Solar Panel Cleaning System - A Brief Review

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Abstract: This paper looks at how cleaning systems for solar panels are really important for making them work well and last a long time. When dust, dirt, and other things build up on solar panels, it can make them not work as well and might even damage the whole system. The paper talks about different ways to clean solar panels, like using robots, water, or special coatings that clean themselves. It also looks at how well these methods work, how much they cost, and how they affect the environment. The paper considers where the solar panels are, what the weather is like, and what kind of panels are being used. It also talks about new technologies and ideas in this area, saying that we need customized cleaning solutions to keep getting energy from solar power and help the environment.

1. INTRODUCTION

In recent years, solar energy has emerged as a pivotal player in the global shift towards sustainable and renewable energy sources. As photovoltaic (PV) technology continues to make significant strides in efficiency and affordability, the maintenance and performance optimization of solar panels have become critical considerations. Among the various factors influencing the efficiency of solar panels, cleanliness stands out as a key determinant. The accumulation of dust, dirt, pollutants, and other environmental debris on the surface of solar panels can hinder their ability to capture sunlight effectively, thereby diminishing energy output.

This comprehensive review paper aims to provide a thorough examination of the latest advancements in solar panel cleaning systems, addressing their design principles, operational mechanisms, and performance evaluations. By synthesizing the existing literature on the topic, we aim to offer insights into the diverse array of cleaning technologies currently available and their respective strengths and limitations. Additionally, the review will explore emerging trends, innovations, and potential future developments in the field of solar panel cleaning, shedding light on the industry's trajectory towards enhanced sustainability and long-term viability.

The significance of maintaining optimal cleanliness in solar panel installations cannot be overstated, especially as the demand for clean energy continues to rise. This review paper seeks to contribute to the evolving discourse on solar panel maintenance by consolidating knowledge, identifying gaps in current research, and paving the way for future advancements in this critical domain.

2. LITERATURE REVIEW

2.1. Photovoltaic Panel Cleaning Systems

Cleaning solar panels is crucial for maintaining their efficiency. Two common cleaning agents are pure water and alcohol-based cleaners. During winter, alcohol-based cleaners are preferred to prevent freezing on cold panels. Although alcohol-based cleaners may leave water on the panels, they are effective in preventing frost. Pure water is the most used cleaning material, as it does not stain the panels. This ensures that sunlight can easily reach the panels after cleaning, allowing for optimal absorption. Cleaning with pure water also enhances safety. Since pure water is non-conductive, the risk of high voltage is eliminated during the cleaning process, reducing the chance of accidents. Additionally, the hazard of corrosion is eliminated.

There are three methods for cleaning photovoltaic panels: mechanical cleaning, manual cleaning, and electrostatic cleaning. The paragraph mentions ongoing efforts to develop robots that can utilize these methods for cleaning solar panels. These robotic solutions aim to automate and improve the efficiency of the cleaning process.

2.1.1. Mechanical Cleaning

Cleaning solar panels is crucial for maintaining their efficiency. Pure water and alcoholic cleaners are commonly used for this purpose. During the winter season, alcohol-based cleaners are preferred to prevent freezing on the panels due to cold weather. Despite leaving water on the panels, these cleaners are effective in preventing frost. Pure water is the most

common cleaning material, especially because it does not stain the panels and ensures that sunlight can reach them without obstruction.

Using pure water for cleaning also offers safety benefits. Since pure water is not conductive, the risk of high voltage issues is eliminated during the cleaning process, and there is no corrosion hazard. There are three main methods for cleaning photovoltaic panels: mechanical cleaning, manual cleaning, and electrostatic cleaning. Various studies have been conducted to develop robots that can clean solar panels using these methods.

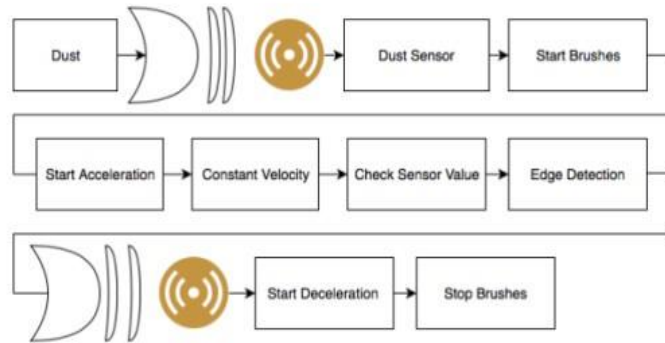Fig. 4: Mechanical cleaning of solar PV panels [12].

Figure 3 System structure of Solar Panel Cleaning Robot [7]

One such system is the Cleaning Robot System (PPVCRS) developed in the United Arab Emirates, where deserts surround the area. This solar cleaning robot is equipped with an object-based sensor design to detect dust on the panels. The robot features a cleaning brush driven by a motor, moving vertically along the top and bottom of each panel to cover the entire array. The system is designed to be expandable for easy adaptation to different panel sizes. The robot's structure includes a dust sensor that activates the cleaning brushes when dust is detected. Once the cleaning process is complete, the robot repositions itself, slows down, stops, and changes direction to find new dust particles, ensuring thorough and efficient cleaning**.**

2.1.2. Electrostatic Cleaning

Solar power plants are usually built in dry areas, but the presence of dust and sand in these areas reduces the efficiency of solar panels. To address this issue, there is a method called electrostatic cleaning. This method involves using a special sheet under the solar panel with electrodes. When sand or dust falls on the panel, the electrodes create a flipping motion that removes the dust particles. A study in Japan found that applying low-frequency, high-voltage electricity, tilting the panel, and minimizing initial dust loading resulted in effective cleaning. This method had low power consumption, and only a small amount of residual dust remained after multiple cleanings. This technology is expected to improve the efficiency of large solar power plants in dusty regions.
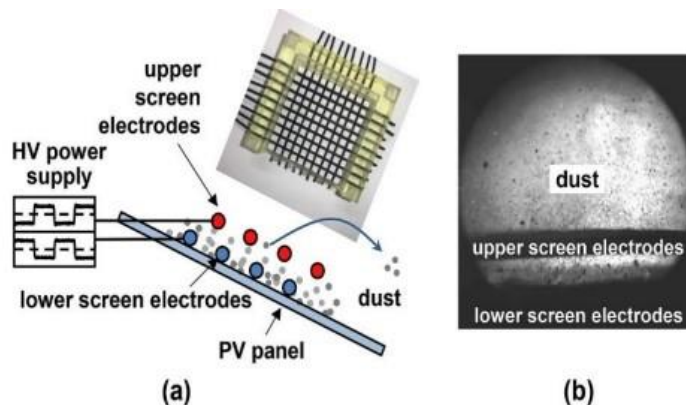
The electrostatic cleaning system's structure is illustrated in above Figure. By applying a high AC voltage between the parallel screen electrodes, Coulomb and dielectrophoresis forces act on dust particles near the electrodes. The electrostatic field activates the dust particles, and some particles pass through openings in the upper screen electrode due to their inertial forces.
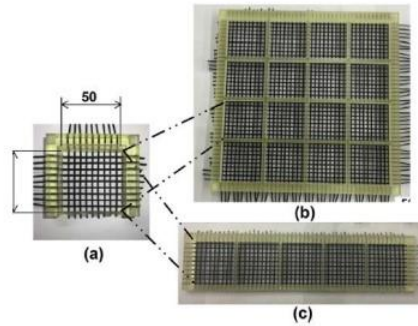

Figure 8 Cleaning devices. Parallel screen electrodes are attached in plastic frames in lattice geometry. (a) small device (b) wide device (c) long device [5]

In the study, three types of cleaning devices were created: small, wide, and long. The small device was used to test the basic performance of the system, while the larger devices demonstrated practical performance for full-sized solar panels, as shown in Figure 8. This research suggests that electrostatic cleaning could be a promising solution to maintain the efficiency of solar panels in dusty environments.

2.1.3. Manual Cleaning

Manual cleaning is a common way to clean solar panels. People decide when to clean based on how dirty the panels look. They clean the panels with pure water about once a month. In Figure 11, there is a picture of a cleaning machine controlled by a person. But doing it by hand takes a long time and can cause damage to the panel surface because of rough brushing. Manual cleaning applies uneven pressure. Too much pressure can harm the panel, and too little won't clean it well. Also, the panels are high up, making it hard for cleaners to reach all parts by hand. So, cleaning by hand isn't a good idea [4].

Figure 11 Manuel cleaning method [18]

The main problem with manual cleaning is that staff decide when to clean. If they don't choose the right time, the electricity generated by the panels goes down. Also, it costs extra money to pay people to clean the panels.

3. EFFECT OF DIFFERENT DUST POLLUTANT ON THE PERFORMANCE OF PHOTOVOLTAIC

Dust can make solar panels less efficient. Different places have different types of dust, like particles from wind, vehicles, volcanoes, and pollution, which are all called dust if they are smaller than 500μm. Dust can contain tiny particles from

various sources, like plants, fibers, and minerals. The type of dust depends on where the solar panels are located. In cities, pollution is higher due to more people and industry, causing more dust and debris
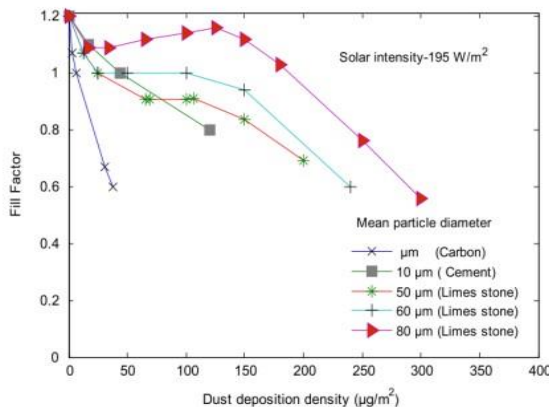

Fig. 10: Showing that fill factor is decreasing with dust collection [18].

When dust settles on solar panels, it reduces the amount of sunlight they can absorb, affecting their performance. The type of dust, its size, and how it accumulates on the panels matter. Some studies found that certain types of dust, like carbon particles, absorb sunlight quickly, affecting the panel's temperature and performance. The researchers identified 14 compounds in the dust, including magnesium oxide, aluminum oxide, and silicon dioxide. The proportions of these compounds vary depending on the area. The environment also plays a role in dust accumulation, influenced by factors like temperature, humidity, rainfall, and wind speed. Different regions experience different reductions in solar panel performance due to dust.

Studies showed that dust accumulation can significantly reduce the output voltage, short-circuit current, and power yield of photovoltaic panels. For example, one study found up to a 40% reduction in short-circuit current and a 34% reduction in power output due to dust. Another study indicated a 10%, 16%, and 20% reduction in conversion efficiency for different amounts of dust accumulation. Different types of pollution, like red soil, ash, sand, calcium carbonate, and silica gel, also affect solar panel performance. Reducing dust accumulation is crucial to maintain the efficiency of solar panels, especially in areas with high pollution and dust levels.
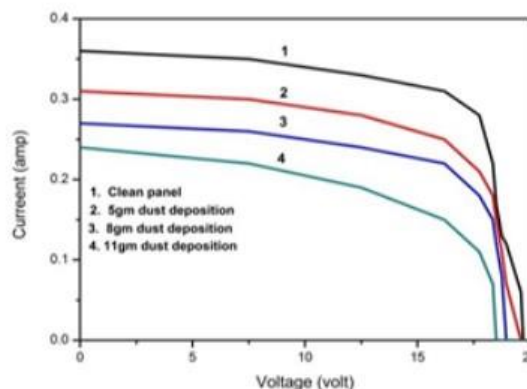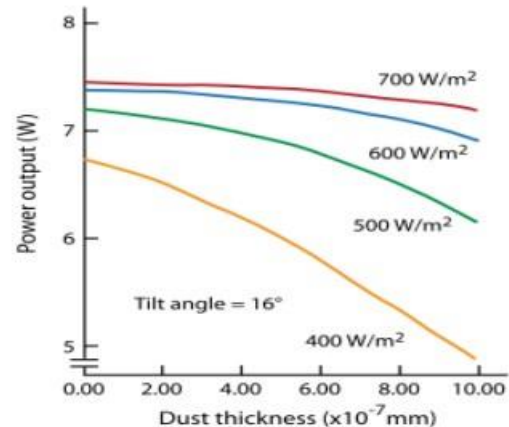

Fig. 12: I-V characteristic of the PV module with limestone dust deposition [2].

4. POWER LOSS DUE TO SOILING ON SOLAR PANEL

Solar energy comes from the sun and can be turned into electricity using photovoltaic (PV) technology. This technology uses solar cells made of semiconductors to absorb sunlight and convert it into electrical energy. Currently, solar energy is important for providing clean and sustainable power globally. However, the efficiency of PV systems is limited to 15-20% due to the nature of semiconductors used in solar cells. To improve efficiency, enhancements like sun trackers and maximum power point tracking controllers have been added to PV system installations.

Solar panels are designed to produce the best output, influenced by changeable and unchangeable variables. Changeable variables allow flexibility in design, while unchangeable variables must be adapted to by default. These factors impact the configuration, design, installation, and operation of solar panels. As larger PV power plants are built, especially in the upper MW and GW power ranges, more attention is needed to address challenges that directly affect power generation efficiency.

The characteristics of a PV module are illustrated through power-voltage or current-voltage curves. These curves show that PV output power depends on solar irradiance and cell temperature. Low irradiance and high temperature can reduce power output. Each curve has a point called the maximum power point (MPP), where the PV module delivers the most power to the load. Besides solar irradiance and cell temperature, the performance of a PV module is influenced by factors like the reliability of other system components and environmental conditions. This section provides a description of these additional factors.

4.1. Nameplate DC rating: The nameplate DC rating, also called sticker DC power rating, shows the highest power a solar module can produce under specific test conditions, mentioned by manufacturers. However, there might be errors in actual performance compared to this rating. One source of error is measurement inaccuracy during testing by manufacturers. Additionally, some modules may experience light-induced degradation when exposed to sunlight for the first time, but they stabilize after a few hours of operation.

4.2. Diode and Connection loss: Bypass diodes are used in solar power systems to protect photovoltaic (PV) modules when they are partially shaded. They help prevent power loss caused by shading. There are two types of connection losses in PV systems. One is power loss, which happens when bypass diodes are used for protection. The other is resistive loss, occurring when PV modules and electrical components are connected to form PV arrays. In 1997, Herrmann and colleagues investigated hot spots in solar cells related to bypass diodes. When PV cells are connected in series, shaded cells can become reverse biased, leading to power dissipation in the form of heat.

4.3. Mismatch losses: Mismatch losses occur when solar panels with different characteristics, specifically current-voltage (I & V) ratings, are connected. Even modules from the same production line in a factory may not have identical characteristics. This mismatch causes a compromise in voltage and current when connected in series or parallel, resulting in total power output less than the sum of individual module outputs. Researchers, like Samad et al in 2014, have explored minimizing mismatch losses. Their study suggests using a genetic algorithm to arrange PV modules in arrays, which proved more effective than traditional sorting techniques in reducing mismatch losses.

4.4. DC and AC Wiring: DC and AC wiring loss comprises of the resistive losses of the cables and wires used throughout the whole PV plant from the PV including the whole route from the PV module to the main power grid.

4.5. Sun-Tracking loss: Sun tracking loss happens when solar panels are not positioned correctly or are misaligned due to mechanical issues. A study by Hossein Mousazadeh in 2009 explored ways to maximize solar panel output using sun-tracking methods. They looked at various tracking systems and found that the most effective and commonly used device is in the form of polar-axis and azimuth/elevation types. These systems ensure optimal orientation of the panels to capture the most sunlight and improve the overall efficiency of the solar panels.

4.6. Shading losses: Shading loss happens when buildings, trees, or nearby objects cast shadows on solar panels (PV modules). This reduces the sunlight reaching the panels, affecting their performance because their output depends on sunlight. When shaded, the relationship between current and voltage becomes non-linear, causing power loss in the PV system. Studies show that shading can lead to power loss ranging from 10% to 70%.

4.7. Soiling losses: Soiling losses happen when dirt, dust, and other particles cover solar panels, reducing their power output. Dust, often less than 10 mm in size, comes from various sources like wind, volcanic eruptions, and vehicles. Accumulated dust worsens this effect, impacting energy production on a daily, monthly, and yearly basis.

5. Critical studying in dust

The performance of solar panels, specifically focusing on the impact of environmental factors like dust, soil, bird droppings, and other elements on the efficiency of photovoltaic (PV) systems. Despite improvements in PV technology,

these external factors can lead to inefficiencies in the system's performance. The paragraph highlights a three-month test near Boston, Massachusetts, which found a 1% loss of solar radiation due to dust accumulation on PV panels. It mentions a study in California that aimed to provide a more accurate model for predicting soiling losses throughout the year, challenging the conventional assumption of a constant annual soiling loss. The study indicated an average daily efficiency reduction of 0.2% in dry weather without rainfall.

Additionally, the paragraph discusses studies conducted in Iraq, emphasizing the potential for solar energy harnessing but acknowledging the challenges posed by dust storms and pollution. Iraqi researchers explore the causes of dust storms, including heavy metal pollution from various sources. The findings emphasize the importance of considering environmental factors in designing and maintaining efficient solar energy systems.
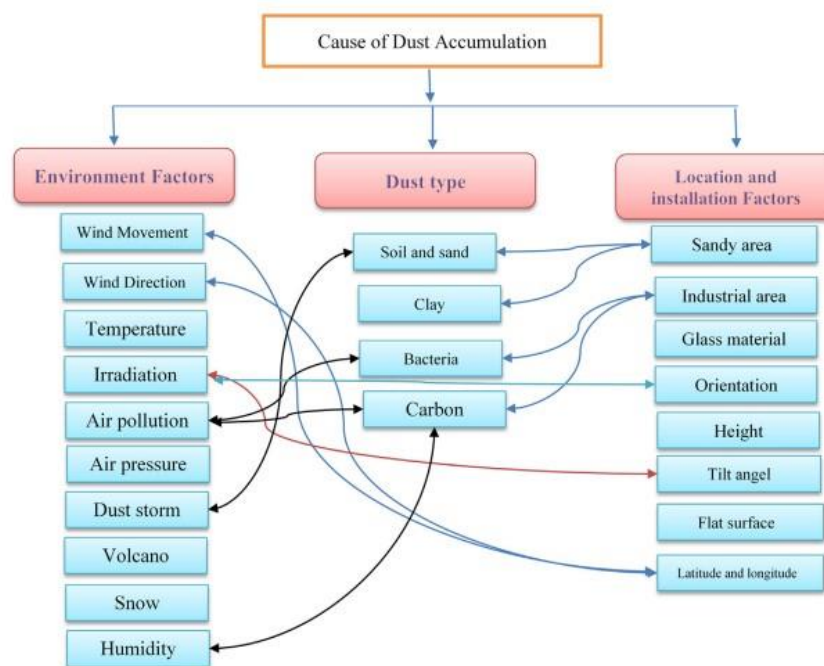
5.1. Cause of dust accumulation

Fig. 4. Cause of dust accumulating on the surface of solar arrays.

The accumulation of dirt on solar panels is influenced by two main things: the type of dust and the environment where the panels are located. The dust's characteristics, such as size, components, shape, and weight, matter. For instance, in Malaysia, the acidic dust can erode the panel surface. The local environment, including human-made surroundings, vegetation, and weather, also plays a role. The condition of the panel surface is crucial; a rough surface allows more dirt to collect. The panel's position, based on sunlight and wind direction, matters too. A horizontal surface accumulates more dust. Wind speed is important; a slow breeze leads to accumulation, while a strong wind clears the surface. However, wind flow can vary across the panel, affecting dirt accumulation.

With many studies conducted in the USA and Asian countries. Dust, especially from sand and soil in Asian regions and deserts in Africa, reduces solar panel power output by 2% to 50%. The paragraph highlights factors influencing soiling and suggests areas for future study.

5.2. Dust removal from PV (Solution)

Cleaning the surface of solar panels is not a popular topic among researchers. Some may think that the rain in certain areas is enough to keep the panels clean. However, dirt can still affect the energy produced even in rainy places. There are different ways to clean solar panels:

Rainfall: Rain is free, but it may not be reliable, especially during intense soiling or insufficient rain.

Wind: Wind can help a bit, but water is still needed for optimal cleaning and power generation.

Manual Cleaning: This method is like cleaning windows. Brushes with special bristles scrub off the dirt. Some brushes connect to water for simultaneous washing. A ladder may be needed for hard-to-reach places.

Mobile Cleaners: Machines are used for cleaning, and a water supply or sprinkler system is effective. Experts recommend cleaning weekly in dry seasons and daily for heavy dust.

In summary, relying solely on rainfall may not be enough to keep solar panels clean. Manual cleaning with brushes or using mobile cleaners with water supply systems are recommended methods to maintain the efficiency of solar panels.

6. ANALYSIS AND OUTLOOK

This review discusses the current state of using smart systems to monitor and clean solar panels. The authors suggest that future assessments can be better planned and integrated by using harmonized data structures. They emphasize the importance of real-time data from solar panel sites for making optimizations. The review identifies some gaps and recommendations, such as the need for more research on communication technologies, cloud platforms, and their analytical soundness

The authors also note that there is a lack of theoretically based research on smart systems for solar panels, hindering progress. Most smart solar panel case studies are in Asia, mainly by Indian and Chinese institutions. The review points out that there are gaps in understanding the optimal cleaning frequency and costs, and more data is needed to prove these factors. Additionally, the modeling of energy output degradation is seen as crucial for making solar plants more reliable, considering the impact of weather conditions on dirt accumulation. Overall, the review highlights the need for more comprehensive and theoretically grounded research in the field of smart systems for solar panel monitoring and cleaning.

7. CONCLUSIONS

In conclusion, this comprehensive review paper delves into the significance of maintaining optimal cleanliness in solar panel installations, emphasizing its critical role in enhancing energy output and overall efficiency. With the increasing global shift towards sustainable energy sources, solar energy has become pivotal, and the paper underscores the importance of addressing factors like dust, dirt, and pollutants that can hinder solar panels' ability to capture sunlight effectively.

The literature review section provides a detailed exploration of various cleaning methods, including mechanical, electrostatic, and manual cleaning, along with emerging technologies like cleaning robots. The paper emphasizes the need for tailored cleaning solutions to suit different environments, considering factors such as weather conditions and the types of solar panels used.

Furthermore, the review identifies key factors contributing to power loss in solar panels, such as soiling, shading, and mismatch losses. It sheds light on the impact of different dust pollutants on the performance of photovoltaic systems, emphasizing the importance of mitigating dust accumulation to maintain efficiency.

The analysis and outlook section of the paper highlight the gaps in current research, particularly in the realm of smart systems for solar panel monitoring and cleaning. It calls for more theoretically based research, especially in regions outside of Asia, where most smart solar panel case studies have been conducted. The review underscores the need for a deeper understanding of optimal cleaning frequency, costs, and the modeling of energy output degradation. In essence, the paper serves as a valuable resource for consolidating knowledge, identifying research gaps, and paving the way for future advancements in the maintenance and optimization of solar panel systems.

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