Dust Accumulation Effects on the Performance of Photovoltaic Panels: An Experimental Study in the Algerian Region of El-Oued

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Abstract – *This paper examines the dust accumulation impact on the performance of photovoltaic panels in the Algerian region of El-Oued, where two similar photovoltaic panels were analyzed: a clean reference photovoltaic panel (PVr) and a dirty targeted photovoltaic panel (PVt) with 14.5 g/m² of dust. The data was collected on May 4th and 13th, 2022, through experimental works and numerical validation. The results show that dust significantly reduces the PV performance. On May 4th, 2022, the PVr produced 330.89 Wh, compared to 216.72 Wh for the PVt, with a difference of 34.65%. On May 13th, 2022, PVr generated 414.01 Wh, while PVt produced 271.16 Wh, with a difference of 34.67%. In terms of PV power generation, PVr reached maximum values of 52.82 W and 66.28 W on May 4th and 13th, respectively, compared to 34.5 W and 43.29 W for PVt. The PVr performance varied between 5.85% and 6.56%, while that of PVt was limited to 3.82% and 4.29%. These results highlight the importance of keeping photovoltaic panels clean to ensure optimal energy production, especially in desert environments like El-Oued,. Moreover, the study confirms that regular panel maintenance is essential to minimize power reduction due to dust and guarantee maximum panel efficiency.*

Keywords: Photovoltaic panels; Dust accumulation; Experimental study; Numerical validation; Power generation; Energy performance.

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I. Introduction

Working operation of photovoltaic (PV) panels under various conditions is extensively studied by researchers around the world [1]. They include analyzes of photovoltaic systems connected to the electricity grid, demonstrating the impact of optimal system design and orientation on energy efficiency. It also evaluates the performance of solar panels at different tilt angles, finding that tighter tilts are more efficient. Additionally, studies have investigated how high temperatures in desert environments affect the production of photovoltaic panels, showing significant degradation in performance. Finally, it evaluates hybrid photovoltaic/thermal (PV/T) systems, comparing different working fluids to determine which provides the best thermal and electrical efficiency [2-5].

The aforementioned studies contribute nuanced understanding of the renewable energy landscape in Algeria, offering valuable insights to improve energy efficiency, reduce CO2 emissions and advance sustainable energy technologies. Research by a research group encompasses an in-depth look at Algeria's transition to renewable energy and its impact on environmental sustainability. A study assesses the asymmetric effects of fossil fuels, renewable energy and technological innovation on CO2 emissions, highlighting the complex interplay between different energy sources and their contributions to environmental mitigation [6]. Another study focused on Algeria's strategic shift towards a green hydrogen future, exploring how renewable energy integration and climate changes are shaping the country's path [7]. Complementing these perspectives, a research on the state of renewable energy potential in Algeria with a comprehensive overview of current renewable energy usages and future opportunities [8]. Additionally, experimental studies on optimal tilt angles for photovoltaic panels in El-Oued and investigations on the performance of solar power plants driven by linear Fresnel reflectors and parabolic collectors provide practical insights into the optimization of solar energy systems in the region were carried out in [9-11].

In recent years, the country has intensified its efforts to diversify its energy resources, by increasingly integrating renewable energies with traditional dominated hydrocarbons power plants [12,13]. In the field of solar energy, Algeria has launched several large-scale projects, such as photovoltaic and thermal power plants, to meet the growing demand for electricity while reducing its carbon footprint. However, despite significant progress, the full potential of renewable energy remains underutilized, hindered by challenges such as inadequate infrastructure, high investment costs, and the need to develop local technological capacity and expertise [14].

Despite the challenges, the Algerian government remains committed to advancing initiatives aiming at increasing the role of renewable energy sources in the national energy mix [15]. The governmental efforts are part of a broader vision to position Algeria as a regional leader in the renewable energy sector. Consequently, the future of photovoltaic electricity in Algeria is very promising, with significant growth and development potential in the next years [16]. The country's exceptional levels of solar radiation, among the highest in the world, provide an ideal basis for the development of photovoltaic energy. This unprecedented solar potential allows Algeria not only to sustainably meet its own energy needs, but also to become an important contributor to regional and global renewable energy markets [17, 18].

Researchers focus on evaluating the performance and efficiency of photovoltaic (PV) power plants in Algeria, with particular attention to the unique environmental conditions of the Saharan climate. By conducting a detailed case study of a photovoltaic power plant in Tamanrasset city [19] , where the overall effectiveness of the plant and its sub-areas, analyzing factors such as energy production, efficiency and region-specific operational challenges. In parallel, the research also undertakes an evaluation of the performance of large-scale photovoltaic plants located in the Saharan climate, using real operational data [20]. This approach provides a comprehensive understanding of how these systems operate in extreme desert conditions, providing valuable insights into their reliability, effectiveness and potential areas for improvement. The results are essential for optimizing photovoltaic installations in similar environments, thus contributing to the development of more robust and efficient solar energy solutions in Algeria and other desert regions.

Other scientific works have explored innovative strategies for optimizing PV systems, focusing on design and performance aspects by integrating a V-shaped cavity with small-scale linear Fresnel reflectors, where the study presented a low-concentration approach that maximizes sunlight capture and improves PV efficiency [21]. In addition, a general algorithm was developed to optimize the arrangement of PV modules on irregularly shaped roofs, thus ensuring maximum power output [22]. Also, research has evaluated the technical performance of grid-connected and rooftop PV systems, providing insights into power output, reliability, and grid integration [23]. To optimize these systems, the Sailfish Optimizer, inspired by the predatory behavior of sailfish, was used to model PV modules more efficiently, providing accurate performance predictions and enabling systematic and improved design choices [24]. Therefore, these developments contribute to more efficient adaptable, and reliable PV systems, driving wider adoption of PV systems..

In this paper, experimental works and numerical analysis are conducted to elaborate the impact of dust and dirt accumulation on the performance of photovoltaic panels in the Algerian region of El-Oued. This city, known for its arid climatic conditions and strong sunshine, is an ideal location for the installation of solar panels. However, these same conditions lead to significant dust accumulation on the panels, which can highly reduce their efficiency. Therefore, the objective of this research is to quantify this effect and to better understand how the PV performance is degraded by dust, both through experimental observations and numerical simulations. The importance of this topic lies in the need to maximize the efficiency of PV installed in desert regions like El-Oued, where solar energy production is essential to meet the growing energy demand. Furthermore, improving the profitability and sustainability of solar projects in such challenging environmental conditions by implementing regular maintenance

II. Materials and Methods

II.1. Photovoltaic panels

The main objective of this study is to evaluate the impact of the presence of dust, with a density of 14.5 g/m², on the performance of PV panels, where two PV panels were used for this experiment: The first, called the reference PV panel (PVr), is oriented towards the south with an inclination angle of 33° and is completely clean. The second panel, designated as the targeted PV panel (PVt), has the same experimental characteristics as the first but is covered with dust and dirt with a density of 14.5 g/m².
The experiments were carried out over two days, May 4th and 13, 2022, on two RAGGIE PV panels, model RG-M165W, 165 watts with similar technical characteristics, as the study took place in the Algerian region of El-Oued (33.57°, 6.77°, and 50 m).The main experimental steps are as follows:

- Acquisition of two PV panels, each with a capacity of 165 watts, technical characteristics are shown in Figure 1.
- Manufacture of metal supports for PV panels, as these supports allow movement in both directions: vertical, to adjust the inclination according to the height of the sun, and horizontal, to follow the path of the sun from east to west. These steel structures are designed to hold the panels in vertical and horizontal positions.
- Acquisition of measuring instruments for climatic conditions, including a PYR 1307 pyranometer for global solar radiation, an anemometer (AM-4206M) for wind speed, and the same model of anemometer to measure ambient temperature.
- Acquisition of equipment for measuring electrical parameters, such as an MX 20 digital multimeter (METRIX type) to measure current, and a CT44053 digital multimeter (CROWN type) to measure voltage. It should be noted that the electrical resistance was fixed at 4.6 Ω using a variable resistive load of the ECODIME type.

Figure 1. Photovoltaic panels and their technical characteristics

II.2. Reference and target electrical circuit

As shown in Figure 2a, the first circuit, called the "reference electrical circuit" (RC), includes the PVr, an MX 20 digital multimeter (METRIX type), an ECODIME electrical resistance set at 4.6 Ω, all connected in series, and a CT44053 digital multimeter (CROWN type) used to measure the electrical voltage is coupled in parallel with the variable resistive load.
The second circuit, illustrated in Figure 2b, designated the "targeted electrical circuit" (TC), includes the PVt, an MX 20 digital multimeter (METRIX type), an ECODIME electrical resistance set at 4.6 Ω, also connected in series, and a CT44053 digital multimeter (CROWN type) is similarly coupled in parallel with the variable resistive load to measure the electrical voltage.

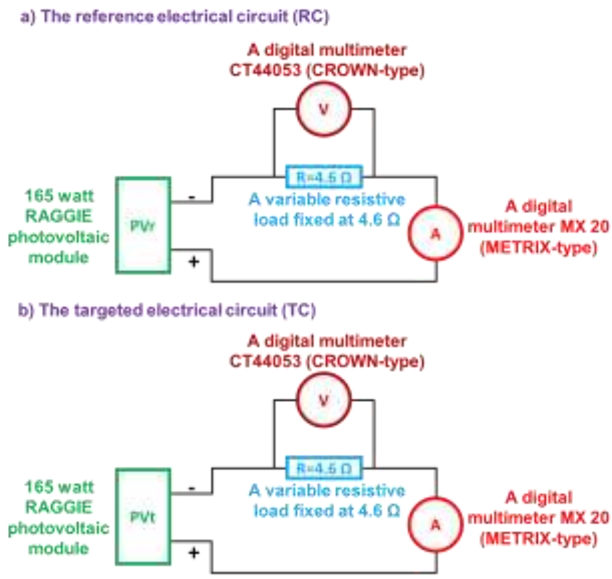

Figure 2. Studied electrical circuits

The experimental conditions applied to the studied photovoltaic systems are demonstrated in Table 1. The equations that control the energy balance of the examined photovoltaic system are as follows:

$$P = I \times V \quad (1)$$

$$\eta = \frac{P}{A_{PV} \times I_G} \quad (2)$$

Where P is the PV power (W), I is the electric current (A), V is the electrical voltage (V), η is the PV performance efficiency (%), A_{PV} is the effective PV aperture (m²), and I_G is the measured global irradiance (W/m²).

Table 1. Experimental conditions applied to the studied PV systems

	PVr			**PVt**		
Day	**Tilt angle (°)**	**Tracking system**	**Effective aperture condition**	**Tilt angle (°)**	**Tracking system**	**Effective aperture condition**
May 04th, 2022	33	Stationary and oriented to the south	clean	33	Stationary and oriented to the south	Dusty and unclean
May 13th, 2022	33	Stationary and oriented to the south	clean	33	Stationary and oriented to the south	Dusty and unclean

III. Results and Discussion

III.1. Weather data

PV productivity is closely linked to changes in climatic conditions because the latter directly influence the quantity of solar energy captured and converted into electricity, with solar radiation being the most important factor.. However, other parameters such as air temperature also play a crucial role, too high temperatures can reduce the efficiency of PV cells by increasing their internal resistance. Likewise, wind speed can influence the temperature of the panels, contributing to their cooling and thus affecting their performance. Therefore, climatic variations, such as changes in solar radiation, ambient temperature, and wind speed, have a direct impact on the efficiency and productivity of PV panels. Hence, the importance of adapting PV systems to align with site conditions is vital to obtaining maximum efficiency.

As shown in Figure 3, the climate data evolution for the two selected days, May 4th and May 13th, 2022, highlights significant variations in weather conditions, essential for understanding the PV performance. On May 4th, 2022, solar radiation reached its peak at noon with an intensity of 917 W/m², accompanied by the highest temperature of the day, at 29°C, where the wind speed, for its part, reached its maximum of 3.62 m/s at 10h00 before gradually decreasing. On May 13, 2022, solar radiation was more intense, peaking at 1027 W/m² at 11h00, while the highest temperature of 31.27°C was observed at 15h00, and wind speed reached its maximum of 3.24 m/s late in the afternoon, at 17h00. These variations in solar radiation, air temperature, and wind speed for the two days of experimentation are crucial to analyzing the impact of climatic conditions on PV performance, particularly when exposed to the accumulation of dust and dirt.

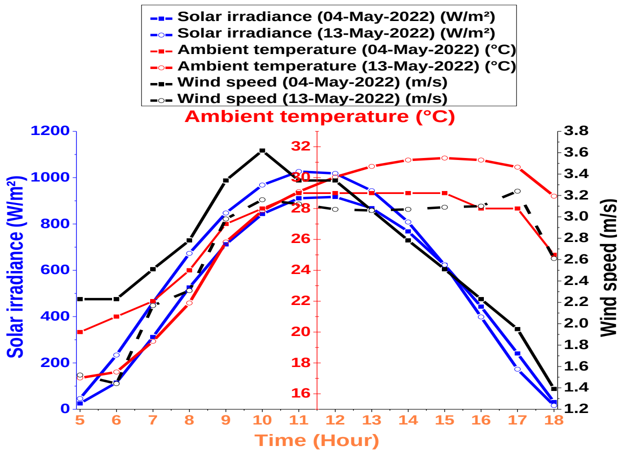

Figure 3. Measured weather data vs. time

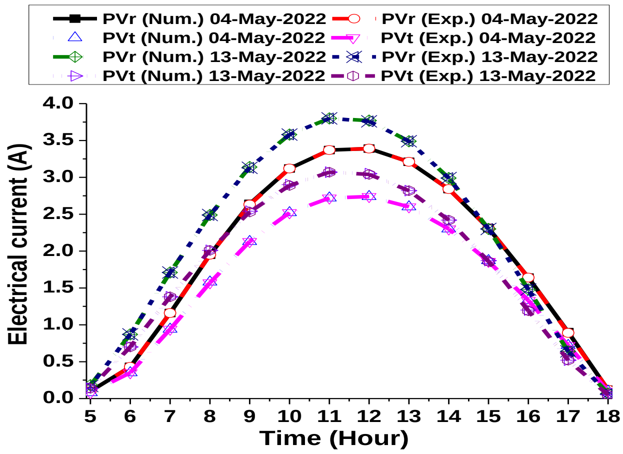

Figure 4. Change in electric current vs. time

III.2. Electric current evolution

Figure 4 illustrates the impact of climatic conditions and dirt accumulated on the PVt on the electric current intensity generated during the two days of study. On May 4, 2022, the PVr showed an increase in electrical current intensity, from 0.1 A to 3.39 A, in direct correlation with the increase in solar radiation during the day from 25 W/m^2 at 05h00 to 917 W/m^2 at 12h00 . In contrast, for the PVt, covered with dust and dirt, the electric current intensity was significantly lower, varying from 0.08 A to 2.74 A, reflecting the negative impact of dust on PVt performance. On May 13, 2022, a similar trend was observed, as the PVr saw its electrical current increase from 0.06 A at a solar radiation intensity of 16 W/m^2 to 3.8 A at a solar radiation intensity of 1027 W/m^2, with better productivity thanks to more favorable climatic conditions, notably more intense solar radiation. However, the PVt again showed a notable decrease in current intensity, with values ranging from 0.05 A to 3.07 A, despite the improvement in climatic conditions.

These results show that the accumulation of dust and dirt on the PVt surface significantly reduces its ability to generate maximum electrical current, even when climatic conditions are optimal. The dust acts as a partial barrier, limiting the amount of solar radiation reaching the PV cells, resulting in a reduction in the current generation, where this reduction in the PVt efficiency compared to the clean panel (PVr) demonstrates the importance of regular maintenance to keep PV panels at their optimal performance. These results also illustrate the effect of fouling is systematic and persists despite climatic variations, which aids the importance of cleanliness management strategies to ensure efficient energy production, particularly in dusty environments like that of El-Oued.

III.3. Electrical voltage evolution

Figure 5 shows the change in electrical voltage evolution of the PV in response to variations in climatic and operating conditions highlighting the significant impact of dust on the PVt Performance. On May 4, 2022, the electrical voltage of the clean reference PV panel (PVr) increased from 0.53 V to 15.58 V, following the evolution of solar radiation throughout the day. In contrast, the PVt, covered in dust, showed a lower voltage, varying from 0.43 V to 12.59 V, indicating that the presence of dust reduces the panel's ability to achieve maximum voltages. On May 13, 2022, more favorable weather conditions allowed the reference panel to reach an even higher voltage, from 0.28 V to 17.44 V. However, the PVt again showed a lower voltage, ranging from 0.22 V to 14.1 V, despite the increase in solar radiation. This decrease in voltage on the PVt, even under optimal climatic conditions, confirms that the dust accumulation and dirt has a noticeable negative impact on the panel's ability to generate maximum electrical voltage.

These results indicate that dust on the PVt surface acts as an optical barrier that reduces not only the current intensity, as discussed previously but also the electrical voltage. Therefore, the reduction in voltage is directly related to the decrease in the amount of light reaching the PV cells, which limits their ability to generate the electrical voltage necessary to produce electricity efficiently. These observations confirm that dirt on PVt panels not only decreases their overall efficiency but also compromises their ability to perform optimally, even under favorable solar radiation conditions. This once again highlights the importance of regular maintenance of the panels to maximize their performance and guarantee reliable energy production, especially in environments where dust accumulation is common.

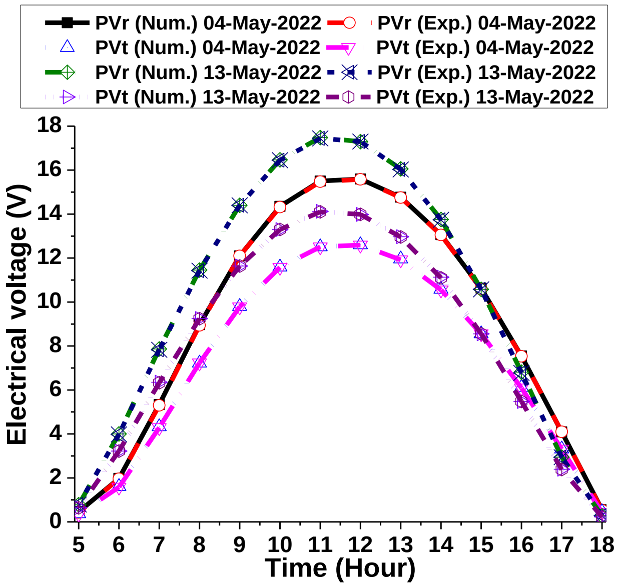

Figure 5. Change in electrical voltage vs. time

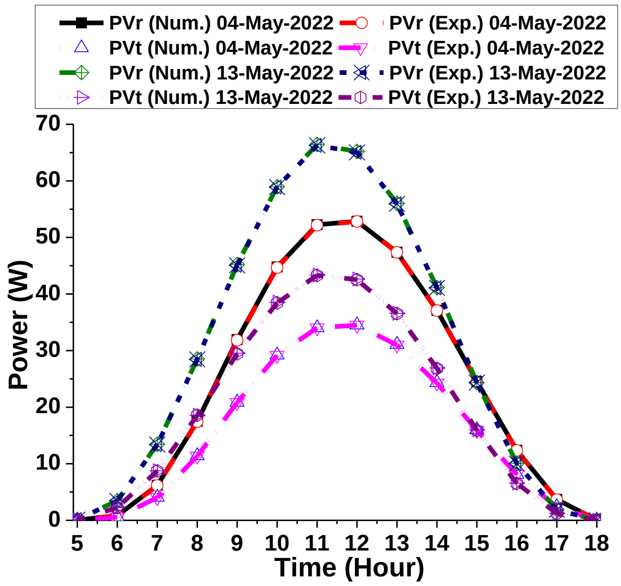

Figure 6. Change in power voltage vs. time

III.4. Electrical power evolution

Figure 6 presents the substantial impact of climatic conditions and fouling on the electrical power generated by the photovoltaic panels during the two study days. On May 4, 2022, the electrical power of the clean reference panel (PVr) increased significantly from 0.064 W to 52.82 W, depending on the change in solar radiation throughout the day. However, for the PVt, covered in dust, the power was notably lower, varying from 0.043 W to 34.5 W, as this significant reduction in electrical power demonstrates that the presence of dust on the photovoltaic panel limits its ability to convert solar radiation into electrical energy optimally. On May 13, 2022, under even more favorable climatic conditions, the PVr reached a maximum power of 66.28 W, while the PVt, despite an improvement compared to the first day (i.e., May 4, 2022), only produced a maximum power of 43.29 W, as this difference in performance, although the two PV panels were subjected to the same climatic conditions. Thus, the PV productivity decreased due to the persistent effect. Analysis of these results shows that dust and dirt accumulated on the PVt not only reduces current intensity and voltage but also reduces the overall electrical power produced, as this reduction in power, observed consistently for the two days of study, reflects the inability of the dirty panel to fully exploit the available solar radiation, even when it is at its maximum.

Figure 7 shows the evolution of the PV performances according to variation in climatic and operating conditions during two days. The PVr performance increased gradually from 0.175% to 5.85% in correlation with the evolution of solar radiation during the day. In contrast, the PVt, covered in dust, showed significantly lower performance, varying from 0.12% to 3.82%, as this notable difference demonstrates that the presence of dust on the PVt reduces its energy efficiency, thus limiting its ability to convert solar radiation into electricity. On May 13, 2022, under even more favorable weather conditions, the PVr performance reached 6.57%, while that of the PVt only reached 4.29%. Despite the better weather conditions, the PVt performance remained significantly lower than that of the clean PV panel (PVr).

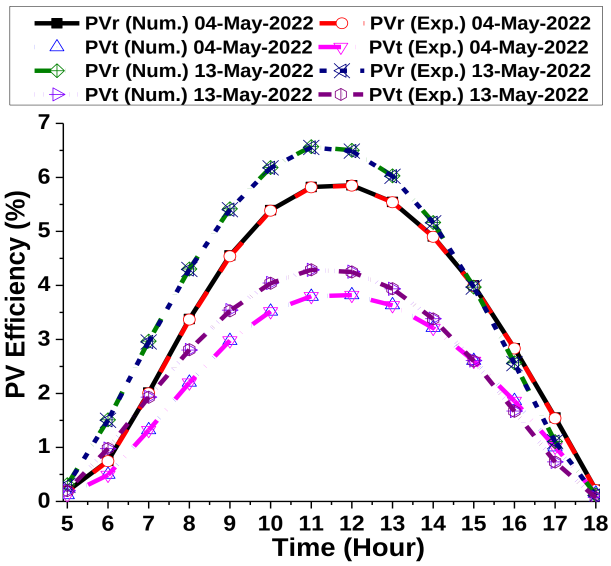

Figure 7. Change in PV performance vs. time.

III.5. Discussion

The experimental results obtained on May 4 and 13, 2022, which are shown in Figures 4 to 7, illustrate the influence of climatic conditions on photovoltaic (PV) performance and the precision of the measuring instruments used. On May 4, 2022, the PVr system generated 330.89 Wh of electrical energy, which is only 0.69 Wh less than the numerically estimated energy. This minor deviation attests to the reliability of the measuring instruments and the rigor of the experimental procedures. Similarly, on May 13, 2022, a higher energy production of 414.01 Wh was recorded, with a deviation of only 0.85 Wh from the numerical forecast. This consistency between the experimental and numerical results not only confirms the precision of the experimental measurements but also demonstrates the direct impact of more favorable climatic conditions, in particular the increase in solar radiation, which peaked at 1027 W/m² at 11h00, allowing the PVr to reach its maximum electrical capacity of 66.28 W.

The results for the PVt system also show a strong correlation between the experimental and numerical data. On May 4, 2022, the PVt produced 216.72 Wh, with a minimum deviation of 0.51 Wh from the numerical estimate. On May 13, 2022, the PVt energy production improved to 271.16 Wh due to better weather conditions, although the measured energy was still slightly lower by 0.7 Wh compared to the numerical prediction. This close agreement between experimental and numerical data further validates the accuracy of instruments and simulation models, while also highlighting the critical role of climatic factors in influencing photovoltaic performance.

A comparison of PVr and PVt systems on the same days reveals the significant negative impact of dust and dirt accumulation on PVt performance. Despite identical climatic conditions, PVt systematically showed a clear reduction in productivity compared to clean PVr. For example, on May 4, PVr generated 330.89 Wh, while PVt only produced 216.72 Wh, indicating a 34.65% reduction in energy production. Similarly, on May 13, PVr produced 414.01 Wh compared to PVt's 271.16 Wh, representing an almost identical reduction of 34.67%. These results clearly illustrate that dust accumulation significantly hampers the ability of PVt to effectively capture solar radiation, leading to a substantial decrease in energy production.

Regular maintenance to minimize dust and dirt on the panels is essential to maximize the energy production and profitability of solar installations. These observations highlight that even in optimal climatic conditions, the presence of dust can seriously reduce the efficiency of photovoltaic systems. Therefore, to maintain high energy efficiency and long-term performance, it is imperative to implement regular cleaning and maintenance strategies for photovoltaic panels, ensuring their efficient operation and maximizing their contribution to energy production renewable.

IV. Conclusion

This work aims to highlight the effect of dust and dirt accumulation on the performance of photovoltaic panels in the Algerian region of El-Oued through experimental and numerical analyses conducted on two separate days, as the results showed that dust and dirt deposition significantly reduces the efficiency of photovoltaic panels.

On May 4, 2022, the clean reference photovoltaic panel (PVr) produced electrical energy of 330.89 Wh, while the dirty target photovoltaic panel (PVt) only generated 216.72 Wh, with a gap of 0.51 Wh between the experimental and numerical results. On May 13, 2022, under more favorable climatic conditions, the PVr reached a production of 414.01 Wh, compared to 271.16 Wh for the dirty panel (PVt), once again confirming the harmful effect of dust on energy generation.

In terms of power generation, the PVr reached peak values of 52.82 W and 66.28 W on May 4th and 13th, respectively, while the PVt reached lower peak values of 34.5 W and 43. 29 W. Similarly, the overall PVr performance varied between 5.85% and 6.56%, while that of the dirty panel only reached 3.82% to 4.29%.

These results clearly show that dust reduces the current intensity, voltage, power, and overall performance of PV panels, underscoring the critical importance of regular maintenance of solar installations to maximize their performance. In a desert environment like that of El-Oued, where dust accumulation is common, the cleanliness of the panels is essential to guarantee optimal and sustainable energy production.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism.

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