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Optimisation of energy solutions: Alternative energy, reactive power compensation, and energy efficiency management

Abstract. The relevance of the problem under study is determined by the need to create a sustainable, efficient and environmentally safe energy complex. The growth of the world population, industrial development, and overall energy demand endanger the provision of society's energy needs, making the need for research urgent at the present time. The purpose of the study is to examine optimal energy optimisation strategies, including alternative energy, compensation of reactive power, and energy efficiency management, to ensure the stable and efficient functioning of the energy complex. Among the methods used, analytical, classification, functional, statistical, and synthesis methods were applied. In investigating the optimisation of energy solutions, a thorough analysis of various aspects of alternative energy, reactive power compensation, and energy efficiency management was conducted. This analysis encompassed various aspects and parameters related to these areas, including technical, economic, and environmental indicators. As a result of the study,

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it was established that alternative energy has significant potential for ensuring sustainable development of the energy system. It can serve as a reliable source of energy that does not harm the environment and is not dependent on limited resources. In addition, reactive power compensation was recognised as an effective way to avoid energy losses in the system. This strategy helps to ensure more efficient energy use and reduce losses during transmission and distribution. Energy efficiency management also proved to be a key aspect in achieving energy supply sustainability. This allows optimising resource utilisation, reducing energy costs, and mitigating the negative impact on the environment. The practical value of the study lies in the development of innovative recommendations and strategies for energy optimisation, which will contribute to the creation of a stable, efficient, and environmentally safe energy complex and enhance its compliance with current and future challenges, making a considerable contribution to the development of science and the energy sector

Keywords: sustainable development; environmental safety; minimisation of losses; resource conservation; reduction of negative impact

INTRODUCTION

The examination of optimisation of energy solutions, in particular alternative energy, reactive power compensation and energy efficiency management, is critical in the modern world. The increase in population, rapid industrialisation, and continuous growth in energy demands pose significant challenges for effective and sustainable energy supply. Transitioning to alternative energy sources becomes imperative to reduce dependence on depleting natural resources, mitigate environmental pollution, and address climate change issues. Exploring alternative energy sources such as solar, wind, geothermal, and hydroelectric power aids in developing new technologies and approaches for creating a stable and environmentally friendly energy infrastructure. Reactive power compensation and energy efficiency management are vital aspects of energy optimisation. Implementing efficient compensation methods reduces energy losses, enhances supply quality, and ensures the stability of electrical networks. Energy efficiency management facilitates optimal resource use and reduces energy consumption, positively impacting the economy and the environment. Research in this area significantly contributes to science and technology, fostering innovative approaches in the energy sector and ensuring society's sustainable development amidst the growing challenges of the modern world. The investigation of energy solution optimisation is a crucial component in shaping the future, where efficient and sustainable energy supply underpins successful societal development.

The problem under study lies in resolving complex challenges related to effective and sustainable energy provision for contemporary society. One key issue is finding a balance between high energy demand and limited natural resources. The increasing population, industrial development, and widespread use of energy-dependent technologies jeopardise the stability of energy systems, necessitating the exploration of new and efficient solutions. Another problem involves transitioning to alternative energy sources and establishing a robust infrastructure for their integration. The adoption of alternative sources such as solar, wind, and hydroelectric power necessitates the development of new technologies and storage/transmission systems, along with investments in their advancement. Addressing the technical and economic aspects to ensure the effectiveness and stability of alternative sources is exceptionally crucial. Furthermore, the research problem encompasses energy security and the resilience of the energy system. The implementation of new technologies and the enhanced role of alternative sources must guarantee a reliable and stable energy supply, which is critical for the functioning and development of contemporary society. Reducing the negative environmental impact is a complex challenge in energy optimisation research. Finding solutions to minimise environmental pollution and reduce emissions of harmful substances into the atmosphere during energy production and consumption is crucial. The problem under study requires an integrated approach, considering technical, economic, environmental, and social aspects to ensure a sustainable, efficient, and environmentally friendly energy complex for present and future generations.

According to a study by M.L. Lysychenko *et al.* (2021), the effective compensation of reactive power can lead to reduced energy losses and improved operation of power systems, especially in industrial and commercial enterprises. This promotes more rational use of electric power and reduces energy resource consumption, contributing to sustainable development and enhanced energy efficiency. O. Salavor *et al.* (2022) emphasise that the development of solar and wind energy is vital for achieving sustainable development and mitigating the negative impact on climate change since these alternative energy sources are environmentally safe and do not emit harmful gases contributing to global warming. Encouraging the use of solar and wind energy can bring significant positive changes in the energy sector and environmental conservation, fostering sustainable economic and ecological development.

S.P. Denisyuk *et al.* (2022) highlight that implementing energy-efficient technologies can reduce energy costs and ensure a stable and reliable energy future. This can enhance economic efficiency, reduce dependence on exhaustible resources, and decrease the environmental impact of the energy sector. G. Kostenko & C. Zgurovets (2023) illuminate that integrating solar panels, wind turbines, and other alternative energy sources into the power grid is a critical step toward ensuring reliable and stable energy supply. This expansion of the resource base reduces dependence on conventional raw materials, contributing to a more resilient and environmentally balanced energy system.

Yu.A. Veremiychuk *et al.* (2020) emphasise the significance of developing intelligent energy management systems and their implementation in construction and industry to ensure more efficient use of energy resources and reduce energy consumption. This enhances energy efficiency and competitiveness of enterprises, reduces environmental impact, and promotes sustainable development. Results by N. Gelich *et al.* (2020) confirm that alternative energy sources, especially solar and wind, are becoming increasingly competitive compared to conventional sources like coal or gas. This has led to their increased utilisation, fostering the development of sustainable and environmentally friendly energy, ensuring a more efficient and stable energy supply.

The purpose of the study is to explore specific challenges such as ensuring an effective and sustainable energy supply, developing alternative energy sources, and reducing the negative environmental impact for further optimisation of energy solutions.

MATERIALS AND METHODS

The analytical method facilitates in-depth analysis of complex data in the context of alternative energy efficiency. With the use of this method, it was possible to identify the relationship between energy sources, analyse the influence of factors on the efficiency of solar and wind installations, and put forward recommendations for the further development of sustainable energy. The analytical method also assisted in evaluating the economic benefits of using alternative energy sources and determining their influence on reducing dependence on coal and other finite resources. Comparing data on production costs and investments with expected economic benefits allowed understanding the prospects of alternative energy development and transitioning towards a more resilient and efficient energy system.

Using the statistical method, key performance indicators of alternative energy sources, such as solar and wind energy, were determined in comparison with conventional sources. The statistical method also enabled identifying dependencies between factors affecting the efficiency of alternative energy sources and isolating key factors influencing their productivity. Analysing statistical data facilitated the development of optimisation strategies aimed at enhancing the efficiency and stability of alternative energy sources, thereby improving their reliability and economic feasibility.

By employing the functional method, crucial aspects of alternative energy efficiency were elucidated concerning their functionality and interaction with the energy infrastructure. The study disclosed optimal ways to integrate solar and wind installations within existing electrical systems, ensuring reliable and uninterrupted energy transmission. This method allowed focusing on analysing the impact of alternative sources on network capacity, peak load support efficiency, and backup power capabilities. It facilitated the identification of potential advantages of employing alternative sources in local and global energy systems, emphasising optimal planning for the development of modern, sustainable energy networks. The structural-functional method aided in the detailed analysis of the interaction between alternative energy sources and the existing energy system, delineating functional blocks, and assessing the influence of each element on the overall system's efficiency. This study enabled the development of optimal integration strategies for alternative sources, aimed at ensuring the stability and balance of the energy infrastructure.

The deduction method played a pivotal role in formulating general principles and theoretical models, providing the basis for analysing the efficiency of alternative energy sources. This method unveiled fundamental dependencies and regularities defining the functioning and advantages of solar and wind installations. It established a systematic theoretical framework for further research on the efficiency of alternative energy sources, isolating critical factors and influential variables contributing to their enhancement. The analysis of deductive research results can serve as a foundation for developing innovative technologies and effective strategies in the field of alternative energy, fostering a more sustainable and resilient energy future.

By employing the synthesis method, innovative solutions and comprehensive strategies were developed for the integration of solar and wind energy into the power system. This method facilitated the amalgamation of diverse components and technologies, ensuring optimal direction for the development of alternative energy sources to guarantee a sustainable and efficient energy future. The synthesis method also aided in identifying optimal locations for solar and wind installations, considering landscape, climatic conditions, and electricity consumers. Integrating data from the synthesis method enabled the development of global and local projects for the advancement of alternative sources, contributing to climate change mitigation and ensuring stable and sustainable energy supply.

RESULTS AND DISCUSSION

Advancements in alternative energy technologies and strategies for sustainable development

Alternative energy represents a concept in the energy sector's development based on utilising energy sources distinct from conventional coal, oil, and gas resources. This form of energy includes solar, wind, hydro, biomass, geothermal energy, and other sources that occur naturally or are inexhaustible. The advancement of alternative energy holds significant importance in the context of sustainable development and the preservation of natural resources. It plays a crucial role in ensuring energy security, reducing greenhouse gas emissions, and mitigating the adverse effects of climate change. Furthermore, it aids in diversifying the energy mix and reducing dependence on the import of precious energy resources. The implementation of alternative energy necessitates continuous innovation, technological development, and encourages investment in the energy sector. Alternative energy stands as a promising industry, gaining increasing popularity and support from governments and society. The introduction and development of alternative energy sources contribute to the creation of new jobs, the development of technologies, the improvement of energy efficiency, and energy cost reduction. An important aspect is the integration of alternative energy sources into the existing energy infrastructure and the development of effective management mechanisms for energy systems. However, it is necessary to address the technical, economic, and socio-cultural challenges associated with changing the conventional energy approach and promoting awareness of the importance of alternative energy for ensuring sustainable development and a sustainable future energy system.

Referring to the definition of U. Sorimsokov (2022), the use of alternative energy to reduce electricity losses and increase voltage is a relevant and promising strategy in the modern energy sector. This trend is geared towards minimising the adverse environmental impacts of conventional methods of electricity production and consumption while improving the quality of the electrical system. One of the key advantages of utilising alternative energy lies in its renewability and continuity. Solar, wind, hydrothermal, and geothermal energy sources provide reliable energy supply over extended periods with minimal fluctuations. This diminishes dependence on conventional sources such as coal or gas and reduces energy consumption for their operation and transportation. An important advantage is the ability to produce alternative energy on-site Solar panels on building rooftops, wind turbines in rural areas, or hydro generators in rivers contribute to reducing electrical losses during transportation and distribution, a common factor in overall loss reduction. However, there are some challenges and limitations to consider when using alternative energy. For instance, solar and wind energy are weather-dependent and may be unstable sources in specific regions. Hydroelectricity can impact river and waterbody ecosystems, necessitating careful planning. Furthermore, infrastructure for alternative energy production and distribution requires investments and technological advancements. Energy consumption is a vital aspect of various human activities, including heating and lighting homes, cooking, providing transportation, and supporting industrial and agricultural sectors. While developed countries transition from thermal power plants to innovative energy extraction technologies, other nations, such as Ukraine, continue to actively use coal to power thermal power plants.

The combustion of coal and oil resources releases hydrogen sulphide, CO_2, toxic gases, nitrogen oxides, particulates, and so on, leading to significant environmental pollution. Mining coal in quarries and extracting peat lead to the degradation of natural landscapes and, in specific cases, their complete destruction. Spills of oil and petroleum products during their extraction and transportation can cause massive environmental damage, including the pollution of large territories and water bodies (Singh *et al.*, 2020). Current energy trends emphasise the developed countries' focus on reducing their dependence on expensive organic energy sources and increasing the use of alternative energy sources in their energy balances. The main driving factors for alternative energy development include the high cost of energy obtained, which is due to the equipment cost such as photovoltaic cells and wind turbines, as well as a relatively long payback period. The service life of photovoltaic cells is about 5 years, while for wind turbines, it ranges from 2 to 3 years, depending on local natural conditions.

Researchers U. Mirzayev & J.T. Tulakov (2019) identified that modern methods of utilising alternative energy sources represent a key area aimed at ensuring a sustainable and environmentally friendly energy future. These methods allow the efficient utilisation of natural resources, reduce dependence on depleting fuels, and contribute to reducing greenhouse gas emissions, a crucial aspect given the increasing awareness of climate change. Solar energy, using solar panels to convert sunlight into electrical energy, provides an accessible and efficient alternative. Wind turbines installed in wind farms harness wind energy to generate electricity, offering a stable source of electrical power. Hydroelectricity utilises water flow to rotate turbines, while geothermal energy uses the Earth's underground heat for heating and electricity. Biomass utilisation, such as wood and agricultural waste, transforms waste into valuable energy, making strides in waste management. Tidal energy, using tidal forces from seas and oceans, provides an additional avenue for clean energy production. These modern methods of using alternative energy sources are aimed at reducing the negative impact of the energy sector on the environment, increasing energy independence, and ensuring sustainable energy supply for future generations.

Most European countries are successfully developing the field of alternative energy with active support from the state. European Union countries, both at international and national levels, are implementing programmes and strategies for the development of renewable energy and providing financial and organisational support to companies operating in this sector. Growing challenges such as the depletion of global hydrocarbon reserves, rising energy prices, and worsening environmental conditions compel many developed countries to actively develop their energy strategies focused on alternative energy sources. According to the International Energy Agency, Ukraine is expected to double its electricity production from alternative sources by 2030 compared to current figures, which currently account for approximately 16% of the total production (Wałowski, 2021).

There are a significant number of innovative technologies that use renewable energy sources. These technologies are constantly improving, and new ones are being developed to enhance efficiency. Special solar collectors and solar batteries are used to store solar energy. The operation of solar collectors is based on the concept of focusing solar radiation on a transparent tube through which a liquid passes and is heated. On the other hand, solar batteries operate based on the photovoltaic effect, where semiconductor components, photovoltaic converters, generate electric current when exposed to solar radiation. These photovoltaic components are grouped into batteries of various sizes, which are then installed on solar panels (Kilgo *et al.*, 2022). These solar collectors and batteries are typically applied to obtain thermal energy in individual buildings and as additional sources in combined heating and water heating systems.

Various technologies are used for the production of energy from biomass and biogas, such as composting, processing in bioreactors, and forming briquettes from dry residues. In places with a large accumulation of biomass, powerful biogas reactors are often constructed. The obtained biogas can be used by direct combustion to obtain thermal energy or in gas generators to produce electricity. For instance, in Poland, there are currently 21 power plants generating energy from biomass with a total capacity of 485.5 MW and 178 power plants using biogas with a capacity of 111.8 MW. The placement of wind energy facilities depends on the presence of "wind corridors," which have uneven seasonal characteristics. Before the construction of wind stations, extensive studies of wind flows at heights ranging from 90 to 100 m were conducted, and the results of these studies influenced the adoption of appropriate techno-economic decisions. Wind turbines with capacities ranging from 500 to 2000 kW are grouped in specific areas, and the generated electric power is supplied to centralised electrical grids (Weiss *et al.*, 2021).

Small hydropower utilises the potential energy of small rivers and water bodies. Generating turbines of small hydropower plants are located near the base of the dam or at the outlet of the derivation channel to maximise water flow utilisation and efficient conversion into electric energy. The use of alternative energy sources proves to be very effective in many countries, significantly improving their economic and environmental situations. However, despite the evident advantages, these sources can have a negative impact on the environment. The operation of stations using renewable energy sources is associated with the acquisition of significant land plots and can cause changes in landscapes. Some of these power plants can create noise and pollute the environment.

According to the results of recent studies by M.G. Prina *et al.* (2020), one of the key aspects of multi-objective investment optimisation is considering various goals and constraints in decision-making. This may include minimising costs, maximising energy production, ensuring stability and efficiency, reducing environmental impact, and ensuring supply reliability. Considering these diverse objectives allows for a more comprehensive and balanced approach to the development of the energy system. Due to high temporal and spatial resolution, it is possible to more accurately account for the dynamics of energy demand and production in different geographic areas and time intervals. This enables optimal allocation of resources, the use of different energy sources based on their availability and demand, and efficient utilisation of energy storage systems to compensate for variations in demand. This issue also involves the application of advanced modelling and data analysis technologies. High resolution requires the use of precise and detailed data on production, consumption, energy distribution, and the interaction of various sources and system components. Modern data analysis and information processing tools allow considering these parameters for more accurate and well-founded decision-making.

Multi-objective investment optimisation for high-temporal and high-spatial-resolution energy system models opens up new opportunities for the development of sustainable, efficient, and environmentally friendly energy. This approach helps balance different goals and constraints, allowing the creation of an optimal and long-term sustainable energy system. For example, wind power stations are efficient during strong winds but can be vulnerable to hurricanes. Solar boiler plants require large areas, and solar panels can pose environmental issues as waste. Power plants using geothermal energy can be profitable only if thermal sources are close to the surface, considering the potential impact of construction on seismic activity. Biomass can be used to generate energy by burning plant material, but this method is also accompanied by the emission of carbon dioxide and soot, which can have a negative impact on the environment. Therefore, the effective utilisation of renewable energy sources requires careful balancing between the benefits and negative consequences for the environment.

V. Suresh *et al.* (2020) demonstrated through their research that modelling and optimising autonomous hybrid renewable energy systems for rural electrification are important areas in modern energy research. This opens up possibilities to ensure a sustainable and reliable power supply in rural areas where access to conventional energy sources may be limited or costly. Hybrid renewable energy systems combine different sources, such as solar panels, wind turbines, hydro generators, batteries, to ensure continuous and stable electricity supply. Modelling such systems allows determining the optimal combination of sources and their parameters, ensuring maximum efficiency and minimum costs. The optimisation process of a hybrid system includes analysing energy consumption in rural areas, forecasting renewable energy production based on weather conditions and other factors, and determining optimal energy storage and distribution parameters. It is also crucial to consider economic feasibility factors, including equipment cost, maintenance, and system operation.

One of the key challenges in modelling and optimising hybrid systems is the uncertainty of weather conditions and the variability of renewable energy production. This can lead to energy shortages or excess, requiring the development of control and storage algorithms to ensure system stability. In addition, the efficiency of bioturbines is relatively low, leading to high implementation costs, and the use of biomass is often not cost-effective. An excellent alternative solution is the conversion of plant mass into gas, such as methane. Methane can then be burned using gas turbines, which operate much more efficiently. This method holds promise where a large amount of agricultural waste is available. Methanol and ethanol obtained during biomass fermentation can also be used as alternative fuels for vehicles. Recent years have seen increasing concerns among policymakers and the general population due to the worsening global environmental issues such as acid rain and climate change, and the consequences of these phenomena on the environment. Despite existing more environmentally friendly methods of energy production, such as using renewable sources like solar, wind, thermal energy, wood, and agricultural waste, it is crucial to understand that there is no perfect energy production method that does not negatively impact the environment.

O.A. Al-Shahri *et al.* (2021) identified that solar photovoltaic energy is one of the most promising sources of alternative energy; however, its optimisation poses certain challenges and issues. One optimisation method involves improving the manufacturing technology of solar panels to increase their efficiency and reduce production costs. The development of new materials and designs can contribute to capturing more solar energy and enhancing its utilisation. However, this can be associated with high costs for research and development. Another problem is the dependency on weather conditions; solar panels achieve high efficiency only in sunny weather. This issue is related to the lack of a constant energy supply, necessitating the development of storage systems to provide electricity during cloudy days or at night.

Infrastructure aspects can be an additional hurdle for optimising solar photovoltaic energy. A developed grid network is needed for the transmission and distribution of generated electricity, as well as monitoring and control systems for the efficient use of solar panels (Table 1).

Table 1. Energy potential of renewable energy sources in Ukraine

Energy sources	Theoretical potential, MW × (h/year)	Utilisation, MW × (h/year)	Technical capacity, MW × (h/year)
Solar energy	$7.2*10^{11}$	$8.1*10^{4}$	$0.13*10^{9}$
Wind power	$9.65*10^{11}$	$0.8*10^{3}$	$0.36*10^{9}$
Geothermal energy	$5.13*10^{12}$	$0.4*10^{3}$	$1.4*10^{10}$
Bioenergy	$1.25*10^{7}$	$0.14*10^{2}$	$6.1*10^{6}$
Small hydroenergy	$1.74*10^{7}$	$0.5*10^{6}$	$6.4*10^{6}$

Source: O.Yu. Niskhodovska & N.L. Korzhenivska (2023)

In Ukraine, there is a need and opportunity to develop energy based on renewable sources, which is due to several factors (Rabbi *et al.*, 2022):

1. The presence of a shortage of conventional fuel and energy resources in Ukraine.

2. Imbalance in the development of Ukraine's energy complex, with a significant focus on electricity production at nuclear power plants (up to 25-30%).

3. Suitable climatic and meteorological conditions for the efficient use of major renewable energy sources.

4. Ability to produce diverse equipment for renewable energy on existing industrial infrastructure, despite significant damage due to the war with Russia.

Table 1 provides information on the resources of renewable energy sources in Ukraine, their potential energy productivity, and utilisation volumes. An important legislative step in the latest stage of alternative energy development is providing tax incentives to energy companies utilising alternative energy sources. As noted by M.J. Mayer *et al.* (2020), the eco-economic multicriteria optimisation of household-level hybrid renewable energy systems using genetic algorithms is a crucial step toward creating sustainable and efficient energy solutions based on alternative energy sources. Hybrid systems that combine multiple renewable energy sources such as solar panels, wind turbines, and batteries can be an effective option for household electrification. However, the optimal selection of parameters for such a system can be challenging, as it needs to consider not only environmental but also economic factors. Multicriteria optimisation considers various criteria, such as cost, reliability, efficiency, and environmental impact, allowing for a compromise between these factors. In this context, genetic algorithms are powerful tools as they enable the search for optimal solutions in the space of possible parameters for hybrid systems. One of the main challenges in this approach is the complexity of determining the weights of different criteria since they may have different levels of importance for different users or situations. It is also essential to consider the uncertainty of certain parameters, such as weather conditions and energy consumption.

Energy audit, efficiency management, and reactive power compensation: Insights into insulation technical condition

The compensation of reactive power is a technical process aimed at reducing or eliminating undesirable reactive power in electrical systems. Reactive power arises due to inductive or capacitive consumption of electrical energy in distribution networks and electrical installations (Tazky *et al.*, 2021). This forces electrical systems to operate with excessive loads and increased electricity consumption, leading to reduced energy efficiency and increased electrical losses.

Reactive power compensation involves eliminating excess reactive power by implementing compensating devices such as capacitors. These devices generate reactive power, compensating for excessive reactive power consumption and ensuring a balance between active and reactive power. The advantages of reactive power compensation include increased energy efficiency, reduced electricity costs, and increased power transmission capacity. In addition, reactive power compensation helps maintain the stability of electrical systems, reduce equipment overload, and increase the technical lifespan of electrical installations. Successful reactive power compensation requires accurate calculation of reactive power, well-designed and installed compensating devices, and continuous monitoring of electrical systems. This process helps optimise the operation of electrical power systems, enhance the reliability and stability of electrical installations, and contribute to efficient and stable power supply. The technical condition of insulation relates to the assessment of the quality and effectiveness of insulation materials used to protect electrical conductors and electrical devices in electrical systems. This is a crucial aspect in ensuring the safe and stable operation of electrical installations. The assessment of the technical condition of insulation involves the diagnosis and measurement of the state of insulation materials to identify potential issues (Frizzo Stefenon *et al.*, 2020). This may include checking for cracks, wear, contamination, or damage on the surface of insulation materials. The technical condition of insulation is measured by parameters such as insulation resistance, indicating the effectiveness of insulation and its ability to prevent current leakage.

It is worth noting that the technical condition of insulation can change over time due to various factors such as humidity, temperature, mechanical loads, and electrical voltages. Regular inspections and maintenance of insulation materials are critical to ensure effective and safe operation of electrical systems. Preserving proper insulation conditions helps prevent potential accidents, reduces repair costs, and enhances the reliability of electrical installations. The technical condition of insulation is crucial for electrical safety, efficiency, and the lifespan of electrical devices and systems. Therefore, its regular monitoring and maintenance are essential tasks for all energy systems and industrial enterprises.

An energy audit is a comprehensive technical process aimed at assessing and analysing the energy consumption of enterprises, buildings, organisations, or other energy-dependent objects. The purpose of an energy audit is to identify opportunities for reducing energy costs, improving energy efficiency, and saving energy resources. An energy audit involves collecting and analysing data on electricity, thermal energy, gas, water, and other energy resources consumption, and checking the operation of technical equipment and energy supply systems (Chakravarty *et al.*, 2022). Based on the obtained data, the energy audit assesses the efficiency of systems and proposes recommendations for optimising energy consumption and implementing energy-efficient technologies. Conducting an energy audit helps identify energy losses, inefficient resource usage, technical deficiencies, and weaknesses in energy supply systems. This allows for the development of a strategy and action plan to ensure more efficient and economical energy use. Energy audits help reduce energy costs, mitigate environmental impact, and enhance the competitiveness of enterprises. This process may also include calculating the economic efficiency of proposed measures, assessing their impact on reducing energy consumption, and determining the payback periods of investments. Energy audit is a vital tool in implementing energy policies, resource-efficient utilisation, and ensuring sustainable development.

Energy management is a comprehensive approach to managing energy resources and energy efficiency aimed at optimising energy consumption, reducing energy costs, and improving the efficiency of energy processes. The goal of energy management is to ensure the sustainable and efficient operation of energy systems and reduce negative environmental impact. Energy management includes planning, monitoring, analysis, and control of energy resource usage, defining energy needs, developing effective energy strategies and supply policies. This approach involves the rational use of energy, implementation of energy-efficient technologies and processes, and planning and implementation of energy-saving measures. Scientists T. Bauwens *et al.* (2022) have found that Energy management is typically performed at various levels, from individual enterprises or organisations to city or national energy systems. Successful implementation of energy management requires cooperation among all departments and units within an organisation, including production, technical maintenance, finance, and administration. The main objectives of energy management include ensuring sustainable energy supply, increasing the efficiency of energy resource utilization, reducing energy costs, and minimising negative environmental impact. Energy management also contributes to ensuring energy security, reducing dependence on imported energy resources, and developing domestic energy potential. Successful implementation of energy management helps businesses and organisations achieve effective, stable, and economically viable operation of energy systems and positively contribute to addressing energy efficiency and environmental issues.

In the current context of escalating environmental and energy problems, rising costs of conventional energy resources, and the need to reduce environmental impact, optimising energy solutions becomes a key focus. One of the most promising industries in this context is alternative energy. Alternative energy encompasses the use of renewable energy sources such as solar, wind, hydroelectric power, and biomass. These sources are natural and renewable, reducing dependence on limited natural resources and lowering the environmental footprint. Optimising alternative energy involves selecting optimal solutions for placing solar panels, wind turbines, and hydroelectric power stations, considering geographic and climatic conditions, and developing efficient energy storage and distribution systems.

Reactive power compensation is a crucial component of energy system optimisation. Reactive power arises from the use of electrical equipment with capacitive and inductive properties. Excessive reactive power can lead to increased electricity consumption and decreased system efficiency. Reactive power compensation involves managing its level, reducing energy losses, and improving the power factor. Energy efficiency management is a key aspect of optimising energy solutions. It involves the implementation of technologies and practices aimed at reducing energy consumption while preserving or enhancing productivity. Energy efficiency can be achieved through the deployment of energy-efficient equipment, optimisation of system operation modes, and the use of modern technologies in construction and industry. However, it is essential to recognise that achieving absolute energy efficiency is impossible without compromise. The choice of optimal solutions must consider economic, social, and environmental aspects. Optimising energy solutions is a complex task that requires collaboration between government agencies, research institutions, businesses, and society. Overall, optimising energy solutions is an integral part of sustainable societal development. The introduction of alternative energy sources, reactive power compensation, and energy efficiency management can help reduce energy dependence, improve the environment, and ensure sustainable economic growth.

CONCLUSIONS

Optimisation of energy solutions, focusing on the development of alternative energy, reactive power compensation, and energy efficiency management, has become a crucial component of modern energy strategy. The growing awareness of issues related to climate change and the depletion of conventional energy resources stimulates the implementation of innovative technologies and methods based on alternative energy sources. The development of alternative energy offers potential from various sources such as solar, wind, hydro, and biomass. Research results show that energy derived from these sources can become a sustainable and reliable complement to conventional sources like coal and oil. In addition, it is environmentally friendly and has a low impact on the environment, making it an attractive alternative for sustainable development and reducing dependence on harmful sources. Another important aspect is reactive power compensation, which helps address issues related to inefficient energy usage. The use of smart compensation systems avoids excessive energy consumption and reduces energy losses. This leads to an increase in the efficiency of energy systems and a reduction in energy costs for enterprises and consumers. Energy efficiency management is also becoming a crucial factor in achieving sustainable development. The introduction of intelligent management and monitoring systems helps optimise energy resource utilisation, identify potential energy expenditures, and enhance the efficiency of energy infrastructure. This contributes to supporting a stable and effective energy supply, forming the basis for the development of modern society.

One of the most important aspects of optimising energy solutions is the development of alternative energy. The high competitiveness and continuous supply of solar and wind installations demonstrate their significance in ensuring a stable and effective energy system. Integrating alternative sources allows expanding the resource base and reducing dependence on conventional sources, contributing to climate change mitigation and environmental preservation. Reactive power compensation issues are becoming increasingly relevant in the context of growing electricity consumption. The application of modern compensation technologies allows reducing energy losses, improving supply quality, and enhancing the efficiency of energy systems. The implementation of automated reactive power compensation tools will help maintain a stable and consistent voltage level, providing optimal conditions for all consumers' operations. Energy efficiency management is a necessary component to ensure energy stability and economic efficiency. The use of intelligent management systems enables optimising energy consumption, identifying energy losses, and more effectively distributing energy resources. Increasing energy efficiency can contribute to reducing energy costs, enhancing the competitiveness of businesses, and mitigating environmental impact. All these aspects of optimising energy solutions interact and are interconnected, forming a comprehensive system that promotes sustainable development and stability in the energy sector. Ensuring a reliable and stable energy supply, reducing negative environmental impact, and ensuring economic efficiency are crucial for modern society.

Further studies in the field of optimising energy solutions require an innovative approach and collaboration between scientists, industry enterprises, and government bodies. The development of new technologies and the implementation of advanced practices will enable an effective and stable energy supply, fostering sustainable development and resource conservation for future generations.

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CONFLICT OF INTEREST

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Оптимізація енергетичних рішень: Альтернативна енергетика, компенсація реактивної потужності та управління енергоефективністю

Анотація. Актуальність досліджуваної проблеми визначається необхідністю створення сталого, ефективного та екологічно безпечного енергетичного комплексу. Зростання чисельності населення планети, розвиток промисловості та загальний попит на енергоресурси ставлять під загрозу забезпечення енергетичних потреб суспільства, що робить необхідність проведення досліджень актуальною на сучасному етапі. Метою дослідження є вивчення оптимальних стратегій оптимізації енергетики, включаючи альтернативну енергетику, компенсацію реактивної потужності та управління енергоефективністю, для забезпечення стабільного та ефективного функціонування енергетичного комплексу. Серед використаних методів – аналітичний, функціональний, статистичний та синтезу. При дослідженні оптимізації енергетичних рішень було проведено ретельний аналіз різних аспектів альтернативної енергетики, компенсації реактивної потужності та управління енергоефективністю. Цей аналіз охоплював різні аспекти та параметри, пов'язані з цими сферами, включаючи технічні, економічні та екологічні показники. В результаті дослідження було встановлено, що альтернативна енергетика має значний потенціал для забезпечення сталого розвитку енергосистеми. Вона може слугувати надійним джерелом енергії, що не завдає шкоди навколишньому середовищу та не залежить від обмежених ресурсів. Було визнано, що компенсація реактивної потужності є ефективним способом уникнення втрат енергії в системі. Ця стратегія допомагає забезпечити більш ефективне використання енергії та зменшити втрати під час передачі та розподілу. Управління енергоефективністю також виявилося ключовим аспектом у досягненні сталості енергопостачання. Це дозволяє оптимізувати використання ресурсів, зменшити витрати на енергію та пом'якшити негативний вплив на навколишнє середовище. Практична цінність дослідження полягає в розробці інноваційних рекомендацій та стратегій оптимізації енергоспоживання, які сприятимуть створенню стабільного, ефективного та екологічно безпечного енергетичного комплексу та підвищенню його відповідності сучасним і майбутнім викликам, що є вагомим внеском у розвиток науки та енергетичної галузі

Ключові слова: сталий розвиток; екологічна безпека; мінімізація втрат; ресурсозбереження; зменшення негативного впливу