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METHOD FOR REDISTRIBUTING ELECTRICITY IN A MICROGRID NETWORK BASED ON AN ONTOLOGICAL MODEL

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Background. Effective management of electricity distribution in microgrid networks is a key factor in ensuring such systems' reliability, stability, and flexibility. Due to the decentralisation of energy systems and the active introduction of renewable energy sources, there is a growing need for adaptive methods of electricity redistribution that can consider dynamic changes in load and generation. Existing approaches are mostly based on rigid algorithms or centralised control, which makes it difficult to implement flexible scenarios and leads to limited adaptability. The absence of a unified knowledge representation complicates the interaction between Microgrid elements and creates obstacles to system expansion.

Objective. The purpose of this paper is to develop a method for redistributing electricity in a Microgrid using an ontological model that will provide a consistent representation of knowledge about system elements, their interconnections, constraints, and priorities. The proposed approach should facilitate context-oriented decision-making and increase the level of the power system autonomy without the need for radical changes in control schemes.

Methods. The paper analyses typical scenarios of electricity redistribution, identifies conflicts of interaction between Microgrid nodes, and proposes an ontological model that reflects the system structure, connections between sources and consumers, load priorities, and decision-making rules. The main attention is paid to the construction of a formalised knowledge base that ensures interoperability and flexibility in management.

Results. The analysis has confirmed that most existing electricity management systems have limited capabilities to adapt to dynamic changes and do not take into account the semantic relationships between system elements. The proposed ontological model allows for realisation of dynamic energy redistribution, taking into account the context and a set of factors. This ensures an increase in the reliability of the Microgrid and also contributes to a faster response to changing operating conditions.

Conclusions. The proposed method of redistributing electricity in a Microgrid based on an ontological model is a promising direction for building adaptive and intelligent energy systems. Further research is planned to be directed to the implementation of a prototype of the software control module, as well as to the expansion of the ontology to take into account the specifics of various Microgrid configurations.

Keywords: *ontology; Microgrid; energy distribution; flexibility; scalability; semantic approach.*

Introduction

Modern energy systems are rapidly transforming under the influence of renewable energy sources, distributed generation, and the growing need for security of supply. In this context, the concept of Microgrid has become widespread as an effective solution to ensure energy autonomy and increase the resilience of power grids. One of the key challenges in the operation of a Microgrid is the efficient management of electricity redistribution between generation sources, storage facilities, and consumers in the face of dynamic changes in load and energy production. Traditional control methods based on centralised algorithms or rigid rules are not always able to provide sufficient adaptability to environmental changes and take into account the context of interaction between Microgrid elements. In this regard, the search for new approaches is relevant. The method of redistributing electricity in a Microgrid based on an ontological model proposed in this paper is aimed at overcoming the above limitations. The ontological approach makes it possible to formalise knowledge about Microgrid objects, their characteristics, roles, and interactions, which allows creating an adaptive decision-making system taking into account a variety of factors, from technical parameters to consumer priorities. The development of the method is necessary for the redistribution of electricity in the Microgrid using an ontological model, which allows for increasing the efficiency and reliability of energy supply through context-oriented management of energy flows.

Main part

Stand-alone microgrids have been used for many years in remote regions where connection to the centralised grid is technically difficult or economically unprofitable. Due to their scalability, relatively low capital investment, and operational variability, fossil fuel-based power sources have long remained the primary power supply option for such systems. However, given the successful examples of more environmentally friendly solutions, such as solar, wind, and small hydropower, their integration into Microgrid is receiving increasing attention as an effective alternative to traditional approaches.

To effectively integrate distributed renewable energy sources, numerous technical obstacles must be addressed. This will facilitate the preservation of the current level of reliability of the energy supply, maximizing the benefits provided by distributed generation. In this context, the key tasks are as follows [1]:

- Building effective algorithms for planning and dispatching power plants that take into account the unpredictability of demand and generation, as well as ensuring an adequate amount of reserve capacity.
- Ensuring stable and cost-effective operation of the Microgrid with a high level of integration of unstable sources in an autonomous mode.
- Implementation of modern electricity consumption management systems (DSM - Demand Side Management), which allow users to adapt their demands to the needs of the power system.
- Development of new market mechanisms capable of integrating unstable energy sources on a competitive basis, while creating attractive conditions for investors.
- Modernization of protection systems in distribution networks for efficient operation in the conditions of two-way energy flow.
- Developing innovative methods of frequency and voltage control to take into account the growing share of power electronics-based generation.
- Development of control solutions that support the plug-and-play principle, facilitating the simple and reliable integration of new sources in the future [2].

Microgrids are seen as a promising solution for the efficient integration of distributed energy resources (DERs), including renewable energy facilities. They can ensure a stable operation of local power systems independent of the central grid. At the same time, despite the positive potential, there are several technical and organisational challenges that require further attention for the comprehensive implementation of Microgrid in widespread practice.

The concept of the Microgrid was first introduced in the technical literature in [3] as a solution for the reliable integration of renewable energy sources, including energy storage systems (ESS) and controlled loads. Such a Microgrid is perceived by the main grid as a single element, responding to appropriate control signals. Although the detailed definition of Microgrid is still being discussed in technical forums, it can be described as a cluster of loads, distributed generation (DG), and ESS facilities working in a coordinated manner to provide a reliable electricity supply, connected to the main grid at the distribution level at a single connection point. The adoption of Microgrid as a paradigm for the mass integration of distributed generation will allow solving technical problems in a decentralised manner, reducing the need for extremely extensive and complex central coordination and facilitating the implementation of the Smart Grid [4].

In general, a Microgrid can be configured in a variety of ways, for example, as shown in Fig. 1. However, some organizations, such as the Consortium for Electric Reliability Technology Solutions (CERTS), recommend a structure in which loads are connected to feeders with existing generation sources. In situations where there is a close interaction between different energy systems, such as heating, hot water, etc., Microgrids can combine these energy sources and manage them efficiently. If necessary, the system can manage all energy sources in a coordinated manner and adjust the management strategy according to current conditions [5].

Various initiatives around the world are contributing to the further development of the Microgrid concept through research, development, and demonstration of the latest technologies. Among these projects are Bella Coola and Hydro-Quebec in Canada, CERTS in the United States, Microgrid and More Microgrid in Europe, Huatacondo in Chile, and the New Energy and Industrial Technology Development Organization (NEDO) programs in Japan [6].

Microgrid is capable of functioning in both a mode connected to the main grid and in an autonomous mode, while also being able to transition effectively between these modes [7]. In the connected mode, the lack of electricity can be compensated by the main grid, and the excess energy generated in the Microgrid can be returned to the main grid or used to provide ancillary services. In off-grid mode, it is essential to maintain a balance between the real and reactive power generated in the Microgrid, while also considering the temporary transfer of energy from/to the storage facilities to satisfy the needs of local consumers. The IEEE 1547 standard provides guidelines for the incorporation of Distributed Energy Resources (DER) modules [8]. Isolation of the Microgrid from the main grid can be both planned and unplanned. A planned disconnection can occur during maintenance or due to a deterioration in the quality of electricity in the main grid, which can affect the stability of the microgrid. Unplanned outages can occur due to technical malfunctions or other unforeseen events about which Microgrid has no information; it is important to detect such outages promptly to ensure the safety of personnel and the stable operation of Microgrid, as well as to implement necessary changes in management strategies.

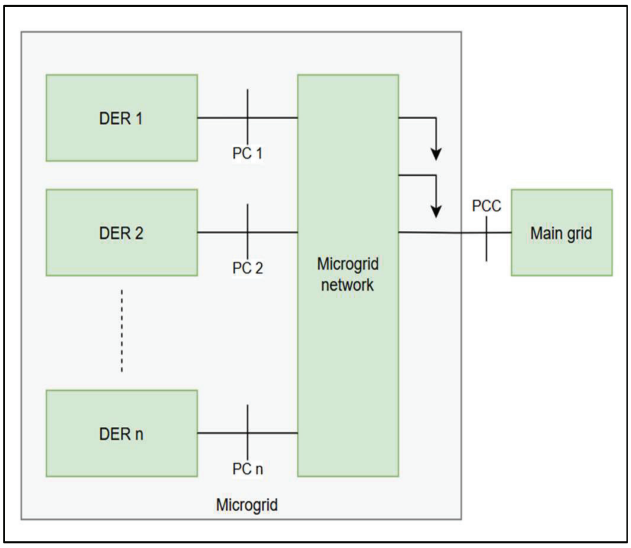

Fig. 1. Schematic diagram of a universal Microgrid with several DERs

Microgrids that do not have a switching point with the main grid (PCC) are called isolated. This applies to remote locations, such as villages or industrial facilities, where connection to the main grid is not possible due to technical or economic constraints. Therefore, these Microgrids operate exclusively in an autonomous mode.

General overview of Microgrid management approaches. The basic principles of Microgrid control include Droop Control, which enables distributed generators to autonomously modify their output by mimicking the behaviour of traditional generators. This facilitates decentralised load distribution, eliminating the necessity for a centralised controller. Another important method is Model Predictive Control, which uses mathematical models to predict future system behaviour and optimize control actions, providing more accurate and adaptive control. In addition, Multi-Agent Systems are used, where autonomous agents interact with each other to achieve a global goal, such as optimal energy distribution or load balancing. However, the implementation of these methods faces several challenges, including the integration of renewable energy sources, which are variable and unpredictable, creating difficulties for stable Microgrid operation. It is also important to ensure the stability and reliability of the Microgrid during changes in loads and generation conditions, as well as to protect the system from cyber threats, as the growing dependence on digital technologies increases the vulnerability of the Microgrid. Future trends include the development of intelligent control algorithms using artificial intelligence and machine learning to improve adaptability and efficiency, integration with smart grids to improve grid efficiency, and the development of common standards and protocols to ensure interoperability of Microgrid components [9].

There are different approaches to Microgrid management, including centralised, decentralised, and hybrid management. In the centralised approach, all decisions are made by a single central controller that has complete information about the system state, ensuring resource optimization and coordination of all components. However, this method has its drawbacks, including high vulnerability to central controller failure, high requirements for communication infrastructure, and limited scalability. Decentralised control implies that each element of the Microgrid, including generators, storage, and loads, has its controller and makes decisions autonomously based on local information. This increases reliability, reduces communication requirements, but can lead to coordination problems between components. A hybrid approach combines centralised and decentralised management, with a central controller responsible for strategic decisions and local controllers for operational decisions. This ensures a balance between global optimization and local autonomy and system reliability, but requires complex coordination between levels of management.

Traditional microgrid management methods have several limitations. In particular, they do not always effectively cope with the integration of renewable energy sources, such as solar and wind, due to their unpredictability and instability, which can lead to system stability problems. Also, traditional systems are often unable to quickly adapt to changes in load or generation, which reduces control efficiency. With the increasing number of components in a Microgrid, traditional methods may have difficulty coordinating and managing. In addition, centralised systems have a single point of failure - the central controller - and if it fails, the entire Microgrid can lose control, which negatively affects system reliability.

Definition and classification of resilience in a Microgrid. Consider a Microgrid in a steady state, where all system parameters have constant values that do not violate operational limits, such as permissible levels of voltage, current, and frequency [10]. Such a system is considered to be stable if, after a disturbance occurs, its parameters return to new or previous steady-state values, while remaining within acceptable limits, and without unforeseen consumer outages. It is worth noting that controlled load shedding within the framework of the demand response concept, when consumers voluntarily participate in the management of the Microgrid [11], is not considered a destabilizing factor if performed within certain technical limitations. In cases where load disconnection occurs to isolate faulty equipment rather than to resolve voltage or frequency problems, and the system remains within the limits of operational stability, it is also considered stable. Unlike centralised power systems, where, due to the large number of consumers, it is permissible to disconnect part of the load for the sake of overall stability [12], a Microgrid serves a relatively small number of consumers. This allows operators to prioritize certain feeder lines, such as those that supply electricity to medical facilities. In this case, if a critical consumer is disconnected, the Microgrid loses its main function. Therefore, disconnecting such loads to keep the rest of the system running, except in the above cases, indicates a loss of system stability according to the criteria presented in this study. The classification block diagram is shown in Fig. 2.

In this definition, disturbances are defined as any external influences on the system, such as changes in load, equipment failure, or adjustments to the operating mode or set parameters. If the disturbances are small and allow the use of a linearized model to describe the behaviour of the system, they are considered small. In cases where the impact is significant, for example, a short circuit, a sudden change in the Microgrid's mode of operation from a connected to an autonomous source, or the loss of a generation source, such disturbances are classified as large. It should be emphasized that pre-planned transitions of the Microgrid to isolated mode are accompanied by less significant voltage and frequency fluctuations, as the protection and control parameters are pre-adapted to the new conditions. The instability caused by small disturbances can manifest itself in both the short-term and long-term horizons, depending on its source. For example, inefficient power distribution between several inverters can cause steady fluctuations that quickly go beyond the permissible limits. In turn, a microgrid with a high load level can demonstrate similar fluctuations even with minor changes in load, but in the long term.

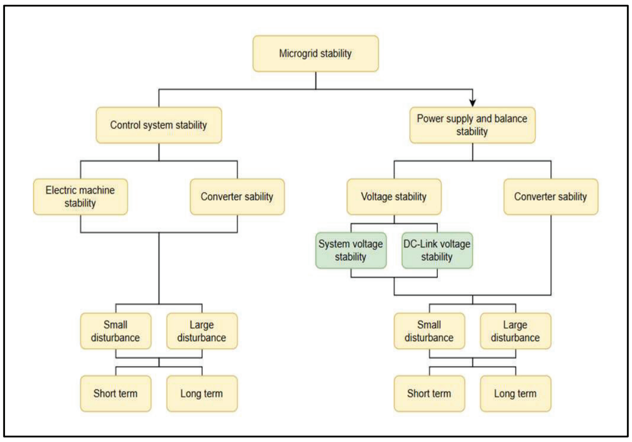

Fig. 2. Classification of stability in Microgrid

The stability of power supply and power balance in a Microgrid includes ensuring that generation and consumption are matched, as well as rational load distribution between distributed energy resources (DERs). Problems arise in cases of loss of generation capacity, excessive loads on DER, incorrect redundancy, or undesirable response of sensitive consumers (e.g., induction motors). This can lead to frequency and voltage stability disturbances.

Frequency stability: A microgrid with low inertia and a significant share of renewable generation is particularly vulnerable to generator failures. In such conditions, frequency changes occur quickly, and traditional regulators may not have time to respond. Furthermore, the close relationship between frequency and voltage makes it difficult to control. Frequency stability can be disturbed due to a sharp increase in consumption, insufficient power reserves, or uncoordinated operation of controllers, which manifests itself in the form of frequency fluctuations or even emergency shutdowns.

Voltage stability: In most cases, the Microgrid demonstrates voltage stability due to short transmission lines. However, problems can arise in weak or outdated networks. The situation becomes even more complicated if there are loads with high sensitivity to voltage fluctuations or if induction motors dominate the system. In the event of component failures, delayed voltage restoration can occur, leading to excessive reactive power consumption. To ensure stability, it is important to coordinate the distribution of reactive power between DERs, as the voltage is not the same throughout the system. Conventional droop control does not always provide a balanced distribution of reactive power, so communication methods are considered to improve the situation. In addition, stabilization of the voltage on the DC bus of the inverters is important, as large fluctuations can cause instability of the entire Microgrid [13].

Functional requirements for the Microgrid control system. The design aspects of the energy management system (EMS), which is a key element of the new Microgrid, address both the functional needs and the technical challenges associated with its implementation. The EMS is responsible for monitoring and controlling distributed energy sources (DERs) and consumers to achieve optimal functioning of the entire system. It also processes data from energy companies and weather services, ensuring interaction with DER, loads, and external platforms.

Basic functional requirements for EMS:

1. EMS forecasting uses historical information and other available data to predict DER generation, load behaviour, and market dynamics. This happens on different time scales and is the basis for further optimization decisions. In the context of a Microgrid, forecasting is complicated by the high variability and unpredictability of renewable energy sources and the behaviour of some types of loads.
2. Real-time optimization ensures uninterrupted power supply and reduced generation costs. Different scenarios use different algorithms, which are usually formulated as nonlinear optimization problems with different objective functions. In particular, strategies can be applied to manage consumption, Demand Response, electric vehicle charging management, and the implementation of V2G (Vehicle-to-Grid) technologies.
3. In data processing and communication, information about DER, load, and market conditions is used for analytics to help EMS better understand system performance, adjust forecasts, and improve optimization efficiency. It also serves as a basis for developing control strategies for new applications. The Microgrid operator interacts with the EMS through an HMI (human-machine interface), which allows for control of key processes.

Given the diversity of energy resources that make up the Microgrid, the EMS must ensure interoperability between the various components and external systems. External data must be adapted to internal EMS formats using appropriate protocols and transcoding. The EMS communication interface must be flexible and scalable to support expanding functions and a stable electricity supply.

Energy management plays a key role in ensuring the stable and efficient operation of the Microgrid in both grid and isolated modes. Its main task is to regulate the output power and/or voltage of each generator in the system. In general, control approaches can be divided into two categories: those that use communication channels and those that do without them. In a communication-based system, data on the state of the Microgrid is transmitted between components to coordinate the operation of each energy source. The choice of communication method depends on several factors: distance to sources, safety requirements, costs, and available technologies (fiber optic lines, microwave channels, PLCs, radio, etc.). These systems are implemented in the form of centralised or decentralised control, or a combination of both. Centralised energy management implies that a single control center makes decisions about the optimal parameters of generator operation. It receives all the necessary measurement data, based on which the operating points for each source are calculated and set. The purpose of such control is to minimize operating costs, reduce the negative impact on the environment, and increase the overall efficiency of the system. Generator control systems execute commands after a decision has been made on the optimal operating modes. This is illustrated in Fig. 3.

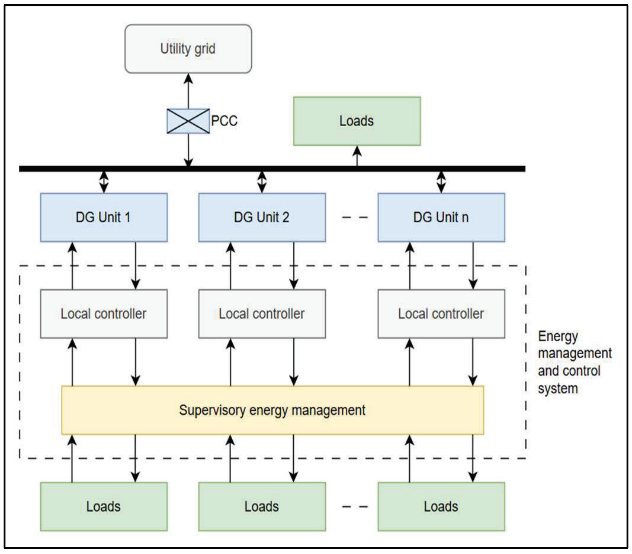

Fig. 3. Centralised electricity management scheme

The main limitations of the centralised scheme are high computing resource requirements and vulnerability to communication failures that can disable the system. At the same time, this architecture allows for global optimization. In the decentralised energy management variant, all local generator controllers are connected by a common communication bus through which data is exchanged between them. Loads are also connected to each of the local controllers. The concept of this system organization is shown in Fig. 4. Based on the information received, each controller independently determines the operating parameters for the corresponding energy source. This approach reduces computational costs and redundancy in communications.

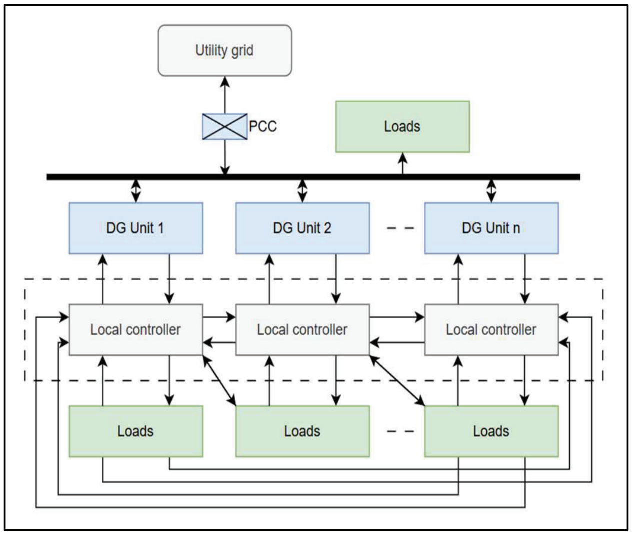

Fig. 4. Decentralised energy management scheme

In cases where the organization of communications is technically difficult or economically unprofitable, each generation module (DG) must function autonomously. Each power source has a separate controller that operates without coordination with the others. The main advantages of this approach include no need for communication infrastructure and easy scalability of the control system [14].

Microgrids are becoming an integral part of modern methods of optimizing energy distribution. Capable of operating both in grid-connected and autonomous mode, they open up new opportunities for both grid operators and end users. In particular, Microgrid helps to improve the reliability of power supply by enabling islanding, which reduces the duration of outages. They also improve the quality of electricity through local load management, ensure economic profitability by selling excess energy to the grid, reduce transportation costs, and reduce CO_2 emissions through the active use of renewable sources of distributed generation [15].

Overloads in distribution lines or failures in the higher-level grid can lead to the inability to fully supply all consumers in the distribution network. In addition, when connecting new loads, there is often a need to modernize or strengthen the existing infrastructure. Various approaches to optimizing distribution networks have been proposed in scientific publications. For example, [16] describes a two-level methodology for expanding networks that takes into account both emergencies and equipment relocation, with investment tasks being solved first and then operational tasks. An algorithm is presented in [17] that considers load fluctuations, generation instability, and the variability of renewable energy sources, optimizing voltage control through Smart Grid technologies, taking into account the number of distributed generation sources. Study [18] proposes a methodology for improving network planning based on the analysis of the load profile of medium and low voltage substations. In [19], an approach is developed for distribution system operators (DSOs) that can be applied to both radial and mesh networks. In this context, both active and passive network modernization measures are considered, including the need to build new lines or replace equipment. Approaches to Microgrid planning where we are talking about models under uncertainty, where the problem is divided into investment and operational subtasks, AC, DC and hybrid Microgrid options are studied, with an emphasis on choosing the optimal size and location of energy sources, although aspects of line losses and power flow are not included in the analysis [20-22].

The above studies have solved the key tasks related to Microgrid planning. However, certain limitations persist, particularly regarding accounting for uncertainty in renewable energy generation. Most previous approaches focus on only one type of generation, either wind turbines (WT) or solar photovoltaic systems (PV), and do not take into account their joint impact in the context of demand response strategies. To the best of the authors' knowledge, there are very few studies that comprehensively analyse the interaction between demand response and uncertainty arising from fluctuations in the production of several types of renewable energy sources, taking into account the interests of different participants in the Microgrid energy system. The study [23] considers the coordination of demand response strategies, taking into account the instability of both types of DER - wind and solar energy. The two-level planning model covers the interests of several stakeholders, including Microgrid operators and end users. Both parties seek to maximize their benefits in the face of variable electricity tariffs. In addition, the paper proposes a hybrid approach that combines analytical methods to achieve the balance. The planning model for isolated microgrids takes into account the characteristics of many stakeholders and the need to achieve a multi-criteria balance. The proposed model is based on a two-level stochastic approach that allows for the coordination of demand and variability of renewable energy generation. The novelty is the use of a real-time dynamic pricing mechanism to balance supply and demand between users and the Microgrid. To solve the formulated model, an approach based on the theory of operational sequences (SOT) is implemented, which allows for effective work with the uncertainty of DER generation. In addition, a combined algorithm, Jaya-IPM, which combines the heuristic Jaya method with the intra-point method (IPM), has been developed to achieve high accuracy and speed of computation. The proposed methodology was tested on a specific Microgrid system, and the results were compared with existing approaches. The comparison showed the effectiveness and advantages of the proposed approach in planning and managing energy resources.

One of the key advantages of using an ontological approach in Microgrid management is the unification of knowledge about grid objects. The ontology allows for the creation of a formalised system model that includes characteristics of distributed energy sources (DER), loads, network topology, consumer priorities, types of generators, and other important components. This approach helps to improve accuracy in stochastic models, as it allows you to more accurately set the constraints and characteristics of the elements, which, in turn, reduces modelling errors. In addition, in co-optimization tasks, an ontology can act as a source of structured data that allows automating the formation of input parameters, increasing the efficiency of computing processes.

Context-aware decision-making. The ontological model in the context of Microgrid management allows for taking into account not only purely physical parameters of the system, but also contextual aspects that are critical for decision-making. In particular, such a model can include load priorities, such as the higher importance of power supply to hospitals compared to residential buildings, time preferences, such as increased consumption at night, as well as logical rules, such as automatically excluding a generator from the optimization process in case of overheating. This approach significantly extends the functionality of classical optimization models, which typically operate only with numerical parameters and mathematical constraints, without taking into account complex logical and contextual dependencies.

The use of ontology in Microgrid modelling ensures flexibility and scalability of the system, allowing you to add new types of objects, events, or scenarios without having to change the core of the algorithm. This is especially important for adapting to dynamic power system conditions. For example, if a new type of consumer or energy source is added, the ontological model provides an immediate interpretation of its role and impact on the optimization process, which eliminates the need to reprogram the entire system and reduces the time to implement changes.

The ontological approach facilitates the implementation of inter-agent or decentralised control in Microgrid systems. In particular, in architectures such as Commelec, each agent can learn about the characteristics and behaviour of other agents through a common ontology. This enables efficient knowledge sharing between distributed energy resources (DERs) even in the absence of a centralised controller, which directly enhances hybrid Microgrid control models. In addition, the ontology provides a semantic justification for the optimization results, which solves one of the key problems of traditional mathematical models - the “black box” effect. Thanks to ontological structures, it is possible to explain why a certain solution was chosen: based on logical rules, priorities, or categories of objects, which is especially important when managing critical infrastructure.

In the two-level Microgrid management model, as shown in Fig. 5, the ontology plays a key role at both levels of decision-making.

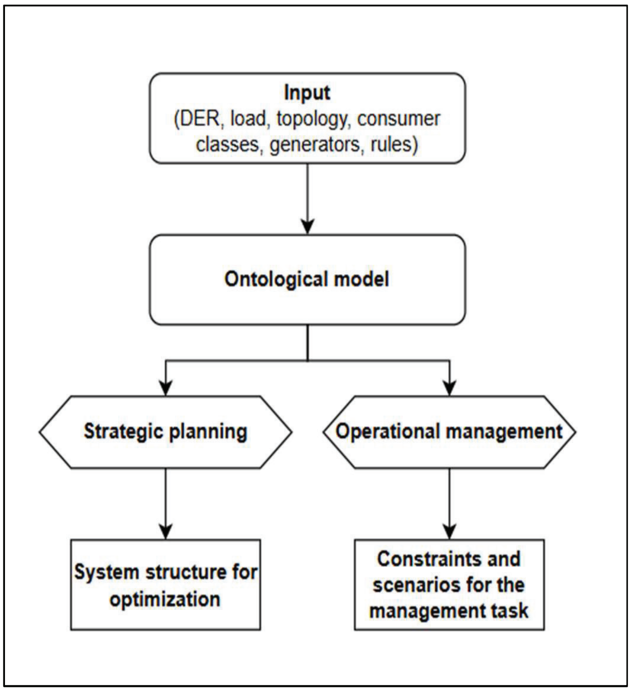

Fig. 5. Using ontology in a two-level Microgrid model

At the strategic planning level, the ontological model is used to automate the construction of the grid structure, classify nodes, and determine types of generators and categories of consumers. This allows for a formalised representation of the system, which serves as the basis for further optimization. At the operational level of management, the ontology provides logical rules that take into account contextual conditions, such as the priority of objects (for example, the impossibility of shutting down a hospital), time modes of consumption, or technical limitations of equipment. Such rules are transformed into constraints for optimization tasks, increasing the accuracy and validity of decisions.

The application of the ontological approach to the management of Microgrid systems allows for a significant change in the decision-making structure compared to traditional methods. Table 1 shows the key differences between these approaches by critical criteria.

In traditional systems, the network structure is formed manually based on fixed configurations. Instead, the ontological model allows you to automatically create the system structure through a semantic description of its components - generators, nodes, and loads. Another important difference is the way parameters are defined. In classical approaches, they are set manually or through predefined algorithms. An ontology provides dynamic extraction and updating of object attributes, which significantly increases the relevance of input data. Decision-making logic in traditional systems is mostly limited to numerical constraints, while the ontological approach allows for the inclusion of logical rules, time dependencies, priority hierarchy, and other semantic aspects. This makes it possible to implement more flexible and realistic management scenarios. In classical systems, decentralised control is usually based on a centralised controller that creates a single point of failure. The ontology, on the other hand, allows each agent to independently obtain knowledge from the overall model, ensuring efficient operation even in the absence of a central node.

Table 1. Comparative analysis of traditional and ontological approaches

Criteria	Traditional approach	Ontological approach
Formation of the system structure	Manually based on fixed configurations	Automatically using the semantic descriptions of objects
Defining the parameters	Parameters are entered manually or using prescribed algorithms	Object attributes are extracted from the ontology and updated dynamically
Decision-making logic	Based on numerical restrictions and conditions	May include logical, temporal, hierarchical rules and priorities
Support for decentralised governance	A centralised controller is required	The agent can get knowledge from the ontology, and it works without a central node

To demonstrate the qualitative difference in system behaviour before and after the implementation of the ontological approach, it is advisable to consider a typical emergency scenario, such as a line break or a failure of one of the generators (Fig. 6).

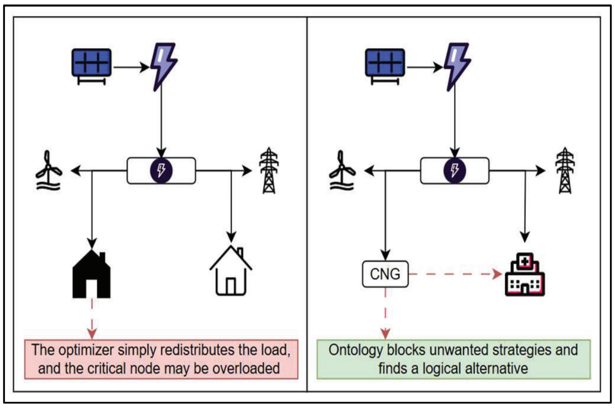

Fig. 6. Using ontology in a two-level Microgrid model

In a traditional control system, the optimizer performs a simple load redistribution between available resources. Such an approach can lead to overloading of critical network elements, including high-priority nodes such as medical facilities. Instead, the ontological model allows taking into account not only technical parameters but also logical rules, priorities, and context. The system uses a CNG (Central Node of Generation) and "understands" that a hospital cannot be shut down, and, guided by semantic knowledge, blocks unacceptable options by offering a logical alternative. A summarized comparison is shown in Fig. 7.

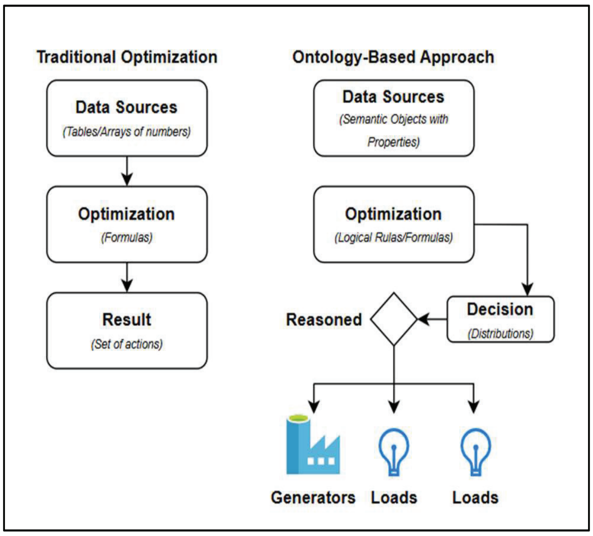

Fig. 7. Comparison of traditional optimization with an ontological approach

The system can justify the choice of a particular option. This approach ensures transparency of management, which is critical for critical infrastructure facilities. On a graphical level, this can be represented as a decision tree or flowchart, where arrows point to factors that influenced the choice: consumer priority (e.g., a hospital is more important than a residential building), current state of energy sources (DER), safety policies (e.g., prohibition of overloading key elements), and contextual conditions such as time of day.

Conclusions

Microgrid, as a promising distributed energy architecture, demonstrates significant advantages in improving the reliability and environmental friendliness of local energy supply, especially in conditions of autonomous operation and isolation from centralised networks. The article proposes a method for redistributing electricity in a Microgrid based on an ontological model, which allows for increasing the efficiency of energy flow management. Particular attention is paid to the principles of Microgrid sustainability, in particular in the context of dynamic changes in load, generation, and transitions between operating modes. It is established that the effective functioning of a Microgrid is possible only with the introduction of adaptive control systems based on predictive modelling, multi-agent interaction, and the principles of energy sustainability.

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Спосіб перерозподілу електроенергії в мережі Microgrid на базі онтологічної моделі

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Проблематика. Ефективне управління розподілом електроенергії у мережах типу Microgrid є ключовим фактором для забезпечення надійності, стабільності та гнучкості таких систем. У зв'язку з децентралізацією енергетичних систем та активним впровадженням відновлюваних джерел енергії, зростає потреба в адаптивних методах перерозподілу електроенергії, здатних враховувати динамічні зміни в навантаженні та генерації. Існуючі підходи переважно базуються на жорстких алгоритмах або централізованому управлінні, що ускладнює реалізацію гнучких сценаріїв і призводить до обмеженої адаптивності. Відсутність єдиного представлення знань ускладнює взаємодію між елементами Microgrid та створює перешкоди для розширення систем.

Мета дослідження. Метою цієї роботи є розроблення способу перерозподілу електроенергії в Microgrid із використанням онтологічної моделі, яка забезпечить узгоджене представлення знань про елементи системи, їхні взаємозв'язки, обмеження та пріоритети. Запропонований підхід має сприяти контекстно-орієнтованому прийняттю рішень і підвищенню рівня автономності енергосистеми без необхідності радикальних змін у схемах управління.

Методика реалізації.. У роботі проаналізовано типові сценарії перерозподілу електроенергії, визначено конфлікти взаємодії між вузлами Microgrid, а також запропоновано онтологічну модель, яка відображає структуру системи, зв'язки між джерелами та споживачами, пріоритети навантажень і правила прийняття рішень. Основна увага приділена побудові формалізованої бази знань, яка забезпечує інтероперабельність і гнучкість в управлінні.

Результати дослідження. Проведений аналіз підтвердив, що більшість наявних систем управління електроенергією мають обмежені можливості щодо адаптації до динамічних змін і не враховують семантичні зв'язки між елементами системи. Запропонована онтологічна модель дозволяє реалізувати динамічний перерозподіл енергії з урахуванням контексту та множини факторів. Це забезпечує підвищення надійності Microgrid, а також сприяє більш швидкому реагуванню на зміну умов експлуатації.

Висновки. Запропонований спосіб перерозподілу електроенергії в Microgrid на базі онтологічної моделі є перспективним напрямом для побудови адаптивних та інтелектуальних енергетичних систем. Подальші дослідження планується спрямувати на реалізацію прототипу програмного модуля управління, а також на розширення онтології для врахування специфіки різних конфігурацій Microgrid.

***Ключові слова**: онтологія; Microgrid; розподіл енергії; гнучкість; маштабованість; семантичний підхід.*

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