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Prospects for the use of energy storage devices in the process of solar energy production

Abstract: Every developing country is beginning to rely on "green" energy in connection with environmental problems, including the global warming of our planet. It is expected that in the future, the production of electricity using the conversion of sunlight would take the dominant place in the energy infrastructure around the world. However, photovoltaic converters mainly generate intermittent energy due to natural factors (weather conditions) or the time of day in a given area. Therefore, the purpose of this study is to consider options for eliminating the interrupted nature of the operation of a solar installation through innovative additional applications. To achieve this goal, issues of the prospect of using energy storage devices and the choice of the most efficient and reliable of them are considered, as are the environmental friendliness of accumulators/batteries and the economic benefits of their use. The results of the analyses provide an understanding of the factors of using existing technologies with regard to their technical and economic aspects for use in solar energy. It was determined that the most common and predominant types of energy storage are lithium-ion and pumped storage plants. Such accumulation systems guarantee high efficiency and reliability in the operation of solar installation systems, depending on the scale of the solar station. Storage devices that are beginning to gain interest in research are also considered – storage devices made of ceramics of various kinds and thermochemical and liquid-air technologies. This study contributes to the

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development of an energy-storage system for renewable energy sources in the field of technical and economic optimization.

KEYWORDS: accumulators, batteries, thermochemical method, renewable energy sources, storage materials

Introduction

Nowadays, energy appears to be an urgent requirement for everything humanity needs. The sun is a favorable and inexhaustible source of light, with the help of which, energy of any kind can be harvested. Solar energy conversion technology is mainly divided into photovoltaic (using semiconductor materials) and thermal technology (using highly absorbent optical surface layers). However, solar energy has its drawbacks such as unreliability, efficiency in terms of the performance coefficient and cost. This is conditioned by the fact that the installation of solar energy conversion technology is expensive, and there are also aspects such as the influence of the inconsistency of sunlight depending on the weather conditions and the time of day. Thus, there is a risk of the loss of continuity of the energy supply to consumers, causing the cost of energy not supplied to increase. For economic purposes, systems that are adapted to the disposal of energy and have the ability to store large amounts of energy and quickly respond to system balancing play an important role. Energy storage compensates for this type of problem by disseminating solar energy that is independent of the radiation itself and its availability, i.e. it increases energy resource integration by increasing the efficiency of energy systems and minimizing energy losses while reducing costs. In addition, energy storage separates electricity production from the load or the consumer of electricity, which facilitates the regulation of supply and demand, and also provides the ability to store energy in local networks, which in turn provides security guarantees (Suleimenov et al. 2020).

Tamme et al. (2012) considered the main functions and prospects of energy-storage devices for thermal systems, where the design of thermal, energy-storage devices and their importance in the distribution and continuity of energy from the standpoint of environmental friendliness and efficiency are analyzed in detail. Recently, the widespread introduction of energy storage devices (accumulators/batteries) has been gaining momentum. These types of battery storage systems have the potential to increase efficiency and cost savings. Energy storage in solar energy is classified into two categories – thermal and electric energy-storage systems. Figure 1 shows a diagram of the types of energy storage. The main parameters of energy-storage devices are rated power, energy intensity, efficiency and the number of work cycles.

The most popular of all accumulators are lithium-ion batteries, the advantage of which is in quality, safety, and other types of capacitive characteristics. In general, the storage capacity depends on the availability of the sun, the nature of the loads, and the technology for supplying

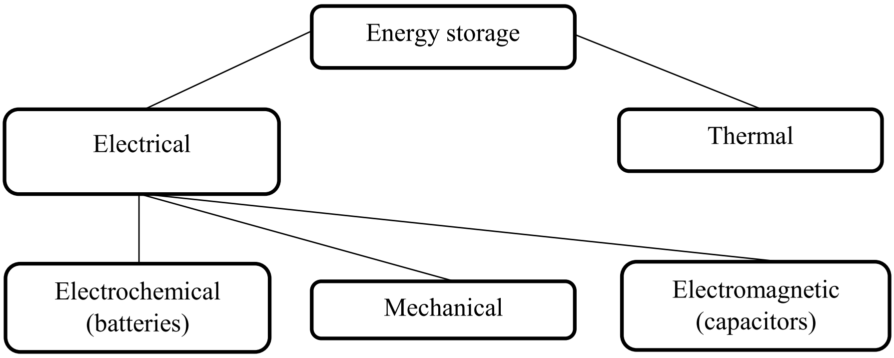

Fig. 1. Diagram of the division of energy storage methods

Rys. 1. Schemat podziału metod magazynowania energii

additional energy. Heat always causes the temperature of the material to rise or fall. All materials are capable of absorbing and storing heat by virtue of their mass "m" and specific heat capacity "cp" at constant pressure.

The use of energy-storage devices adds generation capacity to the solar installation system by using excess energy. The study by Liu et al. (2022), in which a solar energy-generation system was developed, reports on the economic benefits of using an integrated battery in solar power plants. Mohamad et al. (2021) propose a method for introducing a battery energy-storage system to reduce the loss of solar-energy consumption, the results of which show the highest efficiency compared to conventional installations without storage. In the study by Perkins (2020), it is proposed to consider the possibility of introducing storage plants using biomass liquefaction to reduce the cost of electricity, i.e. the results show good prospects for the integration of storage plants.

The work done demonstrates a favorable economic aspect, i.e. the introduction of energy-storage devices into the solar power system has a positive effect in terms of operating and maintenance costs. This paper therefore examines the research question of energy-storage methods and the choice of the most efficient methods, and also raises the issue of the environmental friendliness of accumulators/batteries and the economic benefits of their use. The analysis provides an understanding of the factors of using existing technologies and the technical and economic aspects for their use in solar energy.

1. Materials and methods

When energy is subdivided by quality, high- and low-quality energy is measured in the same units. The amount of energy can be described in several systems of units, for example – joules

[J] or kilowatt hours [kWh]. High-quality energy is more valuable and therefore quality must be maintained during transmission. The transformation of energy never leads to a change in the total energy and it is therefore necessary to focus on the enthalpy. For the temperature difference $\Delta T = T_2 - T_1$, this heat (or enthalpy) equals, by the following formula (1):

$$\Delta H_i = mc_p \left(T_2 - T_1\right) \tag{1}$$

where:

T_2 – material temperature after heat absorption,
T_1 – temperature of the material before heat absorption.

The total amount of heat Q that can be stored in the storage is calculated by the following formula (2):

$$Q = \eta \left(\int_{T_i}^{T_f} c_s dt + \int_{T_f}^{T_i} c_i dt + \Delta H_f + \Delta H_c \right) \tag{2}$$

where

η – amount of element [mol].

Furthermore, the first and second terms of the equality characterize the sensitivity of the thermal change of the solid and liquid, the third and fourth terms characterize the heat of the phase transition and reaction, respectively (Shukla 2007). The rated power of the energy-storage devices is calculated using the following equation:

$$t_s = \frac{P_2 - P_1}{P_{ER}} \tag{3}$$

where:

P_1 – input/output power in the initial state,
P_2 – input/output power in controlled state,
P_{ER} – rated power of the energy storage.

This paper discusses the research on the use and development of various types of energy storage devices in solar energy to optimize energy efficiency and performance, and to determine the best optimal heat storage material for solar energy. Evaluation of the implementation of existing energy-storage technologies connected to photovoltaic converters is carried out to investigate their impact on the processing of fluctuations and uncertainties. Research papers in scientific journals from collections such as Science Direct, Nature Publishing Group, Taylor and Francis, Science and Spinger Link were selected for analysis. Keywords such as renewable energy sources, solar energy storage, thermal and electrical energy storage were used in the search. When processing the results of studies of various types of storage devices, such indicators as the power and physical characteristics of a solar installation, capital costs of the storage technology, control methods, etc., were taken into account. Moreover, when selecting a drive, it is necessary to pay attention to the physicochemical properties of the materials used, such as the melting point (should be within the working ranges of the solar installation), density, specific heat, thermal conductivity, thermal stability (should not decompose at high temperatures), non-toxicity (should not harm the environment) and non-corrosiveness (because the service life of the entire installation would otherwise be reduced). The above factors are directly related to the efficiency and performance of the energy storage system.

2. Results and discussion

The essence of energy accumulation is the transformation of one type of energy into another. Each developed storage system has its advantages and disadvantages, including significantly different technical frameworks that regulate the mechanism of operation. A characteristic feature of thermal energy-storage systems is that they are diverse in relation to temperature, power level, and heat transfer fluids, and each operation has its own specific operating parameters. Each energy-storage technology has its own optimal materials that can exist in various physical phases: in the form of solids, liquids, or through a phase transition. This involves knowledge of numerous design options, media, and storage methods. In general, energy can be stored in several forms – electrical, electrochemical, electromagnetic, etc. However, depending on the variety of energy-storage methods, energy-storage systems are divided by the International Electrotechnical Commission (IEC) into five categories: mechanical, chemical, electrochemical, electrical, and thermal.

Conventional energy storage can be carried out by storage and storage by maintaining certain high temperatures, transferring heat from a working fluid to an accumulator, and transferring heat from one fluid to another through an accumulator. The design of a heat storage system using solid materials is usually based on an additional liquid in the form of a heat carrier for the charging and discharging process. The coolant can interact either in direct contact or in indirect contact with the solid material of the accumulator. Solid storage materials are in direct contact with heat transfer fluids and consideration should be given to the characteristics of the solid materials, such as particle and container size, which affect fluid flow and heat transfer.

Thermal storage devices are mostly classified into three categories: buffer storage (small hourly storage interval); daily storage; long-term storage (long period of energy storage). In general, the characteristics of an energy-storage device can be analyzed according to two criteria: the energy density and its energy efficiency. Dielectric storage devices exhibit excellent thermal stability and other characteristics suitable for use as energy-storage devices. Metals are characterized by more significant thermal conductivity, but from an economic standpoint, they are less favorable in relation to non-metals. High thermal conductivity ensures the fast charging and discharging of the battery storage system. Dielectrics are promising and potential candidates for energy storage applications; however, due to their rapid discharge, they are rarely used in solar installations. In addition, batteries based on electrochemical reactions enable the bridging of the gaps in solar installations with economical and efficient energy storage without detrimental effects on the environment. Considering capacitors as energy storage devices, it is best to use them without the addition of toxic lead. These capacitors include many composite dielectrics that have high efficiency. A more efficient material is bismuth due to its thermal and photocatalytic properties. However, during the development of accumulators from composite materials based on ceramics, signs of corrosion may be observed after a certain interval cycle.

Lithium-ion batteries have high power and low maintenance requirements, but the initial installation costs of this type of storage are expensive. Storage of this kind is efficient and is characterized by a high energy density due to the redox potential – about 3 V. This potential value provides a high level of density. Considering that this kind of drive is becoming more and more popular, a quick decrease in cost can be expected. The popularization of the use of lithium-ion batteries in solar installations would lead to an expansion of the market and to benefits during its operation. These batteries are up to 90% efficient. However, they are environmentally unsafe and the initial costs for integration into the solar installation require huge funds. The impact on the environment will decrease with an increase in the share of renewable energy sources in the structure of electricity generation. But there are also environmentally friendly counterparts, such as redox flow batteries, which demonstrate high performance and a long service life. It should also be borne in mind that the performance of this type of energy storage is short-term, i.e. such batteries are suitable for smoothing out hourly and daily interruptions in solar energy generation.

Thermochemical energy storage systems have become greatly improved in terms of usage and thermodynamics, and one such improvement is the cascade system technology. Due to their characteristics, such batteries are presented as thermal batteries. In the analysis, it can also be assumed that combining different modes of energy storage can improve absorption storage. For example, an absorption thermochemical energy storage cycle with two-stage generation was developed by Wei et al. (2022). The efficiency and range of operation of the cycle is much better than the previously discussed systems. The main problem in this technology is the design and operation of processes conditioned by the dynamic nature of the process and the complex interactions between solids and gases. For this type of storage, it is also necessary to integrate the detailed design of the CO_2 absorption concept to optimize charging and discharging times, which in turn affects costs. Capital costs may increase due to the added complexity of integration as well as the fact that the components used may not have photocatalytic properties. This technology is now beginning to be widely researched and developed in the western world, where patents are already being registered.

Large area energy storage options with pumped storage plants (PSP) and demand management can support a high-demand electricity system at moderate cost. The energy efficiency of this technology implementation reaches 80%. The possible configurations of the solar installation with PSP are spent on the demand of the required loads and on the energy deficit. It would also allow energy to be accumulated on a large scale for a long period up to seasonal cycles. PSP is the only economically viable option for large capacities. Compared to other types of storage technologies, PSPs are an environmentally friendly storage method because they do not require battery replacement, which are difficult to dispose of due to their toxic components. It is also worth paying attention to the compressed air energy storage, which is suitable for stationary and large-scale applications with a long service life. This technology is not popular and there are few studies on this topic, since compressed air storage devices have only just begun to be integrated with renewable energy sources. It is worth noting that their main drawback is low energy efficiency, and therefore, this technology requires improvements to increase competitiveness. A combination of PSP and compressed air technologies can also be considered. Such an energy storage system can combine the advantages and get rid of the disadvantages of each method.

Energy accumulators store excess heat accumulated by solar radiation. The improvement of the operational mobility and energy manageability using thermal storage and hybridization are seen as key technological challenges. The function of solar-thermal power plants is extremely relevant, since the introduction of solar energy into the mass electricity market seems appropriate only when replacing power plants with an intermediate load of about 4,000–5,000 h/year. Solar energy is collected by photovoltaic or thermal panels. The amount of energy received is greatly affected by the degree of radiation. Usually, the panels are composed of various semiconductors. From a technical standpoint, the storage tank must have a high energy density, good heat transfer between the coolant and the storage tank, mechanical and chemical stability of the storage tank, matching between the heat exchanger, coolant and storage tank, full reversibility and minimal heat losses. Storage capability enables demand-driven power generation and offsets solar fluctuations due to weather conditions. Regardless of the type of storage technology, an energy storage device must operate at high temperatures, have high charging and discharging rates, good corrosion resistance, high energy efficiency, high energy density, low cost, and most importantly, environmental friendliness. A compromise is necessary between the advantages and disadvantages of the battery.

In general, with the right choice of energy storage systems, it is possible to increase the peak power supply, reduce standby power and have other multifunctional benefits along with the function of reducing peak loads. Economic benefit is a key driver of practical application. Countries that want to develop their economies, like Armenia, need to pay attention to investing in energy storage as such technologies can significantly reduce energy costs and help prevent harmful effects from greenhouse gases, etc. Popularization would help energy systems gain more benefits through load balancing, which would help reduce the cost of energy storage. In other words, the storage helps reduce the load of the solar installation even during periods of high demand, which leads to a decrease in the initial investment and cost of generating electricity. This in turn shifts energy consumption from high-cost high demand seasons to low-cost low demand seasons. There is an economic benefit by storing energy during cheap periods and using this energy during seasons with high demand. Thus, energy storage lowers costs due to the reserve and compensates for the costs of the consumer. It is necessary to develop new strategies and technologies for energy storage at a commercial level. For this reason, the starting point is an understanding of the technologies currently available and how they can be developed. A proper understanding of the various technologies is necessary for integration and popularization in an efficient-reliable direction. The analyzed energy storage technologies were chosen due to the recent increase in interest in the scientific community. Each energy storage technology demonstrates its significance and efficiency, and has a positive effect on the performance of a solar installation.

Based on the results of the analyzed studies, a table was compiled, which provides the characteristics of each of the methods. Moreover, this table shows the results of calculations using formulas (1), (2), (3), where the values of specific heat capacity and temperature intervals were taken from the papers that were considered during the study (Wang et al. 2022; Sun et al. 2020; Mrinal and Debasis 2021; Chen et al. 2022; Qi et al. 2021).

Table 1. Comparison of energy storage technologies

Tabela 1. Porównanie technologii magazynowania energii

Features	Dielectrics	Lithium-ion batteries	Thermochemical	Liquid air	Pumped hydroelectric storage
Advantages	✦ Simple application ✦ High efficiency.	✦ High efficiency ✦ High storage density ✦ Compactness	✦ High storage density ✦ Low heat loss ✦ Compactness ✦ Transportable over long distances	✦ Flexibility ✦ Low cost ✦ High storage density ✦ Sustainable	✦ Reliability ✦ Large storage capacity ✦ Sustainable
Disadvantages	✦ May be toxic depending on the components ✦ Uneconomical	✦ Unsustainable ✦ Cost-intensive	✦ Used in pilot trials only ✦ Cost-intensive ✦ Low reliability	✦ Low corrosion resistance ✦ Low efficiency	✦ Not beneficial for small scale solar installations
Service life	Short-duration	Short-duration requires permanent replacement	Depends on material degradation and second order reactions	Long-duration	Long-duration
Q [kWh] by equation (2)	10–40	10–60	10–80	60–100	120–150
t [MW] by equation (3)	50–200	50–1,000	50–500	200–1,500	600–5,000

The values are in the interval periods, since several studies were considered to calculate each value, i.e. the interval period has a characteristic of a minimum and a maximum. A boundary condition of the first kind was applied, in which the temperature on the body surface for a certain moment is independently set. When calculating the values in liquid air accumulators, it was considered that the coefficients of thermal conductivity of gases were in the range of values from

0.006 to 0.6 W/(m·K), and the coefficient of liquids was in the range of 0.07 to 0.7 W/(m·K). When calculating the values of other drives, it was noted that the amount of heat and the rated power depends on their density. The thermal conductivity coefficients of solids were taken in the range of from 0.0223 to 2.9 W/(m·K).

Dielectrics as energy storage. Lead-bismuth or bismuth devices are used to store thermal energy due to the thermal properties through eutectics, which favorably affects the operating efficiency, the values of which reach more than 90%. For example, Wang et al. (2022) analyzed the lead-bismuth capacitance in the solar installation. The results of the study show that this type of vessel has excellent potential for implementation in solar energy converter installations. However, in recent years, an increasing number of developments are being made without lead additives, since lead itself is a toxic substance for humans. Therefore, there is an increasing need to replace lead with ferroelectrics, which also have excellent characteristics that satisfy energy storage. According to the physical design principles of energy storage dielectrics, the optimal energy storage material should have significant polarization. Lead-free ceramics are divided into linear dielectrics, antiferroelectric materials. For example, Sun et al. (2020) improved the performance of ceramics based on structured bismuth layers, which can be used as energy storage devices. Mrinal et al. (2021) also improved the performance of lead-free nanoceramics to use energy storage, the operational efficiency of which is up to 95–98%. Chen et al. (2022) designed an eco-friendly lead-free ceramic drive for fast charging.

Lithium-ion batteries are the most popular electrochemical energy storage devices in the solar industry, which mainly consist of a graphite anode with a negative charge and a cathode containing a lithium compound. The efficiency of such batteries reaches up to 90%. During the charging process, lithium is extracted from the positive electrode, the potential of which is higher than 2 V with respect to the electrolyte. However, lithium-ion batteries have a short lifespan, and therefore, some additional measures are being implemented, such as hybrid systems based on a capacitor and the battery itself. In general, electrochemical energy storage is now predominant due to its high power, as a result of which, most technologies use this type of storage. For example, Qi et al. (2021) developed a two-port hybrid diode topology that reduces power loss by 15.5% while reducing the cost of the entire system installation, including photovoltaic converters. There are also problems in the processing of such drives, which require significant resources and also have a negative impact on the environment, i.e. lithium-ion batteries are environmentally unsafe. In a paper by Yudhistira et al. (2022), where the issue of increasing the efficiency of operation and the utilization of storage is considered, the researchers propose increasing the share of renewable energy sources in the structure of electricity at the stage of use, which would contribute to reducing the impact on the environment. In a study by Silva Lima et al. (2021), which investigated the life cycle assessment of lithium-ion batteries, it is reported that lithium-ion batteries lead to the highest environmental impact. Gutsch et al. (2022) found that when using lithium-ion batteries, greenhouse gas emissions reach up to 135 g/kWh, which has been proven to have a detrimental effect on the environment.

Thermochemical energy storage is an energy storage device based on the use of an endothermic chemical reaction for charging/discharging, in which solar energy is stored in the form of a chemical potential. The advantage of this technology is the high concentration of energy. The main parts of a thermochemical accumulator are a tank serving as a reactor and solar receivers connected to each other by vertical coaxial pipes. Energy is accumulated as a result of an endothermic reaction in the form of chemical bonds, which is then restored by the recombination of these bonds in an exothermic reaction. The accumulated and released heat is equivalent to the enthalpy of reaction. Padula et al. (2021) developed a general model of a thermochemical battery that efficiently performs the task of accumulating and extracting solar energy, the efficiency of which is about 90%. Huang et al. (2022) presented the source of a thermochemical battery – a CaO/MgO composite using eggshell membranes as biotissues. The results show that the composites consist of a macroporous structure of MgO/CaO nanoparticles, similar to highly porous fibers. This type of battery saves 92% capacity over twenty carbonization cycles. Thermochemical storage also uses salt hydrates or adsorbents. During the charging stage, thermal energy is applied to the material to extract water as a result of an endothermic reaction. After that, both materials are stored separately for the accumulation of thermal energy with minimal heat loss. Finally, stored energy can be transferred as heat through an exothermic reaction by joining two materials together. Ruby-Jean et al. (2022) demonstrated how improved power output, temperature rise, and operating efficiency are achieved by combining two storage materials in a cascaded system. Wang et al. (2022) considered the $CaO/Ca(OH)_2$ heat storage system, which is significantly superior than other heat storage systems.

Liquid air energy storage is an innovative energy storage technology based on the cryogenic phenomenon. The advantage of this technology, suitable for any part of the world, is high energy density, accelerated process, environmental friendliness, long service life, and low cost. Basically, a part of such a storage tank consists of an air liquefaction unit, an energy storage tank and ventilation with energy recovery. Under these conditions, the use of water-based storage systems to compete with the dominant fossil fuels seems to be the best option due to numerous advantages such as high specific heat, environmental friendliness, low cost, chemical stability, and high charge and discharge capacity. Basically, water vapor or ice is used for the accumulation of solar energy in this technology. However, when using liquids, there are a number of disadvantages, such as corrosion, scale, the high cost of steam accumulators, etc. Nabat et al. (2021) proposed a system using a liquid air energy storage device. The results show that the introduction of such a plant would lead to economic benefits with zero emissions to the environment. Energy storage by combining compressed air and natural gas is based on isothermal processes. The principle is to use electricity to compress air in low-cost periods, after which the air is pressurized and released when necessary. Such a system has an advantage due to the fact that heat transfer occurs between the phase boundaries, and not through a metal element, i.e. thermodynamically, such a process is most advantageous. Luft et al. (1984) reported on the potential of using accumulators, where one of the working fluids is gas, which is economically viable.

Pumped hydroelectric storage (PHS) is the most cost-effective technology for storing large amounts of electricity at relatively low operating costs. The mechanism is in the vicinity of two reservoirs at different peaks, accompanied by the descent of water, the energy of which is converted from gravitational to kinetic energy to drive a turbine generator in order to generate energy. It is worth considering that PHS has a negative impact on the environment, since it requires large-scale integration and can be replaced by batteries. However, this technology can overcome the disadvantages of batteries, specifically regular replacement, high maintenance costs, and toxicity. Pumped hydroelectric power plants are an inexpensive, large scale and widely used energy storage solution. Petrollese et al. (2022) proposed a system for introducing this technology, the results of which showed an increase in efficiency by 60%. The paper by Danehkar et al. (2022) reported that the initial investment for installing a pumped storage pump would be higher while the operating costs would be minimal compared to other types of storage. The paper by Cheng et al. (2019) reported that pumped energy accumulators account for 97% of the global energy storage capacity and more than 99% of the stored energy, and therefore, are one of the leading methods of energy storage. Martínez-Jaramillo et al. (2022) developed a model of a solar installation with an energy storage device based on PHS, with the help of which, it is possible to switch to a 100% renewable electric power system. This technology requires special attention to increase efficiency, as the presented studies show good expectations. Such a system would provide stochastic optimization, simulating the metamorphosis of natural bioevolution.

Conclusions

Energy storage devices act as a high-speed switching power supply that can improve the exchange of energy between the components of the power system. The use of storage systems is promising in relation to the increase in production and the stability of solar energy. In this paper, technologies for energy storage devices obtained from renewable sources are analyzed; several technologies can be used. Each technology has its own advantages and disadvantages. Lithium-ion batteries are the most efficient storage solution for smaller systems that require energy during hourly or daily outages, but the economic costs of their integration into a solar system are high with short lifespans. Optimal for a large-scale solar system is pumped storage technology, which can last up to sixty years with an efficiency of up to 80%. Combining PHS and compressed air technologies should be considered in further studies, as such, an energy storage system can combine the advantages and overcome the disadvantages of each method.

The popularization of solar energy has a positive effect on economic growth and greatly contributes to improving the quality in the continuity of the system. The use of energy storage has excellent prospects in terms of economic benefits and the provision of energy during the required load. The economic benefit is associated with the development of an efficient energy storage system to match the receipt of energy in any period of time. A key factor in choosing an energy storage technology is its cost and the costs associated with its use. A long service life and high cyclic stability are prerequisites for economical use, i.e., at a price competitive with existing storage facilities. Each of the drives presents its own set of advantages and disadvantages. Most of the drives are not popular due to their expensive installation, but it should be remembered that their implementation gives an environmentally friendly result and, most importantly, increases the life of the entire solar system, i.e. it minimizes the need for major repairs, reinstallations, and, most importantly, gives an effective result.

In addition, in the course of the study, it was noted that liquid-based accumulators are a less optimal option for implementation and popularization, since this technology is not environmentally friendly and is the most expensive. For states such as Armenia, with the intention of promoting the economy in the field of energy, it is necessary to implement projects and invest in energy storage. It is advantageous to invest in further improvements in storage technologies that are more reliable and inexpensive rather than in new technologies that are just beginning to be explored. The cost of installing energy storage has the ability to decrease due to technological advances and the development of green energy.

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Perspektywy wykorzystania magazynów energii w procesie produkcji energii słonecznej

Streszczenie

Każdy kraj rozwijający się zaczyna polegać na „zielonej" energii w związku z problemami środowiskowymi, w tym globalnym ociepleniem naszej planety. Oczekuje się, że w przyszłości produkcja energii elektrycznej z wykorzystaniem konwersji światła słonecznego zajmie nadrzędne miejsce w infrastrukturze energetycznej na całym świecie. Jednak konwertery fotowoltaiczne generują energię głównie w sposób przerywany ze względu na czynniki naturalne (warunki pogodowe) lub porę dnia na danym terenie. Dlatego celem niniejszego opracowania jest rozważenie możliwości wyeliminowania przerywanej pracy instalacji solarnej poprzez innowacyjne aplikacje dodatkowe. Aby osiągnąć ten cel, rozważane są kwestie perspektywy wykorzystania magazynów energii oraz wyboru najbardziej wydajnych i niezawodnych z nich, a także akumulatorów/baterii w aspekcie ich oddziaływania na środowisko i korzyści ekonomicznych z ich użytkowania. Wyniki analiz pozwalają na zrozumienie czynników wykorzystania istniejących technologii, ich technicznych i ekonomicznych aspektów wykorzystania w energetyce słonecznej. Stwierdzono, że najpowszechniejszymi i dominującymi rodzajami magazynowania energii są elektrownie litowo-jonowe oraz elektrownie szczytowo-pompowe. Takie układy akumulacyjne gwarantują wysoką sprawność i niezawodność działania systemu instalacji solarnej, w zależności od skali stacji solarnej. Rozważane są również urządzenia magazynujące, które zaczynają coraz bardziej interesować badaczy – urządzenia magazynujące wykonane z różnego rodzaju ceramiki, w technologii termochemicznej i cieczowo-powietrznej. Niniejsze opracowanie przyczynia się do rozwoju systemu magazynowania energii dla odnawialnych źródeł energii w zakresie optymalizacji technicznej i ekonomicznej.

Słowa kluczowe: akumulatory, baterie, metoda termochemiczna, odnawialne źródła energii, materiały magazynowe