

PAPER 58– MITIGATING DUST IMPACT: A COMPREHENSIVE OVERVIEW OF SOLAR PANEL CLEANING DEVICES FOR MAXIMIZED PERFORMANCE

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ABSTRACT

Solar energy usage is rapidly increasing as people become more aware of the limited availability of nonrenewable energy resources such as coal, wood, and gasoline. This review analyzes different solar panel cleaning systems, examining their technical aspects and efficiency. It explores challenges related to panel cleanliness, including dust accumulation, dirt deposition, and their effect on system performance. Thanks to technological advancements, solar panels can now be used in domestic and industrial applications. Rural areas that do not yet have proper electrical connections are now opting for solar panel installations and using solar panels on streetlights. This article gives an insight into the causes of the inefficiencies of solar panels. The main inefficiency was the system's inability to adapt to changes in the sun's position, for which solar tracking systems with solar panels were installed. Another issue that has caused some concern is the accumulation of dust clouds on solar panels. The accumulation of dust and dirt on these solar panels has been observed to reduce system efficiency by approximately 23-50%. This article highlights the performance of existing cleaning devices with their cleaning techniques and gives recommendations based on their design and efficiency improvement.

KEYWORDS: Cleaning Devices, Efficiency, Renewable Energy, Solar Energy, Solar Power

1. INTRODUCTION

The current global energy crisis has resulted in a heightened focus on utilizing clean energy sources instead of depending on fossil fuels. Solar power is among the potential renewable energy sources that show promise. Recent investments in renewable energy have underscored the appeal of solar energy, considered a highly attractive alternative, only behind wind power. Unfortunately, According to a study conducted by (Al-Otaibi et al., 2015), various environmental elements have the potential to impact the energy production of solar panels. One such factor is the accumulation of dust, which has been observed to substantially influence the overall efficiency of photovoltaic modules (Kumar et al., 2015). Studies by Nahar & Gupta (1990) demonstrated that the buildup of dust on unclean cell surfaces can cause performance to decline by as much as 20% each month. Additionally, (Goossens & Van Kerschaever 1999) experiments revealed that high wind speeds encourage dust accumulation on surfaces.

This research paper encompasses three main components, each addressing a distinct aspect of the technology under review. The first part delves into the issue of dust and its effects on solar technology. The second part focuses on the techniques employed for cleaning solar panels, and the third is the performance evaluation of existing solar panel cleaning mechanisms. The literature reviewed for this study covers the papers published from the 1990s to 2022. The methodology of this work revolves around a pair of key questions: (1) What consequences arise from dust accumulation on photovoltaic (PV) panels? and (2) What strategies exist for alleviating and cleansing dust buildup on PV panels?

2.0 CONCEPT OF DUST AND CHARACTERISTICS AND HOW DUST IS ACCUMULATED

"Dust" refers to any substance that becomes airborne, including dust and soil particles (suspended dust), fog, smoke, and particulate matter. These substances come from organic and inorganic land sources, such as sandstorms, volcanic emissions, forest fires, bacteria, pollen, factory emissions, and solid particles that persist in the atmosphere for extended periods and can travel long distances with wind movement are also included. Dust varies greatly in distribution, volume, concentration, and shape. Dust storms, being a natural phenomenon, extend beyond national boundaries, and there is a noticeable rise in their severity and occurrence frequency due to growing desertification and decreasing vegetation coverage, significantly negatively impacting human and socioeconomic development at both national and regional levels. (Guo et al., 2015; A. A. Kazem et al., 2014)

However, this dust buildup on solar panels, as shown in Figure 1, also termed "soiling," significantly affects the efficiency of PV systems, particularly in areas with little to no rainfall for several months during a dry season, in a study by El-Shobokshy & Hussein (1993). The effect of various particles commonly present in the atmosphere, including limestone, cement, and carbon particles of varying sizes, is considered. Studies have shown that fine carbon particulates with an average size of $5\mu\text{m}$ pose a substantial threat to the performance of PV panels. The accumulation of these carbon particles on the panel's surface leads to considerable power output losses. These particles primarily originate from combustion processes and are commonly found in carbon emissions.



Fig. 1 Dust accumulation on panel surface Source: (Walz et al., 2018)

2.1 EFFECT OF DUST ON SOLAR PANEL

The impact of dust accumulation on PV panels has been heavily researched due to its significant effect on efficiency, particularly in desert countries in the solar belt region. Mazumder et al. (2014) found that the deposition of only 4 g/m^2 of dust with particle diameters ranging from 0.5 to 10 μm can cause up to a 40% reduction in the electrical efficiency of the cell. Dorobantu et al. (2011) analyze the consequences of traffic-related pollution. Surprisingly, it was discovered that even a thin layer of dust and pollutants can result in a significant decline of up to 20% in PV performance, which may increase up to 40% with continued accumulation. Furthermore, Zorrilla-Casanova et al. (2011) examined the daily energy generation of a PV system throughout the year. The findings revealed an average daily energy loss of approximately 4.4% attributable to dust accumulation, which could increase to 20% in the absence of precipitation for extended periods.

Similarly, Rahman et al. (2012) conducted laboratory experiments with artificial dust and found that efficiency reduction could reach up to 50%. In hot climates with no precipitation, Kimber et al. (2006) found that daily efficiency reduction could be as much as 0.2%, resulting in up to a 56.2% decline in productivity annually, depending on the system's location. Generally, from the results discussed, photovoltaic cells are reduced by up to 40% as the area of dust deposition increases. However, the next section discusses techniques and technologies employed to prevent dust accumulation.

3.0 PV CLEANING TECHNIQUES: REVIEW AND CLASSIFICATION

Prior research has indicated that a rainfall amount of 5 mm is satisfactory for cleansing photovoltaic systems (Sulaiman et al., 2011). Nonetheless, our analysis of the systems revealed that certain designs necessitate a notably higher level of rainfall to achieve comprehensive module cleanliness. During rains, a thorough cleaning effect is observed, rejuvenating the performance of soiled cells to their initial levels. Surprisingly, even light rainfall below 1mm proves sufficient to cleanse the cover glass, reducing daily losses to less than 5% (Chen et al., 2020). However, dust accumulation can cause daily losses exceeding 20% in prolonged periods without rain, like summer. The mean daily energy loss in a year caused by dust is 4.4% (Moharram et al., 2013). Except for the summer months, where the scarcity of rainfall facilitates dust buildup, the monthly averages of daily energy losses remain below 2%. However, during this particular season, the absence of rain significantly increases losses, surpassing 15%. (Yao et al., 2022). Note that the summer months witness the peak of energy production, making the potential negative impact of dust particularly significant during this period. (Zorrilla-Casanova et al., 2011). Since natural cleaning system such as rainfall is not sufficient and efficient for cleaning the PV system, especially

in locations with low rainfall, researchers have devised various techniques to clean up the solar panel to increase their efficiency.

3.1 FORCED AIRFLOW OF AIR CONDITIONING SYSTEMS

Assi & Hassan (2012) proposed a method to increase the efficiency of solar panels by removing dust and reducing their temperature. The technique utilizes forced airflow from air conditioning systems to clean the panels. The airflow from the air conditioning system's fans is directed toward the solar panels to remove dust. This method has been implemented in the United Arab Emirates. It can also be used in other developed countries where air conditioning is widely used and has an efficiency of about 73%.

Similarly, the self-cleaning solar system developed by Tanesab et al. (2016) utilizes forced airflow from air conditioning systems to remove dust from solar panels. The system applies to all roofs and has proven effective in maintaining solar panels' efficiency. This method can reduce the maintenance cost of solar panels and increase their lifespan. However, this technique has not been proven to have high efficiency at cooling and cleaning photovoltaic cells.

3.2 NATURAL CLEANING USING RAIN AND WIND

The way rainwater falls on a tilted PV panel can be used to clean the surface naturally. PV panels are typically fixed at an angle to maximize exposure to sunlight. However, this cleaning method is imperfect because it does not entirely remove all the dust from the surface. As a result, some dust particles remain on the surface due to their interaction with atmospheric moisture. These particles can only be removed by heavy rain. However, this method can be unreliable in areas with severe pollution and insufficient rainfall. A study by Kimber (2007) found that after a light rain, a layer of clay is formed on the PV surface, causing a dramatic drop in electricity generation. Wind can also naturally clean PV surfaces exposed to it, especially when the wind is moderate in speed and does not produce dust. Although it is challenging to predict precipitation times and amounts, rainfall can increase the efficiency of the PV surface by preventing or reducing pollutant accumulation.

3.3 WATER CLEANING

In this method, a hose channel flows water to the PV surface, as shown in Figure 2, cleaning up the buildup of dust particles. Many water pumps are required to achieve the required high pressure. Modern methods sometimes mix compressed water with a special cleaning agent that aids efficient cleaning to enhance dust removal. Water can also be used to cool PV panels, similar to cleaning the panels with rainwater. However, one significant drawback of this method is water availability in areas where it is scarce (Deb & Brahmabhatt, 2018).

Furthermore, this situation leads to notable water depletion and the potential for chemical sedimentation along the edges of the PV panels. Employing high-pressure water pumps entails consuming PV-generated power, thereby reducing overall efficiency. Moreover, there exists a risk of water pipe obstruction or damage, along with the possibility of thermal shock to the heated PV panels when water descends, given that it will almost inevitably be cooler than the surface of the plates.



Fig. 2. Fully automated water cleaning system Source: (H. A. Kazem et al., 2020)

3.4 MANUAL CLEANING

This method involves using soft-bristled brushes, similar to those used for cleaning building windows, to eliminate accumulated dust from the PV panels, as shown in Figure 3. This method supplies washing water directly to the brushes, making it more efficient than the natural method of cleaning PV with rainwater or compressed air. However, there are some drawbacks to this method. Direct contact of the brush with the PV surface may result in

slurry, as the movement and pressure of the brushes cannot maintain equally across the entire surface. Additionally, this method is more expensive than other cleaning methods, requiring skilled labour to be effective (Deb & Brahmhatt, 2018).



Fig. 3. Manual cleaning technique Source: (Khadka et al., 2020)

3.5 MECHANICAL CLEANING TECHNIQUE

The cleaning of photovoltaic (PV) panels is important for maintaining their efficiency, and several methods have been developed to remove accumulated dust and dirt. One such process involves using soft-bristled brushes similar to those used to clean building windows. However, direct contact between the brushes and the PV surface can result in slurry, which can be detrimental to the PV's efficiency. Al Shehri et al. (2017) conducted a practical examination to enhance PV efficiency by utilizing nylon, cloth, and silicone rubber foam brushes to address this issue. The study outcomes demonstrated that certain materials favourably impacted PV efficiency without any adverse long-term consequences. Figure 4 shows a mechanical PV cleaning device.



Fig. 4 Mechanical PV cleaning device Source: (Rai et al., 2019)

3.6 ELECTRICAL SCREENS (EDS)

An alternative approach to PV cleaning is using electro-dynamic display (EDS) technology, an innovative EDS system developed to efficiently eliminate accumulated dry dust without needing water or mechanical components.

This system utilizes a high-voltage electric field generated on a screen, effectively charging dust particles and facilitating their removal by propelling them beyond the edge of the plate surface. (Deb & Brahmhatt, 2018). Even though the system is faster and more efficient, the system requires a high-voltage supply to power the system. And also It is ineffective for cemented or wet dust particles and is easily affected by ultraviolet rays (Deb & Brahmhatt, 2018).

3.7 SELF-CLEANING ULTRASONIC

One effective cleaning method is standard high-frequency ultrasound, which operates at frequencies above human hearing and can reach up to 20 kHz. This technique is particularly useful for removing various water contaminants, such as polishing compounds, mould grease, dirt, and oil release agents. It can also clean materials such as metals, glass, and ceramics (Vasiljev et al., 2013).

3.8 ELECTROSTATIC CLEANING SYSTEM (ECS)

The automated cleaning technique known as the electrostatic cleaning system (ECS) offers a solution for maintaining the cleanliness of solar cell panels. In the presence of accumulated dust particles on the PV panel, the ECS employs electric charges to dislodge and effectively remove dust from the surface. Applying a high AC voltage to parallel screen electrodes on the panel generates electrostatic forces, which exert an influence on particles located in proximity to the electrodes. This doubles the electrostatic repulsion, effectively removing the dust particles without causing mechanical friction on the panel surface (Kawamoto & Shibata, 2015). Some drawbacks to this system include high voltage requirements in operating the system and the inability to clean tiny dust.

3.9 ROBOTIC CLEANING SYSTEM (RCS)

Robotic cleaning systems (RCS) are a viable alternative to manual cleaning, offering superior precision and accuracy without human intervention. RCS systems offer numerous benefits, such as minimal water usage, convenient control, and exceptional effectiveness. These systems can be seamlessly integrated with two primary cleaning approaches. The first method involves dry cleaning, while the second method entails wet cleaning, which incorporates water or other water-based liquids for effective cleansing. (Deb & Brahmhatt, 2018). Overall, the system is automated and highly flexible (Farrokhi Derakhshandeh et al., 2021). Figure 5 shows a robotic PV panel cleaning device.



Fig. 5 Robotic PV cleaning device Source: (Moreno et al., 2006)

Table 1 summarizes the solar PV cleaning devices reviewed in several works of literature. The table summarizes the advantages and disadvantages of the techniques used in solar PV cleaning.

Table 1 Comparison of cleaning methods

S/N	Cleaning System	Advantages	Disadvantages
1	Forced airflow of the air	Carry out dry cleaning effectively. Do not require any power conditioning systems as it utilizes the rejected air from air conditioning units.	The operation of this system relies on AC power. Prolonged exposure to hot air can potentially diminish PV

			efficiency, making it crucial to minimize its duration.
2	Natural cleaning using rain	No cost or resources	It is weather related method.
3	Water cleaning system (Heliotex cleaning system (HCS))	highly efficient in eliminating dust particles and effectively covering all areas of the PV panels. The cleaning process can be performed using either cooled or heated water, depending on the specific requirements.	This approach necessitates the utilization of water, a pump, and a controller. Depending on the circumstances, either stationary systems or designated vehicles are employed to carry out the cleaning process.
4	Manual cleaning	Environment-friendly, no electricity is needed,	human intervention is required, costly, and it needs water. Scratching happens sometimes.
5	Mechanical cleaning (Brush Cleaning System)	Mechanically remove the dust using a brush	Scratching happened sometime.
6	Electrical screens (EDS)	Effective and efficient dust particle removal with no moving part required.	It is costly and requires a high voltage, converter, and signal device.
7	Super-hydrophobic aircraft (SHOP)	No moving parts. However, natural rain or dew is useful. No need	No need for water or human intervention.
8	Super water jet (SHIP)	No moving parts are used majorly to break down dirt and dissolve it.	Reduce the screening efficiency due to coating
9	Self-cleaning ultrasonic	It's safe and reliable	It has some noises
10	Electrostatic cleaning system (ECS)	It has a high cleaning performance quickly while consuming little energy and power.	For large-scale commercial solar systems, it is not advisable to implement this method due to the need for a high-voltage function, which utilizes a powerful electric field.
11	Robotic cleaning system (RCS)	Offers superior precision and accuracy cleaning without human intervention.	They may not be suitable for cleaning large commercial solar systems, and the sensors used in RCSs may not be effective in all environments.

4.0 RECOMMENDATIONS FOR FUTURE RESEARCH

The preceding overview and discourse present a method for developing a suitable cleaning system by considering essential factors and characteristics when deciding on a recently developed and employed automated cleaning system, it is essential to carefully consider several significant factors to choose the most suitable technology from various mechanical cleaning systems. Depending on the solar farm's size, geographical location, and the prevailing environmental conditions such as pollutant levels, humidity, and temperature, a customized combination of cleaning methods can be devised and put into practice, such as using a combination of a mechanical cleaning system and a robotics cleaning system. An example would be designing a cleaning system that utilizes mechanical means, such as brushes powered by an Arduino board with a microcontroller that can be remotely operated.

5.0 CONCLUSION

This article discusses various automated methods for cleaning solar panels that have been studied. Solar panels experience a range of weather conditions throughout the year, which encompass factors like soil, dust buildup, air pollution, and avian excrement. Researchers have examined several cleaning methods for solar panels, which have positively impacted their performance. This paper indicates that the efficiency of Mechanical cleaning is moderate, with the lowest efficiencies being associated with forced airflow of air and water cleaning. Furthermore, the considerable disadvantages of RCSs include their expensive nature and the extensive duration required for the cleaning process. Therefore, engineers and designers should be mindful of these shortcomings in dusty regions when utilizing RCS, despite its typical robustness and suitability for large solar farms. If minimizing cleaning time is crucial, ECS may be a viable alternative with minimal time wastage. However, it may not be suitable for use in arid regions or where human intervention is restricted. Other cleaning mechanisms have demonstrated satisfactory labor and water usage indicators.

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