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STATE AND PROSPECTS OF SOLAR ENERGY DEVELOPMENT

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Abstract. The potential of solar energy in Ukraine is high enough for widespread implementation. The most promising method of obtaining electricity is a method of direct conversion of radiation into electricity using solar panels. The production of electricity using solar panels prevents air pollution compared to the production of electricity by thermal power plants and reduces greenhouse gas emissions. The conversion of solar energy into electricity is environmentally friendly compared to traditional energy sources, but at the same time, after their operation, they generate waste that is difficult to utilize.

Keywords: renewable energy sources, solar energy, solar power plant, photovoltaic plant.

1. Introduction

Solar energy is one of the main sources of energy on which the existence of all life on Earth is based. The surface of the planet constantly receives $174 \cdot 10^9$ MW of solar radiation. About 20 % is absorbed or reflected by the atmosphere; half of the energy reaching the surface is in the form of visible light; the other half is in the form of infrared radiation, and only a small part is in the ultraviolet spectrum.

The energy of solar radiation received for 1 hour on the entire surface of the planet is sufficient to meet all the needs of mankind during the year. The task of mankind is to master and effectively use this potential. Currently, the world uses solar energy in the following areas:

1. Production of electricity using photovoltaic modules.

2. Electricity generation using heat-dynamic power plants.

3. Partial or complete heat supply and air conditioning.

4. Accumulation of solar energy in chemicals or physical or electrochemical batteries.

The development of solar energy continues to gain momentum. In the future, the sector will be able to meet most of the needs of mankind by 2060, pushing traditional energy far to the background. While maintaining the current dynamics of annual growth of solar power plants capacity by 20–25 %, by the end of 2100, the volume of energy produced by them will be 3–4 times higher than the capacity of coal and oil energy, and nuclear energy – more than 6 times (Kudrya, 2012).

Governments in most countries around the world recognize solar energy as cost-effective and set ambitious goals to increase its production. Comparing the countries of the world directly in terms of the efficiency of using alternative energy sources, Europe will be in the first place, followed by North America and Asia. Among European countries, Spain ranks first, followed by Germany and the Netherlands.

The range of solar radiation intensity in Spain is from 3 to 5 kW·h/(m^2·day), and in the rest of Europe this figure is much lower. More than 17% of electricity in Spain is generated by various solar installations. Another feature of the high level of solar energy in the country is the peculiarities of the legal framework in Spain, which requires the installation of a certain number of solar panels in the construction of new homes (IEEE 1547. Standard, 2003).

Sunlight used to generate electricity comes to the converter only during the day. There are prototype

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converters that are capable of generating a small amount of electricity at night, but it is too early to consider their commercial use.

It is also worth noting that there are countries that have introduced a large amount of alternative electricity capacity in just one year. Thus, after analyzing a number of countries, we can conclude that the EU is extremely interested in developing new technologies not only to improve the world's environment and gain independence from non-renewable energy sources such as oil, gas, coal, etc. but also to provide leadership in the field of energy in the future, selling their developments to the world. Although such installations are expensive and have a shelf life, they are worth the investment they make.

In the case of solar power plants, there is little impact on the environment during operation and great impact at the stage of system development. The potential of energy based on the direct use of solar radiation is extremely large. Note that the use of only 0.0125 % of the amount of solar energy could meet all the current needs of world energy, and the use of 0.5 % would fully cover the needs for the future (Kudrya et al., 2001).

The installed capacity of renewable energy facilities is constantly growing, despite its stochastic nature of electricity generation, mainly due to solar and wind power plants. Today it accounts for more than 8 % of the total balance of the system. Given the great energy potential of renewable energy sources (RES) in Ukraine, the main task is to maintain and, if possible, increase the growth rate of renewable energy with minimal impact on the integrated energy system, which can be achieved by implementing new technical solutions for hydrogen energy storage.

2. Theoretical part

Solar energy for Ukraine is considered a relatively new branch of Ukraine's electricity sector, which is developing rapidly. In 2020, solar power plants (SPP) with a total capacity of 4925 MW was installed. They generate about 1.265 billion kW·h of electricity. In Vinnytsia, Kness Group launched a plant for the production of solar panels.

Regarding the geographical location of Ukraine – it has a high potential for the design and commissioning of photovoltaic plants (PVP). The climate of Ukraine is characterized by a large number of sunny days. The annual intake of solar radiation is at the level of advanced countries such as Sweden, Germany, the USA and others. Indicators of solar radiation are taken from Solargis databases and shown in Fig. 1 (Dmytrenko et al., 2007). The efficiency of solar panels depends on the insolation, in other words, the amount of solar energy falling per unit area of the Earth's surface in a given area per year.

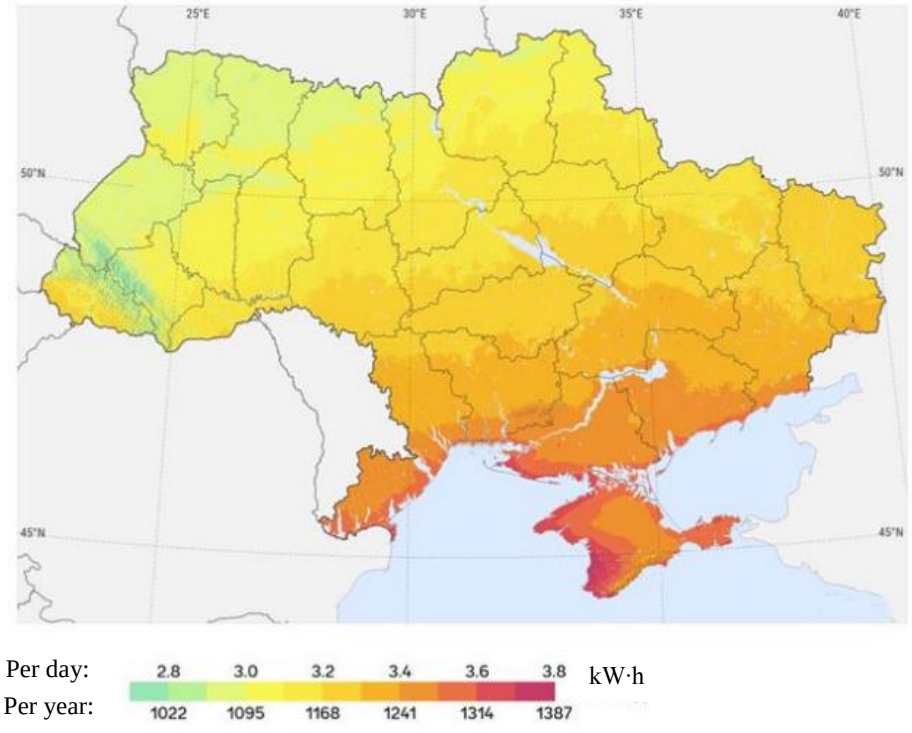

Fig. 1. Map of solar insolation on the territory of Ukraine

At the same time, SPP of European countries generates much more electricity than in Ukraine, which indicates great prospects for the development of solar energy in our country. Another advantage of Ukraine is the fact that at high levels of insolation the temperature can be attributed to moderate. And this has a positive point because at elevated temperatures the amount of electricity generated decreases due to the heating of the solar module. On average, energy losses are about 5 % when the panel temperature deviates by 10 degrees from normal (starting from 20 to 25 degrees) (EN 50160:2010, 2010).

Solar energy is one of the most material-intensive types of energy production, as can be seen from Fig. 2. Large-scale use of solar energy causes a huge increase in demand for materials and, consequently, labour resources for extraction of raw materials, its enrichment, production of materials, manufacture of solar panels, collectors, other equipment, their transportation. Estimates show that the production of 1 MW·h of electricity using solar energy will require between 10.000 and 40.000 man-hours. In traditional energy on fossil fuels, this figure is 200–500 man-hours (Sen, 2004).

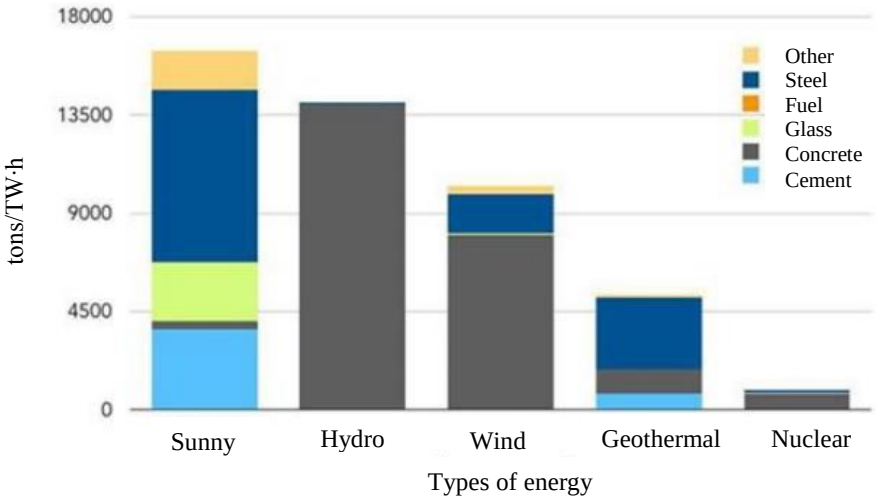

Fig. 2. The need of different energy industries for providing materials

Unlike fossil fuel-based technologies, solar energy does not cause harmful emissions during operation, but the production of panels leads to some pollution.

The International Renewable Energy Agency (IRENA) has estimated the amount of waste from solar panels at 250 thousand tons. According to experts, by 2050, this figure could reach 78 million tons. Solar panels often contain lead, cadmium and other toxic elements that cannot be removed without dismantling the panel itself. The main problem with solar waste is that there is too much of it. Hundreds of thousands of photovoltaic panels are needed for SPP, and for physical reasons, this situation will not change in the foreseeable future. Processing of flux from glass, lead, cadmium requires concerted action at the international, national and local levels (Hrytsyk et al., 2009).

One issue that is often of concern is the use of toxic elements, namely cadmium (Cd), a toxic heavy metal that tends to accumulate in ecological food chains. It is used as a semiconductor component in solar cells. The amount of cadmium used in thin-film solar panels is relatively small (5–10 g/m²), and with proper on-site disposal and emission control techniques from the module production, it can be almost zero. Modern photo module technologies lead to cadmium emissions of 0.3–0.9 mkg/kW/h throughout the life cycle. Most of these emissions are due to the use of coal to make modules, and the combustion of coal and lignite leads to much higher cadmium emissions.

In the case of crystalline silicon modules, the solder material that connects the copper filaments of the cells contains approximately 36 % of lead (Pb). Moreover, the paste used to mount the front and rear contacts contains traces of Pb and sometimes Cd. It is estimated that about 100 tons of Pb should be used for 100 GW of solar modules. However, there is no fundamental need for lead in the solder alloy. Concentrated solar power plants can injure or kill large

numbers of birds due to the intense heat from concentrated sunlight. This adverse effect does not apply to photovoltaic solar power plants.

The vast majority of the world's electricity is used immediately, as storage is usually more expensive and because traditional generators can adapt to demand. Both solar and wind energy are variable renewable energy, which means that all power must be used as soon as it is available. As solar energy is not available at night, its storage can be an important issue, especially in stand-alone consumption and for future renewable energy scenarios to have a constant availability of electricity.

Emissions of solar greenhouse gas emissions range from 22 to 46 grams (g) per kilowatt-hour (kW·h), depending on the type of solar power plant under consideration. In the future, this value may decrease to 15 g/kW·h. For comparison, a gas-fired combined cycle power plant emits approximately 400-599 g/kW·h, a fuel oil power plant 893 g/kW·h, a coal-fired power plant 915–994 g/kW·h or carbon capture and storage. about 200 g/kW·h, and a geothermal power plant of 91–122 g/kW·h. As with all energy sources, where their total life-cycle emissions are mainly in the construction and transportation phases, the transition to low-carbon energy in the production and transportation of solar devices will further reduce carbon emissions (Pidruchniki, 2022).

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Solar energy includes power plants with the lowest level of water consumption per unit of electricity (photovoltaic), as well as power plants with the highest level of water consumption.

Photovoltaic power plants use very little water to operate. The life cycle water consumption for operational services is estimated at 45 litres per megawatt-hour for flat solar panels. Only wind energy, which does not actually consume water during operation, has a lower intensity of water consumption.

Concentrating solar power plants, on the other hand, have the highest water consumption; only fossil fuel installations with carbon capture and storage can have higher water intensities. The issue of water consumption is exacerbated by the fact that concentrating solar power plants are often located in arid environments where water is scarce (JA Solar, 2022).

3. Features and principle of operation of a solar power plant

A solar power plant is an engineering structure that serves to convert solar radiation into electricity. Different methods of converting solar radiation are used, on which the design of a solar power plant depends.

There are two types of SPP: photovoltaic (directly converts solar energy into electricity using a photovoltaic module) and thermodynamic (converts solar energy into heat and then into electricity). The power of thermodynamic solar power plants is higher than the power of photovoltaic power plants).

The elements of SPP include:

1. Photovoltaic panels (solar modules) that convert solar energy into electricity.

2. Controller for controlling the solar photovoltaic system, which does not allow system overload or reverse current at night.

3. Battery required to store electricity generated by solar modules.

4. Inverter that converts direct electric current from solar panels into alternating current needed to power electrical appliances.

5. Electric meter that records the amount of electricity supplied to the general network or consumed if necessary.

In Fig. 3, the scheme of the solar power plant is presented, which demonstrates the interconnection of all elements of the station and the basic principle of its operation.

The work of the SPP takes place in the following sequence: The sun's rays fall on the panel of photovoltaic modules and, due to the transformation, are converted into electricity. Solar modules are used based on crystalline silicon or single crystals. The latter have a much higher service life, and the percentage of production depending on the service life is much higher. The amount of electricity that solar modules can provide depends on their efficiency, size and local level of sunlight.

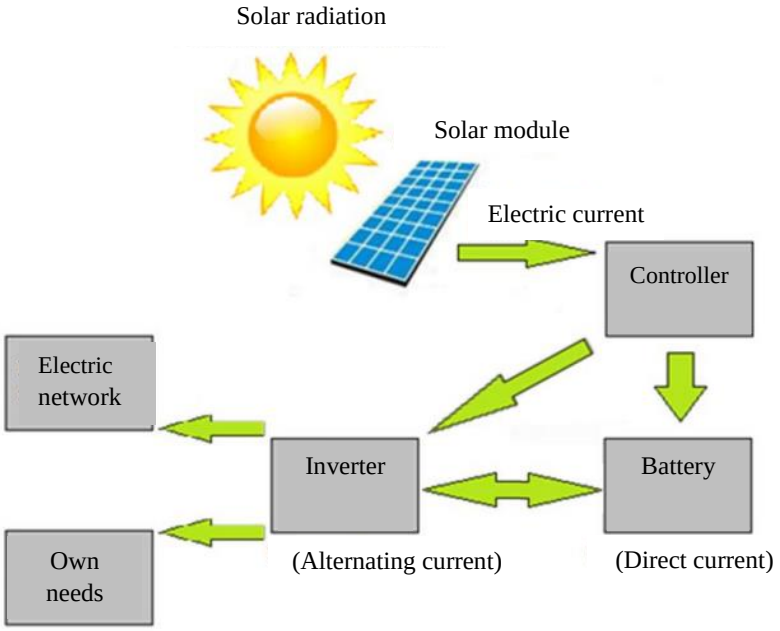

Fig. 3. Scheme of the solar power plant

After the conversion, the electricity passes through the connected battery, thus ensuring the charging of the batteries.

The next stage is the power supply of energy consumers, as well as the connection of the internal circuit of the solar power plant with the external electrical network for the issuance of surplus electricity (Gigavat, 2022).

SPP can be of two types:

1. Mains, which are more powerful. They are connected to an external power grid. Most of the electricity they produce is transmitted to the grid through the appropriate meter. The magnitude of a load of consumption is insignificant (Fig. 4 a).

2. Autonomous, which are designed primarily to meet the needs of the load for their consumption. They are designed for less power (determined by the list of own electrical receivers). They are also connected to external power. In this case, they transmit excess electricity to the grid using a separate meter (Fig. 4 b) (Solar energy, 2021).

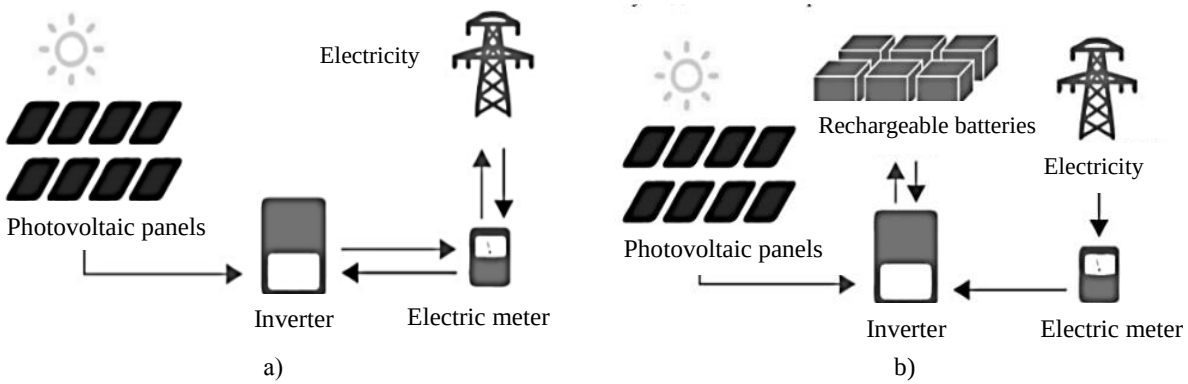

Fig. 4. Types of solar power plant: a) mains; b) autonomous

Due to the current legislation in Ukraine, citizens, along with organizations, can sell energy generated by their alternative source at a special "green" tariff. The "green" tariff is a special tariff grid, according to which the government on behalf of the state company "Energy Market" purchases from commercial organizations and individuals electricity generated from renewable sources – the sun (solar panels), wind (windmills), biological substances (biofuels), as well as water (small hydropower plants) at high prices

This tariff for solar electricity from individuals provides the opportunity for optimal operation of solar panels to supply electricity to residential buildings and increase their profitability. The state always pays the

owners of individual houses for the surplus electricity supplied to the electricity grid (Pro vnesennya zmin, 2015).

The algorithm for selecting SPP involves consistent execution of calculations and comparisons necessary for a reasonable determination of the structure of SPP and its components. The developed algorithm for the selection of SPP is presented in Fig. 5.

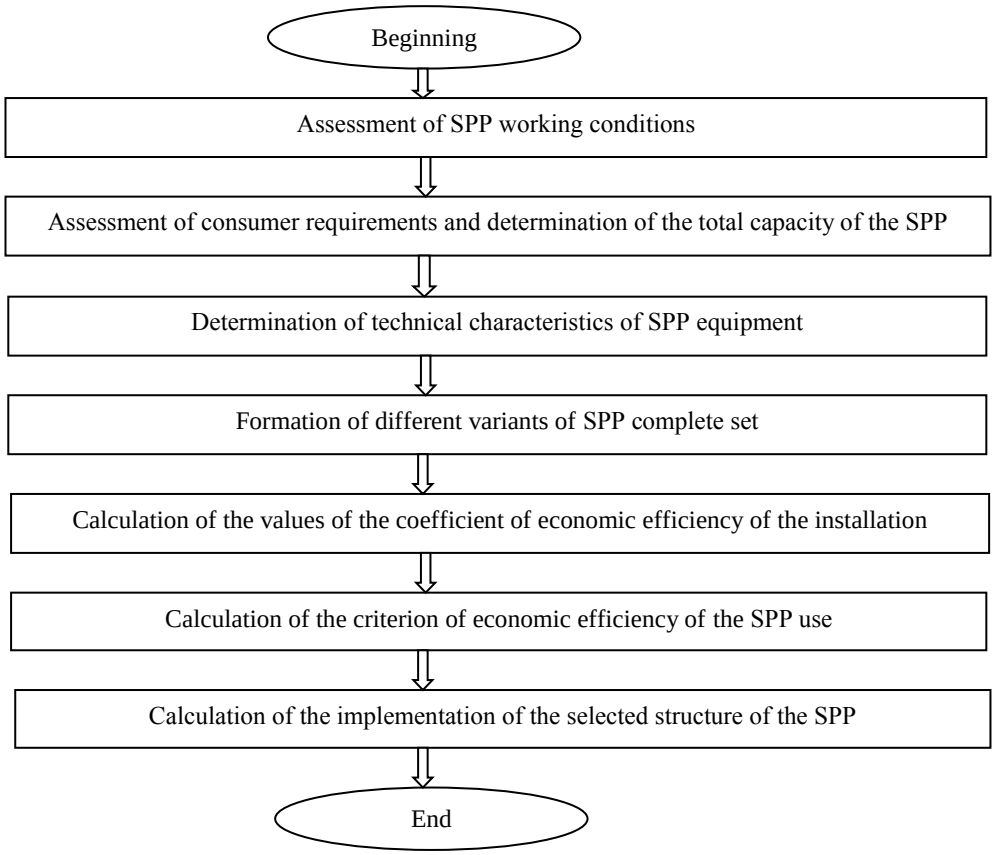

Fig. 5. SPP selection algorithm

To design a solar photovoltaic plant, it is necessary to choose the most modern models of photovoltaic panels with high efficiency of conversion of solar radiation into electricity. This will make it possible to generate more electricity if they are located in a smaller area. To do this, we choose a model from a leading manufacturer in solar energetics, namely, a module that has a single-crystal structure using Half-Cell technology, which reduces losses of electricity generation caused by shading.

Selected photo modules have a number of advantages: high power; low dependence of characteristics on a temperature mode; shading has less impact on electricity generation (Half-Cell technology); high resistance to mechanical loads.

Photovoltaic panels are suitable for use on roofs and are currently produced in sufficient quantities. Electricity generated in some favourable places has almost reached grid parity (the point where the cost of photovoltaic electricity corresponds to the price in a conventional network). The growth in the production of photovoltaic panels was due to government incentives that subsidize electricity costs and stimulate technological innovation (JA Solar, 2022).

4. Conclusions

Nowadays, electricity is an integral part of the development and comfortable living. All types of economic activity consume electricity. Energy production by traditional sources is environmentally unsafe, and every year such production becomes more expensive. Every year the amount of oil and gas reserves decreases, which leads to an increase in their value. That is why humanity is beginning to switch to alternative energy sources.

The use of alternative energy will reduce emissions of harmful substances into the environment and dependence on fuel, as well as create additional opportunities for various sectors of the economy.

Solar radiation reaching the planet's surface is a powerful source of clean energy. This type of energy is radiation safe, and its production does not produce carbon dioxide.

Direct transformation of solar radiation into electricity using solar panels is the most promising method of obtaining electricity. The development of solar energy in Ukraine is important not only because of the exhaustion of resources for traditional energy sources but also because of the increasing burden on the environment.

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