UDC 658.264

I. Kozlov, DSc, Prof.,
V. Kovalchuk, PhD, Assoc. Prof.,
M. Holovin,
S. Vistiak
Odessa Polytechnic National University, 1 Shevchenko Ave., Odesa, Ukraine, 65044; e mail: kozlov_i.l_@ukr.net

FEATURES AND DEVELOPMENT PROSPECTS OF THE ODESSA REGION IN THE ENERGY SYSTEM OF UKRAINE

І. Козлов, В. Ковальчук, М. Головін, С. Вістяк. **Особливості та перспективи розвитку Одеського регіону в енергосистемі України.** У сучасному світі енергетика є основою розвитку базових галузей, що визначає прогрес громадського виробництва. Зростаюча потреба у використанні електроенергії ставить проблеми у пошуку джерел її генерації. Основною проблемою вибору джерел виробництва електроенергії є вплив енергії на навколишнє середовище. Багато країн зосереджують свою стратегію розвитку енергетики на відновлюваних джерелах енергії (ВІЕ) (сонячні, вітрові, біо та інші). Однак через свою специфіку ВІЕ не можуть забезпечити вироблення необхідного обсягу електроенергії. Ключова проблема відновлюваних джерел енергії полягає у забезпеченні безперебійного постачання енергії кінцевих споживачів. У роботі проведено порівняльний аналіз стану існуючої у південному регіоні України структури енергоресурсів та їх доступності. Розглянуто проблему забезпечення енергетичної та екологічної безпеки Одеського регіону в умовах дефіциту традиційних енергоресурсів. Розглянуто сучасний стан та перспективи використання відновлюваних джерел енергії. З використанням методу експертних оцінок для обґрунтування вибору виду прийнятного джерела енергії та підвищення відносної енергозабезпеченості окремих територій обґрунтовано використання атомної енергетики. Розглянуто перспективи розміщення нових енергоблоків з реакторною установкою АР1000 розробленого компанією Westinghouse Electric Company на території колишнього будівельного майданчику Одеської АТЕЦ (м. Теплодар). Наведено технічні характеристики проекту АР 1000. Отримані результати можуть бути основою об'єктивних оцінок щодо перспективи використання атомної енергетики для підвищення енергозабезпеченості Одеського регіону. Актуальність роботи зумовлена важливістю міжнародного співробітництва в атомній енергетиці, що відноситься до стратегічно значимих, інноваційно-ємних галузей сучасної світової економіки в умовах розвитку Одеського регіону.

Ключові слова: енергоресурси, екологічність, експертні оцінки, атомна енергетика, енергобезпека, Паризька угода

I. Kozlov, V. Kovalchuk, M. Holovin, S. Vistiak. **Features and development prospects of the Odessa region in the energy system of Ukraine.** In the modern world, energy is the basis of the development of basic industries, which determines the progress of public production. The growing need to use electricity poses problems in finding sources of its generation. The main problem of choosing sources of electricity production is the impact of energy on the environment. Many countries focus their energy development strategy on renewable energy sources (RES) (solar, wind, bio and others). However, due to their specificity, renewable energy sources cannot ensure the production of the required amount of electricity. The key problem of renewable energy sources is to ensure an uninterrupted supply of energy to end users. In the work, a comparative analysis of the state of the structure of energy resources and their availability in the southern region of Ukraine was carried out. The problem of ensuring energy and environmental security of the Odesa region in conditions of a shortage of traditional energy resources is considered. The current state and prospects of the use of renewable energy sources are considered. Using the method of expert evaluations to justify the choice of the type of acceptable energy source and increase the relative energy security of individual territories, the use of nuclear energy is substantiated. The prospects of placing new power units with the AP1000 reactor unit developed by the Westinghouse Electric Company on the territory of the former construction site of the Odesa Nuclear Thermal Power Plant (Teplodar) were considered. The technical characteristics of the AP 1000 project are given. The obtained results can be the basis of objective assessments regarding the prospects of using nuclear energy to increase the energy security of the Odesa region. The relevance of the work is determined by the importance of international cooperation in atomic energy, which is a strategically significant, innovation-intensive branch of the modern world economy in the conditions of development of the Odesa region.

Keywords: energy resources, environmental friendliness, expert assessments, nuclear energy, energy security, Paris Agreement

1. Introduction

The United Energy System of Ukraine (UES) is a set of power plants, electric and thermal networks operating in the general mode of production, transmission and distribution of electric and thermal energy. In the UES of Ukraine, nuclear (NPP), thermal (TPP) and hydroelectric power plants (HPP), combined heat and power plants (CHP), as well as power plants operating on alternative (renewable) sources of electricity (RES) (solar, wind, bio and others) operate in parallel. All of them are connected by main electrical networks.

According to the Ministry of Energy [1], at the end of 2021, 156.5 billion kWh of electricity was produced in the unified energy system of Ukraine. The shares of each component in the overall structure of electricity generation in Ukraine are:

– Nuclear power plants – more than 55%;

– TPP and CHP – 29.3%;

DOI: 10.15276/opu.2.68.2023.06

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

– HPP and PSP – 6.7%.

The share of renewable energy (solar, wind, bio-stations) was more than 8%.

In terms of quantity, electricity production in Ukraine is carried out by: 4 nuclear power plants; 15 thermal power plants, 2 of which remained in uncontrolled territory; 43 combined heat and power plants, 10 of which are located in uncontrolled territory; the basis of Ukraine's hydropower is a cascade of 6 large hydroelectric power stations on the Dnieper, as well as the Tashlytskaya pumped storage plant on the South Bug River. A total of 8 HPPs and 3 PSPs are in operation.

In 2022, the total production of electricity in Ukraine decreased by 27.5% compared to 2021. Electricity production at nuclear power plants fell by 28%, thermal power plants by 35%, heat and power plants by 32%, and the generation of renewable energy sources decreased by 36% [2].

Due to the Russian invasion, temporary occupation and missile attacks, Ukraine lost about 10 GW of various generation capacities, 6 GW of which is the Zaporizhia NPP. In addition, to date, about a quarter of the installed capacity of renewable energy sources is located in the occupied territories, including 75% of wind power plants and up to 15% of solar energy facilities.

2. Analysis of literary sources and statement of the problem

Energy supply of the Odesa region. In the Odesa region (area 33.314 km², population: 2.368 million people) until recently, the only domestic source of energy supply was the Odesa CHP, the first phase of which was put into operation in 1950, and the second was completed in 1966, with a total capacity of 68 MW. Since 2020, the Odesa CHP has been functioning only as a source of heat supply.

At the end of 2021, the power supply (electricity) of the Odesa region is provided by the generating capacities of the South-Ukrainian NPP and the Moldavian Region Power Station, which are located outside the Odesa region and in the perspective of the next 15 years should be decommissioned due to the exhaustion of the serviceability resource.

Moldavian Region Power Station, PJSC "Inter RAT" (Russia), with a total installed capacity of 2.520 MW (12 units), put into operation in 1964, located in the city of Dnistrovsk in Transnistria.

South-Ukrainian NPP of NAEK "Energoatom" (Ukraine), total installed capacity of 3.000 MW (3 units of 1.000 MW each), put into operation: Unit I – 1982, Unit II – 1985, Unit III – 1989, located in the city of Yuzhnoukrainsk, Mykolaiv region [3].

Based on the demographic forecast, observed from climate trends and under modern consumption standards, the capacity of regional consumers of the Odesa agglomeration, connected with the energy supply of utilities, other non-industrial consumers and the population, should be increased to 240 MW by 2040, and the total consumption of the Odessa agglomeration will be ~2225 MW (150 MW near-port production +152 MW ports with a cargo turnover of 300 million tons +238.5 MW communal, non-industrial, population +1089 MW desalination +594 MW wastewater treatment =2.5 MW) [4, 5, 6].

The last two decades have enriched the Odesa region's energy resources with the emergence of internal sources. As of the beginning of 2019, renewable electricity with a total capacity of about 260 MW was operating in Odesa [7]. In general, the region produces more than 10% of Ukraine's "alternative" electricity at 13 solar plants with a capacity of 1 to 40 MW, and about 100 MW of wind turbines. By 2030, it is expected to double the capacity of electricity production based on renewable energy sources. Under a favorable situation, up to 25% of needs will be provided. However, the problem of capacity building remains relevant and requires certainty in the choice of energy resources.

3. The purpose of the presented work

To substantiate the choice of types of acceptable energy resources, which ensure an increase in the relative energy supply of the territories of the regions, the method of expert assessments was applied [7]. Based on a quantitative comparative analysis of available energy resources and technologies based on them, it is shown that the acceptability index and the environmental preservation index exceed 1 for nuclear, solar, wind and hydropower. This allows us to predict them as the most promising for the region.

4. Prospects for the development of nuclear energy in the Odesa region

A promising source of electricity generation free from atmospheric emissions is nuclear energy [8], which, according to the calculations of a group of experts on climate change [9], during the generation process has greenhouse gas emissions throughout the life cycle that do not exceed those typical for renewable resources (Table 1).

Table 1

Specific emissions of generations

Resource	NPP	Wind	Hydro	Solar	Thermal	
					gas	coal
Release, тequiv CO_2/(GW·year)	12	11	24	48	490	820

If we estimate the planetary scale, then the work of all nuclear power plants in the world saves greenhouse gas emissions at the level of 2 billion tons of CO_2 equivalent per year, which is proportional to the absorption capacity of the entire forest massif of the planet. In addition, nuclear generation is 6 times cheaper than "green" generation and 3 times cheaper than thermal generation.

Research by the Joint Research Center at the European Commission [10] shows that nuclear energy has the lowest specific material intensity compared to other low-carbon types of generation. For example, the metal density for the production of 1 MWh of electricity at a nuclear power plant is 13 times less than that of wind generation. It is also important that a nuclear power plant requires a relatively small area: for example, to install a wind farm with a capacity of 1 GW, 950 hectares of land are needed, and for a nuclear power plant of similar capacity – 28 ha. At the same time, nuclear power plants provide a stable base load of networks, which does not depend on weather conditions, 24 hours a day, 7 days a week for at least 60 years. As of January 2021, there were 449 power reactors in the world with a total capacity of about 393 GW [11], 50 reactors were under construction.

Thanks to the "carbon-free" status granted to nuclear energy by the Paris climate agreement of 2015 [12, 13], the predictable and low cost of electricity production at nuclear power plants, minimal carbon emissions, the ever-increasing safety of nuclear plants, and the rise of energy consumption in the development of regions of the planet that are developing by 2040, the global production of electricity at nuclear power plants will increase, according to estimates, by 28…62%.

Joining the trends of the spread of nuclear power plants around the globe, the Odesa region will receive the most reliable basis in nuclear energy for ensuring energy security, social well-being and economic development.

On August 31, 2021, the head of Energoatom and the president and chief executive officer of Westinghouse Electric signed a memorandum of cooperation, which provides for the placement of AP1000 reactors at Ukrainian nuclear power plants [14], including in the Odesa region on the territory of the former construction site of the Odesa NTPP (Teplodar) [15]. AP1000 is an American double-circuit water nuclear reactor (PWR) [16] with an electrical power unit of about 1.1 GW, developed by the Westinghouse Electric Company. AP1000 became the first reactor for generation III +NPP power units to receive a certificate from the US Nuclear Regulatory Commission (NRC) [16, 17] Table 2.

Table 2

Technical characteristics of the AR 1000 project

Installed electric capacity of the power unit, MW	1100
Nominal thermal power of the reactor, MW	3400
Project term of the NPP, years	60
The coefficient of use of the installed capacity, %	More 93
Efficiency coefficient, net, %	32
Duration of the period between fuel overloads, months	Up to 18
Probability of severe damage to the reactor zone, reactor/year	5.09 E-7
Probability of marginal emergency release, reactor/year	5.94 E-8
Horizontal acceleration at ground level during an earthquake is taken into account in the project	0.5 g (corresponds to 9 and above points on the Richter scale)

The AP1000 reactor is the cheapest among other 3rd generation reactor designs. Service life: 60 years.

In AR 1000 generation III+ reactors, the level of safety has been significantly increased due to the use of passive safety systems, which do not require active control elements or operator intervention, but instead rely on gravity or the nature of convection to mitigate the impact of extreme events [18].

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

The design of the AR 1000 power unit has significantly increased seismic resistance, which enables its placement in the Odesa region.

In the AP1000 reactor, heat is dissipated by atmospheric air passing into the space between the steel containment and the concrete shield building (annular space) and beyond the top of the shield building. There are also tanks with a volume of about 1.500 m^3 of water, located on top of the concrete shield. After LOCA, the water is carried by gravity to the outer surface of the steel containment and is converted to steam, which is carried by the air circulating through the annulus. The system is completely passive as the safety systems are activated and operated by stored nitrogen pressure or gravity, and there is no need for driven pumps, chillers or emergency diesel generators. The passive containment cooling system in the AP1000 [19] is a safety-related system that functions to reduce the temperature and pressure in the containment after a loss of coolant accident (LOCA), main steam line burst (MSLB) accident inside the containment or other events that cause a significant increase in pressure and temperature in the containment. The function of the AP1000's passive containment cooling system (PCCS) is to prevent the containment from overheating and exceeding the design pressure, which could cause the containment to breach and lose the final barrier to radioactive release. PCCS consists of the following components [19]:

– air intake and exhaust paths built into the building structure with shield protection;

– air barrier located between the steel containment and the concrete panel building;

– a passively cooled containment water storage tank (PC CWST) built into the structure of the shield protection building above the containment;

– water distribution system.

Safety systems provide heat removal from the active zone and cooling of the containment for 72 hours without the use of station and external power sources. The time of non-interference of the operator in the operation of automation is 30 minutes.

The energy supply of systems important for safety is carried out from accumulator batteries of class 1 E, which eliminate the need for sources of reliable power supply at the NPP site (blackout conditions).

The strategy of keeping the core melt inside the reactor body has been implemented.

Conclusions

With careful design and proven operation, nuclear power plants are a safe source of energy that can provide large electrical capacities for consumption and significantly reduce the environmental burden. Due to the practically zero level of emissions of greenhouse gases into the atmosphere, nuclear power plants can significantly affect the ecological picture of the world, which is an extremely important task in the context of solving the problem of global climate change. The planned placement of power units with AP1000 reactors can generate electricity for the entire Odesa region, as well as supply electricity and heat to the city of Chornomorsk and Teplodar itself.

Література

1. Особливості вітчизняного виробництва електроенергії. *Новини УЕБ.* 2022. URL: https://www.ueex.com.ua/rus/presscenter/news/osobennosti-otechestvennogo-proizvodstva-elektroenergii/.
2. Vadim Kolisnichenko. Ukrainian steelmakers reduced electricity consumption by 52% y/y in 2022. *GMK.CENTER*. URL: https://gmk.center/en/news/ukrainian-steelmakers-reduced-electricity-consumption-by-52-y-y-in-2022/
3. В'ячеслав Воронков. Одещина нарешті може отримати надійне джерело електропостачання. *Газета Верховної Ради «Голос України», Енергобезпека*, 22 червня 2022. URL: http://www.golos.com.ua/article/361631.
4. Світлана Косаренко. Енергетична безпека Одещини та перспективи молоді в енергетиці. *Газета: Вечерняя Одесса 15-07-2022*. URL: http://newspapers.od.ua/v_odessa/6388-energetichna-bezpeka-odeschini-ta-perspektivi-molod-v-energetic.html.
5. Карта розташування та з'єднання всіх електростанцій України, URL: https://www.imbf.org/karty/images/elektrostantsiy-ukrainy-hq.jpg.
6. Assessing the region's energy provision / Kozlov I., Kovalchuk V., Klymchyk O., Dorozh O., Sigal A., Aksyonova I., Elkin Y. *Eastern-European Journal of Enterprise Technologies*. 2022. 2 (8 (116)), 13–20. DOI: https://doi.org/10.15587/1729-4061.2022.255740 .

7. Україна, Одеська обласна рада. Про затвердження регіональної цільової програми енергоефективності Одеської області на 2020-2022 роки, 03 березня 2020 року, № 1233-VII, URL: https://oblrada.od.gov.ua/wp-content/uploads/1233-VII.pdf.
8. Collier J., Hewitt G. Introduction to Nuclear Power. Moscow : Energoatomizdat, 1989. 253 p.
9. United Nations Economic Commission for Europe. 2021. Согласно докладу ЕЭК ООН, международные климатические цели не будут достигнуты, если исключить атомную энергетику. URL: https://unece.org/ru/climate-change/press/soglasno-dokladu-eek-oon-mezhdunarodnye-klimaticheskie-eli-ne-budut.
10. The Power Reactor Information System (PRIS). *IAEA.* URL: https://pris.iaea.org/pris/home.aspx.
11. Nuclear Share of Electricity Generation. URL: https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.
12. Парижское соглашение: материалы XXI конференции Рамочной конвенции об изменении климата. 2015. URL: https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_russian_.pdf.
13. United Nations. Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. 2016. URL: https://unfccc.int/sites/default/files/resource/docs/2015/cop21/eng/10a01.pdf.
14. Валерий Моисеев. Украина будет строить новые ядерные энергоблоки: как это изменит энергосистему страны. 2023. *Незалежний громадский портал. Єкономика Украіні.* URL: https://thepage.ua/economy/v-ukraine-budut-ispolzovat-yadernye-reaktory-ap1000.
15. ДП НАЕК «Енергоатом» , ВП «Атомпроектіженіринг». Протокол наради з питань розгляду можливості відновлення будівництва об'єктів енергозабезпечення Одеського регіону. 09.03.2023.
16. Schulz T.L. Westinghouse AP1000 advanced passive plant. *Nuclear Engineering and Design.* 2006. Vol. 236, Issues 14–16. P. 1547–1557. DOI: 10.1016/j.nucengdes.2006.03.049.
17. Westinghouse. AP1000. Public Safety and Licensing. URL: http://www.westinghousenuclear.com/AP1000/public_safety_licensing.shtm.
18. Un AP1000 alcanza por primera vez la operación a plena potencia – Foro Nuclea. 2018. URL: https://www.foronuclear.org/actualidad/noticias/un-ap1000-alcanza-por-primera-vez-la-operacion-a-plena-potencia/.
19. Luciano Burgazzi, Rosa Lo Frano. Risk analysis of safety systems devoted to severe accident management in nuclear power plants. 2018. URL: https://www.researchgate.net/publication/329466479_Risk_analysis_of_safety_systems_devoted_to_severe_accident_management_in_nuclear_power_plants#fullTextFileContent (дата звернення: 24.10.2023).

References

1. Features of domestic electricity production. (2022). *UEB news.* 2022. Retrieved from: https://www.ueex.com.ua/rus/presscenter/news/osobennosti-otechestvennogo-proizvodstva-elektroenergii/.
2. Vadim Kolisnichenko. (2022). Ukrainian steelmakers reduced electricity consumption by 52% y/y in 2022. *GMK.CENTER*. Retrieved from: https://gmk.center/en/news/ukrainian-steelmakers-reduced-electricity-consumption-by-52-y-y-in-2022/.
3. Vyacheslav Voronkov. (2022). Odesa can finally get a reliable source of electricity. *Verkhovna Rada newspaper "Voice of Ukraine", Energy Security*, June 22, 2022. Retrieved from: http://www.golos.com.ua/article/361631.
4. Svitlana Kosarenko. (2022). Energy security of Odesa and prospects of youth in energy. *Newspaper: Vechernyaya Odessa*, 07-15-2022. Retrieved from: http://newspapers.od.ua/v_odessa/6388-energetichna-bezpeka-odeschini-ta-perspektivi-molod-v-energetic.html.
5. Map of location and connections of all power plants of Ukraine. Retrieved from: https://www.imbf.org/karty/images/elektrostantsiy-ukrainy-hq.jpg.
6. Kozlov, I., Kovalchuk, V., Klymchyk, O., Dorozh, O., Sigal, A., Aksyonova, I., & Elkin, Y. (2022). Assessing the region's energy provision. *Eastern-European Journal of Enterprise Technologies,* 2 (8(116)), 13–20. DOI: https://doi.org/10.15587/1729-4061.2022.255740.
7. Ukraine, *Odesa Regional Council*. (2020). On the approval of the regional target energy efficiency program of the Odesa region for 2020-2022, March 3, 2020, No. 1233-VII. Retrieved from: https://oblrada.od.gov.ua/wp-content/uploads/1233-VII.pdf.
8. Collier, J., & Hewitt, G. (1989). *Introduction to Nuclear Power*. Moscow: Energoatomizdat.
9. *United Nations Economic Commission for Europe.* (2021). According to UNECE report, international climate goals will not be achieved if nuclear power is excluded. Retrieved from: https://unece.org/ru/climate-change/press/soglasno-dokladu-eek-oon-mezhdunarodnye-klimaticheskie-eli-ne-budut.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

10. *IAEA.* The Power Reactor Information System (PRIS). Retrieved from: https://pris.iaea.org/pris/home.aspx.
11. *Nuclear Share of Electricity Generation.* Retrieved from: https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.
12. Paris Agreement: proceedings of the XXI Conference of the Framework Convention on Climate Change. (2015). Retrieved from: https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_russian_.pdf.
13. *United Nations.* (2015). Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Retrieved from: https://unfccc.int/sites/default/files/resource/docs/2015/cop21/eng/10a01.pdf.
14. Valery Moiseev. (2023). Ukraine will build new nuclear power units: how this will change the country's energy system. 2023. *Independent huge portal. Economy of Ukraine.* Retrieved from: https://thepage.ua/economy/v-ukraine-budut-ispolzovat-yadernye-reaktory-ap1000.
15. *DP NAEK Energoatom, VP Atomproektizheniring.* (2023). Protocol for the purpose of considering the feasibility of updating the life of energy supply facilities in the Odessa region, 09.03. 2023.
16. Schulz, T.L. (2006). Westinghouse AP1000 advanced passive plant. *Nuclear Engineering and Design*, 236, 14–16, 1547–1557. DOI: 10.1016/j.nucengdes.2006.03.049.
17. *Westinghouse. AP1000.* Public Safety and Licensing. Retrieved from: http://www.westinghousenuclear.com/AP1000/public_safety_licensing.shtm.
18. Un AP1000 alcanza por primera vez la operación a plena potencia. (2018). *Foro Nuclea*. Retrieved from: https://www.foronuclear.org/actualidad/noticias/un-ap1000-alcanza-por-primera-vez-la-operacion-a-plena-potencia/.
19. Luciano Burgazzi, & Rosa Lo Frano. (2018). *Risk analysis of safety systems devoted to severe accident management in nuclear power plants.* Retrieved from: https://www.researchgate.net/publication/329466479_Risk_analysis_of_safety_systems_devoted_to_severe_accident_management_in_nuclear_power_plants#fullTextFileContent. (Last access 24.10.2023).

Козлов Ігор Леонідович; Igor Kozlov, ORCID: 0000-0003-0435-6373
Ковальчук Вячеслав Іванович: Viacheslav Kovalchuk, ORCID: 0000-0001-8696-4414
Головін Микола Олегович, Mykola Holovin
Вістяк Сергій Володимирович, Serhii Vistiak, ORCID: 0000-0002-9132-1541

Received October 24, 2023
Accepted December 09, 2023