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USING LIGHT CONCENTRATORS IN PHOTOVOLTAIC PANELS AND A BIONIC SOLAR TRACKING SYSTEM

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Abstract. *This article examines the issue of improving the efficiency (EEF) of semiconductor solar panels used as electric generators, which can be applied in agrivoltaics projects. Agrivoltaics is a system that simultaneously combines agriculture and solar energy production on the same land area.*

Based on an analysis of semiconductor solar panel designs employing light concentrators, it was found that the most effective solution is the use of Fresnel lenses.

As a result of engineering research, a bionic system was proposed that incorporates light concentrators in the panels of semiconductor solar batteries along with a sun-tracking system using a Fresnel lens, which implements the bionic principle of the sunflower – «heliotropism» or solar orientation. This principle ensures an increase in the efficiency of semiconductor solar panels, while the branched root-like structure provides resistance to wind loads, offering prospects for their wide application in solar energy.

Keywords: *agrivoltaics, solar panel, light concentrator, efficiency factor, tracker, mounting method, invention patent, yield increase, farming enterprise.*

Introduction

Ukraine stands on the threshold of a new energy era, where agriculture and renewable energy move hand in hand. Agrivoltaics is a dual-land-use technology that integrates renewable energy systems with agricultural practices and technologies. This approach can significantly improve the use of land resources within united territorial communities (UTCs), ensure energy independence, and support the development of rural regions and communities.

Agrivoltaics is a form of sustainable land use that enables simultaneous agricultural production and electricity generation using photovoltaic panels or other renewable energy systems without compromising the primary agricultural function of the land. Panels are mounted at a certain height, creating partial shade that benefits many crops by protecting them from excessive sunlight and reducing moisture evaporation. In this way, a farmer gains the ability to use the same land for dual purposes [1].

The panels may help create favorable growing conditions for plants, provide protection from hail, and their design can be adapted for livestock grazing—for example, sheep that can take shelter from the sun beneath them. This contributes to the energy independence of a farm.

Farmers can use the electricity they generate for their own needs, reducing costs, and may also sell excess energy.

This approach promotes the optimization of land resources, enables more efficient use of less convenient plots for crop production, and helps mitigate the effects of drought and extreme heat. It enhances both the national and local levels of energy and food security, reduces dependence on external energy sources, and supports production stability and lower product cost. Moreover, it creates new jobs through the emergence of specialists responsible for maintaining this technology.

Our scientific work is aimed at improving the design of solar panels. Its main objective is to create a bionic system incorporating light concentrators within semiconductor solar panel modules together with a sun-tracking system. Several methods exist for mounting solar panels on the ground. One of the known traditional mounting methods is shown in Figure 1. This method is less efficient than others, as it does not include a tracking system and requires removing agricultural land from active use.

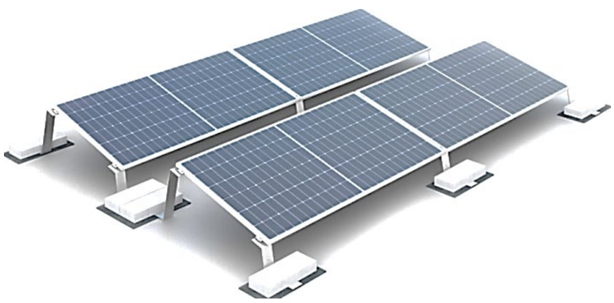

Figure 1. Traditional method of mounting a solar panel on the ground.

Another known method is the stationary mounting of a solar panel on a support above the ground (Figure 2).

The stationary mounting method also has disadvantages – it does not ensure that sunlight strikes the panel surface perpendicularly.

Figure 2. Stationary method of mounting a solar panel on a support above the ground.

The most promising method is the stationary mounting of a solar panel on a support above the ground equipped with a solar tracker (a sun-tracking system), as shown in Figure 3.

Figure 3. Stationary mounting method of a solar panel on a support equipped with the ST1000 solar tracker (sun-tracking system).

A modern solar tracker (such as the ST1000) is an electromechanical device designed to track the movement of a light source (Figure 4).

The main purpose of a solar panel equipped with a tracking system is to adjust the position of photovoltaic modules (solar panels) in order to obtain maximum efficiency. When sunlight hits the panel at a perpendicular angle, reflection is minimized and the energy of the sun's rays is used most effectively.

The advantage of the ST1000 solar tracker lies in the fact that the solar panels mounted on it automatically follow the sun throughout the day and adjust their tilt angle depending on the season. This significantly increases electricity generation compared to fixed solar panels.

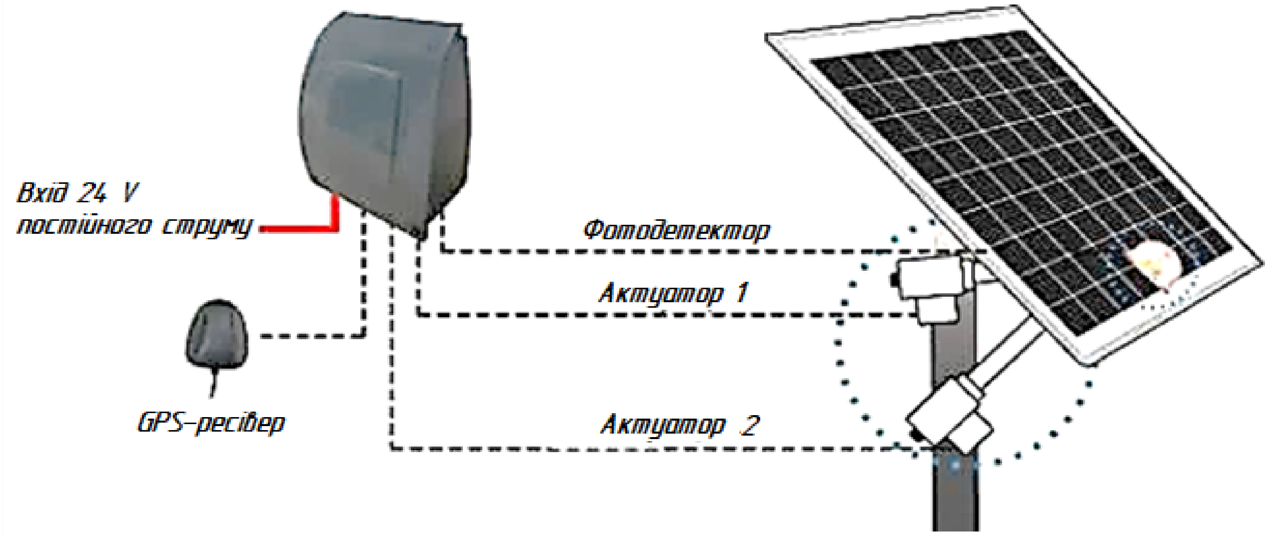

Figure 4. Diagram of the interaction between solar panel elements and the light-source-tracking device.

A comparison of two solar power stations – one without a tracker and one equipped with a tracker – showed a difference in the amount of energy produced during the daylight period:

– energy produced by the station without a tracker: 3762.0 Wh;

– energy produced by the station with a tracker: 6093.0 Wh [9].

The issue of increasing the efficiency (EEF) of semiconductor solar panels used as electric generators has existed since their first application. One of the ways to increase the efficiency of semiconductor solar cells is the use of light concentrators.

An increase in the efficiency of solar cells under concentrated radiation leads to higher electrical output of the panel. The application of optical concentrators allows for a proportional reduction in the area of solar cells relative to the concentration ratio of sunlight, thereby reducing their size and cost, and increasing the panel's service life due to improved protection of semiconductor elements from radiation exposure.

One of the most effective light concentrators is the Fresnel lens; its advantages include small dimensions and low weight. This is a flat lens of square or rectangular shape, characterized by manufacturing simplicity and low production cost. For these reasons, we developed the invention titled «Semiconductor Solar Panel with Light Concentrator and Sun-Tracking System».

The design incorporates the bionic principle of the sunflower (Figure 5).

Young sunflower plants follow the sun through a process known as heliotropism (or solar orientation). This movement occurs due to uneven stem growth: during the day, the eastern side grows more actively, causing the flower head to turn westward; at night, the reverse occurs, with the western side growing faster and turning the flower back east. This continues until the plant matures, after which the stem becomes fixed in one position.

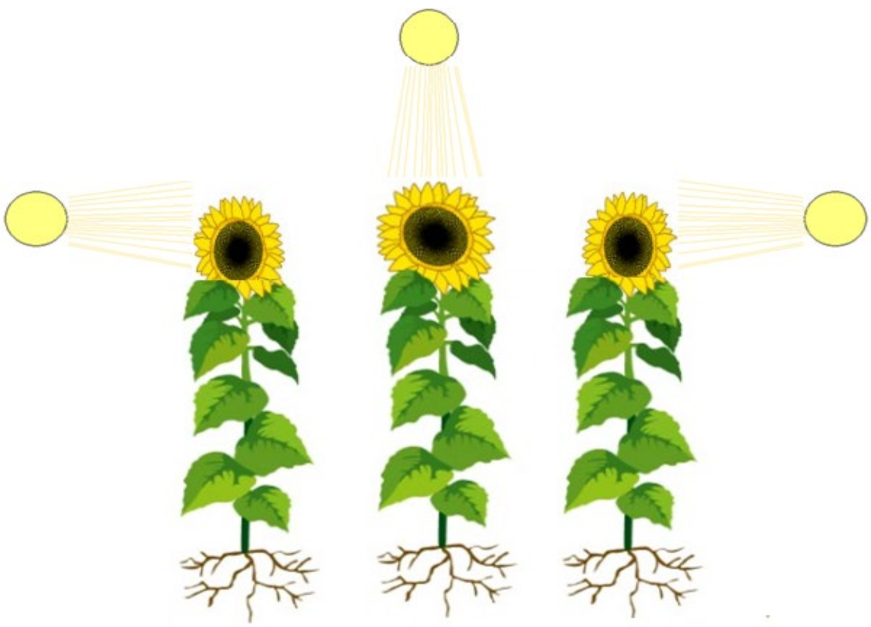

Figure 5. Phases of sunflower rotation following the movement of the sun.

Another bionic principle of the sunflower incorporated into our design is the branched root system (Figure 6). This principle allows the creation of supports with high resistance to wind loads.

The design integrates the sunflower's bionic principle of «branched roots» (see Figure 7).

Figure 6. Bionic principle of the sunflower: «branched roots».

The aim of this research is to develop an adaptive system for utilizing a semiconductor solar panel with a light concentrator based on Fresnel lenses to increase the panel's electrical output by enhancing the efficiency (EEF) of each solar cell, incorporating a light-source tracking system, and orienting the photovoltaic panel based on the bionic principle of the sunflower.

Analysis of current research and publications

Continuous improvements in solar panel design have led to an increase in baseline efficiency, achieved by mounting panels on supports that rotate the solar panels to follow the sun. Solar tracking occurs both horizontally and vertically. According to estimates, installing a single rotating tracker can immediately improve efficiency by 40–50%. Currently, there are high-efficiency multi-junction panels: Sharp's five-layer panels (43.5%), Soy-Tech's four-layer panels (44.7%), and devices developed by the Fraunhofer Institute for Integrated Circuits (Germany), where panel efficiency reaches up to 47% [2].

In the patent review, we refer to research related to solar energy, specifically concentrators for solar panels. A known holographic solar energy concentrator is described in Russian Federation Patent No. 2403510, published 02.03.1999. It represents a semi-cylindrical concentrator with a fan-like arrangement of reflective surfaces and transparent semiconductor solar panels. The concentrator and solar panel form a single integrated unit, with the drawback being significant light energy loss [3].

Disadvantages of such prototypes include manufacturing complexity of an integrated concentrator-panel system, high cost, structural complexity, and the need for precise adjustment. This raises the problem of producing light concentrators for photovoltaic modules.

A planar light guide is also known (RF Patent No. 2488149, IPC H02S10/00, H01L31/042, "Ray concentrator for a solar battery with fan-shaped arrangement of reflective electrodes", published 20.07.2013), in which incident light reaches the solar cell surface after multiple reflections within the concentrator [3].

The main limitation of this light guide is low efficiency because each ray, regardless of the number of reflections, only interacts with the solar cell surface once; thus, the concentrator converts the incident rays only a single time.

Author's work

Our patent considers a spherical concentrator (UA 1528540, IPC H02S 10/00, H01L 31/042, «Portable semiconductor solar battery with a heliographic spherical concentrator for tourism purposes», published 19.04.2023), which is also one variant of solar energy concentrators [6].

One of the most effective types of light concentrators is the Fresnel lens, which has the advantages of low weight and compact size. Typically, such a lens is flat and of square or rectangular shape. Another advantage is its simple, cost-effective manufacturing technology.

In our study, which led to patent UA 153265 (IPC 2023.01: A41D 13/012, A41D 31/10, published 14.06.2023), a method for manufacturing Fresnel lenses for photovoltaic concentrators using thermal forming of acrylic glass was proposed. This method enables the production of concentrators in a simple, cost-effective manner with consistently high quality, minimal time investment, and a high degree of waste-free manufacturing [6].

Based on the thermal forming method for acrylic glass, a semiconductor solar panel with a light concentrator based on Fresnel lenses was developed.

A semiconductor solar panel with a light concentrator and sun-tracking system increases the efficiency of each solar cell, enhances solar energy conversion, boosts panel voltage and power, and can be applied in systems tracking the sun's position on rooftops and flat-area installations [2, 4].

Based on our invention UA 1764908 U – «Semiconductor solar panel section with light concentrator», an improved design was proposed in utility model patent UA 153264 (IPC 2023.01, H02S 10/00, H01L 31/042, «Semiconductor solar panel with light concentrator and sun-tracking system», 28.04.2022, published 14.06.2023, see Figure 7) [5, 8].

The purpose of the proposed invention is to create a bionic system using light concentrators in semiconductor solar panels with a sun-tracking system integrated into a single rigid frame, forming a complete solar panel to enhance efficiency (see Figure 7).

This semiconductor solar panel with a light concentrator and sun-tracking system (see Figure 7) consists of: a metal frame (3), a Fresnel lens (4), mounting eyes (5), solar panel sections (6), electrodes (7). The mechanical components include: panel support (8), post (9), frame reinforcement (10), horizontal gear bearing (11), frame horizontal rotation gear (12), vertical rotation bearing (13), vertical rotation motor gear shaft (14), vertical rotation sector (15), horizontal stepper motor housing (16), vertical stepper motor housing (17), horizontal rotation gear (18), counterweight rod (19), counterweight (20), vertical rotation motor mount (21), and horizontal rotation motor mount (22).

The semiconductor solar panel with a light concentrator and sun-tracking system operates as follows: sunlight (2) falls onto a set of metal frames (3) with mounting eyes (5), which house Fresnel lenses (4) acting as light concentrators along with semiconductor solar panel sections (6). A higher direct current is generated at the electrodes (7), while the mechanical components, controlled by electronic blocks for vertical and horizontal frame rotation (26, 27), track the sun's movement.

The entire structure is anchored into the ground (37), and the panel supports (8) are reinforced and weighted with stones (38), providing stability to the post (9), which is strengthened by frame reinforcements (40) connected to reinforcement holders (39).

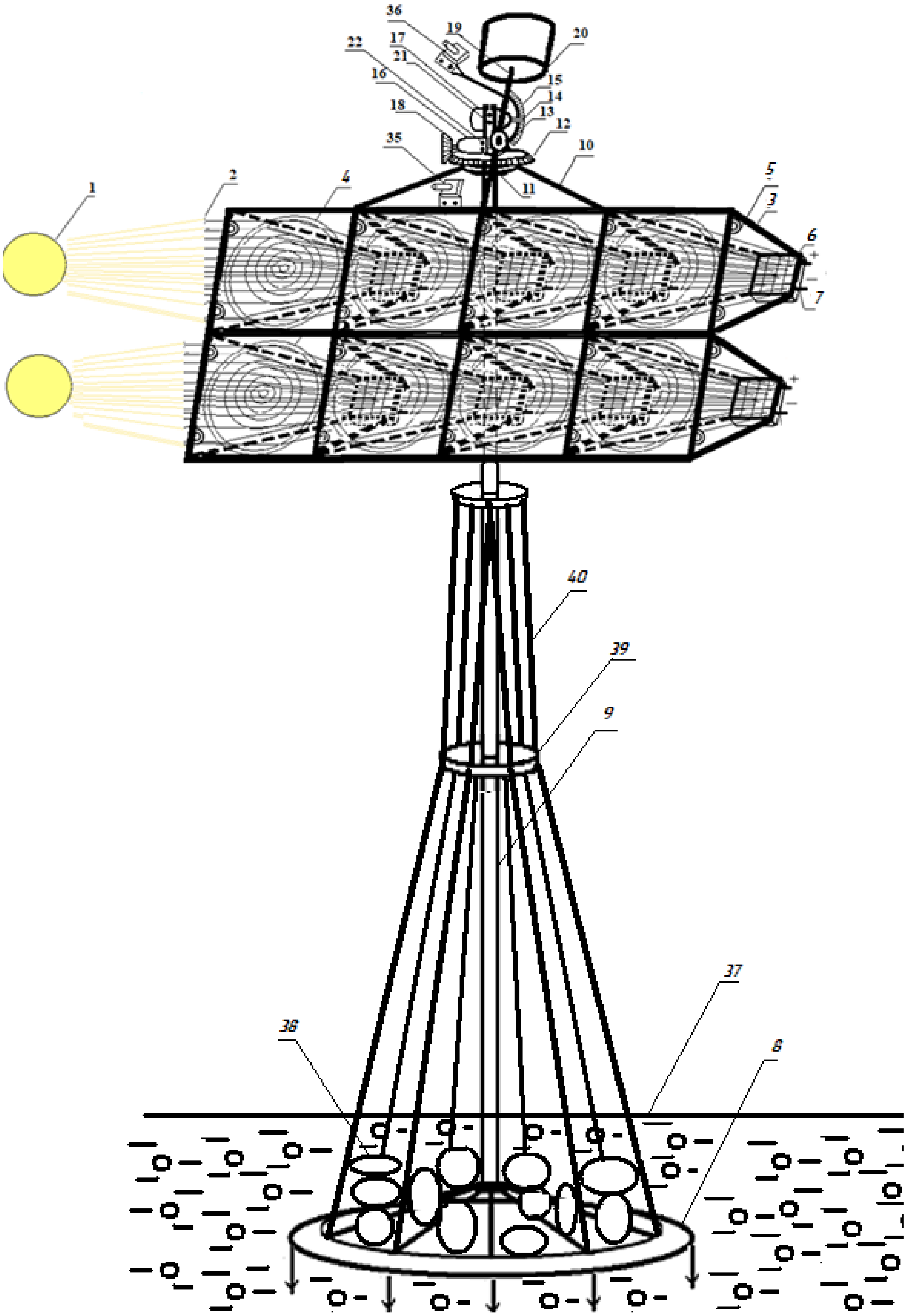

Figure 7. Design of a semiconductor solar panel with a light concentrator and sun-tracking system – developed based on the bionic principle of the sunflower.

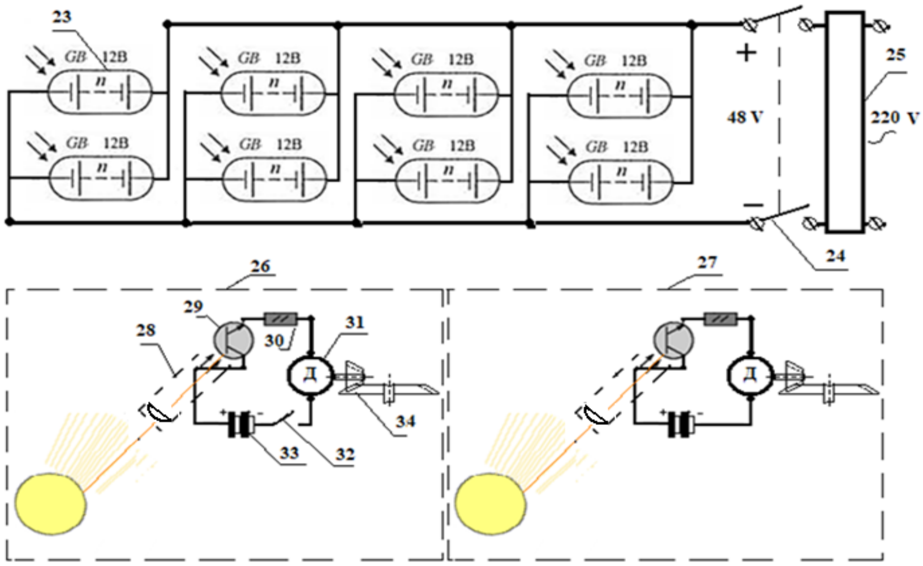

Figure 8. Electrical circuit of the semiconductor solar panel with a light concentrator and sun-tracking system.

The electrical circuit consists of (see Figure 8): semiconductor solar panel section (23), DC switch (24), AC converter (25), electronic block for horizontal frame rotation (26), electronic block for vertical frame rotation (27), tubes with lenses for horizontal and vertical solar beam direction (28), phototransistor (29), resistor (30), electric motor (31), switch (32), battery (33), gear transmission (34), housing of horizontal rotation block (35), and housing of vertical rotation block (36).

The semiconductor solar panel with a light concentrator and sun-tracking system increases the efficiency of each solar cell, improves solar energy conversion, raises the panel's voltage and power, and can be applied in systems tracking the sun's position.

The «Agrovoltaics» project allows optimizing land use by generating dual benefits from crops and environmentally clean electricity, which can be used for farm needs or sold. These panels are installed at a height sufficient to create favorable conditions for many agricultural crops, providing partial shade to protect them from excessive sunlight and drying.

Summary and conclusions

During our research, patents related to solar energy, particularly solar concentrators, were reviewed. It was determined that the bionic principle of the sunflower– «sun tracking», «branched roots», and various approaches to mounting semiconductor solar panels – demonstrates that implementing a sun-tracking system and using light concentrators increases the efficiency of semiconductor solar panels by up to 45%.

As a result of the design studies, a structure was proposed that enhances the efficiency (EEF) of semiconductor solar panels through the use of light concentrators and a sun-tracking system, outlining pathways for further efficiency improvements.

In future research, we will focus on further increasing the efficiency of semiconductor solar panels, their productivity, and serviceability, based on the bionic principle of sunflower «growth», i.e., a telescopic support system for raising and lowering the panel.

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