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# EXPERIMENTAL EVALUATION OF BIFACIAL PHOTOVOLTAIC MODULE PERFORMANCE UNDER REAL ENVIRONMENTAL CONDITIONS

N. R. Avezova<sup>1</sup>

A. A. Kuchkarov<sup>2</sup>,

A. A. Abduraimov<sup>3</sup>

DSc, Professor, Tashkent State Technical University, Tashkent, Uzbekistan<sup>1</sup>,

DSc, Professor, Department of Electronics and Instrumentation,

Fergana State Technical University Fergana, Uzbekistan<sup>1</sup>

PhD, Head of the department of Electronics and Instrumentation,

Department of Electronics and Instrumentation,

Fergana State Technical University, Fergana, Uzbekistan<sup>2</sup>

PhD Student, Department of Electronics and Instrumentation,

Fergana State Technical University, Fergana, Uzbekistan<sup>3</sup>

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## Abstract

An experimental study of the efficiency of bifacial photovoltaic modules was conducted in the climatic conditions of the Fergana Valley, characterized by high levels of solar insolation and moderate surface albedo. The aim of the study was to quantify the increase in electricity generation and determine the optimal panel tilt angle to improve the energy and economic efficiency of solar installations. Experimental measurements were performed on a SolarSpace SS8-72HD-585N bifacial module at installation angles of 30°, 35°, 40°, and 45°, in three operating modes: single-sided, double-sided, and with an insulated rear side. The results showed that at optimal angles of 30–40°, bifacial panels provide a 10–13% increase in daily energy generation compared to traditional single-sided modules. Increasing the tilt angle above 45° was found to reduce the proportion of reflected radiation and diminish the bifacial effect. A redistribution of the panel's thermal balance was also recorded: the temperature of the front surface in double-sided mode is 2–4 °C lower than that of monopanels, which contributes to the stabilization of operating efficiency. The obtained results confirm the high



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efficiency and feasibility of using bifacial systems in Uzbekistan's sunny climate. The experimental data developed can be used to refine energy efficiency models and design solar power plants, thereby reducing the lowest cost of electricity (LCOE) and achieving the Sustainable Development Goals (SDG 7 and SDG 13) in renewable energy.

**Keywords:** Bifacial photovoltaic modules, efficiency, cost of electricity, coefficient of performance.

## I. INTRODUCTION

Bifacial photovoltaic modules are capable of generating power from both the front and back of the panel. This design increases energy production per unit area by 5–30% in real-world conditions, and up to 30% under optimal conditions compared to conventional modules. Furthermore, bifacial panels make better use of diffused light and radiation reflected from surrounding surfaces. Experiments have shown that on cloudy days with low illumination, their relative generation is higher than that of monofacial modules. These advantages have driven an explosive growth in interest in bifacial photovoltaic systems (PVS) over the past decade. As technology improves and module costs fall, bifacial systems are rapidly moving from innovation to the new industry norm. According to forecasts from the International Technology Roadmap for Photovoltaics (ITRPV), the market share of bifacial solar cells could reach 85% by 2032 [1]. Today, large projects around the world are actively implementing bifacial panels, and the global market for bifacial modules is estimated to grow from \$92 billion in 2023 to \$187 billion by 2028 [2].

Unlike traditional monofacial modules, bifacial panels have a transparent rear surface (e.g. double glazing) and capture both direct solar radiation on the front side and light reflected from the surface (albedo) on the rear side. By summing the contributions of both sides (total power  $P_{\text{total}} = P_{\text{front}} + P_{\text{back}}$ ), significantly higher energy production is achieved: studies show an increase in annual generation of approximately 25–30%, and under optimal conditions (high surface albedo, sufficient installation height, and the use of trackers) – up to 30% or more [3]. The achievable gain significantly depends on the bifaciality coefficient of the



solar cells (for PERC approximately 0.70, the latest HJT – up to 0.92) and operating conditions. Increased energy production when using bifacial modules directly affects the economic indicators: the cost of electricity produced (LCOE) decreases and project profitability indicators (NPV, IRR) improve. Despite somewhat higher capital costs (double glazing, reinforced frames, and the occasional need for trackers), the financial impact of additional generation makes bifacial systems quite attractive. Large projects using bifacial panels have already been implemented (for example, the 1600 MW Benban solar park in Egypt), confirming their effectiveness [4]. Thus, examining the actual efficiency of bifacial photovoltaic modules depending on the climatic and actinometric parameters of a given location is relevant and important for improving the performance of solar power plants.

The subject of this paper is bifacial photovoltaic modules and solar systems based on them, capable of generating electricity from both the front and back of the panel. The subject of the study is the economic efficiency and performance of bifacial photovoltaic systems (increased output, reduced LCOE, increased NPV/IRR, and shorter payback period) compared to traditional single-sided modules under various operating conditions [5, 6].

## **II. METHODOLOGY**

Figure 1 shows the location and design of the experimental setup used in the experiment. The experimental studies were conducted on the campus of the Fergana State Technical University (Fergana, Fergana Region, Republic of Uzbekistan) at coordinates  $40.423925^{\circ}$  N,  $71.770538^{\circ}$  E. The site was open and free of shadows from trees, buildings, or other objects during daylight hours.

For the experiment, the setup was placed on a specially prepared site covered with a fine-grained crushed stone base. Figure 1 shows: a) the location of the experimental setup; b) the front view of the experimental setup; and c) the rear view of the experimental setup.



**Figure 1: a) location of the experimental setup, b) front view of the experimental setup, c) rear view of the**

A bifacial solar panel, model SolarSpace SS8-72HD-585N, was used as the primary photovoltaic module for the experimental studies. This module is a high-efficiency monocrystalline photovoltaic panel with a nominal power of 585 W. Table 1 below shows the main parameters of the solar panel under study.






**Table 1: Main characteristics of the SolarSpace SS8-72HD-585N panel.**

| Parameter                                | Value                   |
|--|-------------------------|
| Cell type                                | N-type TOPCon, bifacial |
| Number of cells                          | 144 (2×72)              |
| Nominal power (STC)                      | 585 ±3% W               |
| Maximum supply voltage                   | 44.61 V                 |
| Maximum power current                    | 13.12 A                 |
| Open circuit voltage                     | 54.36 ±3% V             |
| Short-circuit current                    | 13.76 ±3% A             |
| Efficiency                               | 22.45 %                 |
| Bifaciality factor                       | up to 80 %              |
| Operating temperature                    | from -40 to +85 °C      |
| Temperature coefficient P <sub>max</sub> | -0.30 %/°C              |
| Dimensions                               | 2278 × 1134 × 30 mm     |
| Weight                                   | ~32 kg                  |
| Certificates                             | IEC 61215, IEC 61730    |

Experimental studies were carried out on a single bifacial silicon PV module at various tilt angles relative to the horizontal (30°, 35°, 40°, and 45°). The panel was installed in an open area, simulating real-world operating conditions. For each module tilt angle, measurements were performed in three modes: (1) bifacial

open mode—both sides of the panel are open and participate in lasing; (2) monofacial mode (rear side closed)—the rear side is shielded by an opaque coating, simulating the operation of a conventional single-sided panel; (3) front closed mode—the front side is closed, and lasing occurs only due to illumination of the rear side (to assess the separate contribution of reflected radiation). In all cases, the panel was connected to measuring instruments under conditions close to the operating point of maximum power. Table 2 lists the main parameters of the measuring instruments used in the experiment, as well as their error values. The measuring equipment was selected based on the operating range of the photovoltaic system under study and the data recording accuracy requirements. The presented instruments provide reliable measurements of temperature, solar radiation, voltage, current, and other system performance characteristics. The specified error values allow for an assessment of the uncertainty of the obtained experimental data and ensure the accuracy of subsequent analysis of the results.

**Table 2: Characteristics of the measuring instruments used**

| Model   | Parameter             | Measurement range                                     | Accuracy                         | Image   |
|---|-----------------------|---|----------------------------------|---|
| Solar MPPT Meter UNI-T UT673PV                        | Max. Power            | 5 ~ 800 W   | ±(1,0%+10)                       |  |
|   | Max. current          | 0 ~ 35 A  | ±(1,5%+5)                        |   |
|   | Max. voltage          | 12 ~ 60 V   | ±(1,5%+5)                        |   |
|   | No-load current       | 12 ~ 60 V   | ±(1,5%+5)                        |   |
|   | Short-circuit current | 0 ~ 35 A  | ±(1,5%+5)                        |   |
| Solar Power Meter SM206                               | Solar radiation       | 0,1-399,9 W/m <sup>2</sup><br>1-3999 W/m <sup>2</sup> | ±10 W/m <sup>2</sup> or<br>±5%   |  |
| Portable thermal imager Hti HT-19                     | Temperature           | -20°C/+300°C  | ≤100°C ±2°C,<br>100-300°C<br>±2% |  |
| Digital thermometer TRM-10 (panel with remote sensor) | Temperature           | -50 ... +110 °C                                       | ±1 °C                            |  |
| (Anemometer GM816)                                    | Wind speed            | 0 ... 30 m/s  | ±5 %                             |  |



The experiment was conducted on a sunny summer day (03.06.2025) with a fixed panel orientation close to the optimal one (facing south). Measurements were taken from 8:00 to 18:00 with an interval of 1 hour. The recorded parameters included: time, ambient air temperature (degrees Celsius), temperature of the front surface of the panel and the back of the panel ( $^{\circ}\text{C}$ ), solar radiation (illuminance) on a horizontal surface,  $\text{W}/\text{m}^2$ , module output current (A), panel output voltage (V) and panel output electrical power (W), as well as wind speed (m/s) to account for the effect of cooling. Surface temperature was measured with thermocouples, solar radiation – with a pyrometer on a horizontal plane. Thermal insulation screens were installed on the back of the panel in mode (2), blocking light penetration. In mode (3), a similar screen was placed on the front side. Thus, in mode (2), the panel operated solely due to frontal illumination, and in mode (3), solely due to reflected light on the rear side. All other conditions (installation location, weather conditions, instruments) were identical for the three modes at a given tilt angle.

Before measurements began, the panel was exposed to sunlight to reach its thermal equilibrium. Control measurements at midday showed that, when operating on both sides, the temperatures of the front and rear surfaces were similar (within  $2\text{--}4^{\circ}\text{C}$  of each other), while in single-facial mode, the closed rear side slightly reduced the panel's heat output. Weather conditions remained clear throughout the day. The maximum recorded solar radiation reached  $\sim 1080 \text{ W}/\text{m}^2$  (around midday). The reflectivity of the ground surface at the experiment site was estimated to be average (soil and vegetation, albedo of approximately  $0.2\text{--}0.25$ ). The resulting experimental data were processed for each tilt angle: the total daily energy production in kWh was calculated, as well as the relative gain from the rear side

## **V. EXPERIMENTAL RESULTS**

Table 3 presents the average daily electrical energy production of the PV module for various panel installation angles and operating modes. A monopanel is considered to be a mode with a closed rear side (only front generation), a bifacial mode is one with both sides open, and for reference, the energy obtained only from the rear side (with the front side closed) is shown. It is evident that at angles



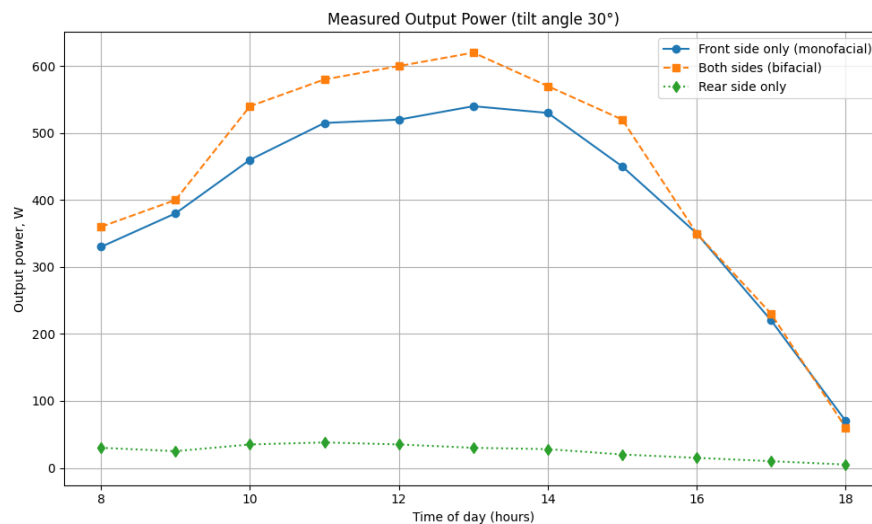
of 30–40°, a bifacial module generates ~12–13% more energy per day than a similar single-sided module under the same conditions. Thus, at an inclination of 30°, daily generation increased from ~4.28 kW h (single-sided) to ~4.82 kW h (bifacial), which corresponds to an increase of approximately 12.8%. At 35° and 40°, the increase was ~12%. However, at a steeper angle of 45°, additional generation was significantly lower – approximately 4–5%. This is due to the lighting geometry: when the panel is tilted significantly, its rear side receives less reflected light during midday hours (when solar radiation is at its highest), and the contribution of rear generation is compensated by partial shading of the front side in the afternoon. (The data were obtained by integrating the power from 8:00 a.m. to 6:00 p.m. on a clear day. Bifacial growth was calculated relative to the monofacial mode.).

Its analysis shows a varied information level on the processed images. In figure 2a, all wet vegetation is shown in red graduation with little distinction of vegetation. The image in figure 2b provides better visualization of vegetation plants formations that are drawn in several graduations of green. Figure 2c representing the vegetation index, tones sink areas covered and the clear bare soil are remarkable. Figure 2d shows the different strata herbaceous, shrub and tree vegetation. In figure 2e (72 bit images), we can easily distinguish different plants vegetation formations like the image in figure 2b (24 bits), but the importance of contrast, the limitations are more obvious. It is therefore more suitable for this study because the representation of vegetation are made in green and levels rose bare soil.

**Table 3. Comparison of daily energy production of a two-sided panel with a one-sided mode at different installation angles.**

| Panel tilt angle, ° | Output (one-side mode), kW·h | Output (double-sided mode), kW·h | Double-sided growth, % | Output from the rear side only, kW·h |
|---------------------|------------------------------|----------------------------------|------------------------|--------------------------------------|
| 30                  | 4,28                         | 4,82                             | +12,8%                 | 0,25                                 |
| 35                  | 4,18                         | 4,69                             | +12,2%                 | 0,26                                 |
| 40                  | 4,03                         | 4,55                             | +12,7%                 | 0,26                                 |
| 45                  | 4,03                         | 4,21                             | +4,3%                  | 0,25                                 |

As can be seen from Table 3, the absolute contribution of the rear side (the "rear side only" column) was relatively small in all tests – approximately 0.25 kWh per day. However, in bifacial mode, this energy is combined with the frontal generation, increasing the overall module output. The best effect was observed at angles of 30–40°, where the total increase reached ~0.5 kWh per day per module (~12%). The minimal effect was at 45°, where the additional energy amounted to only ~0.18 kWh (~4%).



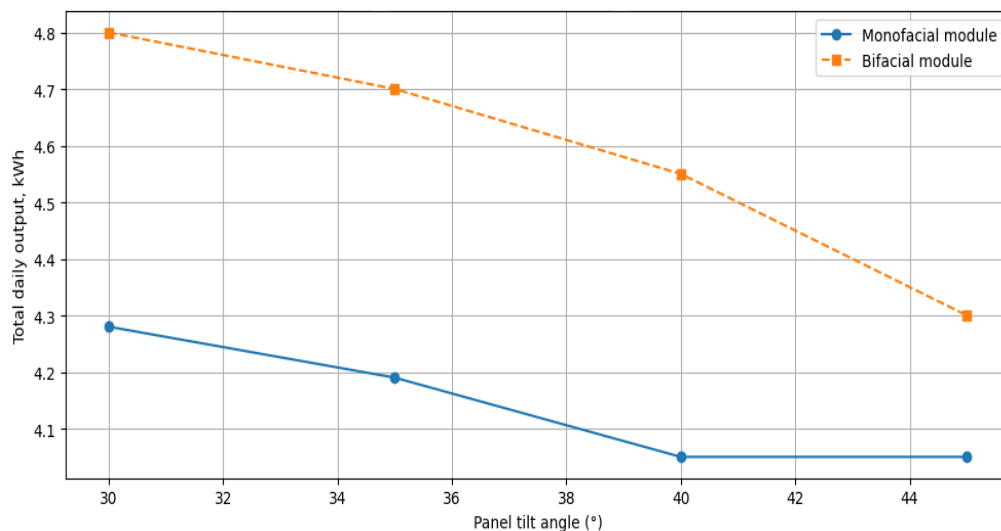
**Figure 2. Daily dependences of the module output power at an angle of 30° for different conditions: single-sided operation (only the front side is active), double-sided operation (both sides generate) and only the rear side.**

For illustration purposes, Fig. 2 shows typical daily dependences of the panel power (angle of 30°) in three modes: single-sided (rear side closed), double-sided, and only due to the rear side. It is evident that in the morning and evening hours (8:00–9:00 and after 16:00), the output power of the panel in double-sided mode only slightly exceeds that of the mono-panel – during these periods, the angle of incidence of the sun's rays is small, and the radiation reflected from the ground is also small. The main gain is observed around midday: for example, at 12:00 for an angle of 30°, the double-sided panel produced ~592 W versus ~516 W for the single-sided panel (an increase of ~15%), and at 13:00 – 619 W versus 477 W (an increase of ~30%, see Fig. 2). These moments correspond to high solar radiation and, apparently, an optimal ratio of direct and reflected light. The power received from the rear side alone is significantly less than the front side throughout the day



(maximum about 32 watts at midday at 30°C) – the curve with pink markers in Figure 1 is at the bottom of the graph. However, even a few dozen additional watts during peak sun hours provides the aforementioned double-digit percentage increase in energy.

To summarize the results, Figure 3 shows how the total daily generation (energy from 8:00–18:00) changes in bifacial and single-sided modes depending on the panel tilt angle. The orange solid line corresponds to the traditional module (generation only from the front side), and the red dotted line corresponds to the bifacial module. It is clear that when moving from 30° to 40°, daily generation decreases for both bifacial and single-sided modes (which is natural, since increasing the tilt angle reduces the projection of the panel onto the horizontal plane). However, the curves for bifacial and single-sided panels are not parallel: the gap between them reaches a maximum at 30–35° and narrows at 45°. In other words, the relative gain of the bifacial panel is greatest at a moderate tilt and decreases at an excessively large tilt. On the graph at 30° the distance between the lines corresponds to an increase of ~0.54 kW h, and at 45° – only ~0.18 kW h, which is consistent with Table 1.



**Figure 3. Comparison of daily energy production of bifacial and single-facing PV modules depending on the tilt angle. The data was obtained by integrating the experimental power curves over the course of a day.**



Temperature effects: panel surface temperatures were also recorded during the experiment. It was noted that in bifacial mode, the front side of the panel had a slightly lower temperature compared to the monopanel. For example, at 30°C at midday, the front surface temperature was ~60°C in bifacial mode versus ~66°C in single-sided mode. This can be explained by the fact that some of the solar energy is removed through the rear side (photons are not absorbed by the front cell, but pass through the panel). In addition, the absence of a rear insulating layer contributes to better cooling. The rear side, on the contrary, in bifacial mode heated up more (up to ~64°C) compared to the closed rear side of the monopanel (~55–58°C), since it absorbed reflected radiation. As a result, the overall thermal balance of the bifacial module is approximately equal to that of the monopanel, but the temperature field is distributed differently. These nuances are important, since the efficiency of silicon elements decreases with overheating; The dual-sided design can slightly reduce overheating of the front cells by redistributing some of the heat load to the rear cells. In our experiment, the difference in operating temperatures did not exceed 5–8°C, which had a negligible impact on power output.

#### **IV. DISCUSSIONS**

The obtained results confirm that bifacial photovoltaic panels can increase energy production compared to traditional single-sided panels. Experimentally, under moderate conditions (albedo of ~0.2 and installation height of approximately tens of centimeters), we achieved an increase of approximately 10–13%. This corresponds to the lower limit noted in the literature: for example, Ghafiri et al. report an improvement in production of ~25–30% for bifacial modules [10], and Johnson & Manikandan obtained an annual increase of 30.5–34.9% for different climatic zones of India [11]. Our more modest values are explained by the absence of special optimization measures, such as a highly reflective surface or a tracking system. The gain from the rear side is known to be sensitive to external factors. With high ground albedo (e.g., snow, white membrane) and optimal panel placement (large ground clearance, use of single-link or dual-axis trackers), a bifacial module can realize its full potential. Specifically, NREL calculations for panels on single-axis trackers yielded an energy gain of ~6–9% (for PERC and



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HJT cells, respectively) compared to conventional modules, while for fixed installations without special reflectors, the gain is typically a few percent. With low albedo or in severely shaded conditions, the gain can approach zero [9]. Our experiment at a 45° tilt actually demonstrates a case close to this: the rear side received little reflected light at midday (when the main generation comes from the front side), and in the morning and evening the sun was too low to effectively illuminate the front surface. As a result, the additional energy amounted to only ~4%, i.e., within the margin of error under certain circumstances. The data are consistent with the conclusion that without favorable conditions (reflector, optimal angle), a double-sided panel can perform almost like a single-sided one. The influence of tilt angle on the efficiency of a bifacial system should be noted. Our results (Fig. 3) indicate that the relative gain is greatest at moderate tilt angles – 30–35°. At smaller tilt angles (close to horizontal), the rear side faces primarily the ground and receives a significant amount of reflected light, but the front side is less exposed to direct sunlight. At larger tilt angles (close to vertical), the opposite is true: the front side performs better in the morning/afternoon, but the rear side receives little other than diffused light. Thus, there is a certain optimum tilt angle for bifacial panels, depending on geography and albedo. Literature suggests that in high-latitude conditions, vertically installed bifacial modules or special "comb" designs, where parts of the array are tilted at different angles, are promising. Such designs capture diffused light in the morning/evening hours and in winter, when the sun is low, increasing overall energy output. Our experiments were limited to relatively large angles (30–45°), typical for summer optimization; in winter conditions, the bifacial effect would likely be different (higher at larger angles). This demonstrates the need to consider seasonal and geographic factors when designing bifacial photovoltaic systems.

Albedo and the surface beneath the modules. The additional energy gained from the rear side is directly proportional to the reflectivity beneath the panels. Several sources note the key role of albedo: for example, installing reflective screens or choosing a light-colored ground surface can significantly increase the efficiency of bifacial modules. In our experiments, the ground surface was normal; one would expect a significantly greater gain against a snow or white background. The practical conclusion is that to realize the full potential of bivalent panels,



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consideration should be given to the surface material beneath them. In desert conditions, for example, the natural reflectivity of sand is relatively low, but projects have shown LCOEs below 4¢/kWh using bifacial tracker systems, meaning the bifacial effect pays off even with moderate albedo.

Temperature and cooling. As noted, bifacial modules have design differences (double-glazed windows instead of a backsheet), which somewhat impacts heat transfer. Many studies record slightly higher operating temperatures for bifacial panels due to reduced heat dissipation through the glass, but in our data, the difference is small (on the order of a few degrees). In real-world conditions, wind and convection play a significant role: the open backside receives more airflow, partially offsetting the heat. An increase in element temperature leads to a decrease in efficiency (~0.4–0.5% per °C for silicon), so it is important to position the panels so that both sides are well cooled by airflow. Our measurements at wind speeds of 1–3 m/s show acceptable thermal conditions even without specialized cooling.

Finally, we note that our results are consistent with the general trend: bifacial panels demonstrate greater efficiency. Numerous independent tests and calculations confirm the advantages of bifacial technology in virtually all climate zones. A direct comparison with monofacial panels under identical conditions, as in our experiment, clearly demonstrates the gain in power generation. While it may not always reach the stated 30%, even a 10–15% increase is a significant effect, especially at the scale of a power plant of tens of megawatts. This increase leads to a reduction in the specific energy cost and an increase in the project's financial return

## **V. CONCLUSION**

1. Bifacial photovoltaic panels provide increased power generation compared to traditional single-facing modules. In our experiments, the increase was ~10–13% at optimal tilt angles (30–40°) and average reflectivity. This is consistent with published data, which indicate increases of approximately 20–30% under favorable conditions.

2. The contribution of the rear side depends on the installation angle and albedo. At moderate tilt angles (around 30°), the rear side most effectively captures



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reflected light, providing a gain of >10%. At extremely steep angles (45° or more), the additional generation decreases (in our case, to ~4–5%). Low surface reflectivity or shading can also practically negate the effect of bifaciality. To maximize the output of bifacial modules, it is recommended to use surfaces with high albedo (light-colored gravel, paint, snow) and optimize the installation angle/height. In high-latitude regions, it is useful to consider vertical or combined module installations to utilize rear generation during the morning and evening hours.

3. The thermal performance of bifacial modules does not undergo any significant changes, although the temperature distribution differs from that of monopanels. A bifacial module dissipates some of the absorbed energy through its rear side, which may slightly reduce the heating of the front cells. Our measurements showed only a slight (2–4°C) decrease in the front surface temperature in bifacial mode. Therefore, concerns about possible overheating of bifacial panels were not confirmed; with normal ventilation (wind speed of 1–3 m/s), the temperature factor does not significantly reduce their efficiency. However, the slightly higher thermal response of bifacial modules due to the glass substrate should be taken into account during design.

4. Practical recommendations. When using bifacial panels, it is important to ensure minimal shading of the rear side and sufficient space for reflected radiation. The distance between rows of panels should be greater than for conventional modules to avoid "shielding" reflected light from adjacent rows. Using a light-colored ground or floor covering under the modules is recommended—this can increase output by several percent without significant cost. Another promising solution is the use of single-axis trackers, which increase the total angle of incidence of light on the panel throughout the day: the combined use of trackers and bifacial modules has already demonstrated record-low LCOEs of approximately 3–4¢/kWh in a number of projects.

5. Prospects and economic impact. Bifacial technologies are making a significant contribution to reducing the cost of solar energy. Increased generation results in lower LCOE and accelerated payback – it is estimated that the additional CAPEX for bifacial modules pays for itself if it does not exceed ~10% of the plant cost. Current developments are aimed at reducing the cost of bifacial cells and



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optimizing system designs. The bifacial efficiency is expected to increase to ~95% for new technologies, further reducing the gap between front- and rear-facing generation. Further research will focus on collecting field data on the performance of bifacial panels in different climatic conditions, including as part of agrophotovoltaic systems (combined with agriculture) and BIPV (building-integrated photovoltaic) systems. Bifacial photovoltaic systems have already proven themselves to be an effective solution, and it is expected that as technology costs decrease, they will increasingly occupy a significant share of the solar energy mix of the future.

Overall, bifacial photovoltaic modules offer significant potential for improving the economic performance of solar power plants. Numerous studies confirm the potential for tangible economic benefits from their use—for example, increased electricity generation leads to increased net present value and internal rate of return [8], as well as a reduction in the specific cost of generated energy [7]. However, widespread adoption of this technology requires further reductions in the cost of bifacial module production, the accumulation of statistical data from real installations, and the development of standard design and operating methods. With proper consideration of all factors (optimal system design, shading prevention, and scheduled maintenance), bifacial technology could become an important component of future solar power plants.

The use of bifacial systems in Uzbekistan, characterized by high solar insolation and a dusty climate, deserves special consideration. Large projects using bifacial modules with trackers are already underway—for example, a 100-MW solar power plant under construction in the Samarkand region is equipped with bifacial panels with automated trackers. Operation of such plants demonstrates that regular dust cleaning of the panels is crucial for efficiency in arid regions. According to the Ministry of Energy, maintaining panel efficiency requires approximately 0.6 liters of water per module per wash. Cleaning frequency depends on dust levels: for example, at a solar power plant in the Samarkand region, washing the panels approximately twice a year is sufficient, whereas in the dustier Navoi region, this procedure is required approximately twice a month. Despite additional maintenance costs, the increased output from bifacial panels often outweighs these costs, especially for large-scale installations. Promising



applications for bifacial modules in Uzbekistan include agriculture, industry, and distributed generation. In the Fergana Valley, an agricultural region with high solar radiation, bifacial photovoltaic systems can be effectively used in agrophotovoltaics (solar installations over farmland). Panels placed over fields or canals generate electricity on one side, while transmitting diffused light on the other, partially shading crops, reducing evaporation. At the same time, the light reflected from the soil and plants is used by the rear side of the modules, increasing generation. Industrial enterprises in the region can use bifacial solar power systems for their own needs, installing panels over large areas with reflective surfaces or on the roofs and facades of buildings. Therefore, given the climatic conditions of Uzbekistan (including the Fergana Valley), the implementation of bifacial photovoltaic systems has the potential to significantly improve the efficiency of solar energy in various regions of the country, ensuring lower energy costs and a high return on investment.

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