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An automated and cost-efficient method for photovoltaic dust cleaning based on biaxially oriented polyamide coating material

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Abstract. Photovoltaic (PV) systems have been at the forefront of renewable energy technologies. However, they are highly dependent on environmental parameters that affect their performance and longevity. Dust accumulation presents a critical factor in the performance of PV systems, leading to minimum system efficiency under largely dusty conditions. Several cleaning methodologies have been proposed in scientific literature to prevent dust accumulation at the forefront of PV modules. However, most cleaning methodologies are cost-consuming, time-consuming, complex in implementation, or require huge manpower to implement them. This paper proposes a cost-efficient and automated method for dust accumulation prevention and cleaning based on Biaxially Oriented Polyamide (BOPA) coating material. This transparent thin film is applied on the front surface and integrated based on an automated control scheme, for controlled rotation every 2 weeks, to prevent dust accumulation on the forefront of the PV surface. The performance of the BOPA coating film was experimentally assessed for 45 days, assessing the irradiance and electrical performance of the PV modules. The application of BOPA maintained a PV module electrical efficiency of 12.19%, while the dusty PV module electrical efficiency is reduced to 7.79% at high dust accumulation levels. Moreover, the BOPA material has demonstrated its ability in capturing solar irradiance, without losses for the visible light, hence maintaining an electrical current of 2.15 A, while the dusty PV module loses its electrical current by 40%, maintaining an electrical current of 1.28 A.

Introduction

Renewable energy resources (RES) have been at the forefront of electricity generation, due to their active contribution to clean energy generation and improved efficiency [1]. Renewable energy has been deployed due to its environmental and technical advantages in integration within the primary energy mix [2–4]. Solar energy has attracted attention in renewable energy technologies due to its abundance, reliability, and zero-cost availability [5,6]. Photovoltaic (PV) systems have been developed for the useful harvesting of solar energy, and its ability for clean energy generation and minimize the carbon footprint [7].

The global demand for solar power generation has been rapidly increasing, leading to the evolution of technology and being commercially available [8–10]. Therefore, it is essential to continuously develop the technology for efficient operation and generation [11]. Dust

accumulation on the front surface of PV modules has been a commonly reported issue in the effectiveness and applicability of PV technologies [12]. Particularly, regions such as the Middle East, China, North Africa, India, and the United States have been developing PV plants with a capacity of Gigawatts. However, such regions are exposed to dusty conditions and harsh weather conditions, leading to severe degradation in PV system performance [13–15]. Dust accumulation is considered a critical factor in regulating the electrical efficiency of a PV system, specifically when large accumulation occurs.

The scientific literature focused on several methods to clean and sustain PV modules, preventing the severe impact of soiling [16–18]. The cleaning may occur naturally through rainfall or wind. Other cleaning methods have been introduced such as manual cleaning, dry cleaning based on a robotics system, electrostatic cleaning, and preventive cleaning based on coating materials.

As aforementioned, the cleaning techniques are of many types with each having several advantages and disadvantages. Natural cleaning techniques are relatively low cost due to the utilization of the natural gravity of water or wind. However, it's not physically possible to induce rainfall or wind in specific regions, particularly depending on the dust particle volume [19,20]. Additionally, manual cleaning benefits from minimum power consumption and allows for periodical cleaning. However, high labor costs are a drawback and other potential hazards may harm the system or laborers [21]. Furthermore, the installation of sprinklers is of good beneficial ability in cleaning PV systems under short periods with feasible installation [22], however, high water consumption and non-uniform cleaning are a potential drawback [23]. Recently, the development of robots for automated cleaning has allowed for the reduction of damage on PV module surfaces and lowering the of energy consumption, through dry cleaning. However, their operation and maintenance require significant investment, and their applicability is limited to small PV plants [24]. Emerging technologies such as electrostatic cleaning and surface coating materials are still developing and need to be studied for their effectiveness due to their cost and coating properties [25–28].

This paper proposes a cost-effective and simple methodology for dust cleaning based on the application of Biaxially Oriented Polyamide (BOPA) film. A thin layer of BOPA is assessed in outdoor experimental conditions in the terrestrial conditions of Sharjah, UAE. An automated and control scheme is proposed for rotation of the transparent layer every 2 weeks, to maintain PV modules in clean conditions for 45 days. The study assesses the impact of dust accumulation on solar irradiance and electrical performance, proposing a cost-efficient solution for dust cleaning and PV module maintenance.

Research Method

This research paper presents an experimental study conducted at the University of Sharjah during solar noon in November and December 2023. The experiment involved two identical photovoltaic (PV) panels, one serving as a reference and the other coated with a colorless and thin layer of Biaxially Oriented Polyamide (BOPA). The power output of both panels was measured before and after dust accumulation. The methodology included four distinct cases: Case one involved cleaning both PV panels to determine the power reduction caused by the BOPA coating. In cases two through four, varying degrees of dust accumulation were applied to the reference panel to observe its impact on power generation. The performance of photovoltaic (PV) panels is crucial for their practical application in solar energy systems. Dust accumulation on PV panels is a common issue, particularly in arid regions like the United Arab Emirates [29,30].

Several strategies have been proposed to mitigate the effects of dust on PV panel performance, including the application of coatings. This study focuses on investigating the effectiveness of a Biaxially Oriented Polyamide (BOPA) coating in enhancing the power output of PV panels under dusty conditions. By conducting a series of experiments with controlled dust levels, this research

aims to provide empirical evidence supporting the efficacy of BOPA coatings in improving PV panel performance.

Biaxially Oriented Polyamide (BOPA) film offers a comprehensive spectrum of properties, making it a versatile choice for using it as a coat to the PV [31]. Its exceptional thermal stability ensures resilience to high temperatures, facilitating processes like heat sealing and sterilization. Coupled with impressive mechanical strength, BOPA provides robust protection during transportation and handling, ensuring the integrity of the coated PV [32]. Furthermore, its clarity and transparency options enhance product visibility and aesthetic appeal allowing the sunlight to reach the panel clearly, while its inherent chemical resistance safeguards against various substances, including oils and greases [33]. Embracing environmental sustainability, BOPA can be recycled and designed to reduce material usage, aligning with eco-conscious coating initiatives. This amalgamation of thermal resilience, strength, clarity, chemical resistance, and sustainability renders BOPA an indispensable solution across industries seeking performance and environmental responsibility in PV coating [34].

The following methodology was employed: Selection and Preparation of PV Panels: Two identical PV panels were chosen for the experiment. One panel was left uncoated (reference panel), while the other was coated with a colorless and thin layer of Biaxially Oriented Polyamide (BOPA). Both panels were cleaned thoroughly before the experiment to ensure baseline performance.

Experimental Setup

The PV panels were positioned outdoors during solar noon to receive maximum sunlight. The experimental setup included instruments for measuring the power output of the panels before and after dust accumulation. Fig. 1 demonstrates a diagram for the experiment setup.

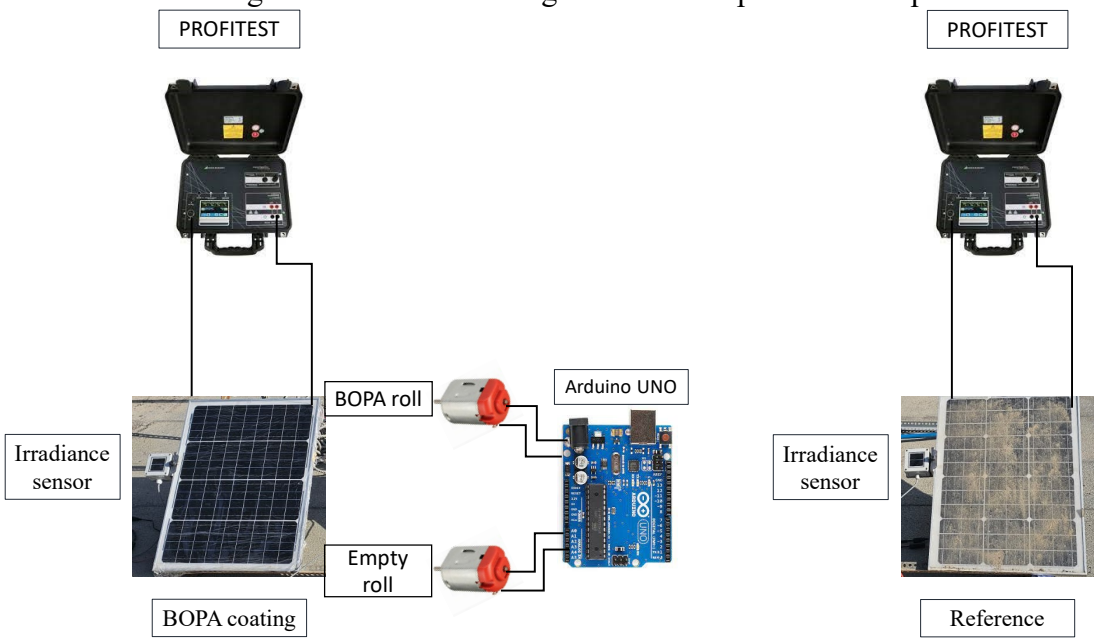

Fig. 1. Experimental setup with and without BOPA coating

The Profitest is used in this experiment to calculate the current, voltage, and power and it works as a load to the PV panel.

Dust Accumulation Procedure: Dust accumulated onto the panels for 45+ days for both panels. Four distinct cases were considered:

a. Case One (Clean Panels): Both PV panels were cleaned to determine the power reduction caused by the BOPA coating alone (day 1).

b. Case Two (Light Dust): After one week, the panels were subjected to light dust accumulation.

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c. Case Three (Moderate Dust): The panels were exposed to a higher level of dust accumulation compared to case two after 3 weeks.

d. Case Four (Heavy Dust): The panels were heavily dusted after 45+ days.

The coating roll for the coated panel was connected to two small DC motors (6V) connected to Arduino Uno, this Arduino was programmed to power the motors for a short time allowing the coat to roll over the panel and have a new coat to the top of the panel, the number of rotation needed increases with time. The average number of rotations was measured (3.5 full rotations on average needed to cover the panel) so the motors were programmed to rotate 3.5 rotations every two weeks anticlockwise, one motor will rotate the BOPA roll and the other one will collect the dusty roll.

The coat was fully rotated and renewed every two weeks, keeping the panel clean and dust-free. The power output of both panels was measured before and after dust accumulation in each case. The data obtained were analyzed to assess the impact of the BOPA coating on PV panel performance under varying levels of dust accumulation. To calculate the cost a simple equation was used.

The number of rotations that the roll can cover the panel (R) is equal to the length of the roll (L_r) divided by the length of the panel (L_p), where the width of the roll and the panel are equal.

$$R = L_r / L_p \quad (1)$$

Then we divide R with 26.5 which is the number of weeks that the roll will rotate per year. Finally, the number of years is divided by the price of the BOPA roll, which gives 0.11 AED per rotation.

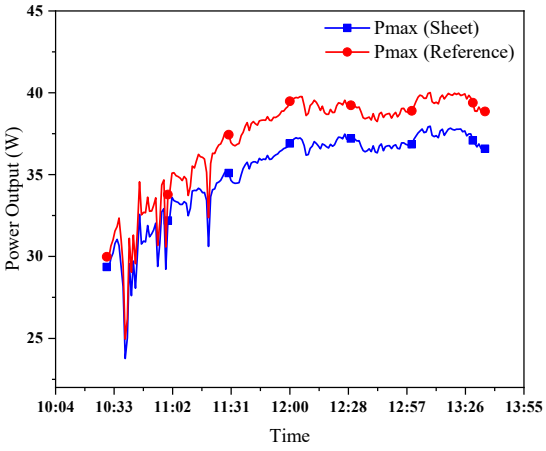
Experimental Results

The experimental results demonstrate that the BOPA-coated panel mostly produces more power than the uncoated reference panel, only after dust accumulation. These findings underscore the potential of BOPA coatings as a practical solution for optimizing PV panel performance in arid regions with high dust levels. Fig. 2 demonstrates the power produced in each case.

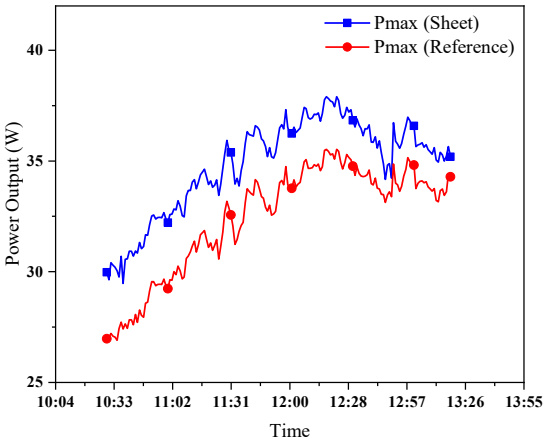
The results of the experiment indicate that the BOPA-coated panel outperformed the reference panel in all cases of dust accumulation. The reference power was more than the BOPA-coated only when both the panels were clean, because of the characteristics of the BOPA (thin and colorless) the reduction of the power was not high. The power output of the coated panel exhibited minimal reduction compared to the uncoated panel, demonstrating the effectiveness of the BOPA coating in mitigating the adverse effects of dust.

This study provides empirical evidence supporting the efficacy of BOPA coatings in enhancing the performance of photovoltaic (PV) panels under dusty conditions. The experimental results demonstrate that the BOPA-coated panel produces more power than the uncoated reference. The data in Table 1 shows that the BOPA coat is more effective when the dust accumulates, the reference power gets lower when the dust accumulation is high. The dust affected the irradiance, causing a reduction in the current and the power. In the fourth case, the efficiency was 4.4% improved with the coat, and 12.51 W increased in terms of power, even though it caused a 5°C increase in the overall temperature, and only 9 watts in 20s was the power needed for the two motors once every two weeks. Comparing other methods in the literature such as robotics systems

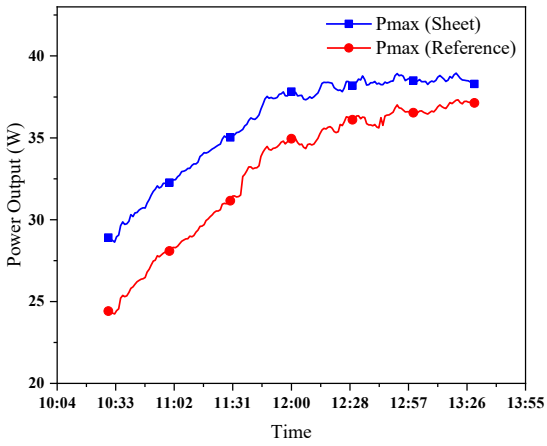
and electrostatic cleaning consume more power for a longer time and require more maintenance.



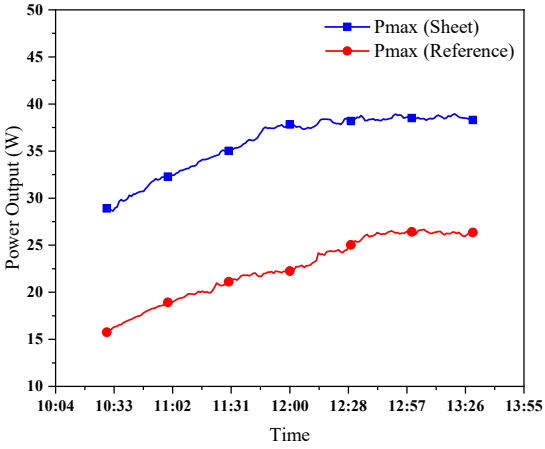
case one Both panels are clean and one is coated



case two the reference panel got light dust accumulation



case three the reference panel were subjected to higher level of dust accumulation



case four the reference panel got heavily dusted

Fig. 2. Comparison of PV modules output power generation

Table 1. Summary of solar irradiance and electrical performance for coated and reference PV module

	Case one (ref)	Case one (coated)	Case two (ref)	Case two (coated)	Case three (ref)	Case three (coated)	Case four (ref)	Case four (coated)
Current (A)	2.19	2.17	1.84	2.11	1.93	2.23	1.28	2.15
Power (watt)	37.17	35.17	32.42	34.69	32.97	35.98	22.54	35.05
Irradiance (W/m2)	807.30	763.62	704.37	744.68	730.80	796.50	490.82	762.16
Efficiency (%)	12.93	12.24	11.53	12.00	10.95	12.35	7.79	12.19

Summary

This study has demonstrated the utilization of Biaxially Oriented Polyamide (BOPA) Coating material as a method for the prevention of dust accumulation. The proposed methodology introduced a thin film of BOPA material, optimizing the PV module performance in arid regions with high dust accumulation levels. An automated controlled scheme was integrated to allow rotation of film every 2 weeks, ensuring clean PV modules across an experimental period of 45

days. The findings suggest that BOPA coatings hold promise as a viable solution for improving the performance and longevity of PV modules under dusty conditions, through the improvement of solar irradiation exposure and electrical performance. The maximum electrical efficiency is maintained up to 12.19% with the BOPA material as compared to 7.79% under the highest dust accumulation. Additionally, solar irradiation is significantly reduced under high dust accumulation, leading to a severe reduction in electrical current, proving the viability of the proposed cleaning method. Further research may focus on optimizing the properties of BOPA coatings for maximum effectiveness and durability in real-world applications.

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