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SUBSYSTEM OF COLLECTION, STORAGE AND VISUALIZATION OF OPERATING DATA OF THE DECISION SUPPORT SYSTEM FOR MICROGRID MANAGEMENT

The paper states that the introduction of various types of renewable energy sources into energy systems turns them into complex cyber technical systems and come to growing complexity of interaction processes in such technical energy systems increases the complexity of the management process. The complexity of management is especially increased when such an energy system is operated as a microgrid because in this case, and effective management is possible only if the decision-maker will have quality information support and be able to fully monitor all information flows. To ensure the efficient operation of the microgrid, it is necessary to collect and use in the analysis process data on the current state of the power system, on the parameters of the environment. The monitoring process must be performed in real-time. The difficulty of data collection is that the data comes from different sources and at different time intervals. To ensure the data collection process, a functional and mathematical model is proposed, which describes the process of pre-processing a large amount of collected data, their verification, and storage. Data exchange and storage for the monitoring process are provided by the operational database, the logical scheme of which is also proposed in this paper. For the successful formation of the solution, a large amount of controlled data and the results of forecasting the production and consumption of electricity are proposed to be implemented as a subsystem of visualization. It is the combination of operational monitoring of the current state of the power system with the decisions of intelligent decision support services through the operational database that provides the decision-maker with a convenient visualized form of information about the current state of the system and the optimal configuration of resource planning and use services plan.

Key words: renewable energy sources, microgrid, information support, monitoring, database, visualization

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ПІДСИСТЕМА ЗБОРУ, ЗБЕРІГАННЯ ТА ВІЗУАЛІЗАЦІЇ ОПЕРАТИВНИХ ДАНИХ СИСТЕМИ ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕНЬ ДЛЯ УПРАВЛІННЯ МІКРОГІД

У статті визначено, що впровадження до енергосистем різного роду відновлюваних джерел енергії перетворюють їх на складні кібертехнічні системами, які потребують інтегрованого інтелектуального управління. Зростання складності процесів взаємодії у таких технічних енергетичних системах підвищує складність процесу управління ними. Особливо збільшується складність управління, коли така енергетична система експлуатується як мікрогрід, оскільки вона у цьому випадку має певну автономію у функціонуванні, і досягти ефективного управління нею можливо лише, якщо особа, яка приймає рішення буде мати якісну інформаційну підтримку, та мати змогу повністю відслідковувати всі інформаційні потоки. Для забезпечення ефективного функціонування мікрогрід необхідно збирати та використовувати у процесі аналізу дані про поточний стан енергосистеми, про параметри оточуючого середовища. Процес моніторингу необхідно виконувати у реальному часі. Це дозволяє відслідковувати різного роду зміни, та вчасно на них реагувати, змінюючи параметри мікрогрід. Складність збору даних полягає у тому, що дані надходять з різних джерел та у різні часові інтервали. Для забезпечення процесу збору даних запропоновано функціональну та математичну модель, які описують процес попередньої обробки великого обсягу зібраних даних, їх верифікацію та зберігання. Обмін даними та їх зберігання для процесу моніторингу забезпечується оперативною базою даних, логічна схема, якої також запропонована у цій статті. Для успішного формування рішення великий обсяг контрольованих даних та результати прогнозування виробництва та споживання електричної енергії запропоновано реалізувати як підсистему візуалізації. Саме поєднання оперативного моніторингу поточного стану енергосистеми з рішеннями інтелектуальних служб системи підтримки прийняття рішень через оперативну базу даних надають особі, що приймає рішення, у зручній візуалізованій формі інформацію про поточний стан системи та оптимальну конфігурацію планування ресурсів і план використання, який орієнтується на підвищення рівня електричних послуг.

Ключові слова: відновлювальні джерела енергії, мікрогрід, інформаційна підтримка, моніторинг, база даних, візуалізація.

Introduction

The global energy crisis, caused by russian invasion of Ukraine, requires the final abandonment of fossil fuels and the rapid transition to renewable energy sources (RES) usage for electricity generation in the housing and utility sector and industry for all sectors of the economy. Therefore, energy production, distribution, and consumption require the development and creation of more innovative and energy efficient approaches. Replacing traditional power generation with generation from RES also poses new challenges to electricity consumption and distribution, and requires the implementation of Smart Grid technology, as well as the integrated management of next-generation power grids. In turn, the modern development of Smart Grid technology turns it into a global concept of energy interconnection, allowing it to replace traditional approaches to the management of production, distribution, and consumption of electricity with more efficient ones.

Thus, the new generation of Smart Grid is transformed into cyber technical systems with integrated intelligent control. This transformation, in addition, allows to save electricity, avoid transportation losses, and develop energy savings. Environmental friendliness and energy efficiency are often achieved by changing the paradigm of "centralized» to the "decentralized" electricity production through the various RES usage, reversing the logic of production and distribution of electricity, and the use of new software to perform functional energy optimization. Along with this, there are many questions related to digitalization the processes that accompany the electricity life cycle, from the moment of its production to storage, distribution, and consumption. The use of integrated intelligent management throughout the energy life cycle can increase profits, and such a transformation is aimed at more efficient use of available energy resources, especially renewable energy resources. In turn, the ability to intelligently manage complex cyber technical systems with RES is the ability of decision support systems (DSS) to collect data, convert it into information, store information, use the results of information processing for decision-making and change the power system behavior. It allows saving expert knowledge gained on the basis of previous experience. Conventionally, DSS tasks for Smart Grid energy management can be divided into those involving decision-makers and those that are not controlled by such a person. The quality of the decision very often depends on how fully the decision-maker receives information and can perceive it. In other words, the quality of management decisions depends on the quality of information support of the decision-maker. Such information support is formed by data collection, storage of data that provides monitoring, as well as the process of providing information in a user-friendly form for decision-making.

Related works

The development of the Internet of Things (IoT) [1] and smart home technologies [2] is designed to monitor and manage energy consumption in buildings. The combination of these technologies allows to monitor energy consumption in different rooms or locations or give information on the current state of functioning of energy sources. An example of successful energy management is monitoring and managing energy consumption via the Internet. The solution proposed in [3] allows for a review of how people use, store, and manage energy. Once connected to this system, any device becomes an intelligent space with a rich set of functions and capabilities for energy consumption monitoring and control.

It should also be noted the advantages of monitoring systems that perform monitoring at the moment. Because the observed objects are constantly changing or evolving, dynamic monitoring systems have the ability to predict the failure of the object to be observed or to determine the probability of danger at the time of its operation [4 - 5].

IoT technologies also facilitate the collection of information about the operation of solar panels or charging stations and monitor the movement of the sun by using special trackers to monitor the sun [6], which increases the amount of electricity generated by about 35-50% [7], as powered by solar panels behind the sun.

Analysis of the results of the previous study revealed that to increase the effectiveness of the decision, information from the decision support system to the decision maker should come in the form of charts, graphs, tables, etc., which visualize data for energy management. Consider a few software products that visualize real-time monitoring data.

The first application was the Microgrid Digital Control Solution from Schneider Electric [7]. It is a desktop software that allows viewing real-time data with a simulation function, where you can see where and where the data comes from, as well as view weather conditions. Additionally, you can see the maximum voltage and energy consumption percentage. In the interface of this software, it is possible to view in the form of graphs how much energy is produced. Its feature is the ability to view individual network components and the percentage of their energy.

The application "Grafana" was also considered [8]. The Grafana Dashboard collects information and displays it in a convenient form for the user via the web interface. The Grafana software consists of a graph of time series so that the operator can observe the evolution of the measured temperatures. The user can zoom in on the graph, as well as select the time interval for visualization. In addition, the sensor illustrates the instantaneous value of one temperature to get a first look at the value on the sensor. Another element that was considered relevant is the table, which presents the indicators, namely the current, minimum, and maximum temperature for each sensor.

The third studied application is a modification of the MathLab software, more precisely its library. Simscape Power Systems is a standard SIMULINK library. It consists of a database of electronic components, as well as modeling and analysis tools for power systems. The library is also designed to develop and test control systems in integration with power systems; this makes it suitable for microgrids modeling [9]. This library allows performing a simulation, as a result of which the program displays visual indicators in the form of graphs depending on the specified parameters.

Consider a full-featured application for real-time microgrid simulation ETAP Microgrid Management [10]. After enabling the simulation, you can view detailed indicators of individual devices in real-time, as if physical devices are now connected. The application displays devices connected to the system and provide the ability to track their performance in real-time. The program can display information in the form of graphs. You can view the performance of a separately connected device. It is possible to view a specific energy capacity in the form of a graph, as well as individual indicators such as speed, temperature, voltage, humidity, etc. in the form of a bar chart and a regular table. It is possible to view individual indicators in the form of a pie chart.

The functions of the information system, which is currently being developed but is attracting attention, are also considered - it is Monash Microgrid [11]. This system allows you to visualize the microsystem as a 3D model. More precisely, it visualizes real buildings on a Google map and depicts the system of connecting power and its connection to buildings.

It would also like to consider the oldest but still popular visualization system - LabVIEW Visualization [12]. The graphical interface is designed using LabVIEW software to visualize system parameters in real-time. As an instance, you can visualize the values of direct current inverters, such as direct current voltage, solar panel power, etc. Using this software, it is possible to make several modes of data visualization in real-time.

After analyzing the existing information technologies and software tools, it can be concluded that in order to collect, store and visualize data in the DSS and to organize effective interaction of the decision-maker, the DSS must provide real-time data visualization and support for several types of data visualization.

Purpose

Increasingly, engineers create smart microgrids with renewable energy sources - systems that can operate separately from the centralized power grid. But such microgrids often have problems related to their internal technological limitations of power supplies [13]. Because of this, it is usually impossible to determine how efficiently energy is produced and how efficiently it is used without monitoring. In this regard, there is the problem of how to perceive the collected data and control the energy of the end consumer. To solve this current problem the tools and methods of data collection, storage and visualization are used, which in turn determines the relevance of this study. Through operational monitoring of the current state of the microgrid system, intelligent DSS services can provide users with a convenient visualized form of the optimal energy resource planning and improve the level of electrical services [14].

The object of the study – to provide information support for the decision-making process in the energy management of microgrids.

The subject of the study – information technology of data collection, storage, and visualization in the energy management of microgrids.

The aim of the study is to develop information technology for data collection, storage, and visualization for the DSS system in the energy management of microgrids. This information technology should be implemented in the subsystem of collection, storage, and visualization of operating data of the DSS for microgrid management.

Proposed technique

In the study, we consider a typical small microgrid, which consists of a set of photovoltaic panels, wind turbines, and a common energy storage bank, and also has a connection to the external power grid.

The process of decision support in the management of such a microgrid pre-includes the collection and processing of data on weather data, the current state of the power system, determining the forecasted value of electricity generation and consumption, and quality indicators, and consists of recommendations for the optimal operating model. This process is divided into sub-processes that are implemented by the respective DSS subsystems. Some of these subsystems have auxiliary functions of data visualization. Appropriate technical and software tools for data collection, processing, and storage are required for the implementation of information collection and pre-processing.

Data that enters the DSS can be input once by the authorized user when it's registering in the system, as well as entered from external information sources online. In turn, operational data are divided into data coming from the automated control system and characterizing the current technical condition of the object of observation - the microgrid, and data collected from external information sources - data on forecast meteorological conditions. At the preliminary stage, it is necessary to check the accuracy and integrity of data transmitted from the automated control system, as well as from weather forecast websites. After the validation collected data are stored in the database. The data obtained online are used in evaluating the list of alternatives to the modes of the microgrid operation, as well as in calculating the criteria for choosing a solution regarding the microgrid operation mode. The decomposition of the process of collecting and pre-processing information in the form of a diagram in the IDEF0 notation is shown in Figure 1. The components of this process are "Data Collection", "Data Validation", "Storage to Database" and "Data Conversion".

All monitored data can be described as a set $M_p = M_{po} \cup M_{pi}$. It consists of two subsets:

- subset M_{po}, that consists of parameters that are collected from external information sources (these data are variable in time) and entered by the user;
- subset M_{pi}, that contains the calculated parameters.

Set of the parameters collected and entered by the user M_{po}, can be presented in the form:

$$M_{po} = \{Mwo, Mres, Mg, MPl, M_{tech}\},$$

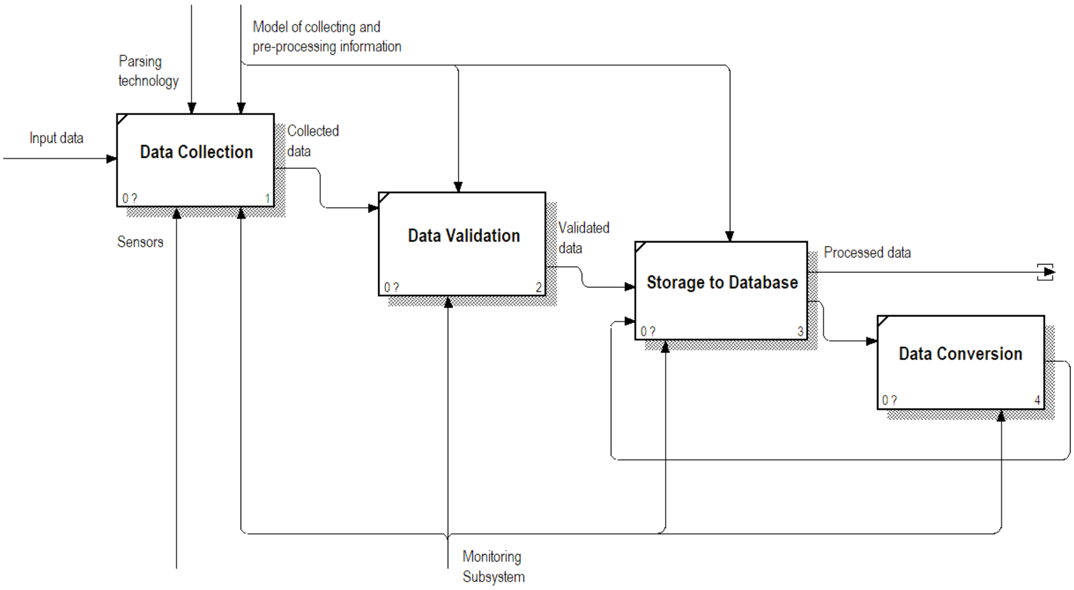


Fig. 1. Decomposition of the process of collecting and pre-processing information in IDEF0 notation

where M_{WO} is a set of forecast weather conditions; M_{res} – a set of data on the available microgrid with RES configuration; M_{Pl} – a set of data on geographical location of microgrid with RES; M_g – a set of data on the local distribution networks to which it is planned to connect the microgrid; M_{tech} – a set of data that characterizes the current technical condition of the microgrid (for example, the battery charge level).

Data M_{res}, M_g, M_{Pl} are entered once at user registration, data M_{WO}, M_{tech} are collected from external sources real-time, в they are the main factors that affect the microgrid current state and are crucial for the formation of energy management decisions.

Model data collected from external sources (M_{wo}), can be presented as a set of weather forecast data that are real-time collected. M_{wo} is described by an ordered set of elements:

$$M_{wo} = \{(t, E, T, V)\},$$

where *t* – time interval for which meteorological indicators are provided on the weather site (hours);

E – the level of insolation and precipitation in qualitative characteristics (clear; variable cloudiness; cloudy; cloudy and precipitation);

T – temperature, (°C);

V – wind speed can also be represented by the range of values from initial to final (м/с).

The data flow diagram in the process of collecting, storing, and displaying information to the user is shown in Fig.2.

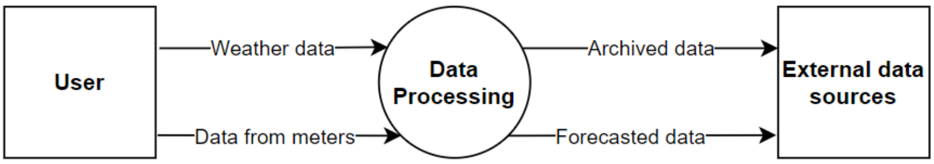


Fig. 2. Data flow diagram

Data on the current state of the microgrid enters the operating base from various sources, such as sensors or meters. At three-hour intervals, forecast weather data is recorded to provide forecasts of energy generation by devices for the day, three days, or a week ahead. Data from microgrid devices are received every hour. These data are visualized on the web interface and used for data warehouse filling. The data in the data warehouse should be updated at midnight Greenwich Mean Time in order to minimize delays in the operation of the entire system.

Figure 3 shows a logical model of the operational database that stores current information.

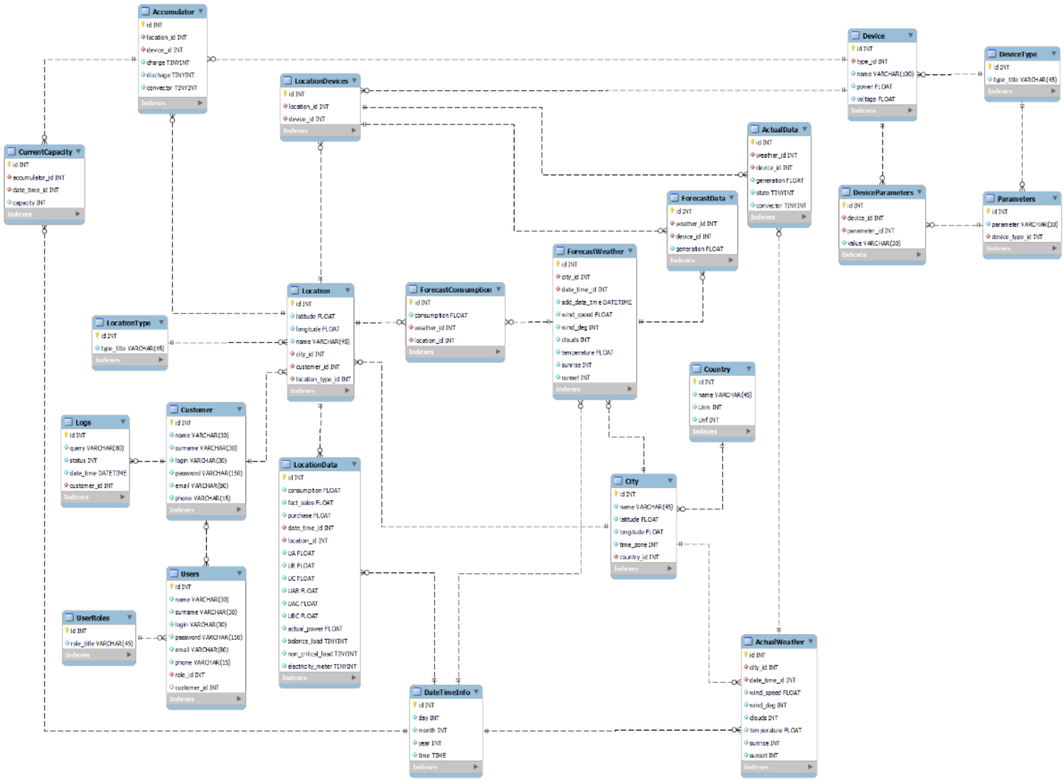


Fig. 3. Logical model of database

Information support of the decision-maker is provided through the subsystem of visualization of monitoring results and analysis. The collected data, processed data and data from analysis process are displayed in an easy-to-understand format in the form of diagrams, graphs and tables.

Thanks to the graphics module, which allows to build different types of graphics and configure them, provides visual output, namely:

– construction of graphs with data updates every 5 minutes with data display: on the X axis time (day, month, or week), on the B axis indicator of electricity use.

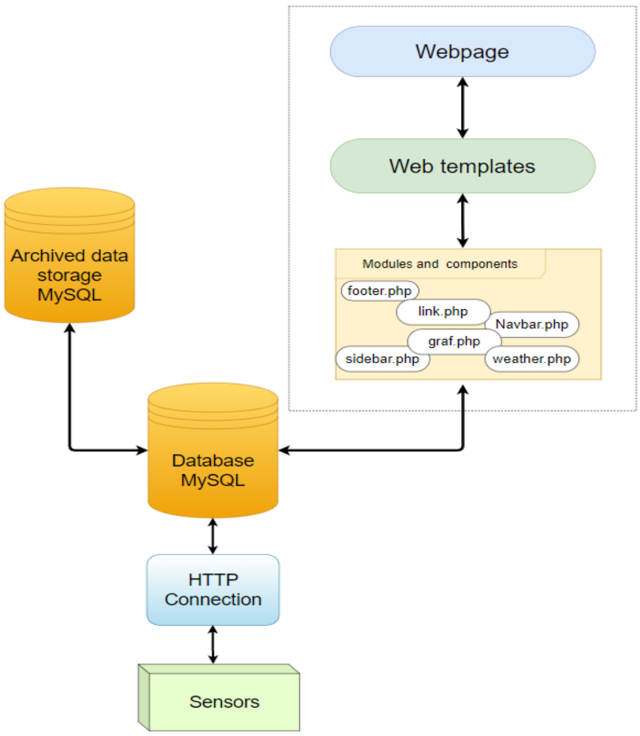


Fig. 4. Architecture of data visualization subsystem

− display tables with the ability to add and edit data with information about users, energy data, etc.;
− display of weather data as a separate widget.

The subsystem of data collection, storage and visualization allows to differentiate access rights of separate groups of users:

− user – does not have full access to the system, namely it can view data and add them to the database;
− administrator – has full access to the system and its settings, such as the user, as well as the ability to add and remove users, delete information from the database. The use case diagram is shown in Figure 5.

The visualization subsystem performs the following functions:

− displays data coming from the database in the form of graphs, tables and charts;
− implements saving data in .png format;
− implements fast work of updating data in the system.

The visualization subsystem allows:

— personal data editing – allows to change or add personal data about the client or administrator;
— authorization – allows to authorize in the system for further work;
— registration – gives the client the opportunity to register in the system;
— remote control for microgrid – allows to turn on or off a separate device in the microgrid;
— view microgrid energy data – the user can view all data in the microgrid;
— editing microgrid data – depending on the access rules, the user can edit the data in the microgrid.

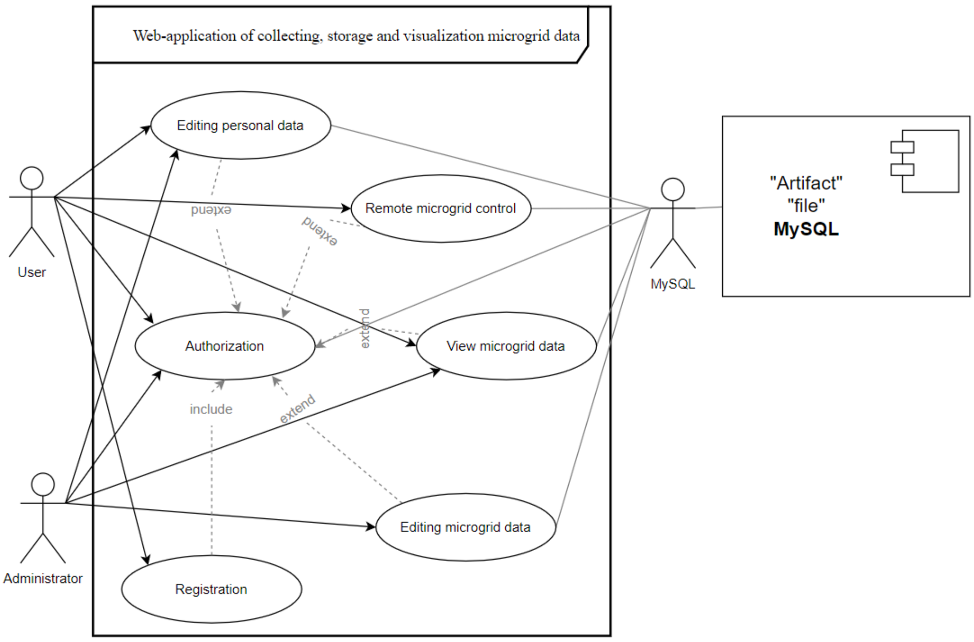


Fig. 5. Use Case Diagram

The data visualization subsystem consists of components and modules, which are listed in table.

Table 1

Modules and components

№	Modules and components	Description
1	link.php	All external links used in the web application
2	grafscript.php	The module contains settings for graphs
3	navbar.php	Navigation menu module
4	weather.php	Configure the weather API used in the web application
5	footer.php	Footer with contact information
6	include_database.php	Database connection module
7	config.php	An application configuration component

The data enters the visualization subsystem from the database. Information is obtained from the OpenWeatherMap API and devices, using the HTTP protocol. The visualization subsystem is created with the help of modules that are interconnected and form full-fledged page templates, and are connected into a full-fledged data visualization subsystem, which provides informational support to the decision-maker in DSS management of microgrids.

Results

Here is an example of working with the data visualization subsystem. After confirming all the data, the user gets to the main administrative page (Fig. 6), where we can view the current weather indicators (Fig. 7).

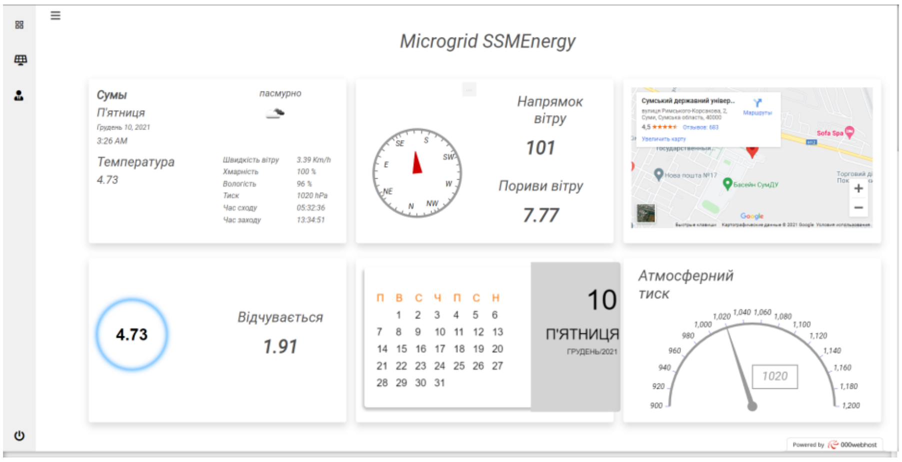


Fig.6. Main administrative page

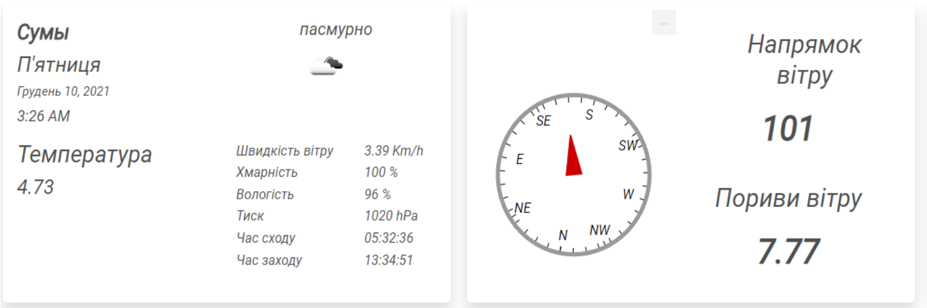
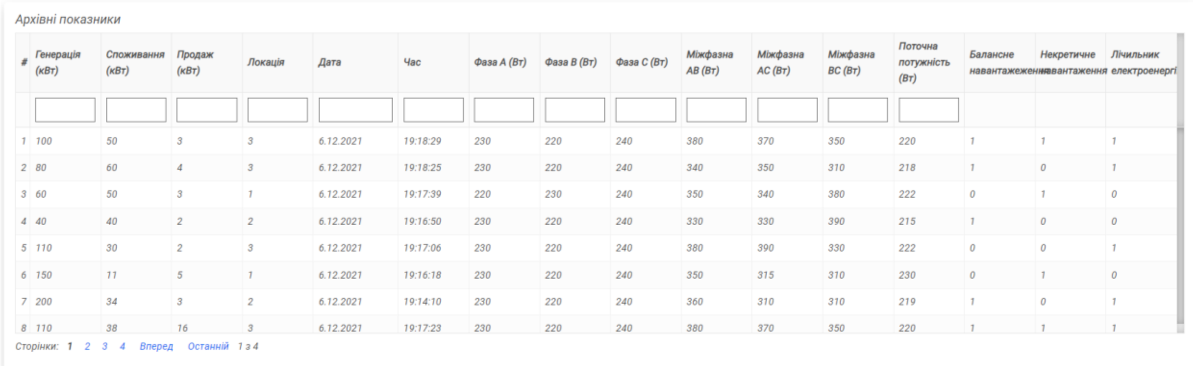


Fig 7. Weather indicators

Below the weather indicators on the same page, the user can view the archived information on the performance of solar panels (fig. 8).



Архівні показники

#	Генерація (кВт)	Споживання (кВт)	Продаж (кВт)	Локація	Дата	Час	Фаза A (Вт)	Фаза B (Вт)	Фаза C (Вт)	Міжфазна AB (Вт)	Міжфазна AC (Вт)	Міжфазна BC (Вт)	Поточна потужність (Вт)	Балансне навантаження	Некретичне навантаження	Лічильник електроенергі
1	100	50	3	3	6.12.2021	19:18:29	230	220	240	380	370	350	220	1	1	1
2	80	60	4	3	6.12.2021	19:18:25	230	220	240	340	350	310	218	1	0	1
3	60	50	3	1	6.12.2021	19:17:39	220	230	240	350	340	380	222	0	1	0
4	40	40	2	2	6.12.2021	19:16:50	230	220	240	330	330	390	215	1	0	0
5	110	30	2	3	6.12.2021	19:17:06	230	220	240	380	390	330	222	0	0	1
6	150	11	5	1	6.12.2021	19:16:18	230	220	240	350	315	310	230	0	1	0
7	200	34	3	2	6.12.2021	19:14:10	230	220	240	360	310	310	219	1	0	1
8	110	38	16	3	6.12.2021	19:17:23	230	220	240	380	370	350	220	1	1	1

Сторінки: 1 2 3 4 Вперед Останній 1 з 4

Fig 8. Table with archived data

Below from the presented table it is possible to view the voltage of the phases of solar panels in the form of a bar plot, which is presented in Figure 9.

Fig 9. Bar plot of solar panel voltages

Also, you can view information about the voltage of solar panels relative to their power, in the form of a scatter plot (Fig.10).

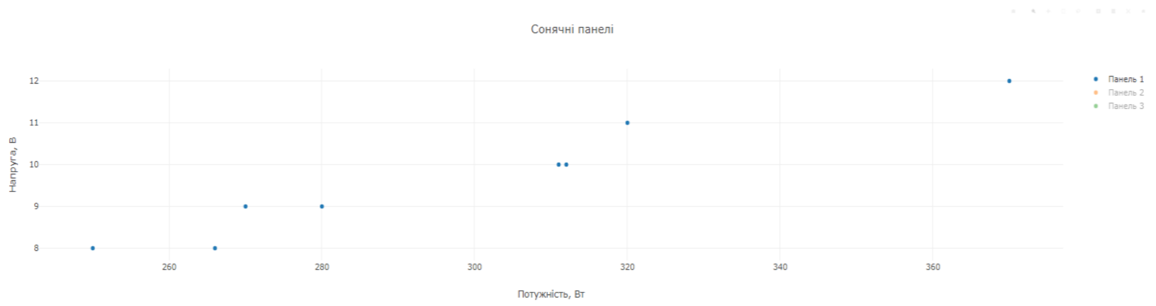


Fig 10. Scatter plot of solar panel voltage relative to their power

Conclusions

The paper presents information technology for data collection, processing, storage, and visualization. Information technology is implemented as a subsystem of the decision support system in the management of microgrids with renewable energy sources.

Previous analysis of technologies and methods that support the collection, storage, and visualization of monitoring data, confirmed the relevance of the study because in the decision-making process in microgrid management to improve the quality of the decision is possible only by improving the information support of the decision-maker.

Developed functional model of data collection and storage, the mathematical model of data monitoring, allow to formalize these processes and provide effective monitoring of a large amount of heterogeneous data at different time intervals.

An operational database has been developed to store the information received in the process of data collection, forecasting of consumption, and production of electricity, in connection with the subsystem of data visualization. The operational database stores information on the current state of the power system and short-term forecast data.

The visualization subsystem outputs data in a user-friendly form. It is designed for different categories of users and provides each user with information following his authority. This subsystem will be used as the component of the decision support system in the management of microgrids with renewable energy sources.

The developed subsystem of the decision support system for microgrid management has an advantage over existing data visualization systems for energy microgrids operation. It is that the use of the subsystem will provide comprehensive information support for decision-making in the intelligent energy microgrids management with renewable energy sources.

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References

1. Vira Shendryk, Olha Boiko, Yuliia Parfenenko, Sergii Shendryk, Sergii Tymchuk. Decision Making for Energy Management in Smart Grid. *Research Anthology on Smart Grid and Microgrid Development* : monorgaph. IGI Global, 2022, P.1742-1776. DOI: 10.4018/978-1-6684-3666-0.ch057.
2. Kholoud Maswadinorjihan Binti, Abdul Ghani, Suraya Binti Hamid. Systematic Literature Review of Smart Home Monitoring Technologies Based on IoT for the Elderly. *IEEE Access*, vol.8., 2020. DOI:10.1109/ACCESS.2020.2992727.
3. S. Karnouskos, P. G. da Silva, D. Ilić, Developing a web application for monitoring and management of Smart Grid neighborhoods: Proceedings of the 11th IEEE International Conference on Industrial Informatics (INDIN), 2013. P. 408-413. DOI: 10.1109/INDIN.2013.6622919.
4. IoT Power Consumption Control and Monitoring, 2016. *Digiteum.* URL: https://www.digiteum.com/portfolio/electricity-consumption-monitoring-remote-control/ (accessed May 27, 2022).
5. Monitoring of Infrastructure and Services, 2018. *Solution Catalog of ProNet company*. URL: https://pronet.ua/en/monitoring-of-infrastructure-and-services/ (accessed May 27, 2022).
6. K. Dinesh, Lakshmi Priya, Preethi. T, Sandhya. M., Sangeetha. P. IoT Based Solar Panel Tracking System with Weather Monitoring System. Recent Trends in Intensive Computing. 2021. P. 795-799. DOI:10.3233/APC210282
7. Microgrid Case study: Schneider Electric helps make an ambitious Microgrid campus project. *Schneider Electric*. 2021. URL: https://www.se.com/ww/en/download/document/998-21080285/ (accessed May 27, 2022).
8. I. G. Pérez, A. J. Calderón Godoy. Monitoring interfaces for photovoltaic systems and dc microgrids: brief survey and application case. *XLII JORNADAS DE AUTOMÁTICA : LIBRO DE ACTAS*, 2021. P. 183–189. DOI:10.17979/spudc.9788497498043.183

9. Energy Management Systems for Optimal Operation of Electrical Micro/Nanogrids / ed. by Maria Carmela Di Piazza. MDPI, 2021, 137 p.

10. ETAP Microgrid Management, 2021. *The official webpage of Operation Technology, Inc.* URL: https://etap.com/solutions/microgrid (accessed May 27, 2022).

11. Monash Microgrid: data visualisation and platform, load and generation management, operating systems. *Monash Energy Institute*. 2020. URL: https://www.monash.edu/energy-institute/news-events/past-events/events/2020/monash-microgrid-data-visualisation-and-platform,-load-and-generation-management,-operating-systems (accessed May 27, 2022).

12. A. Maashri, N. Tarhuni, A. Elhaffar. A Real-Time Monitoring Platform for Distributed Energy Resources in a Microgrid. *Electronics*, vol. 10(15), 2021, P. 1-21. DOI:10.3390/electronics10151803.

13. Manson S. Microgrid Systems: Design, Control Functions, Modeling, and Field Experience. *Schweitzer Engineering Laboratories, Inc.* 2018. URL: https://cms-cdn.selinc.com/assets/Literature/Publications/Technical%20Papers/6701_MicrogridSystems_SM_20180726_Web.pdf?v=20190325-145907(accessed May 27, 2022).

14. Li Y. A Data Warehouse Architecture supporting Energy Management of Intelligent Electricity System : Proceedings of the 2nd International Conference on Computer Science and Electronics Engineering (ICCSEE 2013), P.1-4. DOI:10.2991/iccsee.2013.177.