**Performance Analysis of a 100-kW Grid-Connected Solar Photovoltaic System at Andijan State Technical Institute**

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**Abstract.** This article analyzes the effectiveness and operational performance of a 100kW grid-connected solar photovoltaic system located at the Faculty of Electrical Engineering, Andijan State Technical Institute. The study was conducted in January-December 2024, and it was found that the total electricity generated by the system during the year was 96,974.04 kWh. The annual average intensity of solar radiation in the Andijan region is around 1600–1700 kWh/m², and it was observed that these indicators had a significant impact on the energy production process.  
The results of the study showed the impact of factors such as seasonal changes, cloudiness, air temperature and dust on the efficiency of the system. For example, while maximum capacity was achieved in the summer months, production decreased significantly in the winter months. The ecological effects of the energy generated by the system were also examined, and it was found that it made a positive contribution to environmental sustainability through the reduction of carbon dioxide (CO₂) emissions.  
While this system was able to cover 25–30% of the institute's electricity demand, a number of proposals were made to improve its efficiency, including measures to ensure module cleanliness, increase inverter efficiency, and install it at an optimal angle. The results of this study provide important recommendations for improving the technical and economic efficiency of solar photovoltaic systems.

**Keywords:** Photovoltaic solar system, energy efficiency, economic assessment, environmental effects, Andijan

**INTRODUCTION**

The electricity production industry in the Republic of Uzbekistan has a significant impact on the nation's social and economic progress. Today, the energy sector is undergoing significant changes in terms of production volume and technological modernization. As of 2023, thermal power plants accounted for the majority of electricity production, providing 86% of the total output. Renewable energy sources accounted for 14%, with the majority generated by hydroelectric power plants. The proportion of wind and solar energy is steadily rising.

The Republic of Uzbekistan is implementing strategic initiatives aimed at expanding the adoption of renewable energy sources. Specifically, in accordance with Presidential Decree PQ-103 dated March 9, 2023, and the 'Green Energy' strategy, the country plans to construct solar and wind power stations with a combined capacity of 12,000 MW by the year 2030. In line with these directives, the development of modern solar power facilities has been accelerated in the Andijan region and beyond. As an example, a 100kW solar photovoltaic system was installed on the premises of the Andijan State Technical Institute

**Dynamics of Electricity Production Volume**

Between 2016 and 2023, the volume of electricity production in the Republic of Uzbekistan has shown steady growth. In 2016, the production level was 59.0 billion kWh, and by 2023, it had reached 78.0 billion kWh. During this period, the average annual growth rate was 3.9%. The increase in electricity demand is associated with industrial development, population growth, and the modernization of energy infrastructure [1].

**Forecast for the Next 10 Years**

Uzbekistan’s electricity generation is anticipated to steadily increase in the coming years. By 2033, it is forecasted to reach 115.2 billion kWh. This upward trend will be supported by a growing share of renewable energy, the adoption of advanced technologies, and the execution of energy efficiency enhancement programs. In 2024, electricity output is expected to total 81.1 billion kWh

**TABLE 1.** **Dynamics of Electricity Production Volume**

|  |  |  |
| --- | --- | --- |
| **Years** | **Production Volume (billion kWh)** | **Annual Growth Rate (%)** |
| 2016 | 59,0 | - |
| 2017 | 60,7 | 2,88 |
| 2018 | 62,8 | 3,46 |
| 2019 | 63,6 | 1,27 |
| 2020 | 66,4 | 4,40 |
| 2021 | 71,3 | 7,38 |
| 2022 | 74,3 | 4,21 |
| 2023 | 78,0 | 4,98 |

**TABLE 2.** Forecast for the Next 10 Years

|  |  |
| --- | --- |
| **Years** | **Projected Production Volume  (billion kWh)** |
| 2024 | 81,1 |
| 2025 | 84,3 |
| 2026 | 87,7 |
| 2027 | 91,2 |
| 2028 | 94,8 |
| 2029 | 98,6 |
| 2030 | 102,5 |
| 2031 | 106,6 |
| 2032 | 110,8 |

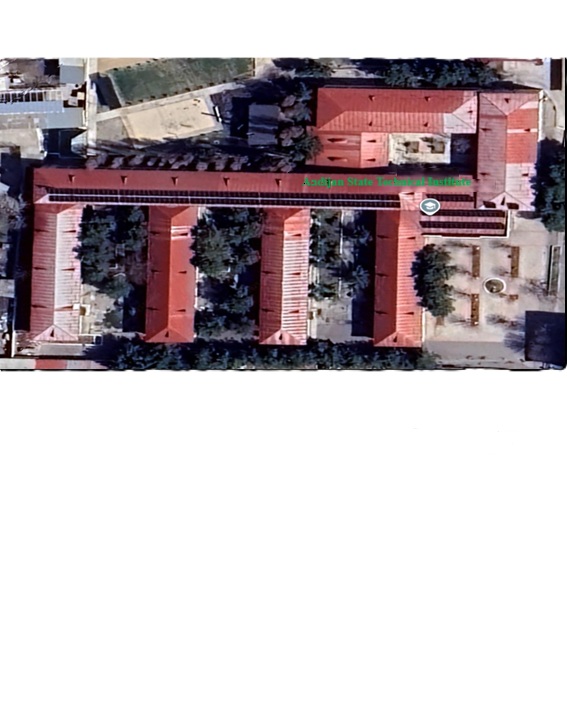
**METHODOLOGY**

The Andijan state technical Institute is located near the center of Andijan city, situated in the southeastern part of Uzbekistan, in the southern region of the Fergana Valley. Geographically, this area is one of the important economic and cultural centers of Uzbekistan. The precise geographical co ordinates of the institute are:

* Latitude: 40.2500° N
* Longitude: 72.3500° E

The altitude of Andijan city is approximately between 400 and 500 meters above sea level, creating favorable geological and climatic conditions for efficient use of solar energy. Located in the middle elevation zone of the Fergana Valley, Andijan experiences a relatively warm and sunny climate throughout the year. These factors establish an enabling environment for harnessing renewable energy, with a focus on solar energy. The geographic location also natural resources of the Andijan region play a significant role in implementing the institute’s projects aimed at improving energy efficiency and environmental sustainability. Moreover, the favorable location of this area offers unique opportunities for the development of solar energy in line with Uzbekistan’s energy strategy.

**Description of the Solar Photovoltaic System**



**FIGURE 1.** Geographic location of the Faculty of Electrical Engineering, Andijan State Technical Institute (Google Earth, 2025)



**FIGURE 2.** Solar power plant installed at the Faculty of Electrical Engineering, Andijan State Technical Institute

**Data Collection and Monitoring: Customized Analysis for Andijan state technical Institute**

A scientifically grounded data acquisition and monitoring system has been established to assess the performance of the solar photovoltaic system installed at the Andijan Institute of Mechanical Engineering. This setup allows for real-time tracking of solar irradiance, ambient temperature, and the system’s output power.

Information on solar radiation and temperature was sourced from the NASA Surface Solar Energy (NASA-SSE) database, with accurate data gathered according to the institute’s geographic coordinates — 40.7824° North latitude and 72.3445° East longitude. The monitoring system collects data from solar inverters and the local grid, transmitting it to central servers. This process is remotely managed in real-time and monitored via the SOLARMAN Smart online platforms [2].

The monitoring system enables the assessment of the solar photovoltaic system’s efficiency on an hourly, daily, monthly, and annual basis. The collected data is utilized to analyze both technical and financial performance metrics

**TABLE 3.** Specifications of the Current System

|  |  |
| --- | --- |
| **Notation** | Solar power system mounted on the rooftop **of Anadijan state technical institute** |
| Power | 100 kW |
| Total Area | 615m2 |
| Tracking system with single-axis or dual-axis movement | Absence of tracking system |
| Inclination Angle | 30°-32° SW 208° |
| Installation Type | Cremini monocrystal |
| Quantity of Inverters | 2 |
| Total Modules | 185 |
| Photovoltaic Panel Surface Area | |

**YEARLY PERFORMANCE OF THE SOLAR PHOTOVOLTAIC SYSTEM, CLIMATIC CONDITIONS, AND ADJUSTED PAYBACK PERIOD**

**Annual Efficiency Degradation**

The efficiency of solar photovoltaic systems naturally decreases annually. This decline is primarily related to the degradation level of the solar panels and typically ranges between 0.5% and 1% per year. In this analysis, an annual efficiency degradation rate of 1% is assumed.

In 2023, the newly commissioned 100 kW solar power plant at the Andijan Institute of Mechanical Engineering produced an initial annual energy output of 96,974.04 kWh. Taking into account the efficiency degradation, the annual energy production decreases as follows:

t (1)

where: — initial annual energy production; d=0,01— annual efficiency degradation (1%); t — project duration in years (t=1, 2...25).

**Weather Conditions Forecast**

Solar radiation in the Andijan region varies throughout the year. The production significantly differs due to fewer sunny days in winter and higher radiation in summer. According to NASA-SSE data, Andijan experiences an average of about 2,800 hours of sunshine annually. Currently, the annual reduction in production volume is estimated solely based on efficiency degradation without considering variability in sunny days [3].

**Total Energy Produced**

The total energy produced over 25 years (ETE\_TET​) is calculated using the following formula:

(2)

**CALCULATION RESULTS**

**Recalculated Payback Period**

The payback period (SPP — Simple Payback Period) is determined by taking into account the annual efficiency degradation. The annual income of the project is calculated as:

CFt=Et⋅P (3)

where: P — price of energy supply; Et — annual electricity production (kWh).

The initial investment cost IC0 is recovered over the years through income, and the payback period is defined by the formula:

(4)

**RESULTS AND DISCUSSION**

The 100kW grid-connected solar photovoltaic system installed at the Faculty of Electrical Engineering, Andijan Institute of Mechanical Engineering, generated a total of 96,974.04 kWh of electricity in 2024 (see Fig. 3). This system was deployed to help fulfill part of the institute’s electricity needs by utilizing renewable energy sources and to minimize adverse environmental effects.

**FIGURE 3.**  Electricity generated in 2024 by the 100kW grid-connected solar photovoltaic system installed at the   
Faculty of Electrical Engineering, Andijan State Technical Institute

Andijan city ranks among the sunniest areas in Uzbekistan, experiencing notable fluctuations in solar radiation and temperature throughout the year. These fluctuations have a direct impact on the performance of solar photovoltaic systems. Below is an analysis of the monthly variations in temperature and solar radiation based on 2024 data.

In 2024, the average monthly temperature in Andijan is projected to vary as follows:

* **Winter (January–February):** Temperatures range from -2°C to +4°C, accompanied by low solar radiation levels of 60–80 kWh/m².
* **Spring (March–May):** Temperatures increase from +10°C up to +22°C, with moderate solar radiation between 120–160 kWh/m².
* **Summer (June–August):** Temperatures peak at around +32°C, while solar radiation reaches its highest levels, ranging from 180 to 210 kWh/m².
* **Autumn (September–November):** Temperatures gradually decline from +25°C to +10°C, with solar radiation varying between 100 and 150 kWh/m².
* **December:** Temperatures stabilize near +3°C, and solar radiation decreases again to 70–90 kWh/m².

Solar radiation attains its maximum value in June, exceeding 200 kWh/m². Radiation levels remain relatively stable and moderately high during spring and autumn. Conversely, during winter months, reduced solar radiation leads to a decline in solar panel output efficiency.

The performance of solar photovoltaic systems is influenced by both ambient temperature and solar radiation. Although Andijan experiences high temperatures in summer that boost maximum solar radiation and energy generation, excessive heat can sometimes slightly reduce panel efficiency. During winter, the low solar radiation results in minimal energy production [4].

**FIGURE 4.** Monthly Variations of Ambient Temperature and Solar Radiation in Andijan for 2024

A 100kW solar photovoltaic system was commissioned in 2023 at the Andijan Machine-Building Institute. The system was implemented to help fulfill part of the institute’s electricity demand and to encourage the adoption of eco-friendly energy sources.

Among the main advantages of solar photovoltaic systems are stable electricity generation, environmental friendliness, and long-term economic efficiency. The electricity output and efficiency of the system are strongly influenced by natural factors like ambient temperature and solar radiation in Andijan.

In 2024, the system generated an average of 96,974.04 kWh of electricity, though this figure can vary depending on weather conditions and the technical characteristics of the system. The system’s efficiency decreases over time due to an annual 0.5% reduction in the useful performance coefficient.

Considering Uzbekistan’s electricity consumption and its tiered tariff structure, the value of electricity produced by the solar photovoltaic system is evaluated at various rates. This project is vital for promoting the future expansion of sustainable energy sources

This system represents a significant milestone in Uzbekistan’s green energy transition strategy, contributing to the reduction of carbon emissions and the diversification of energy sources. The example set by this system in Andijan illustrates the potential for implementing similar eco-friendly energy projects in other institutions

In 2024, the system produced 96 974,04 kWh of electricity. The value of the energy produced by the solar panels was calculated according to Uzbekistan’s tiered tariffs:

**2024 tariff rates and revenue**

For monthly energy production up to 10,000 kWh, the following tariffs were applied:

450 UZS/kWh (up to 200 kWh)  
900 UZS/kWh (201–1,000 kWh)  
1,350 UZS/kWh (1,001–5,000 kWh)  
1,575 UZS/kWh (5,001–10,000 kWh)  
1,800 UZS/kWh (above 10,000 kWh)

The total annual revenue according to these tariffs amounted to 140 648 400 UZS.

**Tariff rates starting from April 1, 2025**

New tariffs for monthly energy production:

600 UZS/kWh (up to 200 kWh)  
1,000 UZS/kWh (201–1,000 kWh)  
1,500 UZS/kWh (1,001–5,000 kWh)  
1,750 UZS/kWh (5,001–10,000 kWh)  
2,000 UZS/kWh (above 10,000 kWh)

According to the new tariffs, the estimated annual revenue is approximately 155 000 000 UZS.

**Payback Period**

Taking into account the total construction cost of the solar power plant (1 billion UZS) and the annual income, the payback period of the system is as follows:

* Based on 2024 revenues: 1,000,000,000 ÷ 140,648,400 ≈ 7.1 years
* Based on 2025 tariffs: 1,000,000,000 ÷ 155,000,000 ≈ 6.5 years

The costs of the monitoring system and technical maintenance are minimal and do not significantly affect the income.

**Efficiency Decline and Its Impact**

Solar panels experience an annual efficiency decline of 0.5–1%. After a decade, their output capacity typically remains around 90–95%. This can affect economic efficiency. However, a 10-year analysis shows that the plant will fully recoup its cost and generate additional income.

**EVALUATION AND ANALYSIS OF FINANCIAL AND ECONOMIC METRICS**

Several essential financial and economic indicators are taken into account to assess the economic efficiency of solar photovoltaic systems. The following formulas and analytical methods were applied for this system:

1. **Payback Period**

The payback period represents the time required for the project’s initial investment to be recovered through generated revenues. The formula to calculate this indicator is:

(5)

where: T— payback period (years); I — initial investment amount (UZS); A — annual net income (UZS).

For example:

* Initial investment for the solar power plant I=1 000 000 000 UZS
* Annual income A=140 648 400 UZS (according to 2024 tariffs)

**Payback Period:**

(6)

According to the new tariffs of 2025, income increases to A=155 000 000 UZS. In this case:

(7)

1. **Net Present Value (NPV):**

Net Present Value calculates the present-day value of anticipated future cash flows by applying a discount rate. The formula is:

(8)

where: Rt - t — income in year; r — discount rate (annual percentage); t — time period (years); n — project duration (years); I — initial investment amount.

1. **Internal Rate of Return (IRR)**

The Internal Rate of Return (IRR) is a metric used to evaluate the profitability of a project. It is found by identifying the discount rate that reduces the Net Present Value (NPV) to zero:

(9)

A project is deemed economically viable if its IRR exceeds the discount rate.

1. **Revenues and Operating Costs**

Project revenues are calculated based on the value of the electricity produced by the solar power plant. Tiered tariffs are applied according to the following formula:

(10)

where: D — total annual revenue (UZS); Ei — amount of energy at tariff iii (kWh); Ti — price per tariff (UZS/kWh); m — number of tariff levels.

In 2024, 96 974,04 kWh of energy was produced and calculated based on tiered tariffs, resulting in an annual revenue of 140 648 400 UZS.

From 2025 onwards, with new tariffs:

(11)

The calculation resulted in revenue increasing to 155 000 000 UZS.

**5. Efficiency Degradation**

Solar panels lose efficiency year by year. The annual degradation rate is usually between 0.5% and 1%. The production capacity of solar panels PtP in year t is calculated using the formula:

t (12)

where: Pt - t — production capacity in year ttt (kWh); P0 — initial production capacity (kWh); d — annual degradation rate (as a decimal); t — time (years).

Given the initial production capacity P0=96 974,04 kWh and an annual degradation rate of d=1%, we calculate:

P10=96,974.04⋅(1−0.01)10≈87,320kVt-h. (12)

This decrease also reduces the revenue over time.

**ANNUAL EFFICIENCY, WEATHER CONDITIONS, AND RECALCULATED PAYBACK PERIOD OF THE SOLAR PHOTOVOLTAIC SYSTEM**

**Annual Decrease in Performance Ratio**

The performance of solar photovoltaic systems declines annually, primarily because of solar panel degradation, usually between 0.5% and 1% each year. In this analysis, the annual efficiency decrease is assumed to be 1% [5, 6, 7, 8].

The initial annual energy production of the 100kW solar power plant commissioned in 2023 at Andijan Machine-Building Institute was EA=96 974,04 kWh. Taking into account the decrease in performance ratio, the annual energy production decreases as follows:

t (13)

where: — initial annual energy production (96 974,04 kWh); d=0.01 — annual efficiency degradation (1%);   
t — project duration (years, t=1, 2, …,25).

**Weather Conditions Forecast**

Solar radiation in the Andijan region varies throughout the year. During winter, fewer sunny days and during summer, higher radiation cause significant fluctuations in production. According to NASA-SSE data, the Andijan region experiences an average of 2800 sunny hours annually. Currently, the decline in annual production volume is mainly assessed based on efficiency degradation without considering stability of sunny days.

**Total Energy Produced**

The total energy produced over 25 years (ET) is calculated by the formula:

(14)

The calculation result is approximately:

ET≈2 085 152 kWh

**Recalculated Payback Period**

The payback period is recalculated taking into account the annual decrease in efficiency. The annual revenue of the project is calculated as:

CFt=Et⋅P (15)

where: P=0.081 USD/kWh — electricity selling price; Et— annual electricity production (kWh).

With an initial investment cost IC0=1 000 000 000 UZS, the payback period, defined as the time when accumulated revenues cover the investment, is calculated by:

(16)

Since annual cash flow decreases due to efficiency degradation, the total payback period is calculated to be approximately 8.3 years.

**CONCLUSION**

Studies on solar energy utilization in Uzbekistan indicate that the 100kW solar photovoltaic system installed in Andijan performs effectively under the region’s climatic conditions. In 2024, the system produced 96 974,04 kWh of electricity, which corresponds to indicators aligned with the project’s goals for the local environment.

High production levels were observed in spring and summer months, while efficiency declined during autumn and winter. The annual decrease in efficiency is mainly related to climate conditions, solar radiation, and technical losses, and accounting for this is crucial for ensuring the system’s long-term stability.

The electricity generated by the system has demonstrated economic advantages according to Uzbekistan’s tiered tariff structure. Calculations based on the initial investment cost and tariffs confirm that the system will fully pay off during its service life and generate economic profit.

**FUTURE SCOPE**

The system can be expanded to 500 kw or above in future projects and this will enable the institute to meet a larger portion of their electricity requirements and possibly a surplus that can be sold to the national grid.

System reliability can be enhanced by integrating hybrid renewable energy solutions, such as combining solar energy with wind power or battery storage, ensuring a stable energy supply during winter months when solar radiation is low.

Predictive diagnostics using AI and machine learning to predict failure of both inverters or modules could minimize the downtime of the system and increase efficiency in the operation leading to minimal maintenance cost.

This should be further developed to enable the use of sophisticated data analytics platforms where efficiency can be measured in real time, carbon offset progress can be monitored and benchmarking of performance verses other institutions or locations can be carried out.

Smart EMS will enhance a balance of energy consumption between buildings, prioritisation of important loads, and optimisation of the schedule of using energy according to the generation trends and hours of peak tariffs.

The existing installation can be used to create a live lab by students and researchers. The potential benefit and contribution to renewable energy education and innovation may be the extension of the scope to involving integration of IoT-based sensors and experimental algorithms.

The logical way is their combination with the developing smart grid system in Uzbekistan, which would permit dynamic pricing schemes, two-way communications, and the participation of energy resource (DER) in a decentralised way.

The system can be used as the pilot model of development of institutional energy policy and local governmental policy. Recorded outcomes may be referred to green finance or grants to carry sustainable development further.

Future is to improve on dust build-up which has massive effects on efficiency. Performance degradation can be curtailed to a considerable level by the use of automated cleaning systems by means of waterless or robotic methods.

Such solar projects can be rendered more economically feasible and internationally viable by selling the reductions in CO 2 emissions internationally via carbon credits or joining in green finance schemes.

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