The authors note that the methodology is still under development and that they continue to improve it. At the same time, it is not indicated whether and how the presented methodology can be used for the implementation of microgrids in other commercial or residential buildings.

In another study [11], the authors developed a web-based application that allows consumers to participate in a demand response program. The application provided consumers with information about their energy consumption and offered them financial incentives to reduce energy consumption during peak load periods. However, the study has a number of weaknesses, namely the focus on a single demand response program, and did not examine residential demand response behavior using long-term models to examine learning effects and motivation levels of response.

Another example of a web application used to support energy microgrids is the Transactive Energy Platform (TEP), a software platform that allows microgrids to trade energy with each other and with the main grid [12]. TEP also provides microgrid operators with real-time data on energy production and consumption, as well as tools to manage microgrid operations. However, the project relies on a market-based approach to managing the microgrid, and it is unclear how this approach will work in practice, especially in areas where market participation is limited. The project does not consider the cyber security risks associated with the use of the system in practice.

Another example of a web application for energy microgrids is the Microgrid Energy Management System (MEMS), developed by GridBright [13]. MEMS is a cloud-based platform that provides microgrid operators with an interface to monitor and manage all aspects of microgrid operations. But the system is primarily focused on North American utilities, and their adoption in overseas projects may be limited.

In addition to research projects, there are also a number of commercial web applications available to support various aspects of energy microgrids. These platforms provide a variety of tools for monitoring and managing microgrids, including real-time data visualization, forecasting, and optimization tools.

Article [14] discusses the use of the RETScreen software product to assess the energy efficiency of a residential building after energy efficiency measures have been taken. RETScreen Expert is a tool that makes it possible to assess the energy efficiency of buildings, industrial enterprises, and other objects. RETScreen provides a free version and supports various types of RES, including solar, wind, hydroelectric, and bioenergy. However, when using RETScreen Expert, the influence of occupant behavior on energy consumption is not taken into account.

In [15], the application of the Pvsyst software product for designing and analyzing solar photovoltaic generation systems, which allows designing, modeling, and analyzing solar photovoltaic generation systems, is considered. It uses data about climatic conditions, characteristics of solar modules and inverters to calculate electricity generation, system efficiency, and other parameters. A weakness of the study is its focus on one specific case. The authors did not conduct a wider study to see if their results could be generalized to other buildings in India or outside India. Also not discussed are the limitations of the Pvsyst software and how to interpret simulation results. Another software, HOMER pro, considered in [16], was used for optimization and design of hybrid energy systems. It makes it possible to optimize and design hybrid energy systems, using data on climatic conditions, equipment characteristics and economic factors to calculate the optimal system configuration. But the article lacks a discussion of the limitations of HOMER Pro and how to eliminate them. For example, HOMER Pro relies on user-provided data, and the accuracy of the results would depend on the quality of that data.

The authors of work [17] considered the software product OpenSolar, which provides open access to data sets on solar radiation. OpenSolar is a web-based platform that allows users to download and process solar radiation data from various sources. These data can be used to design and analyze solar photovoltaic generation systems. However, this software does not include data on solar radiation for all regions of the world, nor does it include data on solar energy consumption. This is a major limitation, as solar consumption is a key metric for understanding solar's impact on the grid. Article [18] examines the use of PVGIS and PVWatts software products to estimate solar radiation and optimal tilt angles for southern facades. PVGIS is a web-based platform that allows users to obtain solar radiation forecasts for various locations. PVWatts is a software that makes it possible to calculate the electricity production of solar photovoltaic systems.

The authors of article [19] propose a new software product that combines the functions of edge computing and power system management. This product makes it possible to process data in real time and make decisions that optimize network performance. The authors argue that edge computing can be used to improve the efficiency and reliability of distributed generation systems, as well as to provide new services to consumers. While the paper provides a theoretical discussion of the use of edge computing in smart grids, it lacks concrete examples of how edge computing is implemented in real projects. This makes it difficult to evaluate the effectiveness and feasibility of edge computing in practical conditions.

In work [20], the authors reported the results of a study into the use of artificial intelligence (AI) technologies for the assessment and design of RES. The authors have developed a new software product that uses AI to model and optimize RES systems. This product makes it possible to evaluate the economic and technical efficiency of various design options for RES systems. The paper focuses heavily on the technical aspects of the proposed framework, including architecture, components, and data processing techniques. However, the user experience and the overall impact on energy consumers are not taken into account.

Article [21] presents an overview of modern approaches to the development of software products for managing distributed energy systems. The authors propose a new methodology based on the concept of a five-level energy management architecture. This methodology makes it possible to develop software products that meet the requirements of different levels of the distributed energy system. The article does not contain a detailed discussion of specific examples or real-world implementations of IoT-enabled intelligent networks. It also ignores socio-economic and political considerations, which are also important for the successful deployment of IoT-enabled smart grids.

Our analysis of SPPs for the management of RES microgrids revealed that most of the problems relate to the lack of a sufficient level of informational support for users [22, 23]. Most of the technologies and developed solutions are not perceived by users, therefore they are not implemented in microgrids. In addition, most decisions are formulated by experts without full consideration of consumer preferences and are focused primarily on achieving economic efficiency. Therefore, the task of information support for all stakeholders in power system management remains unsolved.

3. The aim and objectives of the study

The purpose of this study is to improve the effectiveness of information support for the decision-making process in the management of hybrid energy microgrids with RES. This will allow us to identify the regularities of stakeholder interaction with DSSs, to distribute the roles of stakeholders taking into account the requirements for confidentiality of their data, their level of awareness and information security, to develop access interfaces and to implement them in the decision support information system.

To achieve the goal, the following tasks were set:

– to analyze and implement the architecture of the web application as a practical implementation of DSS;

– distribute the roles of the users of DSS, perform modeling of their interaction;

– to analyze and model the sequence of actions of each of the user groups when using the DSS;

–to provide visualization of information about the state of the microgrid and possible solutions to the user, including through the interaction of user interfaces with the operational database and data storage.

4. The study materials and methods

The object of our research is the process of providing informational support to stakeholders of the life cycle of energy to ensure strategic management of energy systems.

The main hypothesis of the study assumes that the introduction of targeted information support, taking into account user requests and information needs, will make it possible to overcome the problem of managing renewable energy microgrids under conditions of incompleteness and uncertainty of data.

The work assumes that the availability and ease of data perception, implemented in targeted stakeholder interfaces, will increase the quality of user interaction with DSS.

For the sake of simplification, we consider the DSS for managing a smart microgrid, which uses only two types of renewable energy sources – solar panels and wind generators, as well as energy storage – storage rechargeable batteries.

The research used methods of structural and functional modeling, methods of modeling architectural solutions, methods of modeling use cases, and methods of modeling the sequence of actions.

5. Results of research into the development of software interfaces for informational support of stakeholders in power system management

5. 1. Architecture of the information system for supporting decision-making in the management of energy microgrids

The information decision support system (DSS) in the management of energy microgrids is designed according to a three-level client-server architecture for the development of web applications. This architecture ensures the distribution of the application's functionality between the server and the client and provides the possibility of remote authorized access through a web browser, which makes it possible to enable the scalability of the web system and the distribution of access rights for different categories of users. In addition, the architecture is designed taking into account the need to preserve confidential information, such as personal data of customers who are consumers of energy services, location of energy facilities, energy consumption data. The architecture in the form of a UML diagram of components is shown in Fig. 1.

The energy microgrid DSS consists of interconnected subsystems and modules. The subsystems are the monitoring subsystem, the visualization subsystem, the planning subsystem, the forecasting subsystem, and the decision support subsystem.

The monitoring subsystem works in an autonomous mode, and it is used to collect energy generation and consumption data from the relevant metering devices, monitor the current state of operation of energy equipment, and monitor possible emergency situations. The monitoring data is stored during the day in the operational database and a part of it is transferred to the data warehouse in an aggregated form.

The microgrid planning subsystem is used to select the optimal configuration of power microgrid components. For example, such as the number of solar panels, batteries, their technical characteristics. This allows designing the optimal architecture of the microgrid depending on the requests of consumers in a socio-economic, ecological, and energy-efficient scenario.

The forecasting subsystem predicts the generation of energy resources from various sources, for example, solar panels or wind turbines, as well as forecasts the consumption of electrical and thermal energy for different time intervals [24, 25]. In this way, both short-term and long-term forecasts are performed, data from which are used to support decision-making at various stages of planning and operation of energy microgrids. The forecasting subsystem uses a model database that contains pre-trained forecasting models for different types of power plants and types of consumer stakeholders. In particular, for household consumers, industrial enterprises, institutions of the social sphere, various predictive models are used taking into account the consumption profile.

The decision support subsystem uses a fuzzy logic rule base. It is built on the basis of knowledge received from experts on the design and operation of energy systems. This subsystem evaluates the current state of the energy network and determines the need for control to change the energy supply regime. It also makes it possible to maintain a balance between the generation and consumption of electrical and thermal energy with the least energy loss.

As sources of data, DSS uses a database in which operational monitoring data is entered, a data warehouse, which contains both general data about the system and users, as well as tables with data for individual stakeholders – suppliers or customers of energy services. The system uses API interfaces to obtain weather data in the area where the power plant is installed, as well as the exact location. Models for forecasting energy generation and consumption for different time intervals make up the base of the models. Expert knowledge about the management of energy microgrids is stored in the rule base.

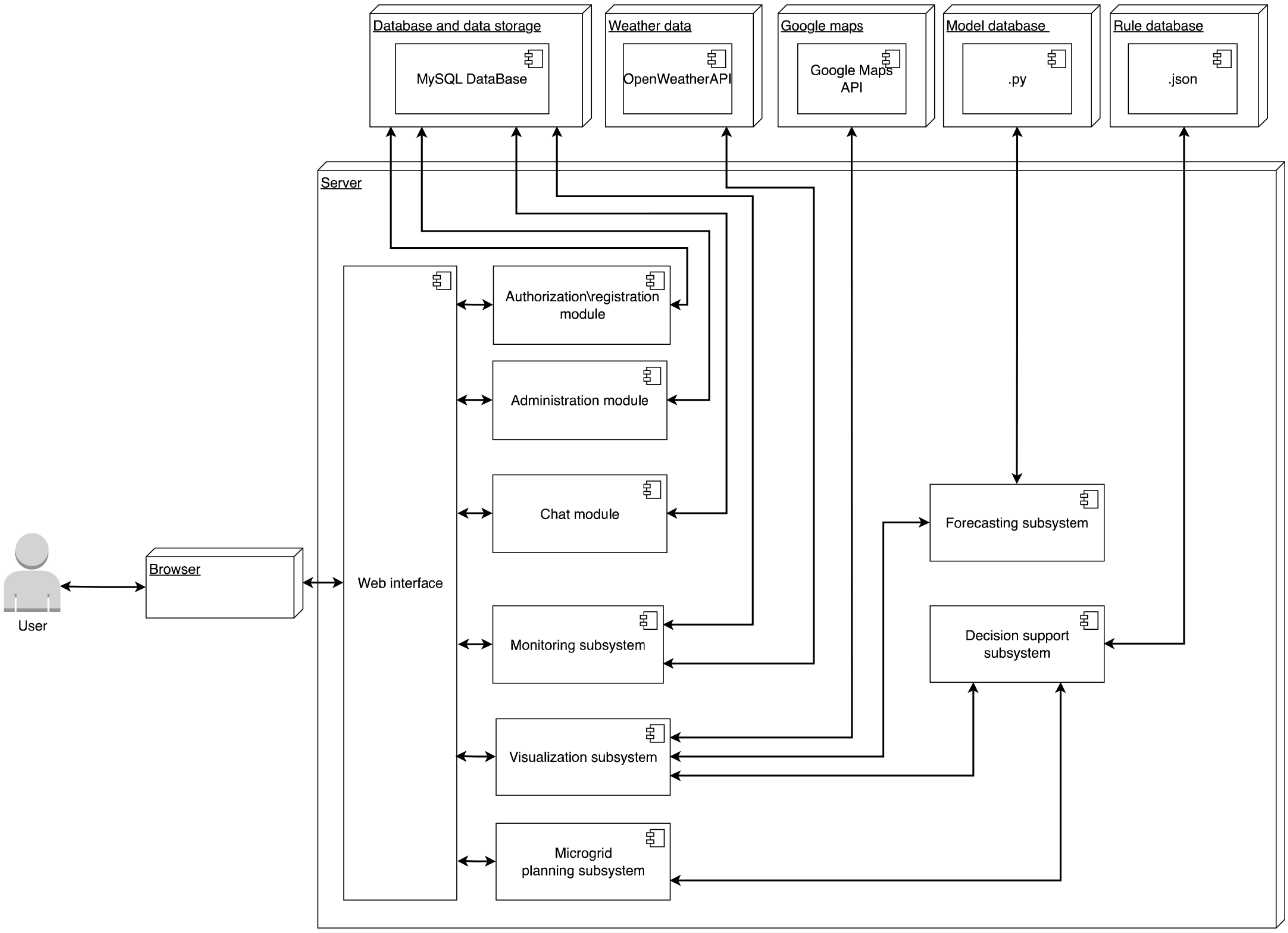


Fig. 1. Architecture of the information system for supporting decision-making in the management of energy microgrids

The visualization subsystem occupies a key place in the information system. It provides clarity of perception of information about the current state of the energy system. It also provides information about the forecast mode, depending on changes in environmental conditions and consumer needs. It displays possible control options for setting different power supply modes, etc.

A chat module for exchanging messages between different categories of users within the system has also been implemented in DSS. The administration module is used to manage the database, manage the categories of users who have access to the information system, energy installations, and also change the display of data in the web interface.

The functionality of DSS can be expanded by adding modules on the server side, which ensures its flexibility and adaptation to the requests of the main stakeholders. It is possible to use additional servers, which could increase the speed of processing requests on the server side.

5. 2. Results of modeling the distribution of roles and interaction of users of the decision support information system

The DSS is available only to authorized users who have previously registered, and their registration request has been confirmed by the administrator, which is the responsibility of a separate system module. The registered user has authorized access to subsystems and modules of the information system through a web browser and the corresponding interface components are available for him to display.

Users of the information system are shown as actors in the UML diagram of use cases (Fig. 2).

A use case diagram identifies system actors and models their functionality through their interaction with use cases, which include actions, functions that must be implemented by the information system. Stakeholders of energy systems, organizations, institutions, households, or individuals, as well as internal components of the system, in particular the database, can act as actors. The diagram of use cases as a way of presenting the interaction of stakeholders in the information system makes it possible to determine their interaction with each other through the roles they perform in the system, without detailing the implementation of functions.

The following categories of users are defined in the information system:

– a client – a consumer of services from energy microgrids, may own several objects on which the relevant equipment is installed;

– operator – a user who monitors data on the state of operation of the energy network for the consumers assigned to him;

– moderator – a person who manages consumer accounts, is responsible for signing contracts with consumers, monitors the status of the account for payment for the services provided for using the information system and the validity of the signed contracts, confirms the registration of new users;

– administrator – a person who has access to all information system data and performs its administration, setting up the information system for a new user and deploying the relevant database tables;

– database – provides data storage and provision of data to individual subsystems upon request.

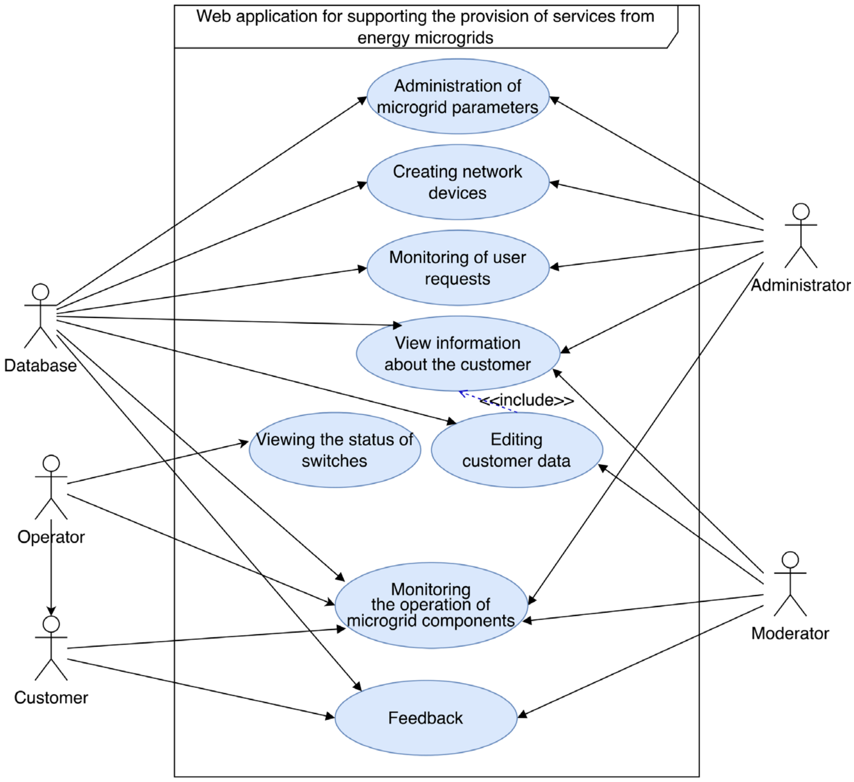


Fig. 2. Diagram of options for using the decision support system in the management of energy microgrids

For a broad understanding of the interaction of actors and elements of the information system, sequence diagrams were designed, which demonstrate the sequence of operations over time. Each component of the information system with which the actor interacts is highlighted in a separate column, and the interaction between them is shown by directional arrows. Objects are placed in the sequence in which they interact in the system.

5. 3. Results of modeling the sequence of actions of the main users in the interface of the decision support information system

The diagram of the sequence of actions of the client of the energy system is shown in Fig. 3 in the form of a UML diagram. First, the client must log in to the DSS web interface. After that, s/he can select the energy microgrid whose data s/he wants to view, if s/he has more than one. Also, the client can choose one of the available functions for viewing data on the installed components of the energy microgrid, the general structure of the network, weather data in the area. The client can make sure that the system is working, review the amount of consumed and produced electrical energy. Indicators related to the cost of services and economic efficiency of the installed system are also displayed. The client can choose under which scenario his/her microgrid will work – social, economic, or ecological.

The diagram of the sequence of actions of the DSS moderator is shown in Fig. 4.

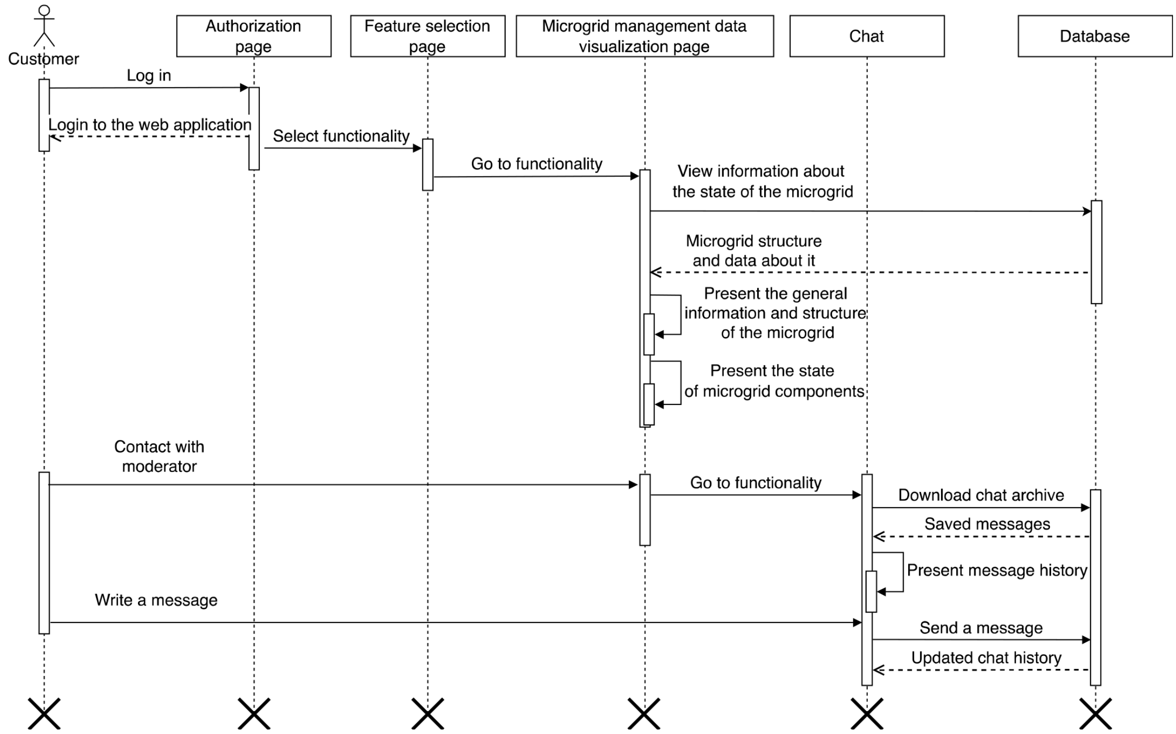


Fig. 3. Diagram of the sequence of actions of the consumer of services from energy microgrids

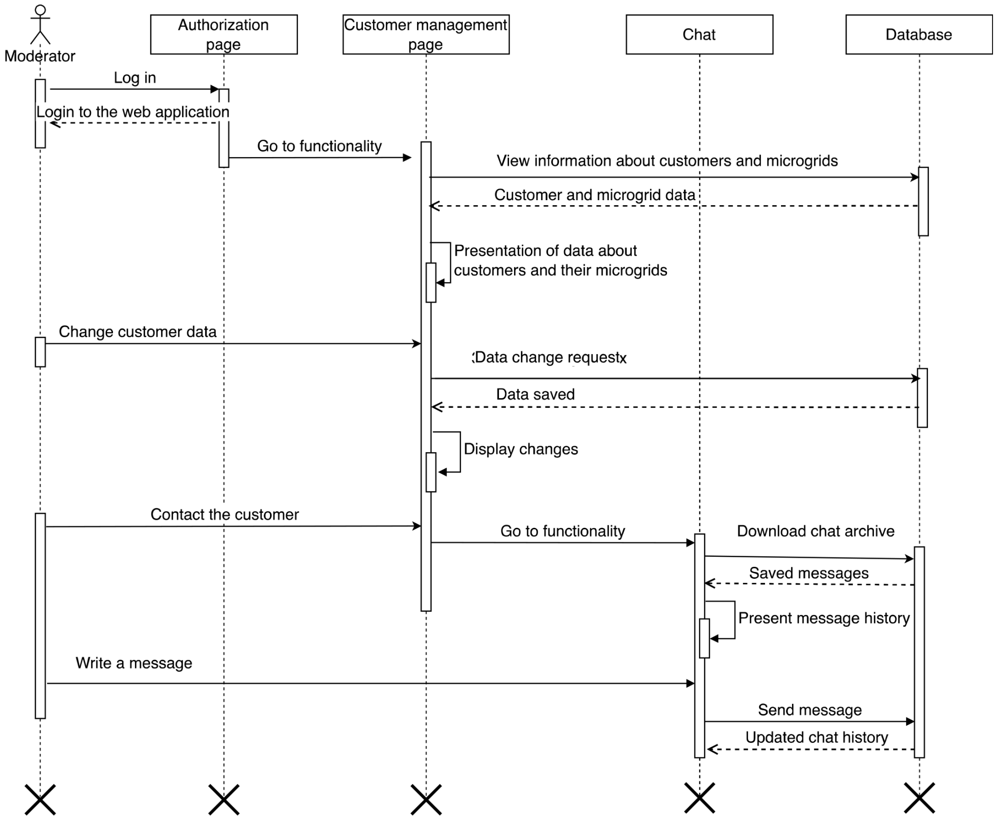


Fig. 4. Diagram of the sequence of actions of the moderator of the information system

S/he directly cooperates with the clients of the information system. The moderator connects new users, changes user data. S/he monitors the status of service provision and payment timeliness through the web interface. Informational support of the client by the system moderator is provided through the built-in chat. The system has the ability to save the history of messages for further analysis of the client's satisfaction with the level of service provision.

The operator monitors the status of the energy microgrids of the customers assigned to him/her in the web interface and can view complete information about the structure of the customers' microgrid and connected components. All energy generation and consumption monitoring data, as well as data from analytical subsystems for forecasting and decision-making support, are available for viewing by the operator. The operator can be considered a decision-maker regarding the management of energy supply scenarios, taking into account the client's requests and changing environmental conditions.

The diagram of the sequence of actions of the energy microgrid operator is shown in Fig. 5.

The results of the software implementation of the designed DSS as a web system and its interfaces are presented in the next chapter.

5. 4. Results of data visualization in the web interface of the decision support information system

The server part of DSS is implemented in the form of separate subsystems and modules that are responsible for certain of its functions. Individual modules are called at the request of the user in the web interface of the system. Some of the subsystems and modules, such as the monitoring and forecasting subsystems, work according to a configured schedule regardless of user requests, and the results of their work are displayed to the appropriate categories of users in the web interface.

The following main modules are generally executed on the server side:

– establishing a connection to the database and executing requests;

– obtaining data on the functioning of energy networks by conducting monitoring;

– data management of information system users;

– administration of data on the state of energy microgrid components;

– forecasting energy generation and consumption;

– collection of official information about the actions of users of the information system;

– connection to third-party API interfaces for extracting weather data and geolocation;

– support for executing transactions to the database and data storage;

– other modules related to information system administration.

The module designed to manage the data of system users downloads and edits data about customers and operators of energy microgrids, access to information about the customer and its contracts, provides access to customer contracts. A fragment of the program code that implements requests to the database on the server side, using the example of a request to receive data about contracts signed by the client, is given below:

```
$query="SELECT u.user_id, u.name, u.surname,
u.login, u.email, u.phone, c.contract_number,
c.status, c.file_name, DATE_FORMAT(c.end_date,
'%d.%m.%Y') AS end_date FROM users u LEFT JOIN
customers_contracts c ON c.customer_id=u.user_id
JOIN userroles ur ON ur.role_id=u.role_id WHERE
u.user_id='{$customer_id}' AND ur.role_title='Client';";
$result=mysqli_query($connection, $query).
```

In a similar way, requests are made to sample all other data that are displayed in the web interface of the DSS.

AJAX technology was used to implement the client part of the DSS, in particular interfaces for all stakeholders.

In this way, data is obtained for visualization in the corresponding web interfaces of DSS. In this work, the interface of the developed system is considered using an example of web pages, access to which is provided to the client and the energy network operator.

An example of displaying data on the state of power network components is shown in Fig. 6, which shows dashboards for different types of connected equipment, actual power generation values, and weather data that feeds into it. The scale reflects the percentage of the maximum operating power of the equipment. This page is available to both the energy network operator and the customer.

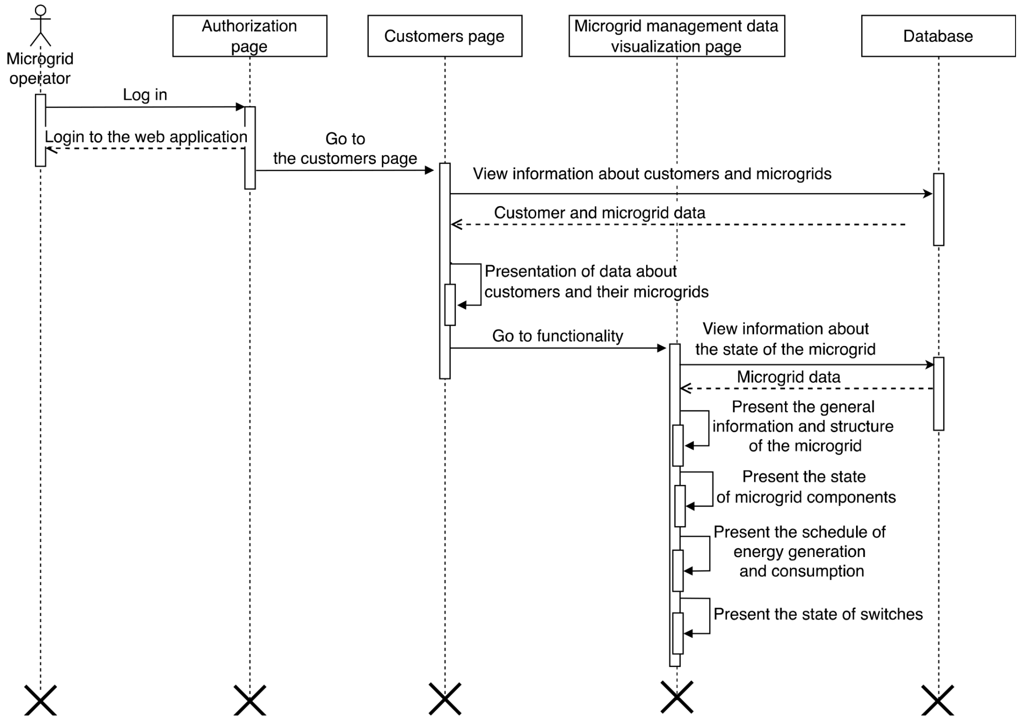
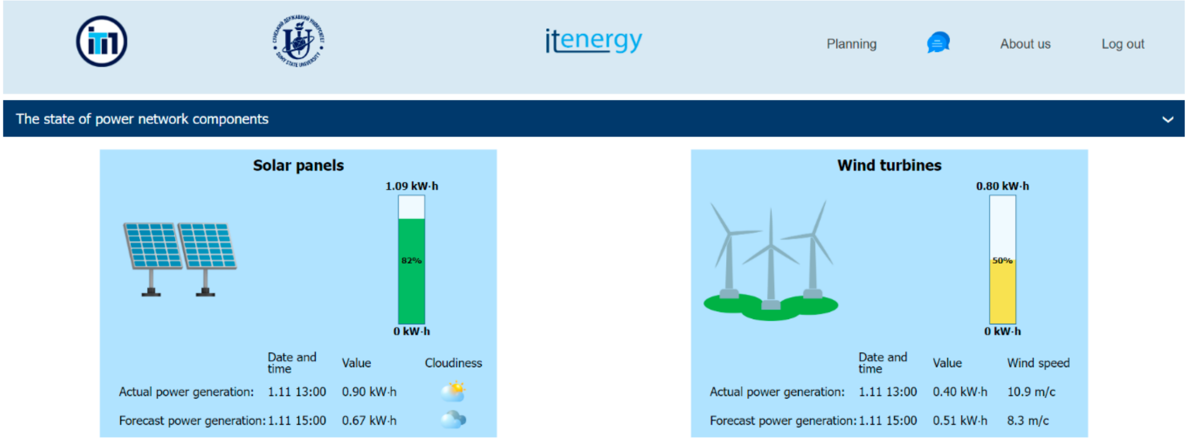


Fig. 5. Diagram of the sequence of actions of the energy microgrid operator



Solar panels

	Date and time	Value	Cloudiness
Actual power generation:	1.11 13:00	0.90 kW·h	
Forecast power generation:	1.11 15:00	0.67 kW·h	

Wind turbines

	Date and time	Value	Wind speed
Actual power generation:	1.11 13:00	0.40 kW·h	10.9 m/c
Forecast power generation:	1.11 15:00	0.51 kW·h	8.3 m/c

Fig. 6. Information panels with data on the components of the energy microgrid

Fig. 7 shows the visualization of the state of the switches, which are used to change the power supply mode. This page is used by the operator to visually monitor both the current state of the information system and possible equipment malfunctions.

Fig. 8 shows the operator's page, which displays detailed data on the hourly consumption and generation of electrical energy by the energy microgrid. There is an opportunity to display on the graph both the current indicators and, for clarity, to compare them with the forecasted ones for different time periods.

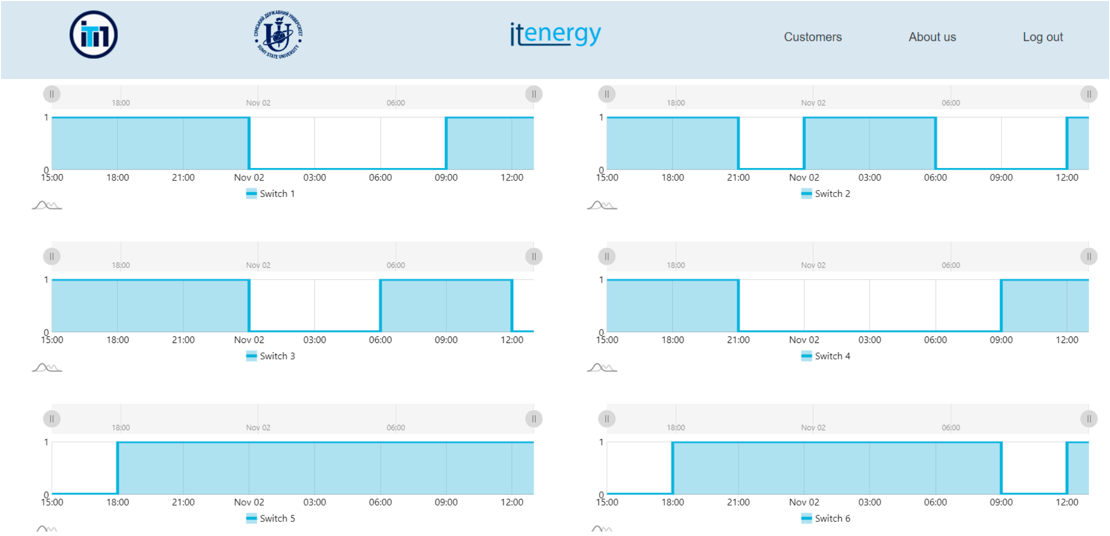


Fig. 7. Diagram showing the states of switches of the energy microgrid operator

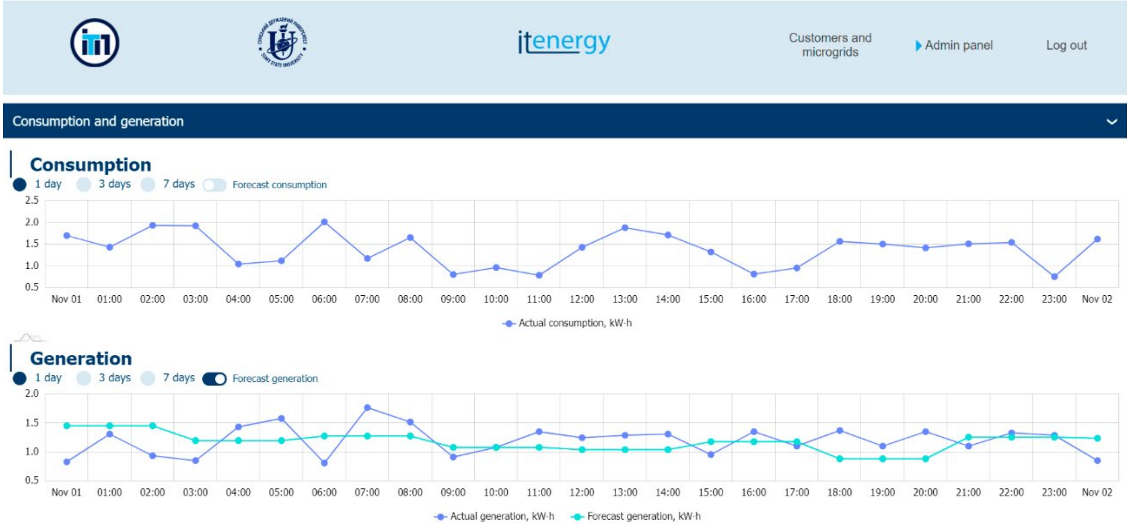


Fig. 8. Graphic representation of data on consumption and generation of electrical energy

The customer is also given the opportunity to view the consumption and generation of electricity for their facilities, but more generalized data for a period from one day during the current month to one year.

For energy managers, the visualization of energy microgrid indicators is a tool used in making decisions about managing the functioning of the energy system. It is also used in the long-term planning of the implementation of energy-saving measures to achieve the strategic goals of sustainable development.

6. Discussion of the research results on data visualization in the web interface of the decision support system

Our results are expressed in the form of the designed DSS architecture, which is shown in Fig. 1. The distribution of the roles of users of the DSS, who are the main stakeholders, is represented in the form of a UML diagram of use cases in Fig. 2. The result of modeling the sequence of actions of each of the user groups is represented in the form of a UML sequence diagram in Fig. 3–5, respectively. The implementation of the task of information visualization for users is confirmed by the developed web interfaces, in particular Fig. 6 shows the information panels available to the operator and the client; Fig. 7, 8 show various forms of data visualization in the operator's web interface.

In contrast to the commercial solutions considered in [14–18], the proposed DSS is web-oriented. This approach makes it possible to combine interfaces for all stakeholders with remote access in a single system, as well as assess the state of the energy network and monitor potential emergency situations. This ensures the safety of operation of the energy network. In addition, unlike the considered solutions [14–21], this information system has different data display interfaces for different categories of stakeholders, which allows all categories of stakeholders to perceive information about the state of the energy network. In addition, the system offers various ways of representing data in the form of tables, graphs, infographic panels with different levels of data detail.

Through an interface that is understandable for all categories of users, the perception of information about the state of operation of the energy network by all categories of stakeholders is achieved. Information is presented and visualized in an easy-to-understand form. This makes it possible to perceive it, both for technical specialists in the design of energy networks, and for household consumers who do not have specialized knowledge but must have information about the efficiency of the system installed in their home. Due to this, consumer confidence in the service provider and implemented technologies is ensured.

The proposed interface solutions have the following limitations. They are designed and demonstrated only for RES energy microgrids that use two types of renewable sources – solar panels and wind turbines. But this is not a global limitation, and the proposed models and solutions can be extended by adding modules to display the state of other energy sources.

The proposed architectural solution is not sufficiently perfect from the point of view of ensuring the confidentiality of information when it is moved from the user's accounting devices to the models on the server. But this is not a significant drawback and can be solved by dividing information into areas of full confidentiality and partial publicity.

It should also be noted that it is possible to implement the tasks more effectively thanks to the combination of cloud-edge architecture with the organization of saving personal information on the user's devices. Such a decision is under consideration and is the area of further research.

The proposed approaches to the distribution of stakeholder authority, database access, interface design, data visualization, and customer support can also be implemented in a mobile application to provide customers with access to the system at any place and at any time.

7. Conclusions

1. A three-level client-server architecture was designed and developed for the organization of shared access of renewable energy microgrid stakeholders to DSS, and the DSS was implemented as a web application. The proposed architecture makes it possible to distribute the application's functionality between the server and client parts, supports the possibility of remote authorized access through a web browser, thus ensures the scaling of the web system and the distribution of access rights for different categories of users. In addition, the proposed architecture takes into account the need to preserve confidential information, allows for safe storage of personal data of customers-consumers of energy services, location of microgrids, data on energy consumption and generation forecast.
2. As a result of the simulation of the use cases, the roles of the users of the DSS were distributed. Five main categories of users are defined: client, moderator, administrator, operator, database. Modeling of their interaction within the DSS was carried out, which made it possible to improve the quality of interaction of users with the web interface of DSS and with each other.
3. Modeling of the sequence of actions of each of the groups of users was performed, which made it possible to understand collisions and interactions of actors with elements of the information system, to analyze the sequence of execution of operations over time.
4. Data visualizations are implemented as charts and dashboards that display both data on the current state of the microgrid and the distribution of data and behavior of the microgrid over time. Customized interfaces simplify the perception of information by users, implement information support of the decision-making process. In this way, the trust of users in the proposed solutions increases and the process of interaction during the strategic management of the RES microgrid, taking into account the preferences of the users, improves.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The manuscript has associated data in the data warehouse.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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