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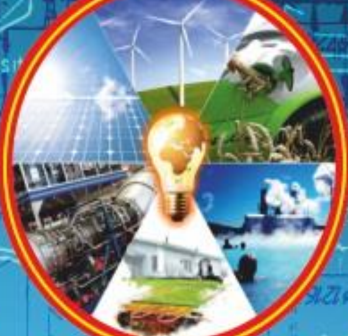

2023

Machinery
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ТЕХНІКА ЕНЕРГЕТИКА ТРАНСПОРТ АПК

Всеукраїнський науково-технічний журнал

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TECHNOLOGICAL PROGRESS IN SOLAR PANELS: ACHIEVEMENTS AND INNOVATIONS

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The modern world faces a major problem of meeting energy needs, which requires us to develop sustainable and environmentally friendly energy sources. Dependence on conventional sources such as coal and oil has a negative impact on the environment and leads to energy insecurity. However, science and technological progress are putting their efforts into developing alternative energy sources, and one of the most promising is solar energy.

However, despite the prospects of solar energy, there is a question that requires our attention and resolution: how to achieve the maximum efficiency and practical applicability of solar panels. Despite the great potential of this energy source, there are a number of technological challenges and limitations that must be overcome for its full use.

This article aims to provide a detailed analysis of technological developments in the field of solar panels, focusing on their achievements and innovations that have transformed them from simple experimental devices into powerful and affordable sources of sustainable energy. Let's look at the important steps taken to improve the materials, structures and efficiency of solar panels, and consider the innovations that ensure their integration into various areas of life.

Solar energy plays a key role in the global search for alternative, sustainable energy sources, helping to reduce greenhouse gas emissions and dependence on conventional sources. One of the main reasons for this breakthrough is technological progress in solar panels, which has transformed them from an experimental device to a powerful and affordable source of energy. This article explores the key advances and innovations that have made solar panels an efficient and attractive solution to today's energy needs.

Key words: *solar panels, renewable energy, technological progress, innovation, solar cells, efficiency, achievements, photovoltaic effect, technological solutions.*

Fig. 7. Table. 1. Ref. 9.

1. Problem formulation

One of the key challenges is the high cost of manufacturing solar panels and the dependence on expensive materials. This limits their mass adoption and availability to a wide range of consumers. In addition, it is necessary to solve the issue of storing excess solar energy, since it may not be available during periods of cloud formation, at night or in regions with low intensity of solar radiation.

Another important issue is the efficiency of solar energy conversion. Despite significant progress in this area, the share of solar energy that is actually converted into electric current remains limited. This is important to improve to ensure maximum use of solar energy

2. Analysis of recent research and publications

Analysis of research in the field of solar panels shows the incredible technological progress that is taking place in this field. Advances and innovations have affected all aspects of solar panel design, production, and use, making them more efficient, affordable, and more integrated into various energy sectors.

First of all, research in the field of materials science has led to the discovery of new semiconductor materials, such as perovskite, which allow the creation of solar panels with higher efficiency and lower production costs. This discovery paves the way for the large-scale use of solar panels in various regions and fields.

Next, researchers are actively improving solar panel designs using thin-film technologies and other innovative approaches. This allows for the creation of flexible and lightweight panels that can be integrated into buildings, vehicles and other objects using a minimum amount of space.

Accumulation and storage of solar energy have also become the subject of deep research. Advanced batteries and storage systems make it possible to accumulate excess energy that can be used during periods of insufficient solar radiation, ensuring more stable and reliable use of solar energy.

In addition, solar cells are beginning to integrate with other technologies such as artificial intelligence and the Internet of Things. This makes it possible to create "smart" energy systems that can predict energy consumption, optimize its use and manage the efficiency of solar panels.

Research in the field of solar panels continues to make a significant contribution to the development of sustainable and efficient energy sources. Technological progress in this field allows us to dream of a more sustainable energy future where solar panels will play an important role in meeting our energy needs.

3. The purpose of research

The article aims to analyze new technological solutions that affect the improvement of efficiency, energy efficiency and sustainability of solar panels.

4. Results of the researches

Energy consumption is one of the main components of modern life, and the challenges associated with its provision are becoming more urgent with the growth of the population and the development of technology. Among numerous research directions in the energy field, solar energy is gaining more and more attention as one of the most promising and environmentally friendly sources of renewable energy. Modern solar panels, which convert solar radiation into electric current, are marked by impressive technological progress and create new horizons for the efficient use of solar energy.

The world is facing the challenges of energy efficiency and sustainable development, and the role of solar panels in this process cannot be overstated. The path to a more sustainable energy future lies through the continuous development and improvement of solar panel technologies, and this is what our further discussion is about.

The history of solar panels goes back a long way and is associated with many scientists and inventors who contributed to the development and improvement of this technology. Here's a brief history of solar panels:

1839: French physicist Antoine-César Becquerel discovered the photoelectric effect when he discovered that certain materials emit an electric current when exposed to sunlight.

1883: American scientist Charles Fritz discovered the photovoltaic effect in selenium, establishing the possibility of generating electricity from light.

1954: The Bell Company Laboratories in the USA developed the first practical solar cell based on silicon, which achieved an efficiency of about 6%. This is considered the beginning of modern solar energy.

1970-1980 years: During this period, significant research and development of solar panels took place, resulting in improved efficiency and reduced production costs.

1980s-1990s: The emergence of solar power on space stations and satellites provided the impetus for further development of solar panel technology.

21st century: In recent decades, solar panels have become more affordable and efficient thanks to new materials, technologies and research. They are widely used in various fields, including residential construction, industrial complexes, agriculture, and also help to solve the energy challenges of the planet.

Modern solar panels are able to collect solar energy and convert it into electric current with a fairly high efficiency. The history of the development of this technology is an example of the interaction of scientific research, engineering efforts and innovative solutions that led to the creation of one of the most important sources of renewable energy.

A solar cell, also known as a photovoltaic cell or solar module, is a device that converts solar radiation, or light, into electrical current. The principle of operation of solar batteries is based on the photoelectric effect, which was discovered in the 19th century.

The main component of a solar cell is a photovoltaic cell, or solar photovoltaic cell. Photocells are usually made of semiconductor materials such as silicon, cadmium telluride or perovskite. The principle of operation is to convert light into electric current using the effect when photons of light knock electrons off atoms in the material.

Here's how it works:

Absorption of photons: When solar radiation reaches the surface of a photocell, photons of light interact with atoms in the material. This results in absorption of photon energy by the atoms, which can knock electrons out of their atomic orbits.

Free electrons: When electrons are detached from atoms, they become "free electrons" and have high energy. This creates free holes, or positively charged sites, in place of the stripped electrons.

Creation of an electric current: Separated electrons and holes create an electric flow - an electric current. This current can be collected and removed from the photocell by means of conductors. The process of releasing an electric current creates energy that can be used to power electrical devices or stored in a battery for later use.

This principle of the photovoltaic effect allows solar cells to convert solar radiation into useful electrical current that is used to power various electrical devices and systems.

There are several types of solar cells that are used to convert solar energy into electricity. Each type has its own structure and principle of operation. Here is an overview of some of them:

Mono- and polycrystalline solar cells:

Structure: Mono- and polycrystalline batteries are made of silicon. They consist of crystalline silicon structures that form a coating, or "cell", on the surface of the panel.

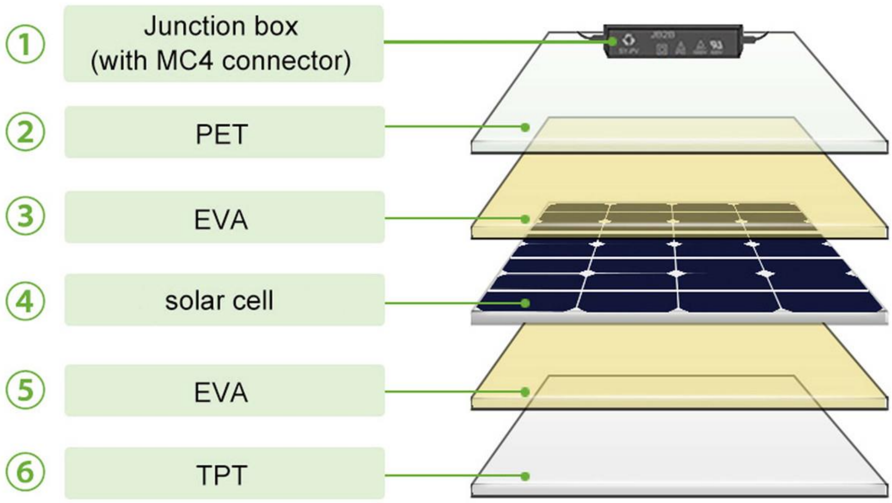

Fig. 1. General appearance of mono- and polycrystalline batteries

Principle of operation: Solar radiation falls on a crystal structure that generates an electric current. Mono- and polycrystalline batteries differ in quality and efficiency, with monocrystalline batteries generally more efficient due to their more uniform crystal structure.

Thin film solar cells:

Construction: Thin-film batteries consist of thin layers of semiconductor materials, such as amorphous silicon, cadmium telluride, or copper indium gallium selenide, deposited on a substrate of glass or other material.

Fig. 2. General appearance of thin-film batteries

Principle of operation: Thin layers of semiconductor materials absorb solar radiation and generate electric current. Thin-film batteries use fewer materials and can be more flexible, but their efficiency can be lower compared to crystalline batteries.

Organic solar cells:

Structure: Organic batteries use organic materials, such as polymers or organic dyes, to generate electricity.

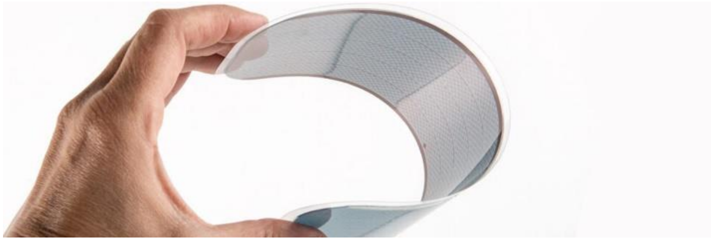

Fig. 3. General appearance of organic batteries

Principle of operation: Organic materials can generate an electric current when light is absorbed. They can be more flexible and can use the principles of organic electronics to create efficient and inexpensive solar cells.

Concentrator solar batteries:

Construction: This type of battery uses lens or mirror systems to focus solar radiation onto a small area of photovoltaic cells.

Fig. 4. General view of focusing batteries

Principle of operation: Concentrated solar radiation significantly increases the intensity of light falling on photocells, which can increase their efficiency. However, these systems require fine tuning and sun tracking.

Each type of solar cell has its own advantages and disadvantages, and they can be used in different conditions and areas.

1. More effective materials

Early solar panels used silicon as the main material to convert solar radiation into electrical current. However, new materials such as perovskite and organic polymers have made it possible to achieve significantly higher efficiency and lower production costs.

2. Thin films and flexibility

The development of technologies has made it possible to create thin films of solar cells, which makes them flexible and adaptable to different surfaces. This opens up opportunities to integrate solar panels into a variety of building and facility designs.

3. Improved storage systems

Innovations in the field of energy storage have made it possible to solve the problem of the volatility of solar energy. Large-capacity batteries and intelligent control systems help store excess energy and use it during periods of insufficient solar radiation.

4. Improvement of conversion and efficiency

Improvements in the design of solar panels and the use of optimized conversion technologies have made it possible to increase the efficiency (efficiency) and ensure more efficient use of solar energy.

5. Integration with other technologies

Solar panels are becoming more than just a source of energy, but are being integrated with other technologies such as the Internet of Things (IoT) and artificial intelligence (AI) to create "smart" energy systems that can predict, optimize and manage energy consumption.

The manufacturing process of solar panels is a complex technological process that includes several manufacturing steps to create functional photovoltaic cells that collect solar energy and convert it into electrical current. Here is a detailed description of the solar panel manufacturing process:

1. Making Solar Cells: The first step is to make solar cells, which are the basic elements of a solar panel. For this, a semiconductor material, usually silicon, is used. The process includes the following steps:

- Growing monocrystalline or polycrystalline silicon: Crystalline silicon is obtained by growing monocrystalline or polycrystalline silicon bars using special furnaces.
- Cutting bars into wafers: Silicon bars are cut into thin wafers called solar wafers or wafers.
- Ancillary Processes: Solar wafers are processed to remove defects, improve purity, and give them the properties of a semiconductor material.

2. Solar cell surface treatment: Solar cells require treatment to prepare their surface for application of contact layers. This stage includes:

- Applying an anti-reflective coating: To reduce light loss, an anti-reflective coating is applied to the surface of the cells, which helps retain more solar energy.
- Application of contact layers: Two electrically charged metal grids (contact layers) are applied to both sides of the solar cell. This allows you to remove the generated electric current from the cell.

3. Assembling the solar panel module: After the solar cells are manufactured, they are assembled into a module which is the main part of the solar panel. The process includes:

- Cell bonding: Solar cells are joined in rows and columns using laser or mechanical bonding to create interconnected cells or "sub-cells".
- Applying a protective layer: A protective layer is applied to the top surface of the solar cells to protect against the negative effects of the environment and humidity.
- Connection of cells into a module: Connected cells are connected together into one module using glass, plastic coatings and metal frames.

4. Testing and Quality: After assembly, each module and panel is tested for quality and performance to ensure proper operation and performance.

This manufacturing process is high-tech and complex, but thanks to constant research and innovation, it is constantly being improved to ensure more efficient, affordable and sustainable solar panels.

The amount of sunlight has a significant impact on the production of energy from solar panels. This is because solar cells use the photovoltaic effect to convert solar energy into electricity, and the intensity of light directly affects the amount of energy that can be harvested.

The main aspects that show the influence of the amount of sunlight on the production of energy from solar panels:

1. Light intensity: The greater the intensity of sunlight, the more photons fall on the surface of the solar cells. This leads to an increase in the number of photoelectrons that bounce off the atoms of the semiconductor material and generate an electric current.
2. Conversion efficiency: Increasing light intensity usually results in greater conversion efficiency of solar energy into electrical current. This means that more energy can be collected from a unit area of solar cells.
3. Diurnal and seasonal cycles: The amount of sunlight varies throughout the day and in different seasons of the year. This means that solar cells may receive less energy in the morning, evening or winter compared to sunny days in the summer.
4. Distance from the Sun: The effect of the amount of sunlight depends on the distance between the Earth and the Sun. It can change due to the orbital parameters of the Earth, which also affects the intensity of light that reaches the surface of the batteries.

In general, for optimal solar cell performance, it is important to consider weather conditions, geographic location, and other factors that affect the amount of sunlight. The application of sun tracking systems and adaptation mechanisms can also help maximize solar energy harvesting even under variable lighting conditions.

There are several methods for improving and increasing the efficiency of solar panels, which allows more efficient use of solar energy. Here are some of them:

1. Use of anti-reflective coatings: Anti-reflective coatings are applied to the surface of solar cells, which helps reduce light loss due to reflection. This allows more light to enter the cells and increases their efficiency.
2. Using light concentrators: Light concentrators increase the intensity of light by directing it onto a small area of the solar panel. This allows you to increase the output energy, but requires precise alignment of the panels in relation to the light source.
3. Use of multilayer structures: Multilayer solar cells contain several layers of different materials with different optical and electronic properties. This allows to increase light absorption and increase the output current.

4. Use of thin films: Thin films use less material but can be more efficient in absorbing light. They can use less energy in production and allow to reduce the weight of the panels.

5. Application of tracking systems: Solar panels that can automatically follow the movement of the sun throughout the day receive more sunlight. This allows you to increase the amount of time during which the panels receive maximum light.

6. Use of heat treatment technologies: Some heat treatment methods can improve the crystalline structure of the materials that make up the cells, increasing their efficiency.

7. Development of new materials: The use of new semiconductor materials, such as perovskite, can improve the efficiency of solar cells.

8. Utilization of maximum area: Placing solar panels in optimal areas with ample light helps to ensure maximum collection of solar energy.

Table 1

Efficiency of solar panels depending on the season and geographical location

Time of year / Location	Low intensity	Medium intensity	High intensity
Spring / Northern latitude	Reduces efficiency	Medium impact	Increases efficiency
Summer / Northern latitude	Reduces efficiency	Increases efficiency	Increases efficiency
Autumn / Northern latitude	Reduces efficiency	Medium impact	Increases efficiency
Winter / Northern latitude	Reduces efficiency	Reduces efficiency	Reduces efficiency
Spring / Equator	Medium impact	Increases efficiency	Increases efficiency
Summer / Equator	Increases efficiency	Increases efficiency	Increases efficiency
Autumn / Equator	Medium impact	Increases efficiency	Increases efficiency
Winter / Equator	Reduces efficiency	Medium impact	Increases efficiency
Spring / South latitude	Medium impact	Increases efficiency	Increases efficiency
Summer / South latitude	Increases efficiency	Increases efficiency	Increases efficiency
Autumn / South latitude	Medium impact	Increases efficiency	Increases efficiency
Winter / South latitude	Reduces efficiency	Medium impact	Increases efficiency

There are several options for connecting solar panels, depending on the needs of the consumer, the size of the system and the purposes of use. The main options include parallel and serial connection, as well as combinations thereof. Additionally, different equipment can be used for efficient operation of solar systems.

Parallel connection: In this version, several solar panels are connected in parallel, that is, plus to plus, minus to minus. This ensures that the total current increases, while the voltage remains stable. This connection method is suitable for systems where high current is important, for example, for charging batteries.

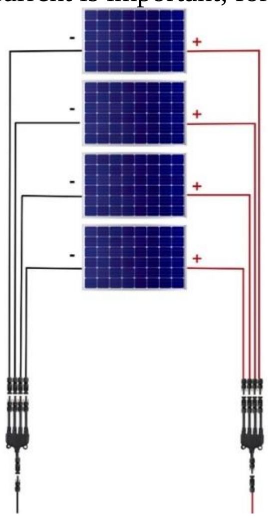

Fig. 5. Parallel connection of solar panels

Serial connection: In this variant, the plus of one panel is connected to the minus of the other, which leads to an increase in voltage, but the current remains stable. This is suitable for systems where high voltage is important, for example when connecting to inverters.

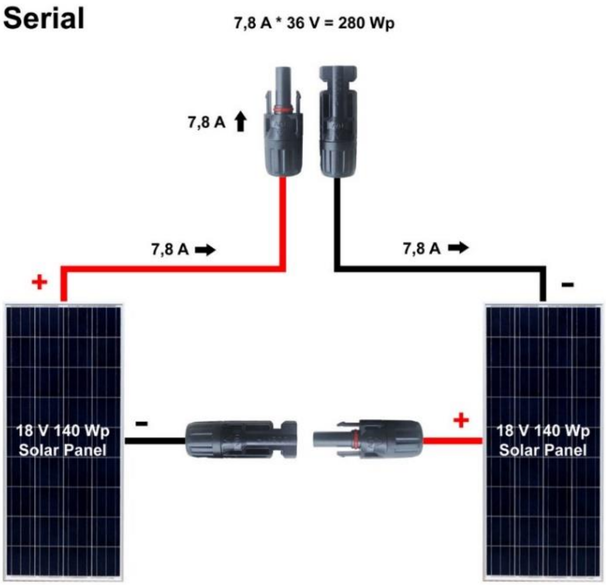

Fig. 6. Serial connection of solar panels

Combined connection: This is a combination of parallel and series connection to achieve optimal current and voltage parameters in the system. A large system size may require different connection combinations to optimize power generation.

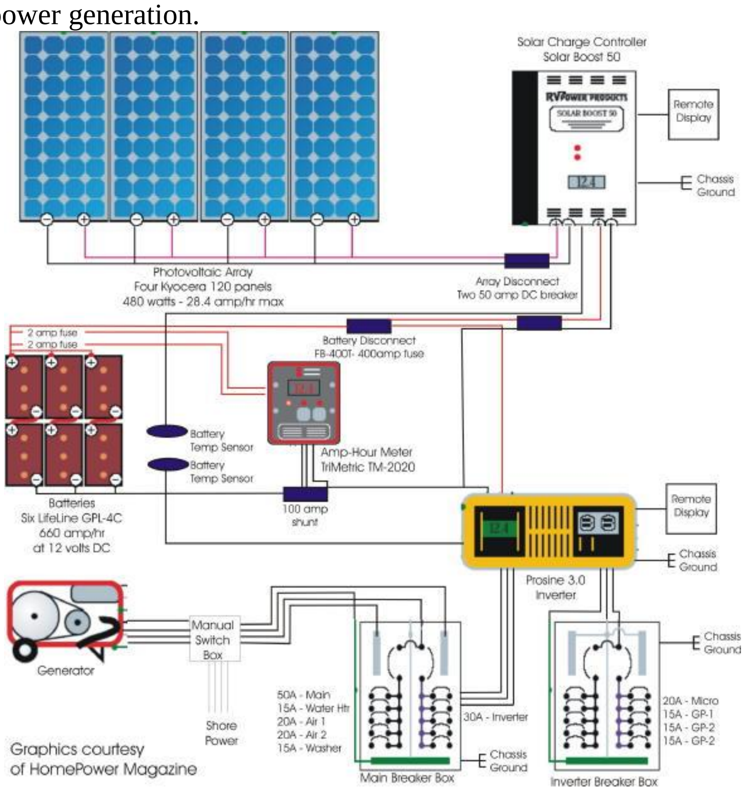

Fig. 7. Schematic diagram of connecting solar panels and additional equipment

Additional equipment:

- Inverters: To convert direct current produced by solar panels into alternating current for connection to the electrical grid or for use in buildings.
- Charge Controllers: Used in battery systems to control charge and discharge, prevent over-voltage and over-discharge.
- Batteries: Used to store excess generated electricity for use at night or in bad weather conditions.
- Mounting system: Helps fix solar panels on the roof or on the ground in the optimal position to receive maximum solar energy.

The choice of connection and additional equipment depends on the specific requirements and conditions of your solar system.

5. Conclusions

The considered innovative approaches in the construction of solar panels open wide prospects for increasing their efficiency. The use of new materials, such as perovskite compounds, contributes to increasing the efficiency of providing electricity from solar energy. Also, the development of integrated systems with optical concentrators and the provision of automatic alignment of panels to the sun open up new opportunities for increasing energy production.

The influence of light intensity on the productivity of solar panels in different seasons and geographical locations was studied. This allows you to understand how to effectively use solar energy in different conditions, which is important for planning and optimizing production.

The expansion of knowledge and the use of new innovative solutions in this area contributes to the growth of interest in the use of solar technologies in various industries, which, in turn, contributes to sustainable development and preservation of the environment.

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ТЕХНОЛОГІЧНИЙ ПРОГРЕС У СОНЯЧНИХ ПАНЕЛЯХ: ЗДОБУТКИ ТА ІННОВАЦІЇ

Сучасний світ стоїть перед великою проблемою забезпечення енергетичних потреб, яка вимагає від нас розвитку стійких та екологічно чистих джерел енергії. Залежність від конвенційних джерел, таких як вугілля та нафта, має негативний вплив на навколишнє середовище та призводить до енергетичної невпевненості. Однак наука та технологічний прогрес вкладають свої зусилля в розробку альтернативних джерел енергії, і одним із найбільш обіцяючих є сонячна енергія.

Проте, незважаючи на перспективи сонячної енергії, існує питання, яке вимагає нашої уваги та розв'язання: як досягти максимальної ефективності та практичної застосовності сонячних панелей. Незважаючи на великий потенціал цього джерела енергії, існують ряд технологічних викликів та обмежень, які необхідно подолати для його повноцінного використання.

Ця стаття покликана провести детальний аналіз технологічного розвитку в галузі сонячних панелей, зосереджуючись на їхніх здобутках та інноваціях, які перетворили їх з простих експериментальних пристроїв у потужні та доступні джерела стійкої енергії. Подивимося на важливі кроки, зроблені в напрямку покращення матеріалів, конструкцій та ефективності сонячних панелей, а також розглянемо інновації, які забезпечують їхню інтеграцію в різноманітні сфери життя.

Сонячна енергія відіграє ключову роль у глобальному пошуку альтернативних, стійких джерел енергії, сприяючи зменшенню викидів парникових газів та залежності від конвенційних джерел. Одним із головних підґрунтя цього прориву є технологічний прогрес у сонячних панелях, який перетворив їх з експериментального пристрою на потужний та доступний джерело енергії. Ця стаття досліджує ключові здобутки та інновації, що зробили сонячні панелі ефективним та привабливим рішенням для енергетичних потреб сучасності.

Ключові слова: *сонячні панелі, відновлювальна енергія, технологічний прогрес, інновації, сонячні клітини, ефективність, здобутки, фотоелектричний ефект, технологічні рішення.*

Рис. 7. Табл. 1. Літ. 9.

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