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Automated Spray Cleaning Systems for Solar Panels

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Abstract: Dust accumulation on solar panels significantly reduces energy output, particularly in arid, dusty, or industrial regions. This paper proposes and evaluates a low-cost, automated spray cleaning system designed to maintain panel performance while minimizing water usage and manual labor. The system uses scheduled or sensor based cleaning cycles, integrating basic mechanical and control components. A simulation-based analysis indicates that regular spray cleaning can recover up to 15-25% of power loss, reduce labor requirements by over 90%, and optimize water consumption by more than 60% compared to traditional manual cleaning. The system provides a scalable and efficient solution, especially for remote or large-scale solar deployments.

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I. INTRODUCTION

Solar photovoltaic (PV) systems play a key role in global clean energy strategies. Yet, the buildup of dust, sand, and other contaminants on the surface of solar panels can lead to substantial energy losses, typically ranging from 10% to 30%, depending on the location and environmental factors. This issue is particularly marked in areas with low rainfall or high levels of airborne particles.

Regular cleaning is crucial but is often carried out manually, making it time-consuming, labor-intensive, and inefficient in terms of water usage. While robotic systems have been deployed in large-scale solar projects, they tend to be costly and require complex maintenance.

This paper introduces a simplified, automated spray cleaning system aimed at increasing PV output, reducing maintenance efforts, and conserving water. The study emphasizes four pillars; Improvement in Energy Efficiency, Ease of Implementation, Operational Impact, and Water Optimization.

II. LITERATURE REVIEW

Numerous studies have confirmed that surface soiling significantly impacts PV output. Mani and Pillai (2010) report energy losses of 15-30% in arid regions. Sayyah et al. (2014) modeled the impact of dust across different climates, highlighting the value of regular cleaning. Manual cleaning continues to be widely used, even though it is inefficient and can pose safety risks when performed on rooftops or elevated installations. While robotic systems show promise, they come with high initial costs and require ongoing maintenance. Few studies focus on low complexity, automated spray systems that balance cleaning effectiveness with water and cost efficiency. This research attempts to fill that gap, proposing a modular system that requires minimal infrastructure yet delivers measurable performance ad operational benefit.

A. System Design and Methodology

➢ *System Componen*

The proposed system includes:

- Spray bars with low pressure mist or fan nozzles mounted above solar panels
- A water pump (low power, automated)
- A control unit with either: a programmable timer, or sensors to detect voltage drop, dust level, or environmental conditions

➢ *Operating Principle*

Cleaning occurs at scheduled intervals (e.g., daily or every 2 days during dry seasons). The spray lasts 30-60 seconds per cycle to remove fine dust and particulate matter. Cleaning is suspended during rainfall or low-dust periods. The system uses simple logic and is scalable for residential or utility scale installations.

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B. Efficiency Improvement

A simulation was conducted for a 100-kW solar array in a semi-arid region. Based on dust accumulation rates and cleaning intervals, the following results were observed:

- Without cleaning: Up to 18-25% efficiency loss
- With daily spray cleaning: Less than 3-5% efficiency loss
- Net improvement: 15-20% gain in daily energy yield

Over one year, this results in a gain of approximately 5,000 to 7,500 kWh, depending on climate and array configuration.

C. Operational Impact

➢ *Time and Labor Savings*

Manual cleaning of a 100-kW system:

- Requires approximately 4 labor hours per session
- Performed weekly: over 200 hours/year

➢ *Automated Spray System:*

- Requires only monthly maintenance checks
- Reduces manual labor by 90%
- No system shutdown is required for cleaning, reducing downtime

➢ *Safety and Access*

By minimizing rooftop work and reducing physical risks, this solution is particularly well-suited for challenging or hard-to-reach installations. Its straightforward, streamlined design further contributes to easier maintenance and reduced operational complexity.

D. Water Use Optimization

➢ *Estimated Usage:*

- 0.3 to 0.5 liters per panel per cycle
- Annual consumption: 5,000-8,000 liters for 100 kW system (versus 20,000+ liters manually)
- Water savings: Up to 75%

➢ *Water Usage can be Further Optimized Through:*

- Nozzle selection
- Rainwater harvesting
- Greywater or recycled water use

III. CONCLUSION AND FUTURE WORK

This paper introduces a practical and scalable approach in order to maintain solar panel efficiency through an automated spray cleaning system. The system enhances power output, lowers operational costs and labor requirements, as well as optimizes water usage—making it especially beneficial in areas with limited resources. However, this proposal can be further expanded in the future through some or all of the following:

- Building a working prototype
- Field testing in diverse environments
- Integrating machine learning for performance driven cleaning scheduling
- Evaluating long term reliability and maintenance needs

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