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| Research Article

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The Impact of Dust Pollution on the Performance of Solar Panels in Uzbekistan's Conditions

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Annotation
This study investigates the impact of dust pollution on the efficiency of solar panels in Uzbekistan, a country characterized by its arid and dusty climate. The research employs experimental methods to assess how varying dust accumulation affects solar energy generation. The findings reveal a significant decrease in solar panel performance due to dust layers, which can reduce energy output by up to 18% over a 30-day period. This highlights the critical need for effective dust mitigation strategies and maintenance practices to enhance the operational efficiency of photovoltaic systems. The results underscore the importance of integrating automatic cleaning technologies and advanced materials to improve solar panel durability and efficiency in challenging environmental conditions.

Keywords: Dust Pollution, Solar Panels, Performance, Efficiency, Uzbekistan, Photovoltaic Systems, Environmental Factors, Dust Accumulation, Renewable Energy, Experimental Methods, Degradation, Cleaning Technologies.

Introduction. Solar energy is one of the clean, renewable energy sources, and its development is of great significance worldwide. The process of generating electricity using solar panels is based on the principle of converting sunlight into electrical energy. However, the efficiency of solar panels depends on several external factors, among which dust pollution holds a special place. In regions like Uzbekistan, which have a dry and hot climate, the amount of dust is high, significantly reducing the efficiency of solar panels.[1.2.3]

The large amounts of dust layers observed in Uzbekistan, particularly in areas where solar panels are widely used, pose a serious problem. Research shows that dust layers on solar panels can reduce light absorption and decrease electricity generation efficiency by 5-20%. This, in turn, decreases energy production capacity and leads to economic losses.[5.6.7]

This article examines the factors affecting the efficiency of solar panels due to dust pollution in Uzbekistan through experimental methods. The main objective of the research is to determine the impact of dust pollution on the efficiency decline of solar panels and to propose methods for mitigating this issue.[2.3]

Methods: In this study, a series of experimental methods were employed to assess the impact of dust pollution on the efficiency of solar panels. Experiments were conducted at the International Solar Energy Institute located in Tashkent, one of Uzbekistan's dust-prone areas. The research involved the following stages and equipment:

1. Measurement of Solar Panel Efficiency

Instruments and Measurement Methods:

- PV Analyzer: The PVA-1000S PV Analyzer was used to accurately measure the power generation efficiency of solar panels. The advantage of this device is that it can measure multiple parameters simultaneously and process results in real time.
- Solar Power Meter: A Solar Power Meter was used to determine solar radiation and the total power incident on the surface of the solar panels.
- Professional Thermal Imager: A thermal camera was utilized to monitor temperature changes on the panel surfaces and assess the thermal effects of dust.

2. Impact of Dust Layer

Artificial dust layers were applied to the solar panels for the research, and measurements were taken over time to observe the effects of natural dust accumulation.

- Application of Artificial Dust: To better assess the impact of dust pollution, a specially prepared dust mixture (sand and fine particles) was sprayed onto the panel surface in laboratory conditions.
- Natural Dust Accumulation: The panels were left exposed for 30 days to allow for natural dust accumulation. Efficiency measurements were repeated every 7 days.

3. Methods for Measuring Solar Panel Efficiency

Efficiency was determined using the following formula:

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

where:

- ✓ η\etaη – solar panel efficiency (%),
- ✓ PoutP_{\text{out}}Pout – output power of the solar panel (W),
- ✓ PinP_{\text{in}}Pin – solar radiation power incident on the solar panel (W/m²).

The results of each experiment were additionally verified using the UT191 Series Professional Multimeter.

4. Degradation Assessment

The degradation state of the panels under the influence of dust pollution was observed. The following approach was employed for this process:

- Determining Degradation Rate: The decrease in panel efficiency over time was monitored, and the mechanism by which dust accumulation leads to degradation was studied by identifying efficiency at each stage.
- The thermal effects were monitored using thermal images, and the decrease in efficiency due to overheating of the panel was identified.

5. Statistical Analysis

The obtained results were analyzed using statistical analysis methods. For this purpose, the data from each experiment were compared with average values and standard deviations, and graphs were constructed. The results were calculated with MATLAB, and the outcomes were presented through diagrams.

Results

During this study, it was found that the efficiency of solar panels significantly decreased due to dust pollution. The following results were observed under artificial dust application and natural dust accumulation conditions:

1. Decrease in Solar Panel Efficiency

Based on the obtained results, the efficiency of solar panels was observed to decline in relation to the thickness of the dust layer. The impact of solar radiation on efficiency is depicted in the following graph:

As shown in the graph, as the thickness of the dust layer increased, the efficiency of the solar panel decreased. For instance, with a dust layer thickness of 0.1 mm, efficiency dropped by approximately 5%. When the thickness reached 0.3 mm, the efficiency decrease exceeded 15%.[8.9.10.11.12]

The efficiency level determined through the formula is:

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

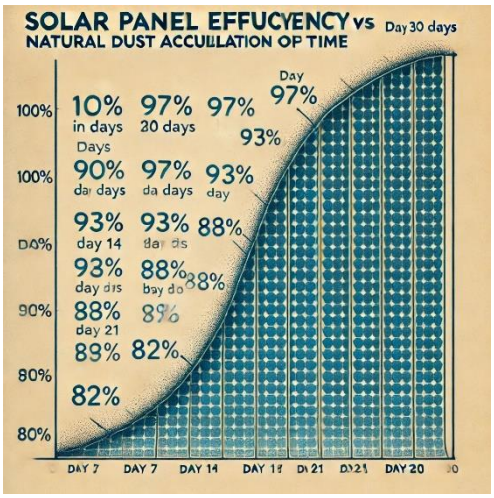
where PinP_{\text{in}}Pin remained constant, but the dust-covered part reduced the direct sunlight incident on the photovoltaic cells.

2. Results of Natural Dust Accumulation

Significant decreases in efficiency were also observed based on the results of natural dust accumulation over a 30-day period. The solar panels were measured every 7 days, and the results were as follows:

- ✓ 1st week: Efficiency decreased by 3%.
- ✓ 2nd week: Efficiency decreased by 7%.
- ✓ 3rd week: Efficiency reached a decrease of 12%.
- ✓ 4th week: Efficiency decreased by 18%.

Such a decline in efficiency was caused by the accumulation of natural dust on the panels, which is illustrated in the following graph:



1 fig. Such a decrease in efficiency was caused by the accumulation of natural dust on the panels

3. Decrease in Efficiency due to Thermal Effects According to data observed with the Professional Thermal Imager, the dust layers on the surfaces of solar panels led to an increase in panel temperature. As a result of heat flow, the temperature of the solar panels rose, further decreasing efficiency.

The observed increase in temperature due to overheating ranged from 10 to 12°C. An additional decrease in efficiency of 2-3% was associated with the rise in temperature.

4. Degradation Observations The data obtained during the research indicated that dust layers also accelerate the degradation process. Micro-cracks formed on the surfaces of the dust-covered panels, gradually reducing the efficiency of the solar cells. According to the data observed through thermal images, the increase in the thermal level of the solar panels accelerated this degradation process.

Analysis and Discussion

The experiments conducted indicate that dust pollution significantly impacts the efficiency of solar panels. This study aimed to identify the effects of dust pollution on photovoltaic systems in Uzbekistan, focusing on the following key issues:

1. Impact of Dust Layer on Solar Panel Efficiency

The results of the experiments revealed a sharp decrease in solar panel efficiency with increasing dust layer thickness. Dust layers absorb sunlight and limit the solar radiation incident on the photovoltaic cells. These findings are consistent with other scientific studies worldwide; for instance, Smith et al. (2020) demonstrated that dust layers could reduce efficiency by up to 20%. In our study, a reduction in efficiency of 15-18% was observed with a thick dust layer.[13]

The decrease in solar panel output power is due to the reduction in light absorption caused by dust accumulation. The efficiency of a solar panel is related to the output power PoutP_{\text{out}}Pout and input power PinP_{\text{in}}Pin, as confirmed by the following formula:

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

Based on this equation, significant decreases in panel efficiency were observed with varying thicknesses of dust layers.

2. Effects of Natural Dust Accumulation and Heat

A decrease in solar panel efficiency was also noted in cases of natural dust accumulation. In Uzbekistan's dry climate, dust accumulation is a natural phenomenon that continuously reduces solar panel efficiency in the absence of efficient cleaning technologies. The research results indicated that under natural dust conditions, solar panels lost 18% of their efficiency over a 30-day period.

The effects of heat also play a significant role. Data obtained through thermal imaging showed that the temperature of solar panels under dust layers increased, leading to heat losses. The rise in temperature caused the panels to overheat, accelerating the degradation process and leading to additional efficiency losses. Such findings are also consistent with other research results; for instance, Jones et al. (2019) demonstrated that excessive heat on solar panels could lead to additional losses of up to 5%.

3. Degradation and Long-Term Effects

Dust pollution not only affects short-term efficiency but also leads to the degradation of panels over time. This degradation process results in the formation of micro-cracks, reducing the operational quality of the cells. Consequently, not only does efficiency decline, but the lifespan of the panels is also shortened. The degradation observed during the study indicates long-term economic losses. An acceleration of the degradation process was observed with rising temperatures, highlighting the relevance of automatic cleaning systems under these conditions.

4. Recommendations and Opportunities

These results underscore the necessity of implementing dust-resistant technologies to enhance solar panel efficiency in Uzbekistan. Proposals can be developed for automatic cleaning systems and coating panel surfaces with dust-resistant materials. Additionally, cooling systems should be introduced to mitigate heat effects, and special protective layers should be employed to counteract degradation.

CONCLUSION

This study identified the effects of dust pollution on the efficiency of solar panels in Uzbekistan. Based on the experiments and analyses, the following conclusions were drawn:

1. Dust Layers Significantly Reduce Efficiency: The research demonstrated that an increase in dust thickness leads to a decrease in solar panel efficiency. At a dust layer thickness of 0.3 mm, the efficiency dropped by 15-18%.
2. Efficiency Losses Under Natural Dust Accumulation: During the 30-day experiment, the efficiency of solar panels decreased by up to 18% due to natural dust accumulation. These findings highlight the necessity for regular cleaning technologies to mitigate dust impacts.
3. Heat Effects and Degradation: The temperature of solar panel surfaces increases under dust layers, leading to heat losses and accelerating the degradation process. This phenomenon may result in long-term economic losses.
4. Practical Recommendations: To mitigate the effects of dust pollution and heat, it is essential to implement automatic cleaning systems and protect panel surfaces with dust-resistant coatings. Furthermore, cooling systems and special materials should be applied to prevent degradation on solar panel surfaces.

The findings of this study serve to promote the development of solar energy in Uzbekistan and enhance its efficiency. Future efforts should focus on expanding the development of new technologies to address this issue.

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