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Transforming City Energy Management: Using Smart Grid Technologies for Improved Control and Energy Efficiency

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Abstract
The research delves into the application of Smart Grid technologies to optimize energy consumption within urban settings. Through the examination of practical examples and a thorough analysis of research findings, the study showcases the efficacy of employing sensor networks and real-time automated systems for monitoring and controlling energy usage. The findings contribute valuable insights and practical recommendations for the implementation of Smart Grid technologies, aiming to enhance the sustainability and efficiency of urban infrastructure. The study not only underscores the theoretical benefits of Smart Grid but also provides concrete evidence through the evaluation of research results and real-world cases. The research emphasizes the considerable potential of Smart Grid in revolutionizing energy management practices in urban areas. The integration of Smart Grid technologies presents opportunities for achieving effective control over energy supply, curtailing energy consumption, and bolstering the stability of electricity distribution systems within the urban landscape. Moreover, the research outcomes offer actionable recommendations for leveraging Smart Grid technologies, fostering improvements in energy supply reliability, and promoting sustainable practices. By embracing these innovations, cities can make significant strides in efficient energy management, ultimately contributing to enhanced urban sustainability. The practical ideas derived from this research serve as a foundation for implementing innovative solutions that address the growing challenges associated with energy consumption in urban environments. Overall, this study lays the groundwork for advancing the discourse on Smart Grid technologies and their transformative potential in shaping the future of urban energy management.

INTRODUCTION

Energy management in an urban environment is a complex task facing a number of challenges and constraints. With population growth and increased energy consumption in cities, problems arise related to the efficiency, sustainability and controllability of the energy supply system. Traditional methods of energy management are becoming limited and not flexible enough to meet the energy needs of urban infrastructure.

However, the Smart Grid concept offers new perspectives and solutions for efficient energy management in cities. Smart Grid is an energy supply network in which advanced technologies, automation and digital systems are integrated. It provides intelligent management and monitoring of energy resources, allowing more accurate prediction and regulation of energy consumption in real time.

The purpose of this study is to investigate the potential of Smart Grid in energy management in the urban environment in order to improve efficiency and control. This article will discuss the main aspects of Smart Grid, its possibilities and advantages for managing energy supply in the city. An analysis of existing solutions and practical examples of successful Smart Grid implementation in various urban environments will also be presented. The organization of the article will consist of a literature review, research methodology, data analysis, discussion of results and conclusions. Through this research, we aim to better understand the role of Smart Grid in urban energy management and identify practical ways of its implementation to improve energy supply and sustainability of urban infrastructure.

The main problem. Managing energy in urban environments is an intricate challenge, amplified by the global population surge and escalating energy

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demands in cities. This surge brings forth multifaceted issues concerning the effectiveness, sustainability, and controllability of energy supply systems. Conventional energy management methods, once reliable, now strain under the evolving energy needs of urban infrastructure.

The primary shortcoming of traditional energy management lies in its rigidity when adapting to the dynamic energy landscape of modern cities. With urban expansion and diversified energy requirements, it's evident that innovative solutions are imperative to cater to evolving energy systems.

Introducing the Smart Grid—a revolutionary approach transforming energy management in urban settings. At its core, the Smart Grid seamlessly integrates advanced technologies, automation, and digital systems into the energy supply network. This integration empowers intelligent management and real-time monitoring of energy resources, facilitating precise predictions and enhanced regulation of energy consumption.

Our study's principal aim is to unlock the untapped potential of the Smart Grid in urban energy management, ultimately bolstering efficiency and control. This article meticulously explores the Smart Grid's fundamental facets, underscoring its transformative capabilities and the benefits it offers for urban energy supply management. Moreover, it embarks on a comprehensive investigation of existing solutions, presenting practical examples of successful Smart Grid implementations in diverse urban contexts.

In conclusion, energy management in urban areas stands as a multifaceted challenge. However, with the emergence of the Smart Grid, urban energy management is on the brink of a paradigm shift—a shift that promises enhanced efficiency, sustainability, and adaptability to meet the ever-evolving energy landscape of our cities.

The purpose of the paper. To investigate and analyze the role of the smart grid in the paradigm shift in electricity distribution networks and its impact on sustainable energy management in cities. In determining the benefits and main components of a smart grid, taking into account implementation challenges and the potential for sustainable urban development.

With the advent of modern information and communication technologies and the expansion of the use of renewable energy sources, there was a need to improve electricity distribution systems in cities. The smart grid is an innovative approach that combines technology, data collection and processing systems, and analytics to optimize and manage energy resources. It provides an opportunity to ensure sustainable, efficient and energy-efficient energy management in cities [1, 2].

A smart grid, also known as a smart grid or smart energy distribution network, is an innovative concept that combines communication technology, information technology, and energy management to improve the efficiency, reliability, and sustainability of the power grid.

The application of a smart grid includes such possibilities as optimizing energy consumption, managing peak loads, improving the reliability of electricity supply, and supporting the use of renewable energy sources [3, 4].

Examining the principles of operation and architecture of a smart grid allows for a better understanding of its functionality and benefits.

THEORETICAL PART

Energy management in urban environments has emerged as a complex interdisciplinary field that intersects various domains, including urban planning, electrical engineering, environmental science, and policy development. To address the challenges and opportunities in this context, it is crucial to establish a theoretical framework that underpins the concepts of urban energy management and the Smart Grid. Urban energy management refers to the holistic approach of planning, optimizing, and controlling energy resources within urban areas. It encompasses a range of objectives, including improving energy efficiency, ensuring energy sustainability, and enhancing energy controllability. Energy efficiency is a core concept in urban energy management. It involves reducing energy wastage and optimizing energy consumption patterns to achieve more output with less input. The aim is to minimize energy losses during generation, distribution, and consumption.

Sustainability in urban energy management focuses on ensuring that the energy sources used are renewable, environmentally friendly, and economically viable in the long term. Sustainable energy sources include solar, wind, and hydroelectric power [5, 6]. Controllability refers to the ability to monitor and regulate energy consumption in real time. It involves the integration of digital systems and automation to manage energy resources efficiently.

The Smart Grid represents a revolutionary concept in the field of energy management, particularly in urban settings. It is grounded in several key theoretical principles.

The Smart Grid leverages advanced technologies such as sensors, meters, and communication networks to collect and transmit real-time data about energy production and consumption.

Automation is a fundamental component of the Smart Grid, enabling automated responses to fluctuations in energy demand and supply. This automation enhances the grid's efficiency and reliability.

Digital systems play a pivotal role in the Smart Grid by facilitating data analysis, predictive modeling, and decision-making. They enable grid operators to make informed choices regarding energy distribution and optimization.

The Smart Grid promotes decentralization by allowing distributed energy resources, such as rooftop solar panels, to feed excess energy back into the grid. This enhances the grid's resilience and reduces the need for centralized power plants.

Demand response mechanisms enable consumers to adjust their energy consumption based on real-time price signals. This theory encourages more efficient energy use during peak periods.

RESEARCH ON THE USE OF SMART GRID IN OPTIMIZING ENERGY CONSUMPTION

Smart Grid technologies open up new opportunities for optimizing energy consumption in the urban environment. One of the vivid examples of research achievements is the paper of Dhlamini and Mawela [7] who conducted an analysis of energy consumption in the urban environment and proposed optimization methods using Smart Grid. They used sensor networks and automated systems to monitor and manage energy consumption in real time. The results of the study indicate a significant reduction in energy consumption and an improvement in the efficiency of the city's energy supply system. Another interesting study was conducted by Bhavani *et al*. [8], they analyzed and optimized energy consumption in urban infrastructure buildings with using Smart Grid technologies. They developed energy management algorithms that took into account peak and off-peak consumption hours and optimized energy distribution in real time. The results showed a significant reduction in energy consumption and an increase in the efficiency of energy use in buildings. These studies demonstrate the potential of Smart Grid technologies for effective energy management in urban environments. The use of such technologies can lead to reduced energy consumption and improved sustainability of the energy supply system, which is important for the sustainable development of cities. There are also a number of examples of successful Smart Grid implementation in the following cities.

Copenhagen, Denmark, known for its innovative approaches to sustainable development. The city has a large area with a population of over 600,000 inhabitants. Modern electricity meters with the possibility of remote data reading, network energy management systems, solar panels and energy storage were used in the project. Various fields, such as residential and commercial buildings, public transport, street and park lighting, use Smart Grid technologies.

The implementation of the Smart Grid in Copenhagen has led to optimization of energy consumption, improved energy efficiency and integration of renewable energy sources. The city actively uses Smart Grid technologies, focusing on the integration of renewable energy sources, energy efficiency of buildings and smart grid management. These measures helped to significantly reduce greenhouse gas emissions and improve energy efficiency.

Thanks to Smart Grid, optimization of energy consumption depending on weather conditions and demand has been achieved. This led to a reduction in the load on the energy network and an increase in the share of renewable energy in the overall structure of the city's energy consumption. The result was a reduction in greenhouse gas emissions and an improvement in the environmental sustainability of urban infrastructure [9].

Stockholm serves as an example of successful implementation of the Smart Grid concept. The city is large, with a population of more than 900 thousand inhabitants. Modern technologies were used in the project, including intelligent power grid management systems, electricity meters with the possibility of remote monitoring and control, intelligent lighting networks and energy efficiency systems.

Various types of energy consumption, such as residential and commercial buildings, public transport and charging stations for electric vehicles, have been covered by Smart Grid technologies. The implementation of the Smart Grid in Stockholm made it possible to effectively manage energy consumption, optimize energy costs in real time and integrate renewable energy sources.

The city actively uses the technologies of smart meters, energy consumption management systems and network monitoring. This made it possible to reduce energy consumption and optimize its use, as well as reduce the load on the energy infrastructure. The Smart Grid system was implemented using smart meters and a system for monitoring energy consumption in homes and businesses. Residents and businesses had access to data about their energy consumption and were able to make informed decisions to optimize energy use. This led to a reduction in energy consumption in the city, which brought economic benefits and reduced the burden on the energy infrastructure [1, 2].

Jönköping is a large city with a population of about 150,000 people. Smart power supply networks, home energy automation systems, as well as energy monitoring and management systems were used in the project. Various types of energy consumption, such as residential buildings, commercial buildings and industrial enterprises, have been included in the Smart Grid system. The implementation of the Smart Grid in Jönköping has brought positive results, including improved energy management and reduced load on the power grid. Thanks to the optimization of energy distribution, the use of energy-saving technologies and the active involvement of residents in the energy optimization process, high energy efficiency indicators were achieved.

The city of Jönköping has implemented a large-scale Smart Grid system that includes smart meters, solar panels and energy storage systems. This approach made it possible to optimize energy use, especially during periods of peak demand, and integrate more renewable energy into the system [10].

Portland is a promising center of smart energy and Smart Grid systems in the USA. With a population of about 650 thousand people, Portland is a large city that is actively engaged in the development of smart energy and Smart Grid systems. The project uses advanced technologies, including smart grid systems, network monitoring and control systems, as well as intelligent electricity meters.

As part of Portland's Smart Grid system, various types of energy consumption are included, such as residential buildings, commercial facilities, public transportation and charging stations for electric vehicles. The implementation of Smart Grid in Portland has significant results and achievements. The city actively manages energy consumption and successfully integrates renewable energy sources [5]. This has resulted in significant reductions in greenhouse gas emissions, increased energy efficiency, and reduced energy costs. Portland is actively using renewable energy, installing solar panels, wind turbines and energy storage systems. In addition, residents have access to data on energy consumption, which helps to improve energy efficiency and conscious use of resources.

Modern cities such as Copenhagen, Stockholm, Jönköping and Portland have become examples of successful implementation of Smart Grid technology in the urban environment. These examples illustrate the powerful potential and effectiveness of this innovative system. The introduction of Smart Grid makes it possible to improve the management of energy consumption and increase the energy independence of cities [11, 12].

These examples clearly demonstrate that Smart Grid technologies have great potential for optimizing energy consumption in urban environments. They enable efficient management of energy distribution, integration of renewable energy sources and reduction of load on the energy grid. This contributes to the creation of sustainable and efficient urban infrastructure, reduces the negative impact on the environment and improves the quality of life of city residents.

One of the key aspects of Smart Grid is the city's ability to effectively manage its energy consumption. This means that smart energy management allows you to maximize the use of available resources and reduce energy costs. It also promotes the adoption of renewable energy sources such as solar and wind power, ensuring sustainability and sustainability of the city's energy sector.

In general, Smart Grid in the urban environment opens up new opportunities for rational use of energy and ensures sustainable development of cities. This is a modern infrastructure that contributes to reducing the environmental impact and improving the quality of life of citizens.

As for Ukraine, for the period from 2011 to 2021, the development of the energy sector in Ukraine is of great importance for ensuring a stable supply of electricity in the country. In recent years, Ukraine has seen a variety of sources of electricity production, including thermal power, nuclear power, wind power, solar power, and hydropower. Each of these types of energy has its own characteristics and contribution to the overall energy complex of the country.

Thermal power plants (TPP) are the main source of electricity production in Ukraine. They use coal, natural gas or oil as fuel. During the reporting period, electricity production at the TPP remained stable or slightly decreased. Thermal energy plays an important role in supplying industrial enterprises and the population with electricity [13, 14]

Ukraine also has several nuclear power plants that generate a significant share of electricity. Electricity production at nuclear power plants showed a certain stability during the considered period. Nuclear power plays an important role in diversifying the country's energy situation and ensuring a stable supply of electricity.

Wind power is gaining increasing importance in Ukraine. After 2011, the production of electricity from wind turbines began to develop actively. In recent years, wind energy has become one of the fastest growing sources of electricity production. Wind farms help reduce dependence on traditional fuel sources and have a negligible impact on the environment.

Solar power also began to grow rapidly during this period. Electricity generation from solar panels has become increasingly popular and their contribution to total electricity generation has increased significantly. Solar power plants are an environmentally friendly source of energy and help reduce carbon dioxide emissions.

Ukraine has significant potential in hydropower thanks to its rivers and reservoirs. Hydroelectric power stations are able to produce electricity using the potential energy of rivers.

In general, sources of electricity production in Ukraine allow for a stable and efficient supply of electricity. Thermal power plants, nuclear power plants, wind and solar power plants, as well as hydroelectric power plants contribute to the country's overall energy mix, contributing to the development of a sustainable energy sector and reducing dependence on traditional fuel sources. In Tables 1, 2 shown the indicator of electricity production by various sources of energy production.

Table 1. Production of electricity by various sources for the years from 2011 to 2015 in Ukraine

Year / Type	2011	2012	2013	2014	2015
Interest	%	%	%	%	%
Nuclear power plant	46.5 ↓	45.5 ↓	43.0 ↓	48.5 ↑	55.6 ↑
CHP/ TES	43.7 ↑	44.7 ↑	44.7 ↓	41.3 ↓	35.2 ↓
HPP/ GAPP	5.6 ↓	5.5 ↓	7.3 ↑	5.0 ↓	4.3 ↓
SPP/ WPP/ Biomass	0.0 ↑	0.3 ↑	0.7 ↑	1.0 ↑	1.0 ↑
Block stations	4.2 ↓	4.0 ↓	4.3 ↑	4.3 ↓	3.9 ↓

Table 2. Production of electricity by various sources for the years from 2016 to 2021 in Ukraine

Year / Type	2016	2017	2018	2019	2020	2021
Interest	%	%	%	%	%	%
nuclear power plant	52.3 ↓	55.1 ↑	53.0 ↓	53.9 ↑	51.2 ↓	55.1 ↑
CHP/ TES	39.7 ↑	35.9 ↓	36.9 ↑	36.2 ↓	35.2 ↓	29.3 ↓
HPP/ GAPP	6.0 ↑	6.8 ↑	7.5 ↑	5.1 ↓	5.1 ↑	6.7 ↑
SPP/ WPP/ Biomass	1.0 ↑	1.2 ↑	1.7 ↑	3.6 ↑	7.3 ↑	8.0 ↑
Block stations	1.0 ↓	1.0 ↑	0.9 ↓	1.1 ↑	1.2 ↑	1.0 ↓

Electricity consumption for 2011 was within 150.8 billion. kW · h. In 2018, the largest consumers of electricity were industry, approximately 42.6%, the share that fell on the share of the population reached 29.5%, communal and household economy and transport together amounted to 18.4%, non-industrial, agriculture and construction 9.6% [15].

In 2021, electricity production in Ukraine amounted to 156.576 billion kWh, which is 5.2% more than in 2020. The main share in the total production in 2021 was nuclear power plants - 55.1%, thermal power plants and thermal power plants - 29.3%, hydroelectric power plants and gas power plants - 6.7% [4].

Electricity production at thermal power plants amounted to 37.225 billion kWh, at thermal power plants and cogeneration plants - 8.6 billion kWh.

Hydroelectric power plants increased electricity production by 37.7% to 10.44 billion kWh, nuclear power plants by 13.1% to 86.2 billion kWh.

Electricity production from alternative sources in 2021 amounted to 12.52 billion kWh, which is 15.3% more than last year.

Electricity consumption increased by 5.7% to 154.82 billion kWh. Excluding technological losses, electricity consumption increased by 6.4% last year.

Export of electricity amounted to 34.96 billion kWh, which is 26.5% less than in 12 months of 2020.

The country's industry, excluding technological losses, increased electricity consumption by 6% - up to 52.27 billion kWh.

Last year, the country's population consumed 38.66 billion kWh (+5.8%), utility consumers - 15.02 billion kWh (+5.8%), other non-industrial consumers - 8.6 billion kWh year (+16.5%).

The share of industry in the total amount of electricity consumption according to the results of 2021 decreased from 41.8% to 41.7%, and the share of the population - from 31% to 30.8%.

THE CITY OF KHARKIV AS A PROJECT TO IMPLEMENT SMART GRID TECHNOLOGIES

Kharkiv is a large city in the east of Ukraine and is the administrative center of the Kharkiv region. It has a number of characteristics that are worth noting. First, Kharkiv is the second largest city in Ukraine after Kyiv, with an area of about 350 square kilometers. The city's population exceeds 1.4 million people, making it one of the largest cities in the country. This city consumes a significant amount of energy through its industrial plants, commercial facilities and residential buildings. This covers both electricity and heat. The city has a developed energy infrastructure, which includes power supply networks, substations, heat networks and other elements of the energy complex.

Transport infrastructure is also an important aspect. The city has a developed system of public transport, including the metro, buses, trolleybuses, trams and railway stations. This also affects the city's energy consumption, as transport requires significant energy resources.

Regarding climatic conditions, the city is located in a temperate climate zone. Winters are mostly cold with low temperatures and snowfalls, while summers reach high temperatures and hot spells are common.

The city of Kharkiv plays an important role in the energy and transport sectors, thanks to its geographical location and size, which contribute to significant energy consumption.

Various mathematical models and algorithms can be used to analyze and optimize the energy system in Kharkiv, for example [16].

Energy consumption model based on statistical data on energy consumption in different sectors of the city. This mathematical model allows you to estimate the current level and dynamics of energy consumption. To develop this model, you can use the methods of regression analysis or time series.

The use of such a model will allow obtaining important data on energy consumption, which will be useful in making decisions regarding the optimization and effective management of the city's energy system. It will help identify consumption trends, identify potential reserves of energy efficiency and ensure rational use of resources.

Such mathematical models and algorithms are a powerful tool for research and optimization of energy systems. They make it possible to understand the complex processes in the city's energy system and to develop effective strategies to ensure sustainability, energy efficiency and sustainable development [4].

An energy network model can be used to analyze and optimize the energy system. This model includes a description of the structure and characteristics of the city's energy network, such as substations, transmission lines, and other components.

The main advantage of this model is its ability to analyze network bandwidth and optimize load distribution. It also allows you to predict possible problems and emergency situations, which allows you to quickly respond to them and ensure the uninterrupted functioning of the energy system.

The application of the energy network model in Kharkiv makes it possible to increase the efficiency of the use of resources, reduce the risk of accidents and ensure a stable supply of electricity in the city. This is an important step in the direction of sustainable development and improvement of the city's energy efficiency [3].

The model of renewable energy sources takes into account the potential and characteristics of solar panels and wind generators. This model allows you to determine the optimal location and capacity of renewable energy sources in the city. It also assesses their contribution to the overall energy system. Thanks to this model, it is possible to effectively use the potential of renewable energy sources and promote sustainable development.

Optimization algorithms such as genetic algorithms, particle swarm algorithms, and linear programming have great potential for power system optimization. They are used to determine optimal energy consumption management strategies, energy distribution and energy network maintenance planning. These algorithms help ensure efficient use of energy resources and improve the functioning of the energy system.

To forecast the future demand for energy in the city of Kharkiv, a mathematical model is used – *the demand forecasting model*. This model is based on historical data and influencing factors, and it helps the power system to effectively adapt to changes in energy consumption and plan resources.

The demand forecasting model takes into account various variables, such as seasonal variations, weather conditions, days of the week, and patterns of energy consumption by various sectors, including industry, residential, commercial, and others. It is capable of forecasting short-, medium-, and long-term demand, which allows the energy system of the city of Kharkiv to plan resources and optimize energy production and distribution.

The application of the demand forecasting model helps to improve the efficiency and reliability of the power system of the city of Kharkiv. It will be able to reduce costs and improve the quality of service for residents. This model is an important tool for the energy system, allowing planning and adapting to changes in energy consumption, ensuring efficient use of resources and optimizing energy production and distribution [6].

It is also necessary to consider the use of *an energy consumption management model*, which will allow optimizing the energy consumption management process. This model takes into account various factors such as energy prices, consumer preferences, availability of renewable energy sources and others.

The main purpose of this model is to develop energy saving strategies, flexible load distribution and effective management of energy consumption depending on changing conditions. It allows you to adapt to changes in energy prices, take advantage of the use of renewable energy sources and make optimal decisions about energy consumption.

The energy consumption management model affects the planning and regulation of energy resources in the city of Kharkiv. It facilitates the implementation of effective energy saving strategies and allows load distribution, taking into account changing conditions.

The application of the energy consumption management model helps to reduce energy costs, ensure optimal use of resources and improve the efficiency of the energy consumption system. It is an important tool for achieving sustainable development and energy efficiency in the city [4].

The model for evaluating environmental indicators is used to assess the impact of the energy system on the environment in the city of Kharkiv. It analyzes greenhouse gas emissions, air pollution levels and other environmental aspects. The main goal of this model is to optimize the energy system in such a way as to minimize the negative impact on the environment and ensure the ecological sustainability of the city.

The risk and crisis management model predicts and assesses the risks associated with the city's energy system and develops crisis management strategies. It takes into account a variety of factors, such as power grid failures, extreme weather conditions and other potential threats. The main objective of the model is to develop action plans and recovery strategies to minimize problems and ensure uninterrupted energy supply in crisis conditions.

The use of a model for evaluating environmental indicators and a model for risk and crisis management are important for ensuring sustainable development and efficient functioning of the city's energy system. These models help reduce the negative impact on the environment, prevent possible crisis situations and ensure the stability and reliability of the city's energy supply [17].

These models and algorithms is the basis for the analysis and optimization of the city's energy system. They allow you to make informed decisions about energy planning, increase the efficiency of energy consumption, reduce emissions and improve the sustainability of the city's energy infrastructure.

When developing a mathematical model of the energy system of the urban environment for the city of Kharkiv, it should be taken into account that this model will be a complex system that will take into account all important aspects of the energy infrastructure. It will take into account energy consumption in different sectors such as residential, commercial, industrial and transport, and will also take into account different sources of energy, including renewable sources, conventional power plants and others.

In addition, the model must take into account energy storage processes, such as batteries and energy storage systems, as well as take into account the transfer of energy through the grid infrastructure. It should model energy flows between different system components, including energy generation, transmission, distribution and consumption.

To optimize the city's energy system, the model should take into account the efficiency of energy conversion and accounting for energy losses. Must evaluate energy efficiency and the impact of various technologies and devices used in the system on the overall performance of the system.

The mathematical model of the energy system of the urban environment will also allow conducting various scenario analyses, optimizing energy resources, predicting the impact of changes in energy consumption and generation on the system, as well as developing strategies to improve the efficiency and sustainability of the city's energy system.

The application of a mathematical model of the energy system of the urban environment is important for achieving sustainable development and effective energy management in the city. This model will help ensure energy sustainability, minimize environmental impact, and develop strategies aimed at increasing the productivity and efficiency of the energy system.[20]

Since 2017, the city of Kharkiv has been actively working on the modernization of its energy system. As part of this process, the following achievements were achieved:

1) Increasing the share of renewable energy sources: Since 2017, the share of renewable energy sources in the overall structure of urban energy consumption has increased by 15%. Thanks to the introduction of solar and wind power plants, as well as the use of biomass in energy production, the city was able to reduce dependence on traditional energy sources and reduce greenhouse gas emissions.
2) Increasing energy efficiency: In the period from 2017 to 2022, an energy efficiency program was implemented, which made it possible to reduce energy consumption by the population and enterprises of the city by 10%. Work was carried out on the insulation of buildings, installation of energy-saving heating and lighting systems, as well as training of the public on the principles of energy-efficient consumption.
3) Implementation of smart networks and monitoring systems: In 2019, the city of Kharkiv started implementing smart networks and energy consumption monitoring systems. This allowed residents and businesses to receive detailed information about their energy consumption, as well as to make informed decisions about its optimization. As a result, for the period from 2019 to 2022, the city was able to reduce energy consumption by 7% thanks to more efficient energy management.
4) Integration of electric vehicles: Since 2020, the city of Kharkiv has been actively developing infrastructure for electric vehicles. Charging stations were installed throughout the city, and benefits and programs to encourage the use of electric vehicles were introduced. During the period from 2020 to 2022, the number of electric cars in the city increased by 50%, which made it possible to significantly reduce emissions of harmful substances and improve air quality in the city. Electric cars have become a popular choice among residents of Kharkiv due to their environmental friendliness, economy and the possibility of charging in public places.

The introduction of a smart charger system allowed to optimize the distribution of electricity and manage the charging process depending on peak demand and energy availability. Such a system increases the efficiency of the use of energy resources and contributes to more efficient management of the electric network.

The economic benefits of using electric vehicles are also significant. Owners of electric cars have a significant reduction in fuel and vehicle maintenance costs. In addition, the city of Kharkiv provides benefits and subsidies for the purchase of electric cars, which makes them more affordable for the population.

The integration of electric vehicles into the urban environment contributes to the reduction of dependence on fossil fuels and promotes the development of environmentally friendly transport. Such measures contribute to the creation of a sustainable and ecologically friendly urban environment, which is an important aspect in Kharkiv's desire for sustainable development and improvement of the quality of life of its residents.

For the period from 2020 to 2022, the city of Kharkiv achieved the following results in the field of energy.

Greenhouse gas emissions reduction. By switching to cleaner energy sources such as renewables and electric vehicles, the city was able to reduce greenhouse gas emissions by 20% over the period. This significantly contributes to improving the ecological situation in the city and reducing the negative impact on the climate.

Improving the reliability of energy supply. The introduction of smart grids and monitoring systems has made it possible to manage the city's energy system more efficiently. Automatic control and management systems ensure a quick response to problems and minimize downtime in energy supply. This has resulted in reduced downtime and improved energy supply reliability for residents and businesses [18].

Economic benefits. The implementation of energy-efficient technologies and renewable energy sources has resulted in economic benefits for the city. Reducing energy consumption, using own renewable energy sources, and increasing electric mobility have reduced energy costs and reduced dependence on energy imports.

Attracting investments. The successful modernization of the city's energy system has attracted the attention of investors and partners. The introduction of new technologies and the development of infrastructure for renewable energy and electric vehicles have opened up new opportunities for investment in urban energy. This contributes to the development of the local economy and the creation of new jobs.

Social well-being. Improvements in energy efficiency and the transition to ecologically clean energy sources in the city of Kharkiv have led to an increase in the quality of life of residents. The reduction of energy consumption has allowed to reduce energy payments, reduce energy inequality and increase the availability of energy for all segments of the population. In addition, the development of infrastructure for electric vehicles helps reduce air pollution and improve the public health of citizens.

Innovation and development. Progressive technologies and modernization of the energy system of the city of Kharkiv stimulate innovative development and attract the attention of scientific and research organizations. This contributes to the development of new solutions and technologies in the field of energy, as well as the creation of new jobs in the field of energy and engineering.

Sustainable development. The process of modernization of Kharkiv's energy system is aimed at achieving sustainable development of the city. The introduction of renewable energy sources, the reduction of greenhouse gas emissions and energy-efficient measures contribute to reducing the negative impact on the environment and creating an ecologically sustainable urban space.

The given results demonstrate positive changes in the energy system of the city of Kharkiv for the period from 2020 to 2022 [19]. They are the result of joint efforts of the city administration, public organizations, enterprises and residents to achieve more sustainable and efficient energy [20–22].

CONCLUSIONS

The use of the Java programming language in Smart Grid systems provides new opportunities for improving energy systems. New technologies in the field of energy and informatization affect the quality of life of residents, business activity and the environmental situation. An important aspect is the concept of decentralization of electricity and increasing the importance of settlements, which contributes to increasing their efficiency and resistance to natural and man-made risks. Informatization and the use of "Big Data" technologies are important for the development of energy systems of settlements. The implementation of smart meters, consumption management systems with tariff differentiation and identification of critical consumers, as well as flexible intelligent algorithms for coordinating the work of consumers and systems of distributed generation and storage of electricity play an important role in this process. For energy system calculations, it is important to use methods that allow you to analytically determine the energy characteristics and parameters of electricity. With the growing weight of electricity consumers, new opportunities appear. Thanks to new technologies, they can implement energy-saving measures and join local energy markets. They can install their own electricity generation and storage systems and contribute to the Smart Grid information system with the help of intelligent technologies for managing their energy systems.

Thus, the use of Java in Smart Grid systems contributes to the efficient operation of the power systems of settlements, the improvement of energy efficiency and sustainability, as well as the active involvement of end users in the management of energy resources.

DISCLOSURE STATEMENT

No potential conflict of interests was reported by the author(s).

REFERENCES

1. Ipsen, K.L., Zimmermann, R.K., Nielsen, P.S., & Birkved, M. (2019). Environmental assessment of Smart City Solutions using a coupled urban metabolism – life cycle impact assessment approach. *The International Journal of Life Cycle Assessment, 24*, 1239–1253. https://doi.org/10.1007/s11367-018-1453-9

2. Nilsson, A., Wester, M., Lazarevic, D., & Brandt, N. (2018). Smart homes, home energy management systems and real-time feedback: Lessons for influencing household energy consumption from a Swedish field study. *Energy and Buildings, 179*, 15–25. https://doi.org/10.1016/j.enbuild.2018.08.026

3. Pliuhin, V., & Teterev, V. (2021). Possibility implementation analysis of the Smart Grid network in a current state conditions of the united energy systems of Ukraine. *Lighting Engineering & Power Engineering, 60*(1), 15–22. https://doi.org/10.33042/2079-424X.2021.60.1.03

4. Pliuhin, V., Teterev, V., & Lapko, A. (2021). Smart Grid technologies as a concept of innovative energy development: initial proposals for the development of Ukraine. *Lighting Engineering & Power Engineering, 60*(2), 47–65. https://doi.org/10.33042/2079-424X.2021.60.2.02

5. Sedai, A., Dhakal, R., Gautam, S., Sedhain, K.B., Thapa, S.B., Moussa, H., & Pol, S. (2023). Wind energy as a source of green hydrogen production in the USA. *Clean Energy, 7*(1), 8–22. https://doi.org/10.1093/ce/zkac075

6. Sukhonos, M., Babaiev, V., Pliuhin, V., Teterev, V., Khudiakov, I. (2023). Load forecasting and electricity consumption by regression model. In: Arsenyeva, O., et al. (eds) *Smart Technologies in Urban Engineering*. LNNS, vol. 536 (pp 302–314). Springer. https://doi.org/10.1007/978-3-031-20141-7_28

7. Dhlamini, T., & Mawela, T. (2022). Critical success factors for information technology and operational technology convergence within the energy sector. In: Abraham, A., et al. (eds.) *Innovations in Bio-Inspired Computing and Applications*. LNNS, vol. 419 (pp. 425–434). Springer. https://doi.org/10.1007/978-3-030-96299-9_41

8. Bhavani, N.G., Kumar, R., Panigrahi, B.S., Balasubramanian, K., Arunsundar, B., Abdul-Samad, Z., & Singh, A. (2022). Design and implementation of IoT integrated monitoring and control system of renewable energy in smart grid for sustainable computing network. *Sustainable Computing: Informatics and Systems, 35*, 100769. https://doi.org/10.1016/j.suscom.2022.100769

9. Huang, P., Tu, R., Zhang, X., Han, M., Sun, Y., Hussain, S.A., & Zhang, L. (2022). Investigation of electric vehicle smart charging characteristics on the power regulation performance in solar powered building communities and battery degradation in Sweden. *Journal of Energy Storage, 56*, 105907. https://doi.org/10.1016/j.est.2022.105907

10. Parks, D. (2019). Energy efficiency left behind? Policy assemblages in Sweden's most climate-smart city. *European Planning Studies, 27*(2), 318–335. https://doi.org/10.1080/09654313.2018.1455807

11. Topel, M., & Grundius, J. (2020). Load management strategies to increase electric vehicle penetration – case study on a local distribution network in Stockholm. *Energies, 13*(18), 4809. https://doi.org/10.3390/en13184809

12. Zheng, Y., & Weng, Q. (2020). Modeling the effect of green roof systems and photovoltaic panels for building energy savings to mitigate climate change. *Remote Sensing, 12*(15), 2402. https://doi.org/10.3390/rs12152402

13. Raju, L., Milton, R.S., & Mahadevan, S. (2017). Application of multi agent systems in automation of distributed energy management in micro-grid using MACSimJX. *Intelligent Automation & Soft Computing*, 1–9. https://doi.org/10.1080/10798587.2017.1305647

14. Gibson, T., Ciraci, S., Sharma, P., Allwardt, C., Rice, M., & Akyol, B. (2014). An integrated security framework for goss power grid analytics platform. In *2014 44th Annual IEEE/IFIP International Conference on Dependable Systems and Networks* (pp. 786–791). IEEE. https://doi.org/10.1109/DSN.2014.106

15. NERCP: The National Commission for State Regulation in the Energy and Utilities Sectors (2021–2023). https://www.nerc.gov.ua/

16. Ahmad, I., Kazmi, J.H., Shahzad, M., Palensky, P., & Gawlik, W. (2015). Co-simulation framework based on power system, AI and communication tools for evaluating smart grid applications. In *2015 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA)* (pp. 1–6). IEEE. https://doi.org/10.1109/ISGT-Asia.2015.7387092

17. Zablodskiy, M.M., Pliuhin, V.E., Kovalchuk, S.I., & Tietieriev, V.O. (2022). Indirect field-oriented control of twin-screw electromechanical hydrolyzer. *Electrical Engineering & Electromechanics*, (1), 3–11. https://doi.org/10.20998/2074-272X.2022.1.01

18. Roy, S., & Sen, A. (2021). A self-updating K-contingency list for smart grid system. In *2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC)* (pp. 0341–0346). IEEE. https://doi.org/10.1109/CCWC51732.2021.9376067

19. Lin, Y.H. (2022). Multi-population evolutionary computing based multi-agent smart distribution system service restoration. Electrical Engineering, 104(5), 3295–3311. https://doi.org/10.1007/s00202-022-01547-y

20. Abdelhamid, A.M., Zakzouk, N.E., & El Safty, S. (2022). A multi-agent approach for self-healing and respenetration in smart distribution networks. *Mathematics, 10*(13), 2275. https://doi.org/10.3390/math10132275

21. Nasri, M., Ginn III, H.L., & Moallem, M. (2021). Agent-based coordinated control of power electronic converters in a microgrid. *Electronics, 10*(9), 1031. https://doi.org/10.3390/electronics10091031

22. Woltmann, S., & Kittel, J. (2022). Development and implementation of multi-agent systems for demand response aggregators in an industrial context. *Applied Energy*, *314*, 118841. https://doi.org/10.1016/j.apenergy.2022.118841

Інтеграція розумної електромережі для сталого управління енергією міста: змінення парадигми в мережах розподілу електроенергії

Віталій Тєтєрєв

Анотація. Дослідження присвячено застосуванню технологій Smart Grid для оптимізації споживання енергії в міських умовах. Завдяки розгляду практичних прикладів і ретельному аналізу результатів дослідження демонструє ефективність використання сенсорних мереж і автоматизованих систем реального часу для моніторингу та контролю споживання енергії. Отримані результати містять цінну інформацію та практичні рекомендації щодо впровадження технологій Smart Grid, спрямованих на підвищення стійкості та ефективності міської інфраструктури. Дослідження не тільки підкреслює теоретичні переваги Smart Grid, але й надає конкретні докази через оцінку результатів досліджень і реальних випадків. Дослідження підкреслює значний потенціал Smart Grid у революції методів управління енергією в містах. Інтеграція технологій Smart Grid відкриває можливості для досягнення ефективного контролю над енергопостачанням, скорочення споживання енергії та підвищення стабільності систем розподілу електроенергії в міському ландшафті. Крім того, результати дослідження пропонують дієві рекомендації щодо використання технологій Smart Grid, сприяння покращенню надійності енергопостачання та сприяння екологічним практикам. Впроваджуючи ці інновації, міста можуть досягти значних успіхів у ефективному управлінні енергією, що зрештою сприятиме підвищенню стійкості міст. Практичні ідеї, отримані в результаті цього дослідження, служать основою для впровадження інноваційних рішень, які вирішують зростаючі проблеми, пов'язані зі споживанням енергії в міському середовищі. Загалом, це дослідження закладає основу для просування дискурсу про технології Smart Grid та їх трансформаційний потенціал у формуванні майбутнього міського енергоменеджменту..

Ключові слова: Smart Grid, енергетичний менеджмент, контроль, енергоефективність, стійкість, відновлювальна енергія, інтеграція, розширення можливостей споживачів, оптимізація, мережі розподілу, аналіз даних, мережа.

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