Shahar elektr ta'minotida taqsimlangan generatsiya manbalarini qo'llash

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Dolzarblik: ushbu maqolada elektr yuklama zichligi o'zgaruvchan va yuqori bo'lgan shahar kichik mikrorayoni hududida taqsimlangan generatsiya manbalarini joriy etish, ularni qo'llash orqali shahar elektr tarmoqlarining texnik-iqtisodiy ko'rsatkichlarini tahlili amalga oshiriladi. Past kuchlanishli shahar elektr tarmoqlarining ish rejimlariga ushbu manbalarning ta'sirini baholash va taqsimlangan generatsiya manbalarining boshqaruv tizimlarini yaratish hamda energiya samaradorlikka erishishda loyihalash jarayoni uchun nazariy asos yaratish muhim hisoblanadi.
Maqsad: past kuchlanishli shahar elektr tarmoqlarida taqsimlangan generatsiya manbalarini qo'llash orqali energiya samaradorlikka erishishni ta'minlash, boshqaruv tizimlarini joriy etish orqali elektr yuklama grafiklarini tekislash hisoblanadi.
Usullar: shahar elektr tarmoqlarining texnik-iqtisodiy ko'rsatkichlarini hisoblash usullari, taqsimlangan generatsiya manbalarini modellashtirish usuli, energiya samaradorlikka erishish va past kuchlanishli shahar elektr iste'molchilarining yuklama grafiklarini tekislash usullari.
Natijalar: tadqiqot natijalari shahar elektr ta'minoti tizimida taqsimlangan generatsiya manbalarini joriy etish orqali elektr tarmoqlarining yuklanish darajasini optimallash, elektr yuklama grafiklarini tekislash va elektr energiyasining isroflarini qisman kamaytirishda, shuningdek, elektr energiyasi sifatini yaxshilash, energiya samaradorlikka erishishni texnik-iqtisodiy asoslash va baholashda, loyihalash jarayonlarida foydalaniladi.
Kalit so'zlar: shahar elektr ta'minoti, taqsimlangan generatsiya, energiya samaradorlik, energiya saqlash tizimlari, quyosh panellari, invertor, elektr energiya isrofi, elektr yuklama grafigi.

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Применение источников распределённой генерации в городском электроснабжении

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Актуальность: в статье проводится анализ внедрения источников распределённой генерации в условиях небольшого городского микрорайона с изменяющейся и высокой плотностью электрической нагрузки. Рассматривается влияние таких источников на режимы работы городских электрических сетей низкого напряжения, а также приводится оценка их воздействия на технические и экономические показатели электрических сетей. Важным аспектом является создание теоретической основы для разработки систем управления источниками распределённой генерации и проектирования процессов, направленных на достижение энергетической эффективности.
Цель: обеспечить высокую энергоэффективность городских электрических сетей низкого напряжения за счёт применения источников распределённой генерации, а также выравнивания графиков электрической нагрузки посредством внедрения систем управления.
Методы: методы расчёта технико-экономических показателей городских электрических сетей, методы моделирования источников распределённой генерации, методы достижения энергоэффективности и выравнивания графиков нагрузки потребителей низковольтных городских электрических сетей.
Результаты: результаты исследования используются для оптимизации загрузки электрических сетей в системе городского электроснабжения, за счёт внедрения источников распределённой генерации, выравнивания графиков электрической нагрузки и снижения потерь электроэнергии. Также они применяются для улучшения качества электроэнергии, технико-экономического обоснования и оценки повышения энергоэффективности, а также в процессах проектирования.
Ключевые слова: городское электроснабжение, распределённая генерация, энергоэффективность, системы хранения энергии, солнечные панели, инвертор, потери электроэнергии, график электрической нагрузки.

Application of distributed generation sources in city power supply

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Relevance: in this article, analyzes the implementation of distributed generation sources in a small city microdistrict characterized by variable and high electric load density. It examines the impact of these sources on the operating modes of low-voltage city power networks and evaluates their effect on the technical and economic performance of city power grids. An essential aspect is the development of a theoretical foundation for designing control systems for distributed generation sources and for planning processes aimed at achieving energy efficiency.
The goal: ensuring energy efficiency in low-voltage city power networks is achieved through the application of distributed generation sources and the leveling of electric load profiles by implementing control systems.
Methods: methods for calculating the technical and economic performance of city power networks, modeling techniques for distributed generation sources, approaches to achieving energy efficiency, and methods for leveling load profiles of low-voltage urban electricity consumer.
Results: the research results are utilized to optimize the loading levels of power grids in the city power supply system through the implementation of distributed generation sources, leveling electric load profiles, and partially reducing energy losses. They are also applied to improve power quality, provide a techno-economic justification and assessment of achieving energy efficiency, and aid in design processes.
Keywords: city power supply, distributed generation, energy efficiency, energy storage systems, solar panels, inverter, electricity losses, electric load profile.

1. Introduction

Currently, targeted efforts are being made globally to ensure the continuous supply of high quality and reliable electricity to consumers. In particular, modern energy efficient technologies are being utilized to form advanced electrical grids for electrical energy transmission, distributed generation sources are being installed near electrical consumers, and measures are being taken to reduce electrical energy loss. Additionally, special attention is being paid to the analysis and evaluation of the load status of electrical grids during peak electricity demand periods, the application of differential tariffs for electrical consumers, and aligning daily electrical load curves into a single straight line [1].

The expansion of cities and the growing population in the Republic of Uzbekistan have led to an increased demand for electricity among consumers. Ensuring the continuous supply of high quality and reliable electricity to consumers is a crucial task in today's context. The Regional electrical grids serving electrical consumers are part of Uzbekistan's energy system, with cities covering the areas where the majority of the country's population resides [2].

Research has shown that the total electrical energy losses in Regional electrical grids can reach 20% or more. The main losses (80-90%) are concentrated in the 0,38-10 kV distribution networks, while the share of commercial losses accounts for 50-70% of the total losses [3].

In the city power supply system, the electricity load density of consumers, i.e., the calculated electrical load per square kilometer, is high. The electrical load generated by consumers forms a vertical characteristic. In city areas, the connection of electrical consumers to the electrical grids is independent and unrestricted throughout the day, resulting in uneven electrical load curves. If the period of unevenness in the load curves lasts for an extended period, it impacts the operating modes of all city electrical grids, including those involved in generation, transmission, and distribution. In this context, implementing electrical energy generation and storage systems near electrical consumers proves to be effective. Therefore, it is essential to establish distributed generation sources and integrate them into the city power supply system [1,4].

Currently, achieving energy efficiency in the city power supply system by applying appropriate types of distributed generation sources, based on the geographic structure of the region, is crucial. This approach aims to reduce additional electrical energy loss (ΔW) caused by overloads in the city electrical grids and to lower the amount of carbon dioxide (CO_2) emissions released into the environment by thermal power plants. This is one of the pressing tasks in the field of energy management.

2. Methods and materials

The widespread integration of distributed generation sources, the growing demand for electricity, and the sudden occurrence of power outages in electrical grids are leading to significant transformations in electrical energy systems worldwide. These changes are particularly evident as renewable energy is expected to make up a large portion of the electricity mix in the coming decades. These shifts have introduced new challenges, particularly regarding system stability and control, due to the reduction in inertia and short-circuit levels. [5,9]. A number of countries have set goals to reduce their reliance on traditional fossil fuel-based energy sources and strengthen the integration of distributed generation sources, including wind, solar, storage, geothermal, hydro, ocean, and biomass. The European Union has set specific targets for the integration of distributed generation sources, aiming for a 25% share by 2025, 30% by 2040, and 40% by 2050, with gradual increases. These goals encompass all member states, each of which has developed its own policies and objectives. For example, Italy aims to achieve a 40% share of distributed generation sources in energy consumption by 2040, while Germany and the UK have set goals to provide 65% and 40% of electricity consumption, respectively, from distributed generation sources. To achieve these ambitious goals, it has been deemed essential to develop real models of electrical grids that include a wide range of technologies, system configurations, and elements such as high voltage direct current networks, microgrids, digital power stations, and substations. These models should take into account various future scenarios, considering local weather conditions, the availability of energy resources, and the seasonal variation in electricity and heat energy demand. Numerous studies have been conducted in regions and countries such as Sweden, the UK, the USA, Canada, China, Japan, Korea, Germany, India, Saudi Arabia, and the United Arab Emirates, many of which have set objectives for fully integrating distributed generation sources [8,9].

The analysis, studies, and research conducted show that the integration of photovoltaic solar power stations and electrical energy storage systems in the city power supply system is effective. The methods for connecting these systems to the existing infrastructure and utilizing them, along with the development of control systems, are crucial. The following Figure 1 presents a general structural diagram of the connection between the city power supply system and distributed generation sources.

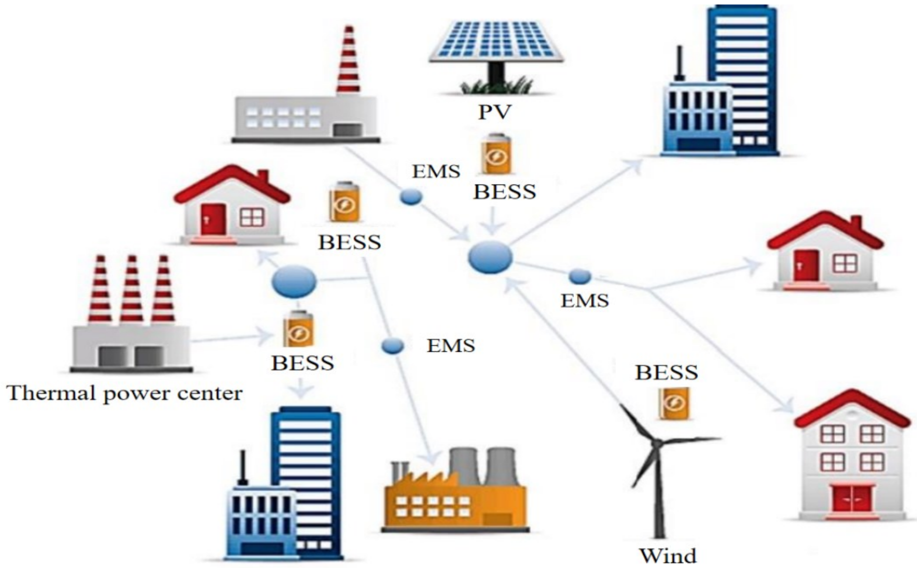

Fig. 1. The general layout diagram of distributed generation sources

The integrated distributed generation sources and all participating electrical grids in the city power supply system can be described in the following sequence [10,13]:
- medium voltage supply transmission line (cable);
- power transformer substion;
- low voltage distribution transmission line (cable);
- photovoltaic power station;
- electrical energy storage systems.

Numerous scientific studies are conducted in these directions. In this scientific article, methods aimed at significantly reducing indicators 2 and 3 are developed. To achieve this, we must first define the object. As the object, we isolate the electrical grids between the electricity supply grids and the electrical consumers. To visualize this, we refer to the one line diagram of the city power supply system, built with distributed generation, created using the PSCAD simulation software package developed in Canada, as shown in Figure 2.

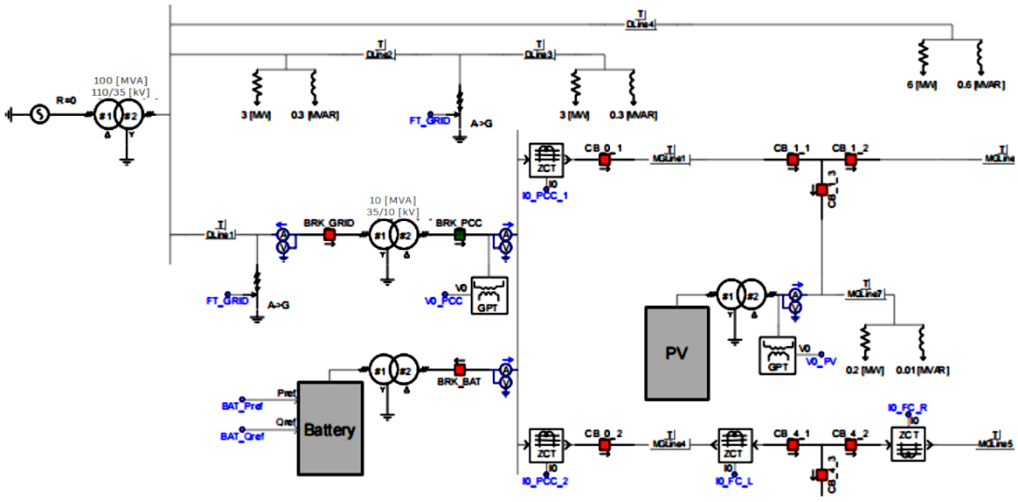

Fig. 2. The one line diagram of the city power supply system taken as the research object

One of the key topics that we need to present in the article is the issue of leveling the electrical load curve. In this case, it is necessary to examine the typical diagram of the electrical load curve in real situations. Figure 3 shows the typical variation graph of the electrical load curve for distributed generation and electrical consumers in the city power supply system. Maintaining a uniform line on this variation graph is considered the main requirement for distributed generation sources.

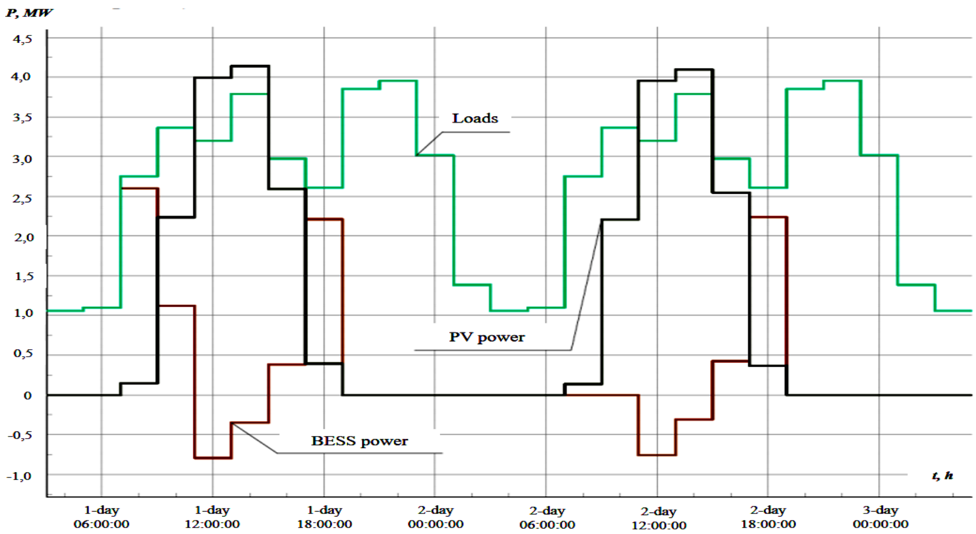

Fig. 3. The typical diagram of the obtained electrical load curve from the research results (daily situation) location

From this electrical load profile (Fig. 3), it can be seen that by applying distributed generation sources, positive solutions can be found for several problematic situations in the city power supply system. In the context of Uzbekistan, the main sources of power supply in the city electrical grid are currently thermal power plants, which provide the main electrical load. For example, the main electricity supplier for the city of Tashkent is the Tashkent thermal power plant. The power station's 220 kV overhead lines are connected, and the voltage is gradually reduced through transformer substations across the city, following 110, 35, 10, and 0,4 kV standards. This ensures that all types of electrical consumers within the city are supplied.

In practice, to achieve energy efficiency in city power supply, it is necessary to calculate energy efficiency indicators through the application of distributed generation sources and use methods for optimizing the nominal parameters of the electrical grids. The following indicators have been established to achieve energy efficiency:

- reduction of the relative cost of electrical energy;
- reduction of electrical energy loss;
- minimization of environmental impact.

The technical-economic indicators of each electrical grids involved must be calculated individually. Each electrical grids that participates in the system has its own technical-economic indicators. [5-8, 13-15].

Below, we present the expressions for calculating the technical-economic indicators of each network:

1) In this case, the given line costs (1) for a specified cross sectional area *F*, normalized to 1 km of its length, as a function of the calculated current *I*, can be written as follows:

$$C_L = К_L \cdot (\mathrm{p}_L + \mathrm{E}_N) + 3 \cdot I^2 \cdot R \cdot \tau \cdot C_W \cdot 10^{-3} \; ; \tag{1}$$

where, C_L - the normalized line costs, *mln.soums.*; K_L - the cost of building the line, *mln.soums./km*; p_L - deductions for depreciation, repair and maintenance of the line; E_N - regulatory efficiency factor; *R* - line resistance, *Ohm/km*; C_W - costs of covering electrical energy losses, *mln.soums/kW·h*; τ - maximum loss usage time, *h*.

2) The considered normalized costs (2, in million soums) as a function of the maximum load of the transformers:

$$C_{TR} = К_{tr} \cdot (\mathrm{p}_{tr} + \mathrm{E}_N) + \Delta\mathrm{P}_{no-l.} \cdot \mathrm{T}_{sw} \cdot C_{W.no-l.} + (\frac{S_{max}}{S_{nom}})^2 \cdot \Delta P_{sh.c.} \cdot \tau \cdot C_{W.sh.c} \; ; \tag{2}$$

where, K_{tr} - the cost of the transformer (capital investment), *mln.soums*; $\Delta P_{no\text{-}l.}$, $\Delta P_{sh.c.}$ - the power losses of no-load and short-circuit modes of the transformer under nominal operating conditions, respectively, *kW*; T_{sw}, τ - annual operating time and losses, *h*; $C_{W.no\text{-}l.}$, $C_{W.sh.c.}$ - the cost of electrical energy losses in no-load and short-circuit modes over the durations T_{sw} and τ, respectively, *mln.soums/kW·h*; p_{tr} - the total percentage of deductions from the transformer's cost.

3) The total constituent costs of a solar photovoltaic power station consist (4) of the following:

$$C_{PV} = C_{Module} + C_{Inverter} + C_{Installation} + C_{Maintenance} \, . \tag{4}$$

4) The total constituent costs of electrical energy storage systems consist (5) of the following:

$$C_{ES} = C_{Battery} + C_{Other\ additional\ costs} + C_{Installation} + C_{Maintenance} \, . \tag{5}$$

The technical-economic indicators of each component forming the city power supply system are calculated through the mathematical expressions presented above. For each case, the internal structure of the parameters to be determined must be explained in more detail. In this case, cable lines are used for medium, low voltage electrical grids as the power transmission lines. The calculations take into account the allowable limitations in relation to the cross sectional area of the cable line. In the transformer substation, the optimal value of the rated full capacity of the power transformer is determined, considering the limitations. In the solar photovoltaic station, each component should be divided into individual nodes. The same approach is applied in energy storage systems [8-12].

Based on this, the total costs of the areas (6) taken as an object for the city power supply system are determined as follows:

$$C_{TOTAL} = C_{M.L} + C_{TR} + C_{L.L} + C_{PV} + C_{ES} \, . \tag{6}$$

It is evident from the general expression that the technical-economic indicators, taken as the nominal value of each power grid component, are crucial for the system. The total value of all expenses incurred for the system is related to the parameters of the electrical grids that need to be optimized [4-8]. The parameters to be optimized in this case include the following:

- cross sectional area of the medium voltage power network;
- length of the medium voltage power grid;
- rated capacity of the transformer substation;
- cross sectional area of the low voltage power grid;
- length of the low voltage power grid;
- rated capacity of the solar photovoltaic station;
- storage capacity of the energy storage system.

The optimal values of the parameters listed above provide the possibility to minimize the value of the costs incurred by the system. The problem of minimizing the total costs is accepted as the objective function, and the parameters are calculated based on this. The technical constraints to be included in the optimization process are of significant importance. The value of the constraints for each parameter must lie within the allowable range.

3. Results

The theoretical and practical results that should be achieved by applying the relevant types of distributed generation sources in the city power supply system, in accordance with the norms of the developing science and technology era, can be attained. As a result, the following directions can be outlined:

1. *Reducing electrical energy losses.* There is an opportunity to reduce transmission losses of electrical energy by integrating distributed generation sources into small city microdistricts. The research reveals that:

- solar panels and energy storage systems are used as renewable energy sources in city electrical grids, the losses occurring due to resistance in the power transmission lines are reduced in relation to the power flowing through them;
- according to the principle of local energy production and consumption, since energy sources are located near the consumer, the need for long distance energy transmission is reduced. If a microdistrict consumes 100 MWh of electrical energy annually, these losses can be reduced by 15-20% with the help of local generation sources. [10-15].

As a result of the complex use of local electrical networks and distributed generation networks, as shown in Figure 4, the total load of electrical consumers, which generates a large amount of electrical energy, is fully met. In local electrical grids, long-term overload conditions and the wastage of additional electrical energy are reduced.

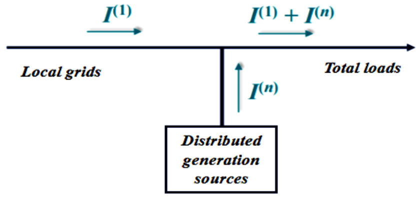

Fig. 4. The complex placement of local grids and distributed generation sources

2. *Smoothing the electrical load curves of power grids.* By using distributed generation sources and energy storage systems, it is possible to smooth and optimize the daily electrical load curves:

- typically, the electrical load in cities is uneven throughout the day: peak load times occur in the morning and evening;
- energy storage systems (batteries) form energy reserves in advance for peak load times, resulting in the smoothing of load curves.

As seen in the graph presented in Figure 5, the use of distributed generation sources and storage systems reduces the height of the load peaks and extends their duration. This allows for the even distribution of the load across the network.

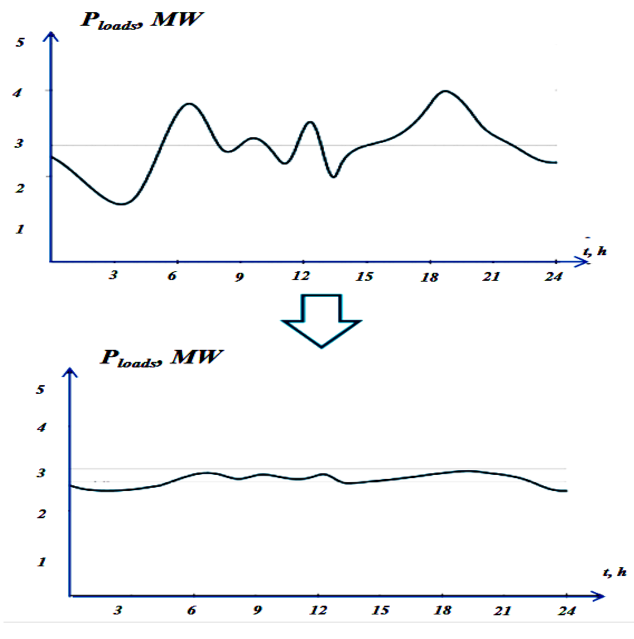

Fig. 5. The change in the daily profile of the electrical load curve due to the power obtained from distributed generation sources

3. *Improving the quality of energy*. Voltage stability in small city power grids is of great importance. With the help of distributed generation sources:

- reducing voltage drops and fluctuations: since the generation sources are located near consumers, voltage stability improves;

- reactive power management: distributed generation sources have the ability to produce reactive power, which enhances the overall quality of the power supply system. In the grids, voltage can typically drop by up to 5%. By using distributed generation sources, this value can be reduced to 1-2%.

4. *Increasing technical and economic efficiency*. The implementation of distributed generation sources brings significant technical and economic benefits:

- reduction in capital expenditure payback period: although renewable energy sources require high initial costs, they pay off in a short period. According to research results, this period averages 5-7 years [11];
- reduction in operational costs: as the electrical grid load stabilizes, the service life of the networks is extended, and maintenance costs decrease;
- energy efficiency: the overall efficiency coefficient of the systems increases, leading to energy savings.

For the microdistrict taken as an object in Tashkent city microdistricts, the installation of solar panels and batteries reduces annual operating costs by 10-12% [4-8, 10-13]. Distributed generation sources are an effective solution for optimizing the electrical supply system in small city microdistricts, helping to achieve the following:

- efficient production and consumption of electrical energy;
- ensuring the stability of electrical network loads;
- improving energy quality and enhancing economic efficiency.

These results are of significant practical importance for the development of the power supply system in small cities. All the results and indicators that need to be achieved will serve as a scientific basis for the designing enterprises of the city power supply system.

4. Discussion

The implementation of distributed generation sources in the city power supply system and the analytical basis for achieving all types of scientific results are derived from the connection schemes, operating modes, and significant characteristics of the electrical grids forming the system. When considering the wind power station as a component located in the city area, it has been proven that the total cost of expenditures does not justify itself in terms of time and technical feasibility. In the article, primarily focused on the introduction of distributed generation sources near electrical consumers, envisions the combination of a solar photovoltaic station and energy storage systems.

The key components, as mentioned earlier, include medium voltage cable lines, a 10/0,4 kV transformer substation, and low voltage cable lines in the city area. The total cost of solar photovoltaic stations and energy storage systems has been decreasing year by year. According to international statistical data, it is expected that by 2030, the cost will decrease by more than 30%. The main components used in these systems are illustrated in Figure 6. A distributed generation source control system has been developed, with control primarily based on power extraction from the solar photovoltaic station, charging, and discharging energy storage systems [3-4].

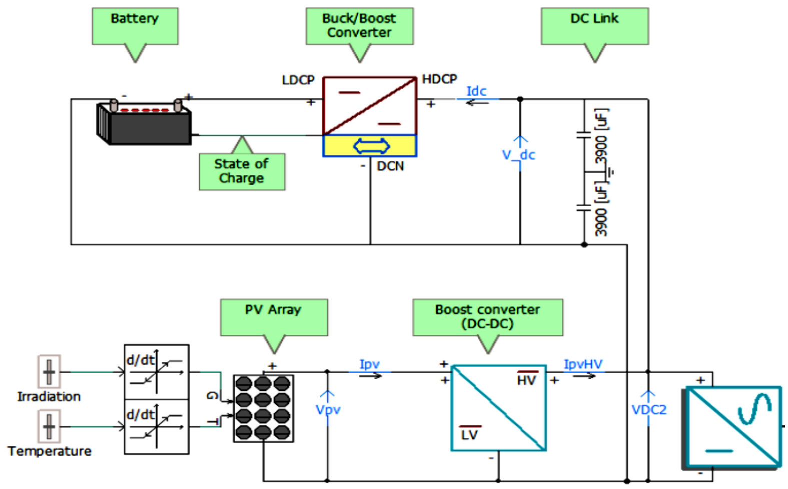

Fig. 6. Overall PV-battery system connected to equivalent voltage source (stand-alone is not activated)

The operation of these two types of distributed generation sources shown in Figure 6 is interdependent. The operation mode of the solar photovoltaic station and the energy storage system complement each other. In developed countries, the experience of complex use of these two systems has proven effective by regulating electricity tariffs. In global practice, the tariff formation system is applied by dividing the daily period into 3 and 5 parts. For the lowest, i.e., cheapest tariff period, energy storage systems are charged by taking power from the electrical grid. During the highest price period, i.e., when the tariff increases, electricity is returned to the grid, generating profit. This approach allows energy storage systems to recover part of their operating time and cover their costs over the years.

Throughout the daily period, the electricity load of the 0,4 kV electrical grid in the city power supply system, the operation graph of the solar energy system, and the battery energy storage system (BESS) are shown briefly. As we can see, the characteristics of each system differ. [15].

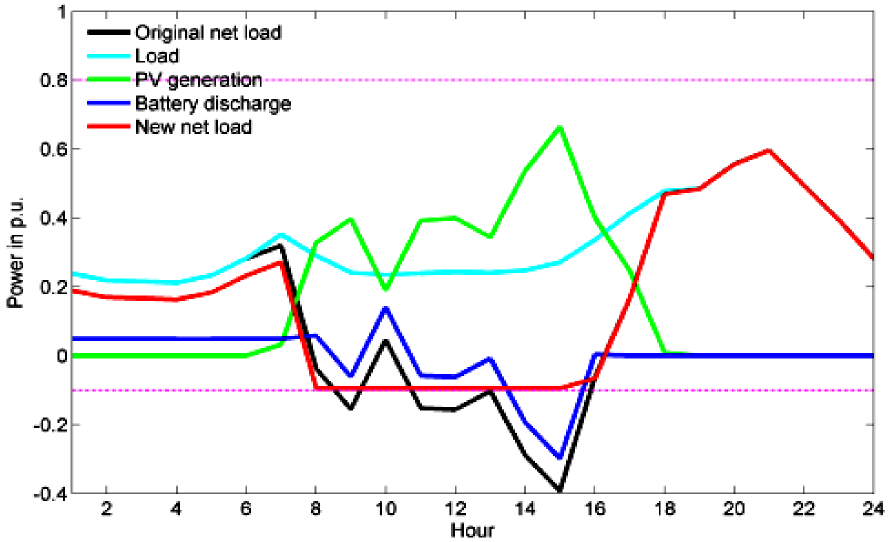

Fig. 7. Operation of a BESS providing peak-shaving and valley-filling services for a prosumer with a variable load and a photovoltaic generator

The electrical load graph in Figure 7 is used as the power installation point for the electrical energy storage system simulation. Cost minimization, voltage, and current boundary conditions are modeled in the PSCAD software. Therefore, the point of change in the electrical load graph is achieved only based on the energy storage system model, and only if it is physically possible at that time. As seen from the electrical load graph, there is an opportunity to optimize the electricity consumption state in electrical grids [9, 11].

5. Conclusion

1. The analysis has demonstrated that the application of distributed generation sources in the city power supply system can improve the technical and economic performance indicators of the electrical grids.
2. The installation of distributed generation sources, such as solar photovoltaic stations and energy storage systems, near electrical consumers, along with their management and the application of differential tariffs, was examined as a means to improve economic indicators and recover the incurred costs within the specified period.
3. By implementing distributed generation sources in the city power supply system, optimizing and flattening the electrical load curves will help limit overloading conditions in the electrical grids and reduce electrical energy losses.

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