Review on Design and Fabrication of Solar Panel Cleaning Mechanism

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Abstract

Today energy demands are increasing sharply therefore as a Renewable source of power, solar energy has an important role in producing the electricity direct from sunlight. The surface of solar panel in solar power plants becomes dirty due to natural factors such as dust and bird droppings. This project aims at increasing the efficiency of solar power plants by solving the problem of accumulation of dust on the surface of solar panel which leads to reduction in plant output and overall plant efficiency. It proposes to develop a Solar Panel Cleaning System which could remove the accumulated dust on its surface on a regular basis and maintain the solar power plant output.[8]

1. Introduction

The design and fabrication of a solar panel cleaning system is a pivotal venture in the realm of renewable energy technology. As the global demand for clean and sustainable energy intensifies, solar power stands out as a key player in the transition towards a greener future. However, the efficiency of solar panels is inherently linked to their cleanliness, making regular maintenance imperative. This project aims to address this crucial aspect by creating an innovative and automated solar panel cleaning system. To commence, it is essential to comprehend the significance of maintaining clean solar panels. Accumulation of dirt, dust, and other environmental pollutants on the surface of solar panels hampers their ability to convert sunlight into electricity effectively. This diminishes the overall energy output and compromises the economic viability of solar power systems. Furthermore, in regions with erratic weather patterns, such as heavy rainfall followed by extended dry periods, a layer of grime can become stubborn, necessitating a more systematic and reliable cleaning solution. The proposed solar panel cleaning system is designed to autonomously traverse the solar array, ensuring comprehensive cleaning coverage. The system incorporates advanced sensors to detect the level of dirt on each panel, enabling it to prioritize and allocate cleaning resources efficiently. This not only optimizes the cleaning process but also minimizes water usage, aligning with the broader sustainability goals of the renewable energy sector. The heart of the system lies in its mechanical design, which involves the integration of durable materials and weather-resistant components. The cleaning mechanism employs soft brushes or wipers to gently remove debris without causing any damage to the delicate surface of solar panels. A robust yet lightweight frame ensures the system's stability and ease of movement across the solar array. Moreover, the cleaning system incorporates smart technology to enhance its overall efficiency. Machine learning algorithms are employed to analyze historical weather data, predict upcoming environmental conditions, and schedule cleaning operations accordingly. This predictive maintenance approach not only enhances the system's responsiveness but also reduces downtime, ensuring that solar panels remain at peak efficiency. In terms of fabrication, the emphasis is on utilizing cost-effective and readily available materials to make the solar panel cleaning system accessible to a wide range of solar power installations. The fabrication process involves precision engineering to achieve the required durability and functionality. Additionally, the system's energy source is a crucial consideration, with options ranging from a dedicated solar-powered unit to grid-connected solutions, ensuring that the cleaning process aligns with the sustainability objectives of the entire solar power system.

2. Solar Panel Cleaning Techniques

2.1 Self-Cleaning Mechanism

Fig.2.1.1 Self-cleaning Mechanism [5]

The self-cleaning mechanism for solar panels involves applying a translucent nano-film made of either super hydrophilic or super hydrophobic materials. The superhydrophilic approach relies on rainwater scattering to clean the dust, but it's not widely adopted, prompting ongoing research. Conversely, super-hydrophobic materials cause water droplets to swiftly remove dust, mimicking the lotus leaf's effect. However, applying such materials to solar panels raises questions, given that solar farms are often located in arid regions with infrequent rainfall. Hence, extensive research is necessary to evaluate the suitability of these materials for solar panel surfaces. While the super hydrophobic method shows promise, its practicality in water-scarce environments needs careful consideration, emphasizing the importance of in-depth studies to ensure effective and sustainable implementation of self-cleaning technologies in solar energy systems.[5]

2.2 Manual Cleaning System

Manual cleaning of solar panels involves the use of tools and techniques operated by an individual. A common tool for this purpose is a cleaning kit, which typically includes extension poles, carrying bags, brushes, cloths, hose connections, and more. Various companies manufacture brushes and hose systems designed specifically for solar panel cleaning. An illustration of manual cleaning at Kathmandu University Hospital depicts an operator using a cleaning kit on a solar panel. While manual cleaning is efficient for smaller solar plants, its feasibility diminishes as the size of the plant increases. The expansion of a solar plant's size results in a proportional increase in operational and maintenance (O&M) costs, making manual

Fig.2.2.1 Manual Cleaning System [5] cleaning impractical and economically burdensome due to the need for a large workforce. As a consequence, alternative and more scalable cleaning methods, such as automated or robotic systems, may be necessary for larger solar installations to ensure cost-effective maintenance and optimal performance.[5]

2.3 Piezoelectric Cleaning System

The utilization of piezoelectric systems for solar panel cleaning is a cutting-edge approach, harnessing the exceptional torque-to-volume ratio, flexibility, and precise positioning capabilities of piezoelectric actuators. Widely employed in optics, biomedicine, and space exploration, this technology employs an acoustic piezoelectric system using water as the cleaning agent. A thin water layer (0.1 to 1 mm) is spread over the solar panel's surface, creating an ultrasonic cavity during the rarefaction cycle of compression waves. This cavity efficiently cleans the panel by suctioning dust during the vacuum in the liquid rarefaction. The same principle applies when using air as the cleaning medium.

Fig.2.3.1 Linear Piezoelectric System [5]

Moreover, a linear piezoelectric actuatorbased cleaning system ensures optimal pressure force between the wiper and the solar panel. This actuator's vibrations effectively remove dust, providing a dynamic and automated solution to solar panel maintenance. The implementation of this system holds the potential to reduce operational and maintenance costs while enhancing cleaning precision. Figure 2 visually illustrates the application of a linear piezoelectric system in solar panel cleaning, showcasing its transformative role in advancing sustainable energy technologies. [5]

2.4 Electric Curtain Cleaning System

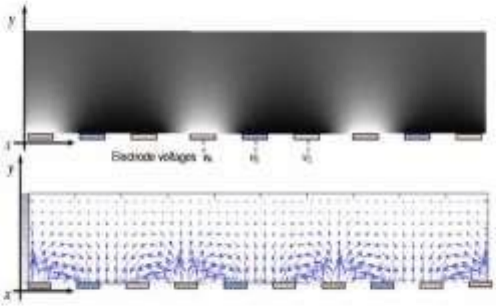

Fig.2.4.1 Electric Curtain Cleaning System [5]

The electric curtain system offers a novel approach to combat dry dust accumulation on module surfaces. By applying an electric field to dust particles, a standing wave-type electric curtain is formed, creating an oscillating electric field with amplitude and direction. This frequency is tuned to guide dust particles along the electric field lines, effectively cleaning the module's surface as they move towards its edges. Uncharged particles are induced through polarization or electrostatic induction, subsequently removed from the module. An alternative technology, the Electro-Dynamic Screen (EDS), employs a high voltage three-phase electric source to generate a traveling wave with strong translational energy, enhancing dust removal efficiency. Figure 4 illustrates the application of different phases to module substrates, aligning with respective lines of force in the Electrodynamic Screen. This cleaning mechanism is particularly effective in dry conditions, preventing vapor-based bonding of dust particles to the module. The system's application is recommended in regions with extremely low humidity and negligible precipitation. Studies on concentrated solar power plants indicate a 90% efficiency in restoring reflectance lost due to soiling, emphasizing its practicality in arid environments. Mars, with its inherently dry conditions, is identified as a suitable candidate for implementing this technology.[5]

2.5 Robotic Cleaning System

The integration of robotic systems in solar panel maintenance has become a highly sought-after technology due to its versatile applications in both small and large photovoltaic (PV) systems. These robots, equipped with actuators, drives, and advanced features facilitated by 3D printing and nanotechnology, outperform manual cleaning. Automation advancements, particularly in 3D printing and nanotechnology, enable the creation of highly efficient robots that reduce complexity between human operators and machines. The incorporation of automation in robotic systems allows self-decisionmaking, reducing human-machine interfacing time. Microcontrollers and programmable logic controllers play a crucial role in simplifying the cleaning process for robotic systems. Fuzzy logiccontrolled algorithms further enhance decision-making by considering factors like solar irradiance and output current values. The emerging Internet of Things (IoT) adds a transformative dimension to solar panel cleaning. IoT-enabled systems leverage sensors for real-time data collection, facilitating remote monitoring through cloud-based platforms. This reduces inspection costs, as cleaning teams can deploy robots only when necessary. The Smart Solar Photovoltaic Panel Cleaning System exemplifies this concept, featuring robotic units for cleaning and an autonomous unit for decision-making based on solar radiation and generated power. This entire system can be supervised remotely via internet connectivity, minimizing the need for on-site visits and enhancing overall operational efficiency.[5]

There are some types of Robotics Cleaning System

2.5.1 Water Based Robotic Cleaning System

Water-based robotic cleaning systems have emerged as efficient solutions for maintaining solar photovoltaic (SPV) panels, especially in urban and tropical climates where water is abundant. Serbot Swiss Innovations has developed a mobile cleaning mechanism for SPV panels utilizing a rotating brush and demineralized water. The robot moves on vacuumed feet with trapezoid-shaped geared belt drives, offering radio control and easy mobility. Gekko Solar Farm is designed for largerscale applications in utility-scale solar farms, demonstrating the scalability of water-based cleaning systems. Greenbotic's GB1 is a wireless and rechargeable robotic cleaner featuring rotating brushes and a wiper system, effectively removing various types of dirt and bird droppings. Hector, another mobile robot, carries a water solution tank for autonomous navigation among modules without human intervention. Numerous similar systems exist in the market, differing in water delivery methods, swiping techniques, and panel traversal mechanisms. These innovations enhance cleaning efficiency, tackling hard stains and bird excrements on SPV panels, contributing to the overall performance and longevity of solar power plants. The industry showcases a diverse range of water-based robotic cleaning solutions, each tailored for specific array configurations and power plant sizes.

2.5.2 Waterless Robotic Cleaning System

Waterless robotic cleaning systems offer an effective solution in environments with limited water resources, such as deserts. In these dry regions where solar panel soiling is primarily due to dust accumulation, water-based cleaning methods become impractical. Instead, robots equipped with dust-repellent brushes efficiently swipe away the dust without the need for water. An example of this technology is the Solar Brush, a wireless and rechargeable robot designed for solar PV panel cleaning. With a dust-repellent brush, it navigates up to a 35-degree inclination, providing a lightweight and water-free cleaning solution. In the realm of drone technology, Aerial Power's Solar Brush drone targets desert regions, introducing a drone-based cleaning system for solar panels. The Boson solar farm cleaning robot operates fully autonomously, utilizing IoT connectivity and a solar-powered unit for night-time cleaning. It features gap-spanning capabilities, overcoming challenges posed by gaps between panels. This robotic system enhances reliability through automatic cleaning features. Numerous waterless cleaning products are available in the market, employing advanced techniques such as dust-repellent and attracting brushes and wipers. These innovations contribute to efficient solar panel maintenance in water-scarce environments, showcasing the continuous evolution of technology in the field.

2.5.3 Automated Water Sprinkle System

Automated water sprinkler systems, particularly designed for regions with abundant water resources, offer an efficient solution for routine cleaning of solar panels.
These systems mimic a rain-like environment by employing hoses that spray water directly onto the solar panels. The inclined panels facilitate the natural flow of water and gravity aids in washing away accumulated dirt and bird excreta. The key component of these systems is a programmable controller that orchestrates wash and rinse cycles. This controller's programming can be adjusted to align with seasonal requirements, ensuring optimal cleaning effectiveness. Notably, the design and introduction of this fully automated system were pioneered by Heliotex. In essence, the innovative system enhances the efficiency of solar panels by preventing the prolonged accumulation of soiling particles. It achieves this through a systematic and automated approach that optimizes water usage and adapts to seasonal variations, ultimately contributing to the overall effectiveness and longevity of solar power installations.[5]

3. Different types of Solar Panel Cleaning Mechanism

3.1 Novel Dry Cleaning Machine

The proposed solar panel cleaning system consists of three stages initiated by an onboard processor triggered by sunlight detectors. The first stage involves compressed air spraying to remove coarse dust and humidity. The second stage uses a polyurethane foam roller to clean remaining dust, while the third stage repeats air jet spray at a faster speed. The fourth stage deploys a synthetic duster to remove fine particles. The system can clean multiple panels on guiding rails in two complete runs. Mechanical design involves components attached to triangular plates rotated by stepper motors. The structure

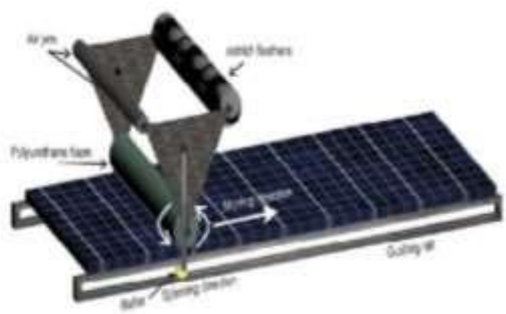

Fig.3.1.1 Novel Dry Cleaning Machine [6]

moves on metallic rails, providing D.C. power. The lightweight composite material reduces electric noise and overall power consumption. [6]

3.2 Wash Panel Cleaning Over SPV

Wash Panel, an Italian company, specializes in producing autonomous 'solar panel cleaning robots' equipped with a horizontal brush spanning 1 to 16 meters. These robots operate on a 12V battery and feature a water hose for efficient panel wetting during cleaning. Their fully autonomous system boasts double programmable functionality via a rain sensor and water jets, ensuring constant and uniform cleaning. With modular design, it requires no additional support structures and can be installed on various surfaces, including ground systems, buildings, and different roof types. The system offers remote supervision and management, sending text messages for continuous monitoring and enabling command control from distant locations.

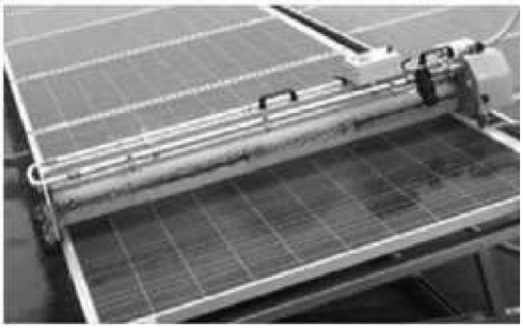

Fig.3.2.1 Wash Panel Cleaning over SPV [4]

This innovative solution eliminates the need for extra frames or guides, providing versatility and ease of deployment. The integration of advanced features, such as rain sensing and water jet control, enhances its adaptability to different environmental conditions. Wash Panel's commitment to autonomy and remote operation positions its solar panel cleaning technology as a efficient and versatile solution for maintaining photovoltaic arrays.[4]

3.3 MFv01 Solar Panel Cleaning Robot

- **Cleaning Quality**: The MFv01 robot boasts impressive cleaning quality. It utilizes dual brush sets (front and back) to tackle dirt, dust, and even bird droppings effectively. Suction technology captures loosened debris, leaving panels sparkling clean. Tests show it outperforms popular rivals like Antonelli and Ecoppia T4 in terms of cleanliness.
- **Cleaning Strategy**: Cleaning strategy is autonomous and efficient. No rails or guides are needed, thanks to ultrasonic sensors that map the solar array and guide the robot's movements. It employs short path movements, minimizing travel time and maximizing cleaning coverage.
- **Cleaning Speed**: Speed is another highlight. The MFv01 cleans significantly faster than many competitors. Estimates suggest it can cover up to 1600 square meters per hour, making it ideal for large-scale solar farms.
- **Cleaning Pattern**: The cleaning pattern is methodical and thorough. The robot typically follows a zig-zag or spiral path, ensuring every corner of the panel receives attention. Its ability to navigate obstacles and uneven surfaces further enhances its coverage.

The MFv01 shines in cleaning quality, speed, and autonomy. Its efficient cleaning strategy and adaptable movement make it a powerful tool for keeping solar panels generating at peak capacity. [1]

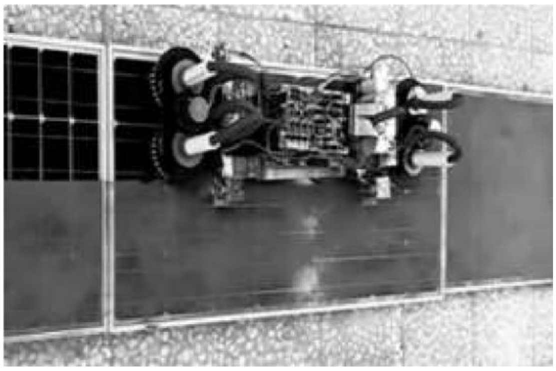

Fig.3.3.1 MFv01 Solar Panel Cleaning Robot [1]

3.4 Antonelli Solar Panel Cleaning Robot

- **Cleaning Quality**: Utilizes a combination of soft brushes and highpowered suction to remove dust, dirt, pollen, and even bird droppings without harming the delicate solar panels. Studies have shown that Antonelli robots can improve panel efficiency by up to 18% compared to uncleansed panels.
- **Cleaning Strategy**: Operates autonomously on pre-programmed paths, navigating around obstacles and uneven surfaces. Sensors detect the edges of the panels and ensure complete coverage without missing any spots. Can be programmed for different cleaning

patterns depending on the layout of the solar array and the type of debris.

- **Cleaning Speed**: Capable of cleaning up to 250 square meters of panels per hour, significantly faster than manual cleaning methods. This translates to reduced labour costs and increased uptime for solar power plants.
- **Cleaning Pattern**: Offers various cleaning patterns, including:

Linear: Moves back and forth in straight lines across the panels.

Spiral: Starts from the centre and moves outwards in a spiral pattern.[1]

Zig-zag: Covers the panels in a zagging pattern for thorough cleaning.

Overall, Antonelli robots are a valuable asset for maintaining the efficiency and productivity of large-scale solar installations. Their combination of advanced cleaning technology, autonomous operation, and efficient cleaning patterns make them a reliable and cost-effective solution for solar panel cleaning.

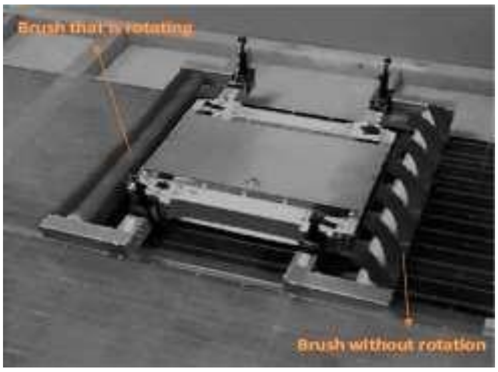

Fig.73.4.1Antonelli Solar Panel Cleaning Robot [1]

3.5 Ecoppia T4 Solar Panel Cleaning Robot

- **Cleaning quality**: The Ecoppia T4 robots can remove up to 99.5% of dust and dirt from solar panels, which is significantly better than traditional cleaning methods such as manual washing or water-based systems. This is because the robots use a combination of soft microfiber brushes and controlled airflow to gently remove dirt and debris without scratching the panels.
- **Cleaning strategy**: The T4 robots are designed to clean solar panels at night, when the panels are not producing electricity. This is because the robots need the panels to be in a stowed position (tilted at a low angle) in order to clean the safely and effectively. The robots navigate along the rows of panels using a series of sensors and cameras, and they clean each panel in a systematic pattern.
- **Cleaning speed**: The T4 robots can clean up to 400 square meters of solar panels per hour, which is equivalent to about 200 panels. This means that a

single robot can clean a large solar farm in a relatively short amount of time.

- **Cleaning pattern**: The T4 robots use a spiral cleaning pattern, which is designed to ensure that all of the panels are cleaned evenly. The robots start at the center of the array and work their way outwards, making sure that no areas are missed.

Overall, the Ecoppia T4 is a highly effective and efficient solar panel cleaning robot. It can remove a large amount of dirt and debris from solar panels, and it can do so quickly and safely. As a result, the T4 can help to improve the performance of solar farms
and reduce the cost of solar.[4]

Fig.3.5.1-Ecoppia T4 Solar Panel Cleaning Robot [4]

3.6 Four-Side Stretch Sling -Based Solar Cleaning Robot

The mechanical design of the four-side stretch sling-based solar cleaning robot encompasses crucial components: chassis, brushing mechanism, sling guide and measurement system, and winch mechanism. The sling measuring system employs an acrylic plate, aluminum roller guides, pulleys, and an encoder-driven mechanism to measure sling length and speed. The sling endpoint features a tethered metal hook linking to an anchor at the working area's edge. The winch system, responsible for pulling and releasing the sling wire, consists of an acrylic base, pulleys, belts, rubber wheels, steel rods, and gears. The brushing system employs a rolling brush, coupling, acrylic holders, stainless bushes, and a DC geared motor to clean PV panels. The brushing angle is adjustable from 0 to 25 degrees, and an Hbridge MOSFET drives the DC motor. The chassis, constructed from aluminium profiles and acrylic plates, forms an 'X' pattern. The robot is identical on all four sides, each at a 90-degree angle. Six rubber ball caster wheels beneath the aluminium profile support the robot's movement. This comprehensive design ensures efficient and flexible solar panel cleaning capabilities.[2]

Fig.3.6.1-Four-side Stretch sling based solar cleaning robot [2]

3.7 SOLARBRUSH Solar Cell Cleaning Robot

The SOLAR BRUSH cleaning robot revolutionizes solar panel maintenance by addressing several key challenges.
Operating exclusively at night mitigates the risk of shadows hindering solar power production, ensuring optimal energy yield.
This innovation is particularly advantageous in extremely hot environments, demonstrating its versatility and resilience in harsh conditions, such as deserts. Importantly, the robot's design contributes to water conservation, a crucial factor in arid regions, as it minimizes water usage during the cleaning process. Powered by five electric motors, this cleaning robot employs two horizontal and two vertical motors for precise movement along rows of solar panels. Additional motors are dedicated to rotating microfiber components, ensuring effective cleaning while maintaining stability in vertical motion. With an operational capacity of 54 square feet in just 30 seconds, the robot initiates its cleaning process at sunset, strategically avoiding any shadow impact on electricity generation. Overall, the SOLA BRUSH cleaning robot stands as a sustainable and efficient solution for enhancing the performance and longevity of solar panels in diverse environmental conditions.[3]

Fig.3.7.1 SOLARBRUSH solar cell cleaning robot [3]

3.8 Cleaning Machine For Photovoltaic Panels

The cleaning machine, as illustrated in Figure 1 (6), integrates a washing system with a low-

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pressure water jet (~2 bar) and a brushing mechanism for photovoltaic panels. R&D institutes, ICTCM Bucharest and INOE 2000 – IHP Bucharest, collaborated to develop the mechanics, kinematics, and mechatronic drive system. The machine is mounted on a Toyota Hilux utility vehicle and features a 180° rotatable pivot, driven by a toothed rack-gear wheel mechanism. A hydraulic cylinder (14) controls the left or right movement of the rack, while a hydraulic cylinder (2) adjusts the arm's inclination. A hydraulic motor (32) facilitates brush rotation, and nozzles on the brush holder ensure waterjet washing. The hydraulic cylinders (2 and 14) constantly correct the brush's vertical and angular positions due to panel mounting irregularities and terrain variations along the route. The utility vehicle also carries a hydraulically driven water pump, a hydraulic station for driving motors, a combustion engine powering hydraulic pumps, and a water tank for washing. The energy source for the hydraulic station is a 4.5 kW diesel engine running at 2200 rev/
[7]

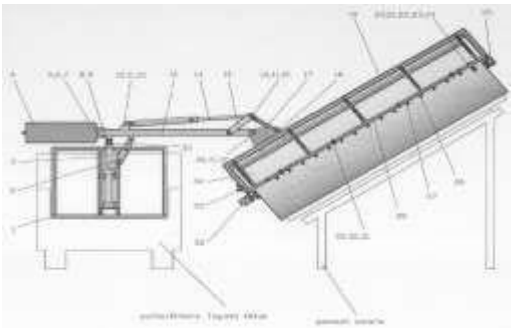

Fig.3.8.1 Cleaning machine for photovoltaic panels [7]

4. Conclusion

The comprehensive review of solar panel cleaning mechanisms and techniques highlights a diverse range of approaches in design and fabrication. Various cleaning methods, such as robotic systems, waterbased solutions, and self-cleaning coatings, have been explored to address the efficiency challenges posed by dirt and debris on solar panels. The observed mechanisms include both mechanical and automated systems, each exhibiting unique strengths and limitations. While some mechanisms focus on precision and targeted cleaning, others emphasize costeffectiveness and simplicity. It is evident that the choice of cleaning technique depends on factors like environmental conditions, panel materials, and energy requirements. Despite advancements, challenges like water scarcity for cleaning and potential damage during mechanical cleaning persist. In conclusion, ongoing research and development are essential to refine existing mechanisms and explore novel approaches. A holistic strategy considering environmental impact, costeffectiveness, and adaptability is crucial for widespread implementation. As the solar energy sector continues to grow, optimizing panel cleaning processes becomes imperative for maximizing energy output and sustaining the long-term viability of solar power.

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