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ANALYSIS OF ENERGY COSUMPTION IN THE NETWORK USING IOT SOLUTIONS

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Abstract. The article explores the importance of implementing IoT systems to analyze energy conditions in current locations. The designed system architecture ensures scalability and flexibility, which allows to effectively collect, save and analyze data. The research results confirm the hypothesis about the value of reduced control and optimization of energy consumption due to automated monitoring and compensation of reactive energy. A practical solution is being developed to automate the monitoring and balance of phase pressures, which promotes energy supply and reduces energy costs.

Keywords: sensors, energy management, IoT - internet of things, CEM - energy management system, API - application programming interface, CRUD – (create, read, update, delete), IDE - integrated development environment, ISO 50001 - international standard for energy efficiency management system, MDM - Meter Data Management

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IOT ШЕШІМДЕРІН ҚОЛДАНА ОТЫРЫП, ЖЕЛІДЕГІ ЭНЕРГИЯ ШЫҒЫНЫН ТАЛДАУ

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Аннотация. Мақалада Ағымдағы орындардағы энергия жағдайларын талдау үшін IoT жүйелерін енгізудің маңыздылығы қарастырылады. Жобаланған жүйенің архитектурасы деректерді тиімді жинауға, сақтауға және талдауға мүмкіндік беретін ауқымдылық пен икемділікті қамтамасыз етеді. Зерттеу нәтижелері реактивті энергияның автоматтандырылған мониторингі мен өтемақысы есебінен энергия тұтынуды төмендетілген бақылау мен оңтайландырудың мәні туралы гипотезаны растайды. Фазалық қысымның мониторингі мен тепе-теңдігін автоматтандыруға арналған практикалық шешім әзірленуде, бұл энергиямен жабдықтауға ықпал етеді және энергия шығындарын азайтады.

Түйін сөздер: Сенсорлар, Энергияны басқару, Заттар Интернеті IoT, CEM - энергияны басқару жүйесі, API - Қолданбалы Бағдарламалау Интерфейсі, CRUD - (Жасау, Оқу, Жаңарту, Жою), IDE – Интеграцияланған Даму Ортасы, ISO 50001 - энергия тиімділігін басқарудың халықаралық стандарты.жүйе, MDM - Есептегіш Деректерін Басқару

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АНАЛИЗ ЭНЕРГОПОТРЕБЛЕНИЯ В СЕТИ С ИСПОЛЬЗОВАНИЕМ IOT-РЕШЕНИЙ

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Аннотация. В статье рассматривается важность внедрения систем интернета вещей для анализа состояния энергоснабжения в текущих местах. Разработанная архитектура системы обеспечивает масштабируемость и гибкость, что позволяет эффективно собирать, сохранять и анализировать данные. Результаты исследований подтверждают гипотезу о ценности снижения контроля и оптимизации энергопотребления за счет автоматизированного мониторинга и компенсации реактивной энергии. В настоящее время разрабатывается практическое решение для автоматизации мониторинга и балансировки фазных давлений, которое способствует энергоснабжению и снижает затраты на электроэнергию.

Ключевые слова: датчики, управление энергопотреблением, IoT - интернет вещей, CEM - система управления энергопотреблением, API - интерфейс прикладного программирования, CRUD – (создание, чтение, обновление, удаление), IDE - интегрированная среда разработки, ISO 50001 - международный стандарт для систем управления энергоэффективностью, MDM - управление данными счетчиков

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Introduction

The new solution to IoT in the context of monitoring and managing energy consumption opens new horizons of possibilities for the place of their management. These technologies will ensure the automation of the processes of collecting data on stored energy, analyzing it, and promoting approaches to its effective recovery. Sensors and intelligent healers, located at various points in the energy infrastructure of a place, collect a large amount of data in real time. This data includes information about the energy generated by residential buildings, commercial facilities, and municipal installations, as well as energy management parameters. Analytical platforms that collaborate with IoT allow you to collect data, see trends, identify anomalies, and optimize the distribution and distribution of energy resources. Such in-depth analysis encourages the development and promotion of innovative methods of energy saving, for example, adaptive control of street lighting, optimization of thermal measures, or automated control of energy consumption in households.

The stagnation of the Internet not only reduces energy consumption and saves money on the local budget, but also has a positive impact on the quality of life of the population. Through effective management of energy resources, the stability of energy supply will be ensured, tariffs for terminal residents will be reduced and the comfort of living in the middle class will be improved. In addition, the reduction in the vicinity of fossil fuels and the optimization of energy consumption result in a decrease in greenhouse gas emissions, which is a crucial step towards environmental safety and development.

Material and methods

Energy management is a vital component of the integrated management system at enterprises of any city and aims to optimize the use of energy resources. It covers the necessary tools, structural organization, and strategies to implement energy saving in accordance with corporate policy. The implementation of energy management systems at local enterprises will help increase control over energy consumption and reduce its costs within the framework of production cycles. Considering energy management as a set of management practices aimed at improving energy efficiency is different from other approaches, such as engineering or technical solutions. It is important to realize that the division into managerial and technical measures is conditional.

Effective use of energy resources at the enterprise can be achieved only under the condition of the interaction of management and technical measures, selected specifically for the needs of each specific case. Engineering innovations and technical improvements will certainly contribute to a more rational use of energy, but their integration into a structured management system at the enterprise will ensure the long-term effectiveness of the energy efficiency improvement process and the overall stability of the company's work.

In the traditional approach, energy management includes a set of functions that ensure the collection of important data about the main energy consumers, the efficiency of the use of resources in various processes and production lines, as well as about the possibilities of reducing energy consumption. Modern methods of managing energy consumption at enterprises often turn out to be insufficiently effective and require optimization. The key role in this process is played by the chief energy department, which, however, usually faces limitations in the resources and organizational structure necessary for in-depth analysis and control of energy consumption at all stages of production.

There is also a noticeable lack of technical means for comprehensive monitoring and evaluation of the efficiency of energy use at production sites. The current system of energy consumption management is characterized by the centralization of responsibility on one person - the chief energy engineer, who, without proper tools and support, is unable to effectively manage and optimize energy consumption processes. This emphasizes the need to develop and implement a new, more efficient energy resource management system, based on modern principles and technologies, capable of providing an organized and responsible approach to energy consumption.

First, it is necessary to determine the basis for the development of an energy consumption management system, to assess the current state of control over the use of energy in cities, to identify weak points in the existing energy accounting system and to propose ways to improve them. Energy consumption management includes the following steps:

- fixation of important parameters;

- comparison of received data with target indicators;
- determination of actions to correct the situation.

This technique is also applicable in the field of energy management, as shown in the practice of managing and regulating energy consumption at the global level (Voloshyn et al., 2023).

This management approach demonstrates high efficiency and can be adapted for energy management at any type of enterprise. The main concept of building these systems is based on the individual responsibility of department heads for the level of energy efficiency in their departments. The development of the system, considering the unique features of a particular enterprise, allows to achieve significant results in energy saving.

The fact that energy audits do not lead to significant improvements can be explained by the fact that the review of energy consumption only provides a snapshot of the situation and does not ensure long-term preservation of high energy efficiency. Practice shows that only some of the recommended measures are implemented after the energy audit. Usually, these are the initiatives that have a solid foundation and are the basis for the business of energy service companies (ESCOs), while other proposals lose their relevance over time and are forgotten (Brych et al., 2023).

Changes in technologies, the introduction of energy-saving initiatives and the use of more efficient equipment should lead to a decrease in specific energy consumption in CHPs. Accordingly, it is necessary to adjust the planned indicators, considering these changes, toto establish new target indicators that will reflect the actual situation in the management objects (Dreshpak et al., 2023).

The management system is characterized by a closed loop, where the interaction between the adopted measures for improvement and the object of management is ensured through effective feedback. The development of effective mechanisms to provide this feedback is critical to the functioning of the system, and its absence can lead to its inefficiency. The system involves the active interaction of personnel involved in its work, and not just automated management.

The success of the implementation of the energy management system depends on the support of the company's management, where active participation and initiative determine the direction of further actions, whether it will be the continuation of reforms or the limitation of only formal documentation. However, the key role in this process is played by the energy manager - the person responsible for managing and optimizing energy efficiency at the enterprise (Oryshchyn et al., 2016).

Energy consumption monitoring allows you to promptly track changes in energy supply and assess the energy efficiency of production processes for accurate assessment of achieved results. The transfer of responsibility for energy consumption to the level of the company's subdivisions strengthens control and expands its functions, contributes to timely detection and correction of problems. The highest, fifth, level of control is achieved when implementing full-fledged energy management, which is based on the principles of system control and regulation of energy consumption, thereby realizing all its advantages (Logutova et al., 2011).

The essence of the ISO 50001 international standard is to assist organizations in creating structured systems and procedures aimed at improving the efficiency of using energy resources. This includes considering the intensity of energy consumption and the amount of energy used. The use of this standard aims not only to reduce greenhouse emissions, but also to optimize energy consumption through a systematic approach to energy management. It enables companies equipped with the necessary information about their energy consumption to set goals, develop effective strategies and plans to optimize energy use, while considering current legislation (Denisyuk et al., 2015).

In accordance with the requirements of the DSTU ISO 50001 standard, first of all, it is necessary to identify all the main energy-consuming departments, processes, equipment and mechanisms, and then to determine the energy base, which will be formed on the basis of key energy and production indicators for the base period. The energy consumption management system (EMS) should include documented confirmation of the process of developing such an energy base (Danilkova et al., 2015).

To analyze the efficiency of energy use and the degree of achievement of the set goals, it is necessary to establish energy efficiency indicators. These indicators should be regularly updated and compared with previous indicators of energy consumption.

One of the effective approaches to energy consumption management is the use of the target energy monitoring (TEM) method, which is widely implemented in large industrial facilities in Western Europe and the USA and is part of their overall management structure. According to the estimates of the British Energy Efficiency Agency, the implementation of the CEM method can reduce energy costs by 10-20% without the need for additional investments in modernization. Implementation of CEM is often recommended as a primary step in comprehensive energy efficiency improvement programs.

The relevance of research and deployment of energy consumption analysis systems based on IoT technologies in modern cities is explained by a number of key factors. First, global energy challenges require a focus on reducing the carbon emissions of human activity. This applies not only to industrial production, but also to the everyday life of city dwellers. Climate change and its consequences force us to reconsider approaches to the use of energy resources, emphasizing the need for more efficient use of them.

The next factor that emphasizes the relevance of this issue is the growing need to optimize the use of available energy resources. Every year, the demand for energy in cities is growing, which requires city administrations and their residents to implement innovative methods to ensure energy efficiency. Innovative solutions, such as IoT, pave the way for smart energy consumption management, allowing not only to monitor, but also to adapt energy consumption to actual needs.

Another important aspect is the modern development of technologies, which provides unique opportunities for the creation of efficient and scalable energy consumption analysis and management systems. These technologies allow not only to collect data on energy consumption, but also to analyze them in real time, identify places of irrational use of resources and take measures to optimize them. The implementation of such systems is of great importance for the urban economy, ensuring its efficiency and sustainability, as well as improving the quality of life of residents.

Considering the above aspects, the importance of research and analysis of energy consumption systems using IoT solutions for modern cities is indisputable. This will not only increase energy efficiency, but also contribute to the sustainable development of urban areas, ensuring a balance between the needs of the present and the future requirements.

Discussion and results

In the process of system development, the key is the selection of technologies that best meet the needs of the project, guaranteeing its efficiency and adequacy. Such selection involves an in-depth review of the existing range of technologies, analyzing their functionality, limitations, and degree of compliance with the unique requirements and goals of the project. Consideration should be given to aspects such as the scalability and flexibility of the system, the efficiency of data processing, the intuitiveness of the interface, and the level of personalization that the system can provide. In addition to technical parameters, the economic feasibility of the chosen solution, its compatibility with existing systems and ease of integration should also be evaluated. Attention to these criteria is a guarantee of high quality and the ability of the product to compete in the information technology market.

The choice of programming language is a critical decision at the initial stage of development of any project in the field of information technology. Each language has its own unique features that make it ideal for certain types of tasks. This overview examines Python, Java, and C#, focusing on their key features and applications. The choice of C# as the main programming language for our research justifies itself due to its performance and ability to work on different platforms with active support from Microsoft. This language is characterized by the ability to easily modulate and scale, which is key to developing programs that can be reliably adapted to changing requirements. In addition, the extensive library of resources and frameworks within the C# ecosystem provides greater efficiency in the development of complex control systems.

Among software development tools, integrated development environments (IDEs) play a key role in simplifying and optimizing the process of creating applications. They provide developers with powerful tools for coding, debugging, and testing applications, which greatly improves the productivity and quality of the final products. Among the most popular IDEs today are Microsoft Visual Studio, Visual Studio Code, and JetBrains Rider, each of which has its own unique features and advantages.

The choice of Visual Studio as the main integrated development environment for research was determined by its high adaptability and an expanded arsenal of tools that greatly facilitate the process of creating a software product. With a large number of project templates available, Visual Studio helps you get started and develop quickly, and code completion features help improve programming productivity. Its comprehensive debugging and testing capabilities help detect and eliminate errors in a timely manner, ensuring the high reliability of the developed applications. Graphic design tools that allow you to intuitively create user interfaces adapted to the specifics of construction and repair management are of particular value in Visual Studio.

Choosing a database management system (DBMS) is a key decision for any research that requires data storage, processing, and analysis. Each DBMS has its own characteristics, advantages, and limitations that should be considered in the context of specific research requirements. MS SQL Server, MySQL, and Oracle are three widely used DBMS that support a variety of applications from simple websites to complex enterprise systems. In this study, it was decided to use MS SQL Server as the key DBMS, due to its affiliation with Microsoft, a leading company in the field of software development. The choice in favor of MS SQL Server is due to its close integration with other Microsoft products, including Microsoft Office and SharePoint, which is an important aspect for companies that have already implemented these solutions in their business processes. In addition, MS SQL Server offers wide support for various programming languages, high security standards and reliability, thereby ensuring the stability of the system and protection against possible threats.

The Smart-MAIC sensor is a modern high-precision device designed to measure various parameters of energy consumption. The sensor can conduct constant monitoring of energy consumption, which allows detecting anomalies and optimizing the use of energy resources. IoT Integration: Smart-MAIC easily integrates with other IoT devices and systems, making it an ideal solution for building comprehensive energy management systems.

In the research process, the three-level architecture in Fig. 1 was used, which is known for its high efficiency and adaptability in the distribution of various system functions. This approach was chosen to provide the system with a harmonious balance between ease of management, scalability, and performance.

The architecture divides the functionality of the system into three main levels: presentation, business logic and data access, where each level is responsible for its specific area of work in the system. The presentation layer creates a user-friendly interface that allows users to efficiently interact with the system while providing security by isolating user access from direct interaction with the database.

The business logic level focuses on processing and analytical work with data, using modern technologies and algorithms for analysis, which contributes to making informed decisions. Thanks to its modular structure, this level allows flexible modification and updating of algorithms without affecting the stability of the system.

At the data access level, the system's interaction with databases and other sources of information is managed, ensuring effective data collection, storage, and processing.

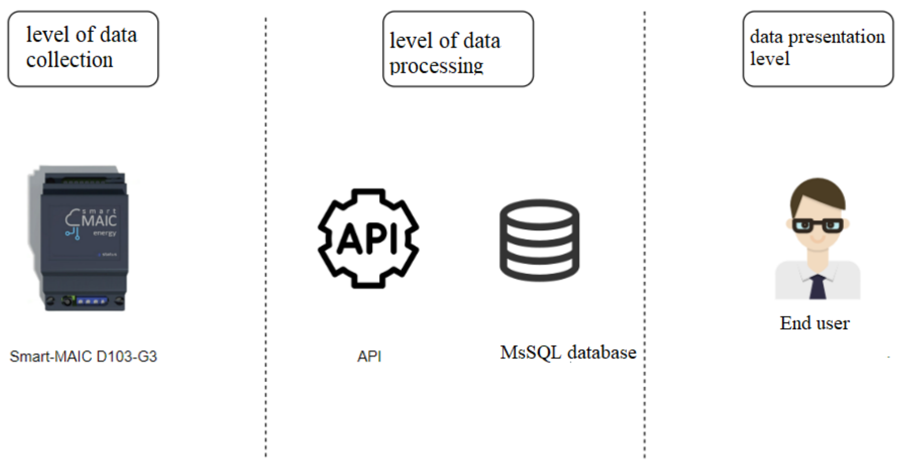

Fig. 1 - Architecture of the energy consumption analysis system

The control scheme of the energy consumption analysis system consists of the following components:

- database. A central repository for storing all data received from the monitoring system and the controller. The database serves as a basis for analysis, processing, and long-term storage of energy consumption information;

- monitoring system. Responsible for collecting energy consumption data from the electricity meter. The system analyzes the received data and sends it to the database for storage. Also provides communication with a personal computer for management and monitoring and cloud storage for data backup;

- controller (Smart-MAIC D103-G3). Receives information from the monitoring system and performs system control and analysis. Can accept commands to perform certain actions based on data analysis. Also, it has direct access to the database to collect or update information;

- electricity meter. It measures the amount of electricity consumed and sends this information via Ethernet to the controller. Next, consumption data is forwarded to the monitoring system;
- a personal computer. It is used to manage and monitor the energy consumption analysis system. Provides a user interface allowing viewing of reports, system settings, and command execution;

The proposed research architecture demonstrates how system components interact with each other to collect, analyze, store, and manage energy consumption data, providing effective control and optimization of electricity use (Voronina et al., 2015).

Management of energy consumption analysis systems plays a key role in today's energy industry, helping to reduce costs and improve resource efficiency. In the context of growing demands for economy and environmental friendliness, as well as the constant growth of energy prices, accurate monitoring and management of energy consumption is becoming a decisive factor for businesses, residential complexes, educational institutions, and other institutions. Traditional approaches to measuring and analyzing energy consumption are often not flexible enough and do not provide the required granularity of data or agility in responding to changes.

Using the developed system for researching the analysis of energy consumption in the network, we obtain the data shown in Fig. 2.

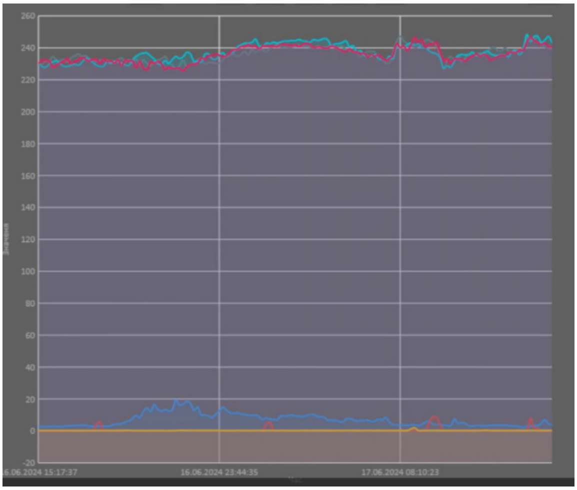

Fig.2 - Current and voltage graph for three phases

Based on the analysis of the graph, it can be concluded that the voltage in the system remains stable throughout the monitoring period, without significant deviations. The current shows several peaks, indicating a short-term increase in power consumption, due to the start of powerful devices or equipment. In general, the power supply system works reliably, with a normal level of voltage stability, but possible fluctuations in current consumption require additional control to prevent overloads. Such analyzes can be useful for monitoring the electrical system to identify potential problems or to determine when and why system loads are increasing. Let us also examine the data from Fig. 3.

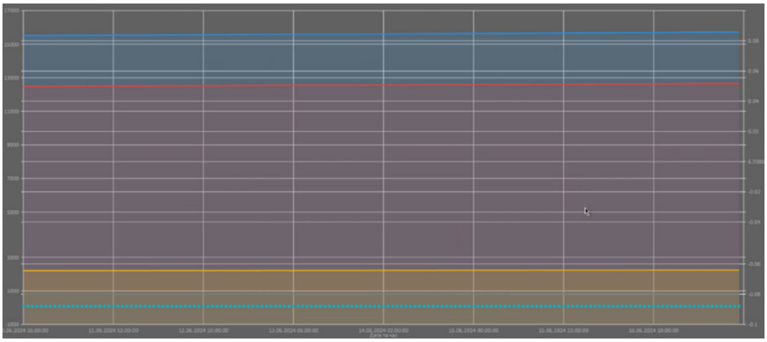

Fig. 3 - Graph with active and reactive energy in three phases

Fig. 3 shows the distribution of active energy between phases, with the largest load on phase L1. This indicates the unevenness of the phase loads, which can lead to inefficient operation of the power grid and possible overloads on individual components. Reactive energy has a relatively small value, but even such indicators can affect the overall efficiency of the system. Optimizing the system through phase balancing and reactive power correction will help improve performance and reduce losses. It is recommended to review the load distribution between phases and, if necessary, to implement reactive energy compensation measures to achieve better energy efficiency.

To increase the efficiency of energy consumption and reduce losses in the system, it is necessary to balance the load between phases, by redistributing the load and installing automatic balancers to avoid overloads and uneven energy consumption. Let us offer a general assessment of the efficiency of the energy system:

$E_{overall}$ — overall efficiency of the energy system.

E_{load} — load balancing efficiency.

E_{comp} — effectiveness of reactive energy compensation

$E_{monitoring}$ — effectiveness of monitoring and control systems.

Assume that all these factors have the same weighting factor (can be adjusted depending on importance). Overall efficiency can be calculated as an arithmetic mean:

$$E_{overall} = \frac{E_{load}+E_{comp}+E_{monitoring}}{3} \quad (1)$$

The proposed model will provide a comprehensive assessment of the impact of various measures on the overall efficiency of the energy system. Depending on specific needs, you can modify the model by adding additional factors or changing weighting factors. Implement measures to compensate for reactive energy, through the installation of capacitor banks or other compensating devices, which will increase the power factor and reduce losses. systems. These actions will help to optimize the operation of the electricity grid, reduce electricity costs, and ensure the stability of its supply.

Conclusion

The study highlights the importance of implementing IoT systems to analyze energy consumption in modern cities, given the global energy challenges and growing ener-gy demand. The proposed architecture of the energy consumption analysis system provides scalability and flexibility, which allows efficient collection, storage, and analysis of data. The results confirmed the hypothesis that the use of IoT systems significantly improves the management and optimization of energy consumption. Data analysis demonstrated voltage stability, but also revealed current consumption peaks and phase load unevenness, highlight-ing the need for automated reactive energy monitoring and compensation to improve energy efficiency. This confirms that such systems contribute to more precise control and optimization of energy use in accordance with modern requirements. The practical contribution of the work consists in the development of specific solutions for the automation of monitoring, bal-ancing of phase loads and compensation of reactive energy, which contributes to improving the quality of energy supply and reducing energy costs.

Further research

For further research, it is recommended to study in detail the impact of different types of IoT sensors and data processing algorithms on the efficiency of energy management systems, and to explore integration with other smart city systems, such as smart lighting and transportation. The development of advanced energy management systems using IoT, cloud computing and artificial intelligence can make a significant difference by automating the collection, analysis, and monitoring of real-time data to quickly respond to problems and optimize energy consumption.

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ХАЛЫҚАРАЛЫҚ АҚПАРАТТЫҚ ЖӘНЕ КОММУНИКАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАР ЖУРНАЛЫ

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