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Volodimir Mamalyga[1], Oleksii Kondrashin[2], Yan Jiyong[3], Yu Qiang[4]

Looking for the optimal choice of generating units during the restoration of the Ukrainian power system

Abstract: Damage to critical infrastructure, including the energy sector, has led to a lack of generation capacity in Ukraine's energy system and has negatively impacted the economy and civilians' lives. One of the ways to solve Ukraine's energy problems may be the use of cogeneration gas turbine units. In this case, it will ensure more economically efficient use of gas and electricity generation. This approach will allow responding promptly to changes in the load in the power system during the day (week, month, year), since the operation of cogeneration gas turbine units does not depend on weather conditions or landscape, and uses the resources available in the country. The restoration and modernization of Ukraine's power system can be realized through the connection of 5–10 MW power generation units. Calculations show that the use of less powerful turbines can be more flexible due to the possibility of locating them directly at the places of consumption, i.e., distributed cogeneration units of low power will be used in the power system. Waste heat can be additionally used for heating, and the needs of enterprises and civilians. The Solar Taurus T60 was considered an

✉ Corresponding Author: Volodimir Mamalyga; e-mail: v.mamalyga@gmail.com

[1] National University Kyevska Politechnika, Ukraine; ORCID iD: 0000-0001-5922-4066; e-mail: v.mamalyga@gmail.com

[2] National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine; ORCID iD: 0009-0009-0939-7837; e-mail: oleksii.kondrashin@gmail.com

[3] Zhejiang Nuocai Technology Co., Ltd., China; ORCID iD: 0009-0007-4258-6555; e-mail: yx@1000top.cn

[4] Zhejiang Omnipotent Spring Machine Co., Ltd., China; ORCID iD: 0009-0003-6515-3737; e-mail: 125664409@qq.com

example of a cogeneration gas turbine unit. The paper presents a calculation model for determining the cost of electricity. As a result of the calculation, it was shown that it is the least cost-effective to use Solar Taurus T60 only during peak hours at a cost of money of up to 0.26. And in the case of cogeneration plant operation around the clock, as well as in peak and semi-peak hours, their operation is economically feasible for a cost of money of less than 0.40 and 0.45 relative units, respectively. The analysis of three generator operation strategies shows that each of them remains economically feasible as long as the cost of money does not exceed 0.26 relative units. Considering that the current interest rate set by the National Bank of Ukraine is below 20% (NBU 2025), which is significantly below this threshold, all three strategies can be regarded as financially justified under present economic conditions.

Keywords: feasibility study, gas fuel power plants, traditional energy sources

Introduction

Damage to critical infrastructure, including the energy sector, has negatively impacted the economy and civilians' lives (Ukrinform 2024a). This has led to a lack of generation capacity in Ukraine's energy system. One way to solve this problem is to connect additional capacities to the power system in Ukraine and from abroad.

Importing electricity from other countries is associated with geopolitical risks (Epravda 2022). The involvement of new generating units can reduce dependence on external energy supplies and strengthen economic resilience to external pressure.

One way to solve this problem is to implement a green transition (Ministry of Economy of Ukraine 2025) using wind and solar energy. However, the use of these technologies is associated with certain risks, in particular due to their dependence on weather conditions. The experience of other countries (The Times 2024) demonstrates the need to limit the total installed capacity of non-conventional energy sources, as their use can lead to difficulties with the even distribution of loads throughout the day, week, month, and season.

Unlike solar and wind power plants, nuclear power provides stable electricity generation throughout the aforementioned time periods, and it is already the largest source of electricity in Ukraine (Slovo i Dilo 2024). However, nuclear power plants (NPPs) cannot be used as a source of load balancing during peak and semi-peak hours. Moreover, the construction of new NPP units requires significant material resources and takes a long time to implement (World Nuclear Association 2023).

Unlike NPPs, hydroelectric power plants are usually used to level the power system's load schedules, but their capacity in non-mountainous areas is limited, and their construction can be even more expensive than NPP construction. The possibility of building pumped storage power plants in Ukraine is also limited, with the exception of the Tashlyk PSPP (South Ukrainian NPP 2013).

In general, to solve the problem of energy deficit, it is advisable to use the resources available in the country. And the solution should contribute to relatively low atmospheric emissions, be cost-effective, and not depend on weather conditions or landscape.

One such resource is Ukraine's natural gas, of which it already has a developed transportation system (State Service of Geology and Mineral Resources of Ukraine 2018). Natural gas, compared to other fossil fuels (Our World in Data 2023), results in lower emissions to the environment. In view of the above, the task of generating electricity using natural gas is relevant.

1. Proposed solution

The restoration and modernization of Ukraine's power system can be realized through the connection of power generation facilities with a capacity of up to 10 MW (Ukrinform 2024b). It should be borne in mind that as the unit capacity of the plant decreases, the costs per 1 MW increase. The proposed solutions can be used not only after the end of the war in Ukraine, but even now.

The Solar Taurus T60 could be used as an example of a cogeneration gas turbine plant. The main advantages of this model, according to Solar Turbines, are high efficiency, long service life, and low atmospheric emissions (Solar Turbines n.d.a; Solar Turbines n.d.b). In the case of cogeneration plants (Caterpillar n.d.), waste heat can be used for heating or for the technological needs of enterprises.

Modern gas turbines have a significant service life, and with proper maintenance, their service life can reach 30 years (Allied Power Group n.d.).

2. Calculations

Let's analyze the efficiency of using these cogeneration units in round-the-clock, peak, and both semi-peak and peak hours compared to purchasing electricity. To determine the costs of implementing a cogeneration unit based on the Taurus T60, we can use formulas (1), (2), (3), and (4). These formulas take into account all significant factors: the cost of gas, electricity tariffs, the cost of equipment, and the costs of operation and maintenance over the duration of operation of the equipment.

C1 – costs of using a generator to generate electricity without interruption;

C2 – the cost of using the generator only during peak hours;

C3 – costs of using the generator during peak and semi-peak hours;

C4 – costs of purchasing electricity without using a generator.

$$C1 = \frac{C_{gen}}{(1+i)^0} + \frac{C_t \cdot 24 \cdot t + C_f \cdot Q_{en}}{(1+i)^1} + ... + \frac{C_t \cdot 24 \cdot t + C_f \cdot Q_{en}}{(1+i)^T} \quad (1)$$

$$C2 = \frac{C_{gen}}{(1+i)^0} + \frac{\left(C_t \cdot H_p + C_{hp} \cdot Q_{en} \cdot H_{hp} + C_n \cdot Q_{en} \cdot H_n\right) \cdot t + C_f \cdot Q_{en}}{(1+i)^1} + \dots$$
$$\dots + \frac{\left(C_t \cdot H_p + C_{hp} \cdot Q_{en} \cdot H_{hp} + C_n \cdot Q_{en} \cdot H_n\right) \cdot t + C_f \cdot Q_{en}}{(1+i)^T} \quad (2)$$

$$C3 = \frac{C_{gen}}{(1+i)^0} + \frac{\left(C_t \cdot H_p + C_t \cdot H_{hp} + C_n \cdot Q_{en} \cdot H_n\right) \cdot t + C_f \cdot Q_{en}}{(1+i)^1} + \dots$$
$$\dots + \frac{\left(C_t \cdot H_p + C_t \cdot H_{hp} + C_n \cdot Q_{en} \cdot H_n\right) \cdot t + C_f \cdot Q_{en}}{(1+i)^T} \quad (3)$$

$$C4 = \frac{(C_p \cdot Q_{en} \cdot H_p + C_{hp} \cdot Q_{en} \cdot H_{hp} + C_n \cdot Q_{en} \cdot H_n) \cdot t}{(1+i)^1} + \dots$$
$$\dots + \frac{(C_p \cdot Q_{en} \cdot H_p + C_{hp} \cdot Q_{en} \cdot H_{hp} + C_n \cdot Q_{en} \cdot H_n) \cdot t}{(1+i)^T} \quad (4)$$

where:

- C_{gen} – the cost of the generator set (3,250,000 USD) (USPE Global n.d.),
- C_{gas} – the cost of gas (0.19 USD/m^3) (Minfin 2025),
- Q_{gas} – gas consumption to generate Q_{en} (1,500 m^3/h),
- t – the operating time (365 days),
- H_p – the number of peak hours per day (5 h),
- H_{hp} – the number of semi-peak hours per day (11 h),
- H_n – the number of night hours per day (8 h),
- C_p – the cost of electricity during peak hours (160 USD/MW) (24 Channel 2025),
- C_{hp} – the cost of electricity in semi-peak hours (100 USD/MW) (24 Channel 2025),
- C_n – the cost of electricity during night hours (42 USD/MW) (24 Channel 2025),
- Q_{en} – the electricity produced (5 MW/h),
- i – the cost of money (relative units),
- T – 30 years,
- C_f – the fixed component of operation and maintenance costs (25,000 USD/MW-yr),
- C_v – the variable component of operation and maintenance costs (2 USD/MWh),
- C_t – the cost of using the turbine unit for one hour at capacity Q_{en} (5).

$$C_t = C_{gas} \cdot Q_{gas} + C_v \cdot Q_{en} \tag{5}$$

Figure 1 shows the costs (USD) at different costs of money and operating modes (round-the-clock, peak, both semi-peak and peak hours compared to purchasing electricity), taking into account formulas (1), (2), (3), and (4).

The x-axis represents the cost of money (relative units) that can be attracted for the project implementation. The y-axis represents the level of discounted total costs for the project implementation period T.

Software in the form of a web application was developed to perform calculations and visualize them. This software is an interactive analytical tool designed to compare the long-term costs of electricity generation using a generator and purchasing it from the grid.

Calculations are based on a set of technical, economic, and operational assumptions provided by the user. The results of cost calculations for different operating strategies are presented in the form of discounted cost dependencies throughout the project implementation. The user can freely adjust the input data, which allows for the analysis of multiple hypothetical scenarios. The resulting dependencies reveal potential changes under specific financial conditions and indicate which option is more economically viable.

3. Risk analysis

Let us analyze the dependencies shown in Figure 1. Dependency C1 represents the discounted costs in the case of round-the-clock operation of the generator covering all loads.

Dependency C2 represents the costs in the case of generator operation during peak load hours. Electricity is purchased from the grid during other hours. Compared to C1, the costs in graph C2 are higher at any cost of money.

Dependency C3 represents the costs in the case of generator operation during peak and semi-peak load hours. Electricity is purchased from the grid exclusively at night, when electricity tariffs are lowest. Compared to C1, C3 shows slightly lower costs at all points, but this ratio is heavily affected by changes in nighttime electricity rates, gas rates, and the variable component of operation and maintenance costs.

Graph C4, which represents the cost of purchasing electricity from the grid, is the basis for determining the economic feasibility of using a generator at the corresponding cost of money.

Let us analyze the feasibility of using generators using the example of gas pumping stations on gas pipelines:

- The lowest costs at a cost of money of up to 0.46 relative units (46%) are associated with the operation of generators during peak and semi-peak hours.

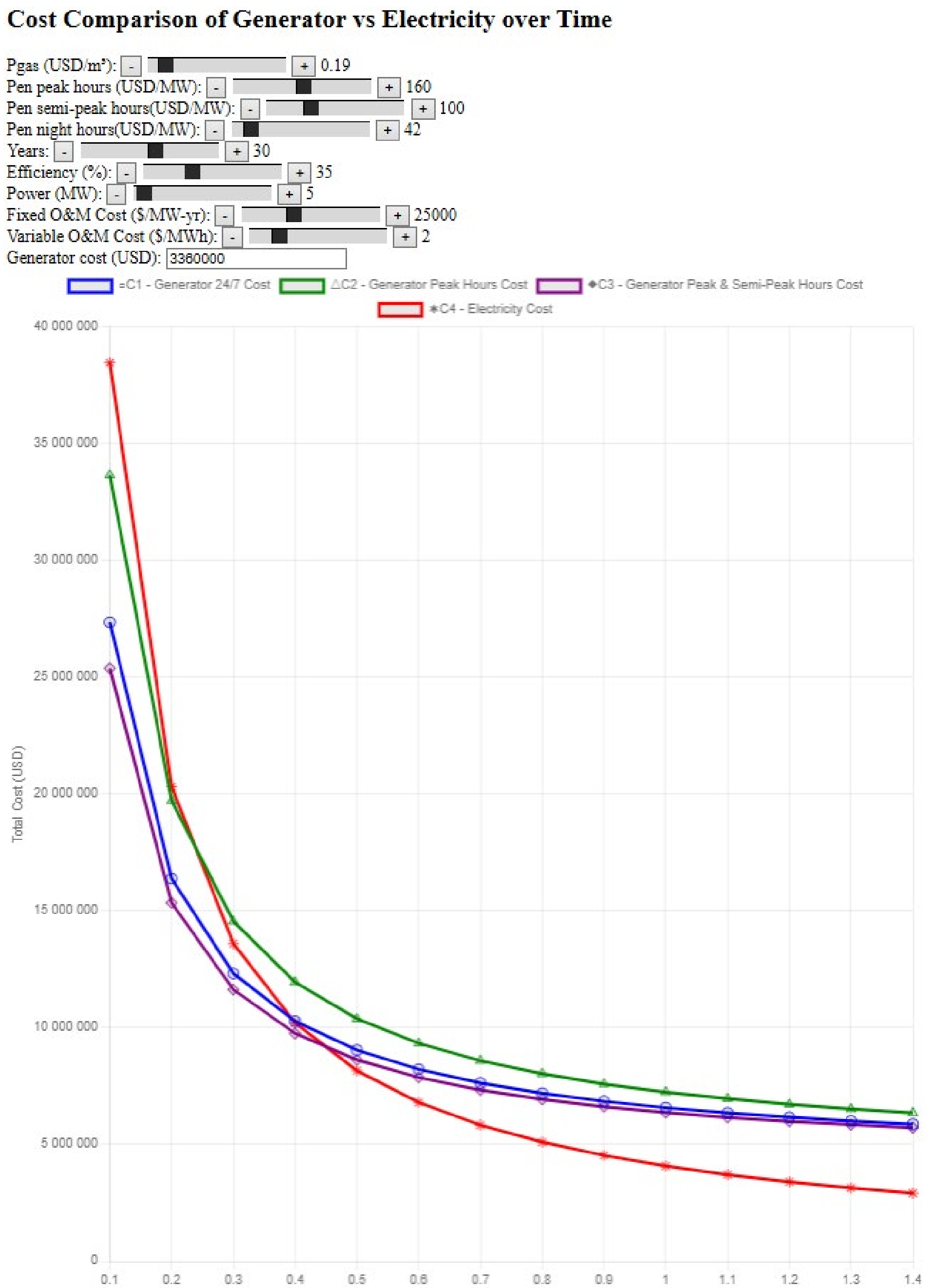

Fig. 1. Costs [USD] for different costs of money and generator operating modes (24 hours, peak hours, semi-peak hours and peak hours compared to purchasing electricity from the power grid)

Rys. 1. Koszty [USD] dla różnych kosztów energii i trybów pracy generatora (24 godziny, godziny szczytu, godziny półszczytowe i godziny szczytu w porównaniu z zakupem energii elektrycznej z sieci energetycznej)

- The second least expensive scenario is round-the-clock (24/7) operation of generators. The difference between the costs of the peak and semi-peak hours scenarios is insignificant (up to 4–5%).
- Generator operation exclusively during peak hours has an advantage only when compared to the performance of the power grid.
- At a cost of money above 0.46 relative units (46%), the cheapest scenario is the operation of gas pumping stations when using electricity from the power grid.

The difference in costs (USD) when generating electricity under different generator usage strategies, depending on the cost of money (relative units) relative to the cost of electricity from the grid, is shown in Figure 2.

The areas of the graphs shown in Figure 2 that are greater than 0 reflect economically viable scenarios for using the generator at different costs of money. The higher the point on the graph is positioned, the greater the advantage of this scenario compared to purchasing electricity from the power grid. The analysis showed that the least economically viable option is to operate the generator only during peak hours. Even operating the generator around the clock (24/7) is more economically rational. The best performance is achieved when the generator is operated during peak and semi-peak hours.

Interestingly, the performance of strategies C1 and C3 is almost identical. Therefore, even small changes in parameters can affect the economic feasibility of one strategy compared to another. Thus, if nighttime electricity rates increase by 30% or gas rates decrease by 26%, the C1 and C3 curves will coincide (see Fig. 3 and Fig. 4).

An analysis of the dependencies shown in Figure 3 showed that it is least expedient to use generators exclusively during peak hours. The economic feasibility of using a generator around the clock (24/7) and during peak and semi-peak hours is practically the same and has an advantage over powering from the power grid at a cost of up to 0.46 relative units (46%).

The change in gas tariffs introduced in Fig. 3 had the most impact on the dependency C1, reducing total cost (USD) at every point of the curve and allowing it to catch up to less dependent C3. Conversely, changes of parameters introduced in Figure 4 produce the opposite effect, making C3 align with C1.

For the scenario of a 30% increase in night-time electricity tariffs (see Fig. 4), the least expedient option is to use generators only during peak hours at a cost of money of up to 0.26 relative units (26%). The analysis showed that for the scenario shown in Fig. 4, the economic feasibility of using a generator around the clock (24/7) and during peak and semi-peak hours is practically the same and has an advantage over powering from the power grid at a cost of money of up to 0.55 relative units (55%).

Considering the possibility of such changes (see Fig. 3 and Fig. 4), it should be noted that although the considered parameter changes have a significant impact on the ratio of dependencies C1 and C3, the impact on their ratio to the C4 graph is insignificant. The use of a gas turbine will remain a more economically viable solution at a certain cost of money, and various turbine usage scenarios can be applied in accordance with parameter changes during operation.

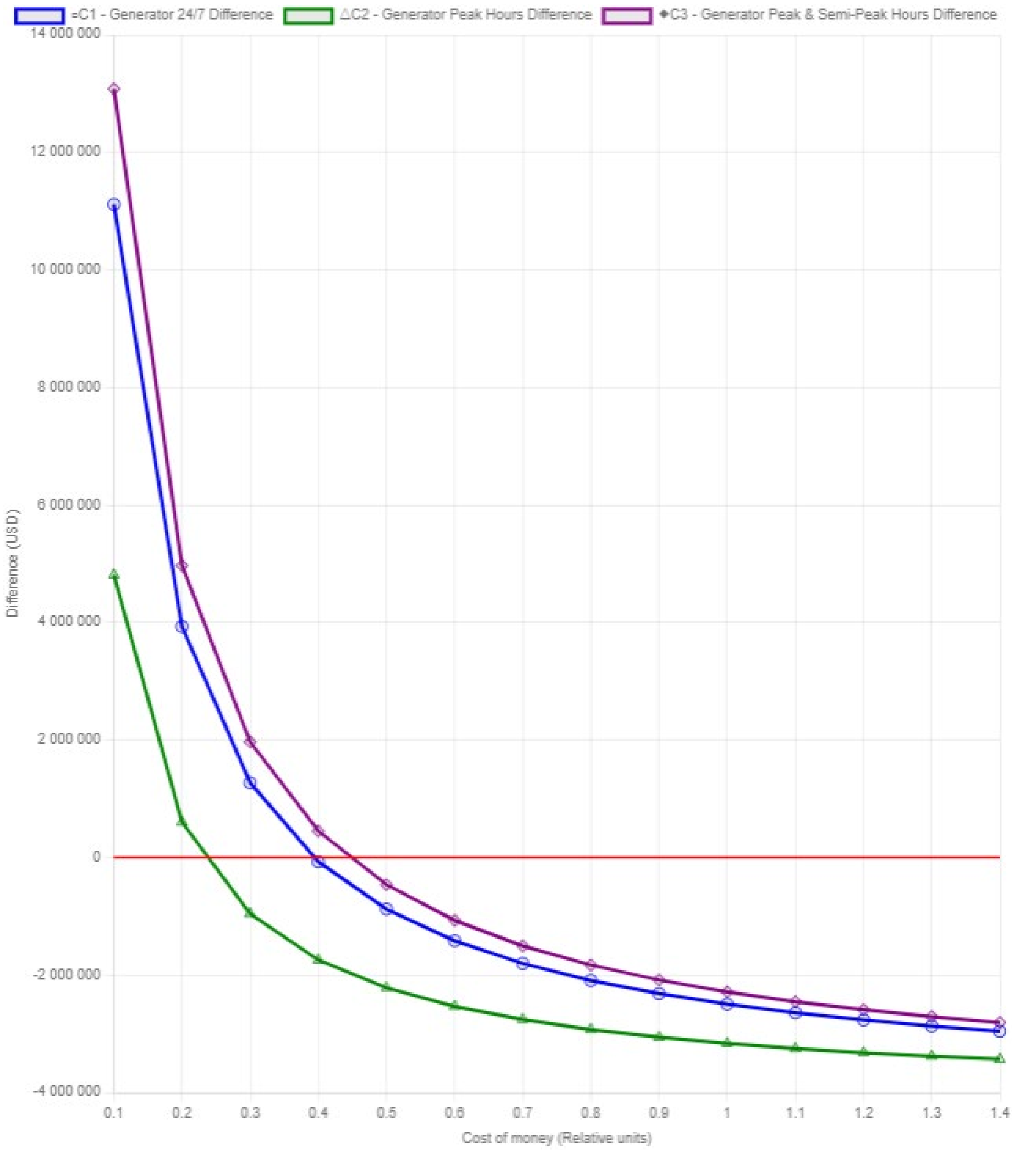

Fig. 2. Difference in costs [USD] when generating electricity under different generator usage scenarios, depending on the cost of money (relative units) compared to the cost of electricity from the power grid

Rys. 2. Różnica w kosztach [USD] przy wytwarzaniu energii elektrycznej w różnych scenariuszach wykorzystania generatorów, w zależności od kosztu pieniądza (jednostki względne) w porównaniu z kosztem energii elektrycznej z sieci energetycznej

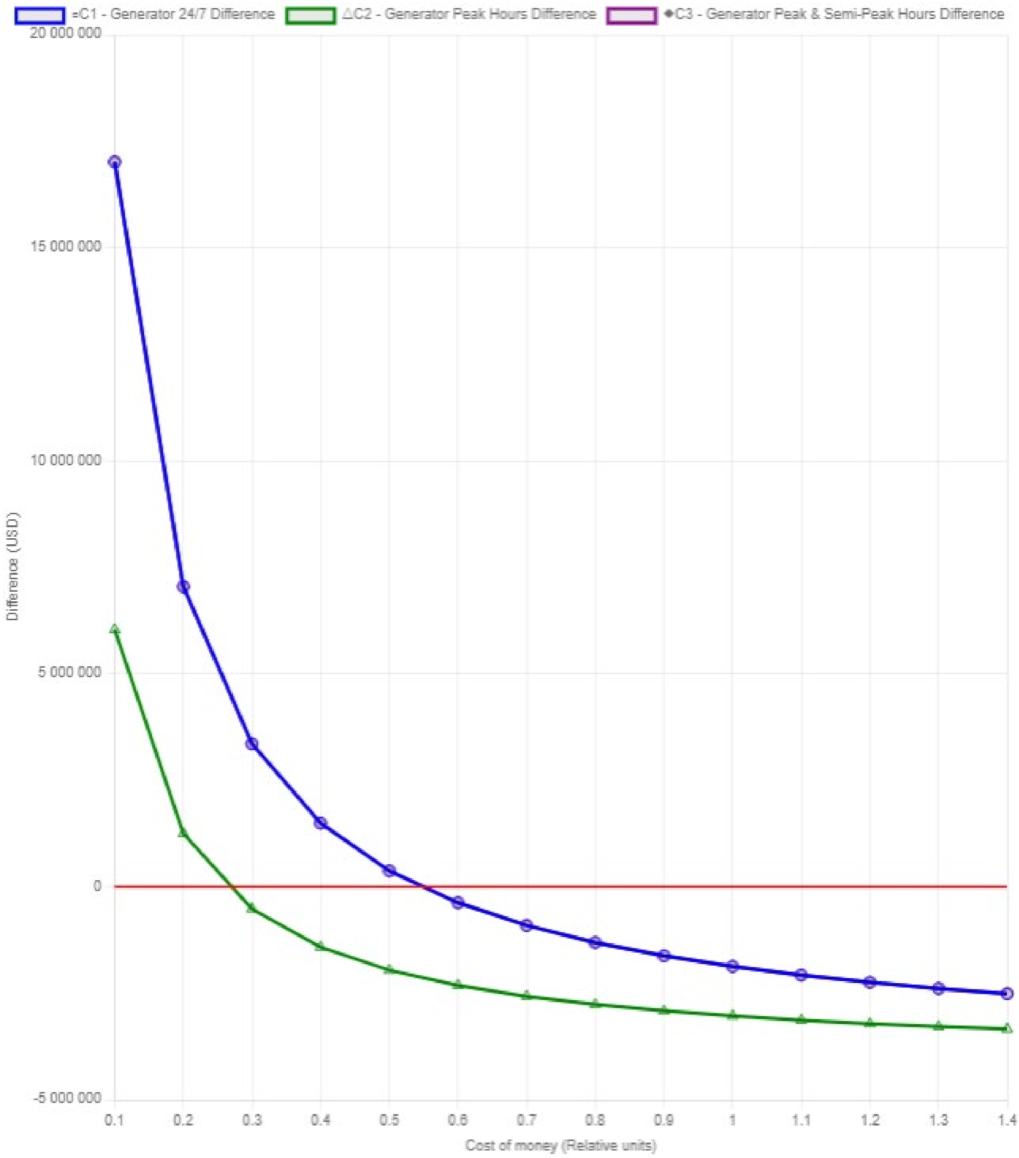

Fig. 3. Difference in costs [USD] when generating electricity under different generator usage scenarios, depending on the cost of money (relative units) compared to the cost of electricity from the power grid in the event of a 26% reduction in gas tariffs

Rys. 3. Różnica w kosztach [USD] przy wytwarzaniu energii elektrycznej w różnych scenariuszach wykorzystania generatorów, w zależności od kosztu pieniądza (jednostki względne) w porównaniu z kosztem energii elektrycznej z sieci energetycznej w przypadku 26-procentowej obniżki taryf gazowych

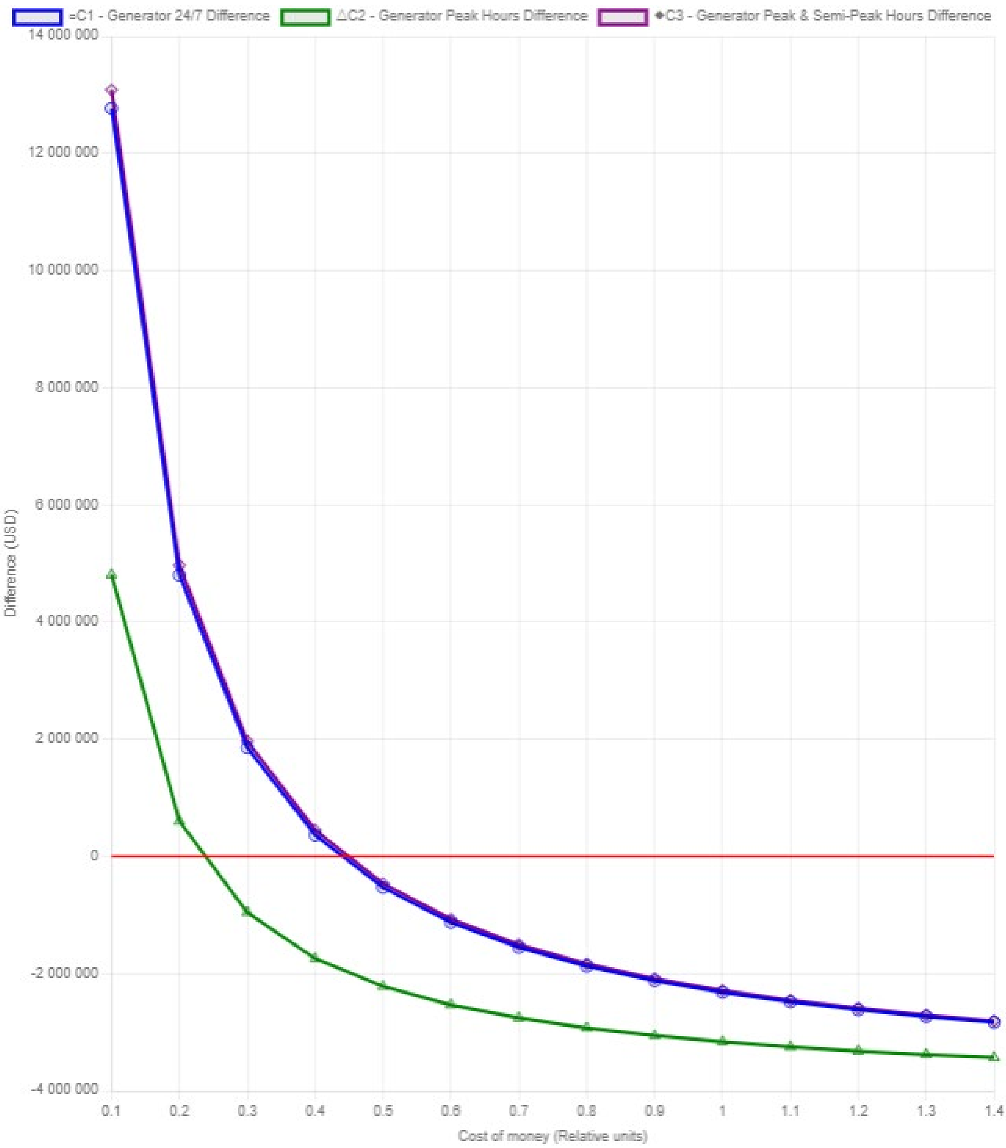

Fig. 4. Difference in costs [USD] when generating electricity under different generator usage scenarios, depending on the cost of money (relative units) compared to the cost of electricity from the power grid in the event of a 30% increase in nighttime electricity tariffs

Rys. 4. Różnica w kosztach [USD] przy wytwarzaniu energii elektrycznej w różnych scenariuszach wykorzystania generatorów, w zależności od kosztu pieniądza (jednostki względne) w porównaniu z kosztem energii elektrycznej z sieci energetycznej w przypadku 30-procentowego wzrostu taryf za energię elektryczną w nocy

The analysis of the dependencies presented in Figure 1 shows that it is more economically feasible to use Solar Taurus T60 at a cost of money of less than 0.25 in the case of round-the-clock operation of the cogeneration unit. And in the case of operation of the cogeneration unit in peak, as well as in peak and semi-peak hours, their operation is economically feasible at a cost of money of 0.40 and 0.45, respectively.

It should be borne in mind that the ratio of the cost of one cubic meter of gas to the cost of one megawatt of electricity (hereinafter referred to as the ratio) will affect economic indicators. Figure 5 shows the results of the study of this ratio according to the information provided in (Slovo i Dilo 2020; 2021) over the past 30 years. Thus, from 2014 to 2023, this ratio was less than 200. In this case, the use of electricity generation from natural gas is economically infeasible.

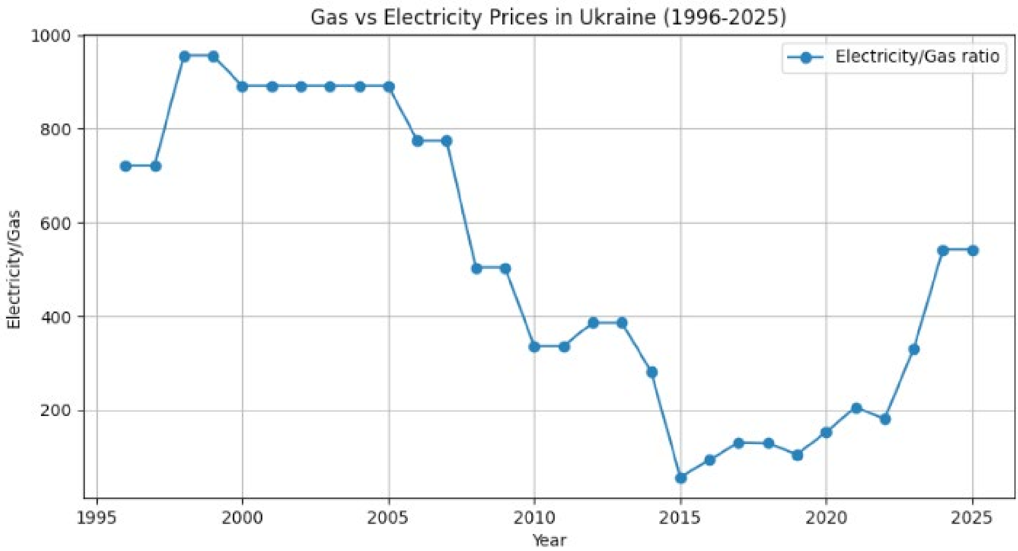

Fig. 5. Graph of the ratio of electricity and gas tariffs in 1996–2025

Rys. 5. Wykres przedstawiający stosunek cen energii elektrycznej i gazu w latach 1996–2025

Conclusions

Given the destruction of the energy infrastructure, one of the ways to solve Ukraine's energy problems may be the use of cogeneration gas turbine units. In this case, it will ensure more economically efficient use of gas and electricity generation. This approach will allow responding promptly to changes in the load in the power system during the day (week, month, year), since the operation of cogeneration gas turbine units does not depend on weather conditions or landscape, and uses the resources available in the country. It should also be noted that connecting cogeneration plants to the power grid requires relatively little time.

The restoration and modernization of Ukraine's power system can be realized through the connection of 5–10 MW power generation units (Ukrinform 2024b). Calculations show that the use of less powerful turbines can be more flexible due to the possibility of locating them directly at the places of consumption, i.e., distributed cogeneration units of low power will be used in the power system. Waste heat can be additionally used for heating, and the needs of enterprises and civilians. The Solar Taurus T60 was considered an example of a cogeneration gas turbine unit. The paper presents a calculation model for determining the cost of electricity. As a result of the calculation, it was shown that it is more economically feasible to use the Solar Taurus T60 at a cost of money less than 0.25 in the case of round-the-clock operation of the cogeneration unit. And in the case of cogeneration plant operation in peak, as well as in peak and semi-peak hours, their operation is economically feasible for a cost of money less than 0.40 and 0.45, respectively.

The ratio of the cost of one cubic meter of gas to the cost of one megawatt of electricity was investigated. It is shown that at the level of prices and tariffs from 1996 to 2014 and from 2022 to 2025, the use of electricity generation from natural gas is economically feasible.

The feasibility of using generators was analyzed using the example of gas pumping stations on gas pipelines (see Fig. 1). It was shown that:

The lowest costs, at 0.46 relative units (46%), are associated with the operation of generators during peak and semi-peak hours.

The second lowest cost scenario is the round-the-clock (24/7) operation of generators. The difference between the costs of the peak and semi-peak operation scenarios is insignificant (up to 4–5%).

Generator operation during peak hours is only advantageous compared to the performance of the power grid.

At a cost of money of more than 0.46 relative units (46%), the cheapest scenario is the operation of gas pumping stations when using electricity from the power grid.

An analysis was conducted of the difference in costs when generating electricity under different generator usage scenarios, depending on the cost of money compared to the cost of electricity from the power grid (see Fig. 2). It was found that the least economically viable option is to operate the generator exclusively during peak hours. Even operating the generator around the clock (24/7) is more economically rational. The best results are achieved when the generator is operated during peak and semi-peak hours.

Possible scenarios of a reduction in the cost of gas and an increase in the cost of electricity at night were also analyzed. Thus, if gas tariffs are reduced by 26% (see Fig. 3), it is least feasible to use generators only during peak hours. The economic feasibility of using a generator around the clock (24/7) and during peak and semi-peak hours is practically the same and has an advantage over powering only from the power grid at a cost of money of up to 0.46 relative units (46%). If nighttime electricity rates increase by 30% (see Fig. 4), it is least cost-effective to use generators only during peak hours at a cost of money of up to 0.26 relative units (26%). In this case, the economic feasibility of using a generator around the clock (24/7) and during peak and semi-peak hours is practically the same and has an advantage over powering only from the power grid at a cost of money of up to 0.55 relative units.

The analysis of three generator operation strategies shows that each of them remains economically feasible as long as the cost of money does not exceed 0.26 relative units. Considering that the current interest rate set by the National Bank of Ukraine is below 20% (NBU 2025), which is significantly below this threshold, all three strategies can be regarded as financially justified under present economic conditions.

The results of the study can be used to determine the optimal choice of generating units during the restoration of the Ukrainian power system. This technology does not entail the disadvantages identified in the alternatives considered. Gas turbines can bring additional benefits due to their cogeneration capability. According to the analysis of gas and electricity tariff dynamics, the proposed solution may stay economically feasible in the future.

The Authors have no conflicts of interest to declare.

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Volodimir Mamalyga, Oleksii Kondrashin, Yan Jiyong, Yu Qiang

Poszukiwanie optymalnego wyboru jednostek wytwórczych podczas przywracania ukraińskiego systemu energetycznego

Streszczenie

Uszkodzenia infrastruktury krytycznej, w tym sektora energetycznego, doprowadziły do braku mocy wytwórczych w ukraińskim systemie energetycznym i miały negatywny wpływ na gospodarkę oraz życie ludności cywilnej. Jednym ze sposobów rozwiązania problemów energetycznych Ukrainy może być wykorzystanie kogeneracyjnych turbin gazowych. W tym przypadku zapewni to bardziej ekonomiczne użytkowanie gazu i energii elektrycznej. Podejście to pozwoli na szybkie reagowanie na zmiany obciążenia w systemie energetycznym w ciągu dnia (tygodnia, miesiąca, roku), ponieważ działanie kogeneracyjnych turbin gazowych nie zależy od warunków pogodowych ani ukształtowania terenu i wykorzystuje zasoby dostępne w kraju. Odbudowa i modernizacja systemu energetycznego Ukrainy mogą zostać zrealizowane poprzez podłączenie jednostek wytwarzających energię o mocy 5–10 MW. Obliczenia pokazują, że wykorzystanie turbin o mniejszej mocy może być bardziej elastyczne ze względu na możliwość umieszczenia ich bezpośrednio w miejscach zużycia, tzn. w systemie energetycznym będą wykorzystywane rozproszone jednostki kogeneracyjne o małej mocy. Ciepło odpadowe może być dodatkowo wykorzystywane do ogrzewania oraz zaspokajania potrzeb przedsiębiorstw i ludności cywilnej. Jako przykład jednostki kogeneracyjnej z turbiną gazową rozważano Solar Taurus T60. W artykule przedstawiono model obliczeniowy służący do określania kosztów energii elektrycznej. W wyniku obliczeń wykazano, że najmniej opłacalne jest stosowanie Solar Taurus T60 tylko w godzinach szczytu przy koszcie pieniądza wynoszącym do 0,26. Natomiast w przypadku pracy elektrociepłowni przez całą dobę, a także w godzinach szczytu i półszczytowych, ich eksploatacja jest ekonomicznie opłacalna przy koszcie pieniądza wynoszącym odpowiednio mniej niż 0,40 i 0,45 jednostek względnych. Analiza trzech strategii pracy generatorów pokazuje, że każda z nich pozostaje ekonomicznie opłacalna, o ile koszt pieniądza nie przekracza 0,26 jednostki względnej. Biorąc pod uwagę to, że obecna stopa procentowa ustalona przez Narodowy Bank Ukrainy wynosi poniżej 20% (NBU 2025), co jest znacznie poniżej tego progu, wszystkie trzy strategie można uznać za uzasadnione finansowo w obecnych warunkach gospodarczych.

Słowa kluczowe: studium wykonalności, elektrownie gazowe, tradycyjne źródła energii