https://doi.org/10.31891/csit-2024-2-3
UDC 620.91

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MODERN RENEWABLE ENERGY SOURCES AND METHODS FOR DETECTING THEIR DEFECTS

The article offers an overview of the current state and prospects of research in the field of renewable energy. The article presents the main sources of renewable energy (RES), including solar, wind, hydropower, as well as biomass energy and geothermal energy. The importance of these sources lies in reducing the dependence on fossil fuels and reducing greenhouse gas emissions. An analysis of renewable energy facilities and their implementation technology was carried out. The current state and prospects for the development of renewable energy sources in Ukraine and around the world are analyzed. In 2018, Ukraine joined (International Renewable Energy Agency) IRENA to develop renewable energy sources. This organization was founded to support the use of all forms of renewable energy sources.According to the agency, by the end of 2023, renewable energy sources accounted for 43% of the installed capacity. The total number of renewable energy facilities is increasing annually, but renewable energy sources account for half of the total capacity. 2023 was a year of the largest increase in renewable energy capacity to date (with the addition of 473 GW of renewable energy), a 13.9% increase in renewable energy reserves. Renewable energy accounts for a record 86% of the increase in world electricity, largely due to the significant growth of solar and wind power. In addition, the article emphasizes the importance of the reliability and efficiency of installations using renewable energy sources. The main methods for detecting damage in renewable energy systems are described. Detection methods based on acoustic emission, ultrasound, vibration, thermography, machine vision, and strain measurement are used most frequently to detect energy damage of renewable sources. The development of renewable energy sources stimulates economic growth and creates new jobs in the production, installation, maintenance, and management of energy installations. Investments in green energy contribute to the development of technologies, increasing competitiveness, and the creation of innovative sectors of the economy.

Keywords: renewable energy sources, methods of damage detection, RES object, IRENA.

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СУЧАСНІ ВІДНОВЛЮВАНІ ДЖЕРЕЛА ЕНЕРГІЇ ТА МЕТОДИ ВИЗНАЧЕННЯ ЇХ ДЕФЕКТІВ

У статті представлено основні відновлювані джерела енергії (ВДЕ), зокрема сонячну, вітрову, гідроенергію, а також енергію біомаси та геотермальну енергію. Важливість цих джерел полягає в зменшенні залежності від викопного палива та скороченні викидів парникових газів. Проведено аналіз об'єктів ВДЕ та технології їх впровадження. Проаналізовано сучасний стан та перспективи розвитку відновлюваних джерел енергії в Україні та світі. У 2018 році Україна приєдналася до Міжнародне агентство з відновлюваних джерел енергії IRENA (International Renewable Energy Agency) з метою розвитку ВДЕ. Ця організація заснована для підтримки використання усіх форм відновлюваних джерел енергії. Згідно даних агенства на кінець 2023 року відновлювані джерела енергії становили 43% світової встановленої потужності. Загальна кількість об'єктів відновлюваних джерел енергії збільшується щорічно, втім відновлювані джерела енергії становлять половину загальної потужності. У 2023 році відбулося найбільше зростання потужностей відновлюваної енергетики на сьогоднішній день (з додаванням 473 ГВт відновлюваної енергії) – збільшення запасів відновлюваної енергії на 13,9%. Відновлювані джерела енергії становлять рекордні 86% світового збільшення електроенергії, в основному завдяки значному зростанню сонячної та вітрової енергії. Крім того, у статті наголошується на важливості надійності та ефективності установок, що використовують відновлювані джерела енергії. Описано основні методи виявлення пошкоджень у системах відновлюваної енергетики. Для виявлення пошкоджень ВДЕ найчастіше використовуються методи виявлення, засновані на акустичній емісії, на основі ультразвуку, вібрації, термографії, машинного зору та на основі вимірювання деформації. Розвиток відновлюваних джерел енергії стимулює економічне зростання та створює нові робочі місця у виробництві, установці, обслуговуванні та управлінні енергетичними установками. Інвестиції в зелену енергетику сприяють розвитку технологій, підвищенню конкурентоспроможності та створенню інноваційних галузей економіки.

Ключові слова: відновлювані джерела енергії, методи виявлення пошкоджень, об'єкт ВДЕ, IRENA.

Introduction

Today, Ukraine is actively developing renewable energy sources (RES) with the aim of reducing dependence on coal and natural gas imports, as well as reducing greenhouse gas emissions. State programs and strategies are aimed at supporting the development of solar, wind, hydropower, and biofuels.

Solar energy is the most developed branch among RES in Ukraine. The country has a significant potential for the use of solar energy, which is reflected in the constant growth of the number of solar power plants [1].

Fig. 1. Solar power plant

Wind energy is also actively developing, particularly in areas with high wind energy capacity, such as the Western and Northern parts of the country. However, there are certain challenges associated with high construction costs and lack of infrastructure for connecting wind farms to power grids [2].

Fig. 2. Wind farm

Hydropower in Ukraine is developing on the basis of existing hydroelectric power stations, as well as the development of micro-hydroelectric power stations that can be installed on rivers and streams [3].

Fig. 3. Hydroelectric power station

Biofuel also takes its place in the RES mix of Ukraine, in particular, biomass and biogas are used for the production of electricity and heat [4].

Fig. 4. Biofuel power station

Despite certain achievements, the development of renewable energy in Ukraine also faces challenges, such as an unstable legal and regulatory framework, financial constraints, and the need to modernize energy networks to efficiently connect new RES.

Modern RES facilities

Renewable energy sources (RES) facilities can be classified according to various criteria, such as energy source, type of technology, location, etc. (Table 1).

Table 1

Types of RES facilities

Energy source	RES object	Technology
Solar energy	Photovoltaic power plants (PVE)	Using solar panels to convert sunlight into electrical energy
	Thermal solar power plants	The use of solar heat to heat the working medium (for example, water or a liquid solar coolant) and generate electricity
Wind energy	Wind power plants	The use of wind turbines to convert the kinetic energy of the wind into electrical energy
Hydropower	Hydroelectric power stations	Using the flow of water or the height of a waterfall to turn turbines and generate electricity
	Micro hydroelectric power stations	Small-scale hydroelectric power plants that can be installed on rivers and streams
Biomass	Biofuel power plants	Using organic materials such as wood, biomass, or biogas to produce electricity and heat
Geothermal energy	Geothermal power plants	Using the heat found in surface or underground sources to generate electricity

The main characteristics of these facilities include their capacity, efficiency, cost of construction and operation, impact on the environment, potential for development in a specific area, degree of implementation of technologies and infrastructure, as well as the possibility of their integration into the general energy system. Each type of facility has its advantages and limitations, and it is important to balance its use with the specific conditions and needs of society [5].

In 2009, the International Renewable Energy Agency (IRENA) was established to support the use of all forms of renewable energy. In 2018, Ukraine joined IRENA to develop RES. The agency collects and processes statistics that are constantly reviewed to improve renewable energy sources.

According to the agency's data, by the end of 2023, renewable energy sources accounted for 43% of the world's installed capacity. The total number of renewable energy sources increases annually according to the IRENA statistics (Figure 5).

However, renewable energy sources comprise half of the total capacity. 2023 saw the largest increase in renewable energy capacity to date – with the addition of 473 GW of renewable energy – a 13.9% increase in renewable energy stocks. Renewable energy accounts for a record 86% of the increase in world electricity, largely due to the significant growth of solar and wind power. Solar power accounts for nearly three-quarters of renewables,

with a record 346 GW, while wind power accounts for 116 GW. Despite these unprecedented inflows of renewable energy in 2023, the world still falls short of the goal of tripling installed renewable power capacity by 2030 to 11 TW. For this, it is necessary to increase the RES capacity by approximately 1050 GW every year [6].

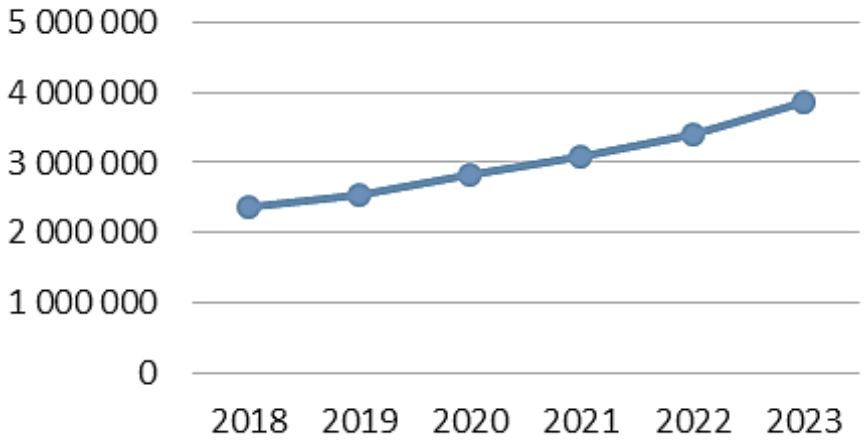

Fig. 5. Total number of renewable energy sources

The current state and prospects for the development of RES in Ukraine

In May 2022, the European Union adopted the REPowerEU plan, which provides for an increase in the share of RES from 40% to 45% by 2030. European goals specifically for wind energy: the capacity of the industry of the EU countries should increase from today's level of about 190 GW to 510 GW by 2030.

EU countries must install 39 GW of new wind power capacity each year. The industry is changing due to the development of technologies, the efficiency of modern wind turbines is increasing, and the utilization rate of installed capacity is increasing every year. For onshore wind energy, it is from 40%, and for "offshore" (sea) wind energy, it is from 60%.

The dynamic development of wind energy is impossible without the stability of the energy system. Therefore, further development should take place together with the construction of energy storage systems, maneuvering capacities, and hybrid RES power plants. The Ukrainian government presented the goals set in the draft plan for the Recovery of Ukraine until 2032 in Lugano in July 2022. The plan envisages the construction of 5 to 10 GW of wind-solar capacity by 2032 and an additional 30 GW for the production of "green" hydrogen.

In the presence of unchanged stable legislation, wind energy alone can install 7 GW of capacity by 2030. Now we already have 1.7 GW and by 2030 we have prepared projects that can be implemented [7].

From 16 March 2022, the energy system of Ukraine works synchronously with the continental European grid ENTSO-E and is part of the European energy space. At first, the Ukrainian energy system worked in the trial emergency synchronization mode of the trial, which did not involve export-import operations with European counterparties. The situation changed on 30 June when Ukraine and ENTSO-E started export-import operations. Ukraine's energy system is still in test mode - to complete synchronization, Ukraine must prepare and sign a lot of technical documentation.

ENTSO-E is an association of European electricity transmission system operators (TSOs) headquartered in Brussels, which, on a noncommercial basis, promotes the cooperation of European TSOs both at the pan-European and regional levels. It coordinates TSO activities in the areas of transmission system operation, system development,, market development and research.

The governing body of ENTSO-E is the Assembly, which represents 39 transmission system operators. ENTSO-E's work is focused on facilitating the creation and functioning of the internal energy market for electricity and cross-border trade. In addition, it plays an active and important role in the European rule-making process in accordance with EU legislation.

Synchronization means connecting power systems to work together in a unified network, allowing power systems to work together, combining generation and consumption. That is, synchronization allows power generation to supply electricity to the common power system. Ukraine started preparing for synchronization with the EU energy system in 2017. Synchronization was carried out in 2022.

As of the beginning of October 2022, commercial exports are carried out from Ukraine to Romania and Slovakia. Electricity is also supplied to Moldova and Poland, but this export is not commercial and is carried out under separate intergovernmental agreements.

The EU's interest in Ukrainian electric power can also be evidenced by the accelerated increase in capacity at interstate crossings. In particular, if at the beginning of electricity export on 30 June 2022, the permitted capacity was 100 MWh, then a month later, on July 30, the capacity was increased two and a half times, to 250 MWh. At the

same time, with the start of exports, ENTSO-E announced an increase in capacity no earlier than October 2022. On 1 October 1, 2022, the permitted capacity was already 300 MWh, and its further increase is planned.

Ukraine has great potential for the production of green energy, and many power plants (mainly solar and wind) have already been built and put into operation. Currently, European organizations involved in planning the restoration of Ukraine's energy system after the war are talking about the priority of "green" or energy-efficient projects. That is, when restoring a destroyed power plant that previously produced energy from gas or coal, it makes sense to build a new facility that will instead produce energy from renewable sources. If this is impossible or impractical, then such a power plant should be reconstructed using the most modern energy-efficient technologies.

According to pre-war estimates of the International Renewable Energy Agency**(Irena)**, Ukraine has the potential to install more than 320 GW of wind and 70 GW of solar power plants. This is without taking into account the assessment for the potential of installing wind and floating stations in the waters of the Crimea, which, according to the World Bank, can be greater than 250 GW. That is,**the total installed capacity of renewable sources in Ukraine may reach 415 GW in 10 years**, and taking into account the approximate capacities of the Crimean projects -**700 GW**.

The development of renewable energy sources stimulates economic growth and creates new jobs in the production, installation, maintenance, and management of energy installations. Investments in green energy contribute to the development of technologies, increasing competitiveness, and the creation of innovative sectors of the economy.

Advantages and disadvantages of RES

Renewable energy sources have a number of advantages, such as reducing greenhouse gas emissions and dependence on fossil fuels. However, there are also some major challenges they face:

1. Solar energy depends on the availability of sunlight, which varies throughout the day and year, and also depends on weather conditions. Wind energy depends on the presence of wind, which can be unpredictable and change over time.

2. Energy storage - efficient energy storage systems are needed, which are still quite expensive and have limited capabilities.

3. The current infrastructure of electrical networks is often not adapted to the integration of large amounts of RES. Significant investments are required for the modernization and development of smart grids.

4. The initial investment in a RES installation can be high. Although costs are reduced in the long run, the initial capital investment can be a barrier. There is also the question of economic feasibility in regions with limited natural resources suitable for RES.

5. The production and disposal of RES components, such as solar panels and wind turbines, also have a negative impact on the environment. Additionally, some forms of RES can have a local impact on ecosystems (for example, hydroelectric power plants).

6. More scientific research and technological development are needed to increase the efficiency of RES.

These problems are not insurmountable and active work is underway to solve them. Advances in science, technology, and policy are gradually improving the efficiency and cost-effectiveness of renewable energy sources, making them increasingly attractive for widespread adoption.

The constant monitoring of defects in renewable energy sources is one of the most important stages of RES operation. Detection and timely elimination of defects can prevent serious accidents and equipment damage, ensuring the safe and uninterrupted operation of installations. Defective or inefficient installations can have an increased negative impact on the environment.

The timely detection and elimination of defects contribute to the extension of the service life of power plants, reducing the need for frequent replacement of components. Furthermore, monitoring allows the detection and elimination of defects that can reduce the efficiency of energy generation. This helps maintain maximum system performance and reduce energy loss.

Regular monitoring and early detection of problems allow for planned maintenance, which is much cheaper than emergency repairs. This helps to avoid high costs for repair or replacement of equipment. The reliable operation of renewable energy sources is important for a stable energy supply.

The analysis of the defect data helps to improve existing technologies and develop new solutions that reduce the frequency of defects. It also contributes to training of personnel and the development of competences in the field of RES maintenance.

Taking into account these aspects, continuous monitoring of defects is a key element for the efficient and sustainable use of renewable energy sources.

Modern methods of research on RES defects

The following methods are most often used to detect RES damage:

1. Detection methods based on acoustic emission - the method aims to detect electrical signals arising from damage, plastic deformation, or crack propagation [8].

2. The ultrasound-based detection method allows detecting reflected waves of damage, which helps to track the development of damage [9].

3. Vibration detection methods. These methods are intended to monitor vibrations that may occur as a result of damage or deformation [10].

4. The thermographic-based detection method allows measuring temperature differences, which can indicate the presence of material damage [11, 12].

5. Machine vision-based detection methods use images to obtain information about the state of RES [13].

6. Detection methods based on strain measurement allow small changes in length or strain to be detected using strain sensors [8].

Results and Discussion

In particular, for solar panels, the main methods are thermography, electroluminescence, and performance analysis. In wind turbines, vibration analysis, ultrasonic control, and oil condition monitoring are used for diagnostics. Hydropower plants and bioenergy systems also require regular maintenance and diagnostics, which includes checking mechanical components, analyzing working fluids, and monitoring operational parameters.

These techniques help to effectively detect and diagnose damage to ensure safety, performance, and longevity.

Conclusions

Renewable energy sources are a key element of sustainable development, ensuring that current energy needs are met without compromising the capabilities of future generations. This helps preserve natural resources, maintain ecological balance, and ensure a high quality of life.

The introduction of innovative diagnostic and maintenance methods in renewable energy systems contributes to their sustainable development and widespread use, which is an important step on the way to an environmentally clean and energy-independent future.

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