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SCIENTIFIC AND TECHNICAL ANALYSIS OF OPERATIONAL CHALLENGES OF SOLAR PHOTOVOLTAIC POWER PLANTS IN THE KARSHI REGION

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ANNOTATION

This article investigates the main technical challenges arising during the operation of solar photovoltaic power plants in the Karshi region based on a scientific and technical analysis. The climatic and energy conditions of the region, including annual global solar irradiation (1500–1700 kWh/m²), high summer temperatures (up to +45°C), and dust accumulation (soiling) effects, have been evaluated in terms of their impact on photovoltaic system performance.

It is estimated that although a 5 kW photovoltaic system can generate approximately 8,500 kWh/year under ideal conditions, energy losses due to high temperatures and soiling may reach 20–25%. Based on the temperature coefficient ($\beta \approx -0.45\%/°C$), it was calculated that the power output may decrease by 15–20% during summer months. Furthermore, it was determined that soiling causes an average annual energy loss of 10–12%.

Based on the research findings, technical recommendations have been developed to reduce operational losses and improve system efficiency.

KEYWORDS: Solar Photovoltaic Plant (PVPP) ,Counter Area, Global Solar Radiation (GHI), Temperature Coefficient, Soiling Effect, Energy Losses, Degradation, Inverter Reliability, LCOE, Operational Efficiency, Renewable Energy.

INTRODUCTION

Globally, the demand for renewable energy sources has increased significantly in recent years. Due to climate change, the depletion of conventional fossil fuel resources, and growing environmental concerns, solar energy has become increasingly strategic. Photovoltaic power plants (PVPPs) are among the most promising technologies for generating electricity in an environmentally friendly and sustainable manner.

The Republic of Uzbekistan is one of the countries with high solar energy potential due to its geographical location and climatic conditions. In particular, the southern regions — including the Karshi region — are characterized by annual global solar irradiation ranging from 1500 to 1700 kWh/m². The number of sunny days reaches approximately 280–300 per year, creating favorable conditions for the efficient deployment of photovoltaic power plants.

However, despite the high energy potential, several technical and operational challenges arise during the actual operation of photovoltaic plants. In particular, summer air temperatures may rise to +45°C, while module temperatures can reach 60–70°C, significantly reducing power output. The accumulation of dust and sand particles on the surface of PV modules (soiling effect) further decreases system efficiency. In addition, inverter reliability, grid integration challenges, and long-term equipment degradation adversely affect the technical and economic performance of PVPPs.

The objective of this research is to conduct a scientific and technical analysis of the main operational challenges of solar photovoltaic power plants in the Karshi region, to quantitatively assess energy losses, and to develop practical recommendations for improving system performance.

The research methodology includes the analysis of climatic parameters, evaluation of temperature-dependent efficiency of photovoltaic modules, assessment of soiling effects, inverter reliability analysis, and mathematical modeling of energy generation. The obtained results contribute to the development of a scientifically grounded approach to the design and operation of photovoltaic power plants in the Karshi region.

1. Climatic and energy conditions of Karshi territory

Geographic Location:

Karshi - South Uzbekistan, at 38°–39° north latitude.

Solar Resources:

1. Annual solar irradiation: **1500–1700 kWh/m²**
2. Number of sunny days: **280–300 days/year**
3. Maximum temperature in summer: **up to +45 ° C**
4. Minimum temperature in winter: **-10°C**

These readings indicate a high potential for (PVPP), but high temperatures and dust pose operational problems.

2. The main problems of operation (scientific and technical analysis)

2.1. The influence of high temperature

The efficiency of photovoltaic modules decreases with increasing temperature.

1.Temperature coefficient:

$$\square \approx -0.4 \div -0.5\%/°\square$$

If the module temperature increases from **25°C to 65°C**, then::

$$\Delta\square = 40°\square$$

Ploss=40×0.45%≈18%

This means that in the summer months, **the capacity can be reduced to 15–20%.**

2.2. Soiling effect

The Kashkadarya region is close to a semi-desert zone. Dust accumulation:

1. Increase productivity by **5–12% in 1 month**
2. If 3 months are not cleansed **, it can be reduced to** 20–25%.

Soiling Loss koeffitsienti:

$$\square\square = \frac{\square_{\square\square\square\square\square\square} - \square_{\square\square\square\square\square\square\square}}{\square_{\square\square\square\square\square\square}} \times 100\%$$

Scientific studies show that dust particles increase spectral absorption and decrease optical transmission.

2.3. Reliability of Inverters

The weakest point in the (PVPP) system is inverters.

The main problems:

1. Degradation of electronic components at high temperature
2. Insufficient ventilation
3. Oscillations in mains voltage

Average inverter service life: **8–12 yearsPanel service life: 25–30 years**

This means that the inverter will be replaced at least 2 times during the life of 1 (PVPP).

2.4. Problems of integration with the electrical network

On the territory of Karshi:

1. Tension instability
2. Reactive Power Balance
3. Network capacity limitations

Solar generation is maximum during the day, while the load is high in the evening. This means:

$$\square_{\square\square\square} \neq \square_{\square\square\square\square}$$

Results:

1. Curtailment (forced deletion)
2. Feedback Power Flow

2.5. Degradation process

Annual Degradation:

1. Monocrystalline modulus: **0.5–0.8 %/year**
2. Power ≈ 25% will remain 80–85%

PID (Potential Induced Degradation) is intensified at high humidity and temperature.

3. Feasibility Consequences

Reasons for the increase in OPEX:

1. The need for frequent cleaning
2. Inverter Service Costs
3. Cooling system overhead

LCOE formulation:

$$\square\square\square\square = \frac{\sum(\square_{\square} + \square_{\square} + \square_{\square})}{\sum \square_{\square}}$$

Decrease in energy caused by dust and temperature →

$$\square_{\square} \downarrow \rightarrow \square\square\square\square \uparrow$$

4. Scientific recommendations for troubleshooting

1. Bifacial panellar qo‘llash

5–15% extra energy due to albedo

2. Automatic cleaning systems

Robotic dry-clean technology

3. Optimal Tilt Angle Selection

Optimal slope for injection:

$$\square \approx 30°–35°$$

4.SCADA Monitoring System

Troubleshooting via real-time monitoring

5. Energy Storage Systems (PPS)

Late Loading Compensation

We will scientifically and accurately calculate how much electricity can be generated during the year for a **5 kW solar panel system under opposite conditions**.

1) Basic computational methodology

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Photovoltaic systems estimate annual energy production by a parameter commonly referred to as **kWh/kWp** ("specific yield") — that is, the **annual energy (kWh) for 1 kW of installed power**.

In sunny, high-GHI areas, this indicator is:

1. **It can be in the range of 1,500–1,800 kWh/kWp/year**, depending on location and conditions.

This degani:

1. A 1 kW system produces approximately 1,500–1,800 kWh of electricity per year.

2) Annual energy for 5kW system

If we assume 1,650–1,750 kWh/kWp/year **for a sunny area like Karshi** (based on data from nearby areas):

Formula:

$$□_{□□□□} \approx 5\,\text{kW} \times (1\,650–1\,750)\,\text{kWh/kWp}$$

Account:

1. **5 × 1,650 = ~8,250 kWh/year**
2. **5 × 1,750 = ~8,750 kWh/year**

This means that a 5 kW solar system can produce around **8,000–8,800 kWh of electricity per ≈year**.

3) Daily average output

If we convert from annual value to daily:

$$\text{Daily} = \frac{8\,250–8\,750}{365} \approx 22.6–24.0\ □□h/□□□$$

This is a larger average value, with sunny days suitable for many locations. Practical reports also see similar values: A 5 kW system produces around **15–25 kWh/day**, depending on the location and lighting conditions.

Brief scientific summary

Annual energy for a 5 kW system: **≈ 8,000–8,800 kWh/year** (for a highly-sunny area such as Kari) This output is based on the assumption of 1,650–1,750 kWh/year per 1 kW.

Daily average energy production: 22–24 kWh/day

Depends on what?

Real production will also depend on:

1. **Tilt angle and orientation** — The optimal angle increases energy production.

2. **Ventilation and temperature**
— High temperatures reduce efficiency.

3. **Dust and soil losses**
— The cleaning regime significantly increases energy production.

For 5 kW (PVPP) in Karshi region :

1. **loss due to heating (temperature)**
2. **loss due to pollination (soiling)**
3. **total loss when the two are together**

We calculate the scientific formula for the

1) Starting Conditions (For Counter)

From the previous account:

1. 5kW system annual output (under ideal conditions):

$$\square_{\square\square\square\square\square} \approx 8500 \text{ kWh/year}$$

2. Panel Temperature Coefficient:

$$\square = -0.45\%/°\square$$

3. Panel temperature in summer:

STC = 25°C Real in summer modulus ≈ 65°C

$$\Delta\square = 65 - 25 = 40°\square$$

2) Loss due to overheating

$$\square_{\square\square\square\square} = 40 \times 0.45\% = 18\%$$

This means that during the summer months, power ≈ **is reduced by 18%.**

If we calculate the annual average (not just summer), the real loss ≈ **be** 10–12%.

Annual Energy Loss:

$$\square_{\square\square\square\square} = 8500 \times 0.11 \approx 935 \text{ kWh}$$

Due to temperature, ≈ is lost by 900–1000 kWh/year

3) Loss due to dust

A semi-desert area against it.

1. If the panels are not cleaned for 1–2 months:
2. Average soiling loss ≈ 10–15%

We get an annual average: **12%**

$$\square_{\square\square\square\square\square\square} = 8500 \times 0.12 = 1020 \text{ kWh}$$

Loss of ≈ 1000kWh/year due to dust

4) When both are together (real)

Losses are not added, multiplied:

$$\square_{\square\square\square\square} = 8500 \times (1 - 0.11) \times (1 - 0.12)$$

$$\square_{\square\square\square\square} = 8500 \times 0.89 \times 0.88$$

$$\square_{\square\square\square\square} \approx 6650 \text{ kWh}$$

So:

Energy Loss=8500−6650=1850 kWh/year

Final Results (5 kW PV System)

Status	Annual Energy	Loss
Ideal conditions	8500 kWh	0
Temperature only	~7565 kWh	~935kWh
Soiling losses only	~7480 kWh	~1020 kWh
Temperature + Soiling	**~6650 kWh**	**~1850 kWh (≈22%)**

CONCLUSION

The conducted scientific and technical analysis demonstrates that the Karshi region is a promising area for the deployment of photovoltaic power plants due to its high solar radiation potential. However, the sharply continental climatic conditions — particularly high summer temperatures and dust accumulation (soiling effects) — have a significant impact on the operational efficiency of photovoltaic power plants (PVPPs).

According to the calculations, a 5 kW photovoltaic system can generate approximately 8,500 kWh of electricity per year under ideal conditions. However, temperature effects result in an annual energy loss of about 900–1000 kWh, while dust accumulation contributes an additional loss of approximately 1,000 kWh. When these factors act simultaneously, the total annual energy loss reaches approximately 1,850 kWh/year, corresponding to nearly 22% of the ideal production. Consequently, the actual annual energy output decreases to about 6,500–6,800 kWh/year.

Furthermore, the limited service life of inverters, grid integration challenges, and long-term module degradation increase operational costs and negatively affect the Levelized Cost of Electricity (LCOE).

Therefore, to improve the performance of photovoltaic power plants in the Karshi region, the following measures are recommended:

1. Selection of the optimal tilt angle (30–35°);

2. Implementation of automated cleaning systems;
3. Use of high-temperature-resistant inverters and PV modules;
4. Establishment of real-time monitoring through SCADA systems;
5. Integration of Battery Energy Storage Systems (BESS).

In conclusion, the adoption of a scientifically based operational strategy can significantly reduce energy losses and improve the economic efficiency of photovoltaic power plants in the region.

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