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Improving Solar Panel Efficiency with Automated Dust Removal

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Abstract

The rapid growth of the global population has led to raise in energy consumption, resulting in a higher demand for energy production. This production is classified into two categories, conventional and non-conventional sources. Conventional sources of energy release a large amount greenhouse gas, which have detrimental effects on the environment. To combat these negative effects, it is crucial to transition towards non-conventional, renewable energy sources. Conventional energy is more sustainable and clean option compared to fossil fuels. Utilizing technology such as photovoltaic cells can greatly lessen our reliance on traditional energy sources. One challenge that renewable energy faces is the deposition of dust on solar panels, which can decrease their efficiency. Various coatings can be applied to prevent dust buildup, but they do not completely eliminate the issue. This study aims to investigate that how much effectively using an automated mechanical vibrator with a water injector to remove dust and debris from solar panels in which the efficiency of the panel is increased from 18% to 20 %. By improving the maintenance of solar panels, we can increase their efficiency and overall performance in generating renewable energy.

Keywords: Solar panel, mechanical vibrator, water injector, conventional sources, energy production.

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1. Introduction

The growing global population has increased both the demand for and consumption of energy worldwide. The utilization of fossil fuels in conventional methods generates a substantial quantity of damaging greenhouse gases (GHGs) that negatively impact our biosphere. But given that solar energy is renewable by nature and can reduce greenhouse gas emissions from the generation of clean energy, it is a good solution to the world's current energy crisis. Nevertheless, since PV systems are susceptible to global environmental factors, the generation of dust impairs the technology's functionality. Dust is the term used to describe any material or particle in the earth’s atmosphere that is smaller than 500 µm, or ten times the diameter of an individual hair. The term 'dust' refers to coarse solid particles that naturally occur in the environment and do not change in size or composition except through breaking. This includes, but is not limited to, inorganic solids and organic particles such as soil particles, smoke (including smoke from factories, cars, and firewood), volcanic vapor, fungi, bacteria, pollen, microfibers, and eroded limestones [1]. These particles come in various forms, sizes, volumes, and chemical concentrations. The types of particles also vary based on local activities and geographic locations. The accumulation of dirt, dust, and contaminants on a surface is represented as "soiling." This can have a poor impact on the optical disturbance to the transmission of solar irradiance to solar PV cells, reducing entire performance efficiency. Dust collection is considered the third most important factor affecting the efficiency of a photovoltaic module, after temperature and solar radiation. The intensity of soiling varies depending on geographic location and seasonal climate conditions, making it challenging to generalize the level of loss caused by soiling on a PV module [2,3]. Understanding the ramifications of dust deposition and accumulation on photovoltaic (PV) modules is crucial for optimizing their performance, especially in regions like high land temperature, abundant in solar potential yet hindered by low PV integration. This review delves into recent research, offering a comprehensive exploration of PV soiling dynamics. By elucidating the multifaceted factors influencing performance degradation, it aims to equip PV engineers with the insights needed to design advanced systems capable of mitigating dust impacts. Moreover, by considering local variations in dust properties stemming from both environmental factors and human activity, it seeks to empower developers and installers to tailor solutions that resonate with high land temperature unique context. This effort aims to better understand how dust affects solar panel technology. It will inspire new ideas to create solar energy systems that work better in tough environments.

2. Related Work

From the past decade, Mahnoor Rashid a et.al [5] intensive research has scrutinized the cause of dust on PV modules, predominantly in arid regions characterized by high sand content in the air and minimal precipitation, exacerbating rapid dust accumulation. The absence of regular rain necessitates proactive cleaning programs to mitigate inevitable power losses. As PV technology rapidly expands, understanding the myriad factors influencing efficiency becomes increasingly complex. Both internal and external elements, including smoke, aging, irradiance, partial shadowing, structural characteristics, and notably, dust accumulation, contribute to performance fluctuations in photovoltaic modules. Wind-delivered dust layers diminish modules' solar radiation absorption capacity, consequently altering surface temperatures and sunlight intensity. J. Tanesab et.al [6] deposition consequently curtails energy yield, underscoring the critical need for proactive maintenance and cleaning protocols. The cause of dust accumulation on PV panels is profoundly influenced by local conditions, encompassing terrain characteristics, human behavior, and the type of Photo voltaic module deployed. Mitigating these losses necessitates regular cleaning protocols. Research by H. Lu et al [7] underscores that dust accumulation rates are heightened when panels are positioned horizontally above the ground. Maghami et.al [8] deploying solar panels in desert environments poses formidable challenges because the prevalence of blowing dust particles, diminishing panel effectiveness. Studies conducted in Egypt underscore the imperative of frequent cleaning, suggesting intervals as short as every four days, particularly following dust storms Ali et.al[9]. Furthermore, Sulaiman et.al [10] accumulated dust can precipitate efficiency reductions of up to 50% in PV systems. This gradual accumulation phenomenon is exacerbated in arid locales like Egypt. These findings emphasize the critical importance of proactive maintenance strategies to optimize PV performance, particularly in regions prone to rapid dust deposition. M.Z. Al-Badra Et.al[11] Experimental findings reveal significant declines in electrical efficiency over a six-week operational period: panels treated with coatings and mechanical vibrators experienced a 12.94% decrease, while coated panels exhibited a 24.46% drop, and reference panels suffered a 33% efficiency loss. Dust mitigation strategies employing coatings, particularly when combined with mechanical vibration systems, prove effective in cleaning solar panels. Fırat Ekinci et.al [12] the prevailing climatic conditions contribute to the deposition of dust and grime on PV panels, obstructing sunlight penetration. Consequently, regular cleaning becomes imperative to maintain optimal performance. Tareq Salama et.al [13] presents an experimental that setup simulates real-world environmental conditions, incorporating dirt and dust. etao Wan et.al [14] analyses the factors and methods that influence the accumulation of the dust on the solar panel. This research attempts to look into the synergistic benefits of employing photo voltaic panels in tandem with automated mechanical cleaning mechanisms. The electrical functionality of PV panels can be influenced by the introduction of a vibrator and water spraying system. The vibrator's role is to agitate the panel periodically, facilitating the natural dislodging of settled dust three times a day. Girma T. Chala et.al [15] experiment created to clean the solar panel at different inclination angle. Concurrently, water spraying aids in dislodging minute particles, enhancing sunlight absorption. This experimental research looks into the impact of incorporating a mechanical vibrator and water spraying system on a 20-W monocrystalline PV panel. Two panels are evaluated: one with accumulated dust serving as a reference, and the other subject to mechanical vibration and water injection for comparison.

3. Proposed Work

3.1 PV Panels

A specialized hardware prototype has been devised to assess the electrical output as well as efficiency of two identical 20 W monocrystalline PV panels across varying ambient conditions, such as panel temperature and solar irradiance. Here the tangible and electrical specification of the PV panels under scrutiny has 36 cells weight of 1.7 Kg, dimensions of 450 mm length, 350mm of width ,22 mm of height ,20 watts power , maximum voltage at 18.20 Maximum current at 1.10 A with open circuit voltage of 22.40 V and short circuit current of 1.45 A . This meticulous approach enables a comprehensive evaluation of how external factors impact the performance of the panels, offering insightful information about the operational characteristics and potential optimizations We looked at two PV panels: the first is a reference panel that has non coating or vibration, and it was installed at the back of the panel. The second panel has a mechanical vibrator system installed along with water injection. It is measured how much power the PV panel produces.

3.2 Mechanical Vibrator

There has been built a mechanical vibration arrangement with help of 12 Volt DC motor in which the rotor is welded with a 1.97-inch length thread blot gives better vibration compare to half weighted vibration motor to shake the PV panels twice a day. The two main parts of the vibration system are the motor control circuit and charging, as shown in Figure 1.

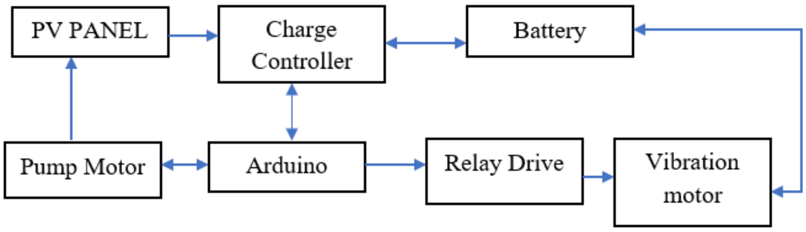

Figure 1. A Block Diagram Showing the Battery Circuit, Pump Motor, and Vibration System.

To facilitate the removal of dust from the panel's surface, the vibration motor is positioned stationary behind the solar panel, away from its surface. The connection between the vibration motor and the PV panel's back is illustrated in Figure 2.

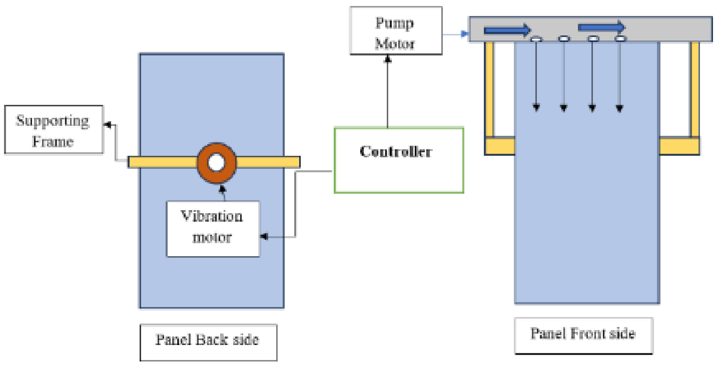

Figure 2. Model Diagram of Vibration and Water Pump Setup in Solar Panel.

The cylindrical vibration motor, also known as a bar-type vibration motor, operates by utilizing an off weight centered attached to its rotational shaft, generating centrifugal force during rotation. This imbalance causes the motor to displace and wobble, hence the term "vibrating motor." Positioned on a base affixed to the PV panel's frame, the motor transmits vibrations to the entire panel. Concurrently, a water pump motor activates, distributing water across the panel's surface. As a result, water along with dust particles slide down the sloped structure. Approximately 18% of the PV panel's total cost is allocated to the vibration and water pumping system, which operates three times daily for a duration of 145 seconds each. The first cleaning cycle occurs at 4 a.m. to pre-empt dew and ensure a clear panel surface at daybreak. The second cleaning at 11 a.m. precedes noon to maximize daytime power output, while the third at 5 p.m. ensures thorough dust removal before day's end. This meticulous cleaning regimen is designed to optimize the panel's efficiency and performance throughout the day.

3.3 Experimental Procedure

The efficiency assessment of two photovoltaic (PV) panels, each consisting of 36 cells with a weight of 1.7 kg and dimensions of 450 mm length, 350 mm width, and 22 mm height, as well as a power rating of 20 watts, maximum voltage of 18.20 V, maximum current of 1.10 A, open circuit voltage of 22.40 V, and short circuit current of 1.45 A, was meticulously conducted over a 5-week period. This assessment included testing both with and without a vibration setup and encompassed varying operational parameters such as solar radiation and panel temperature. Testing sessions occurred thrice weekly, as shown in Figure 3 flowchart, with each session lasting three hours from 8:00 am to 11:00 am. To ensure consistent starting conditions, non-automated cleaning of the PV panels preceded each experimental session.

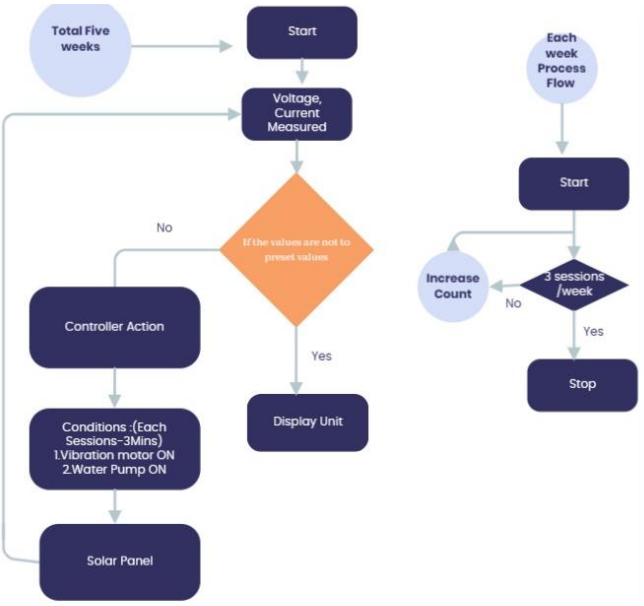

Figure 3. Flowchart for the Experimental Procedure

Throughout the study's duration, no additional cleaning was administered, allowing for the evaluation of performance under realistic, non-maintained conditions. Prior to the study's initiation, all panels underwent a comprehensive cleaning process to establish uniform starting efficiency levels and ensure standardized cleanliness across the board. During the three-hour measurement period, efficiency data was collected at 20-minute intervals, enabling a detailed assessment of performance trends. To accurately gauge the influence of vibrations and coating on PV panel efficiency, regular monitoring at a designated time of day was imperative. To minimize measurement discrepancies due to external factors such as clouds, shade, and wind, measurements were aggregated over the three-hour period, yielding an average efficiency value. Here the Figure 4 shows the hardware setup It's essential to note that computing efficiency over an entire day merely provides an average value, overlooking the real-time impact of vibrations and coating on performance—a crucial consideration for comprehensive performance analysis.

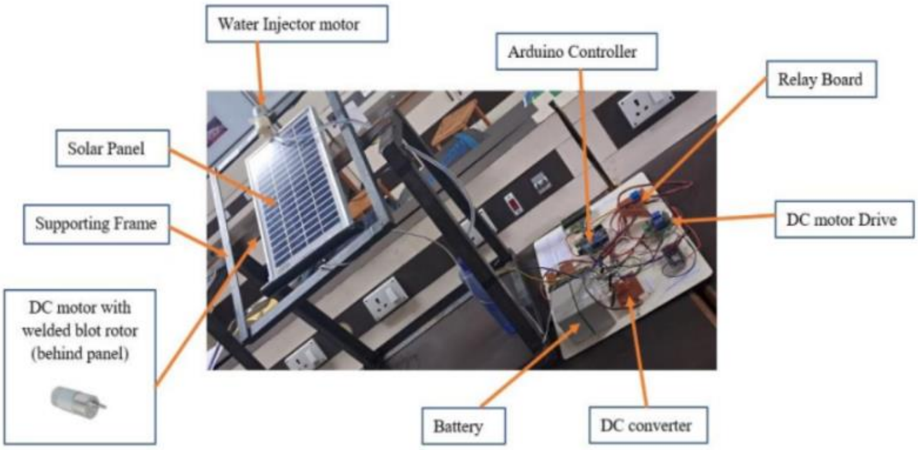

Figure 4. Hardware Prototype

The PV panels' efficiency, η, is determined using the following formula:

$$\eta = (Vmpp*Impp)/(Ac*G) \quad (1)$$

where G is the solar irradiance and Vmpp and Impp are the maximum voltage and maximum current at the maximum power point, respectively. The I-V characteristic device is used to measure each of the aforementioned parameters. The PV panel's aperture area is denoted by AC.

$$\eta_{avg} = \frac{\sum_{i=1}^{n} \eta_i}{n}. \quad (2)$$

Using equation 2 where n is the daily measurement count and ηi is the instantaneous efficiency, which is recorded every 20 minutes. The percentage decline in PV panel efficiency caused by dust accumulation on a particular day is represented as %η drop, which is computed using the following formula:

$$\%\eta_{\text{drop}} = \frac{\eta_{\text{ref}} - \eta_{\text{avg}}}{\eta_{\text{ref}}} \times 100. \quad (3)$$

4. Results and Discussion

The Figure 5 illustrates that the performance of the uncoated and non-vibrated PV panel plummeted to 12% by the conclusion of week 5, translating to a 6% decline in efficiency. Notably, according to predetermined standards, a cleaning intervention is warranted when the efficiency drop surpasses 7%. Conversely, the vibrated PV panel's efficiency dwindled to 5% by the end of week 5, reflecting a 4% efficiency decrease. These findings underscore the efficacy of vibration in mitigating efficiency losses attributable to dust accumulation, highlighting its potential as a proactive maintenance strategy for sustained PV panel performance were measured using digital multimeter, insulation tester. All measured values that are stored is illustrated in Figure 5

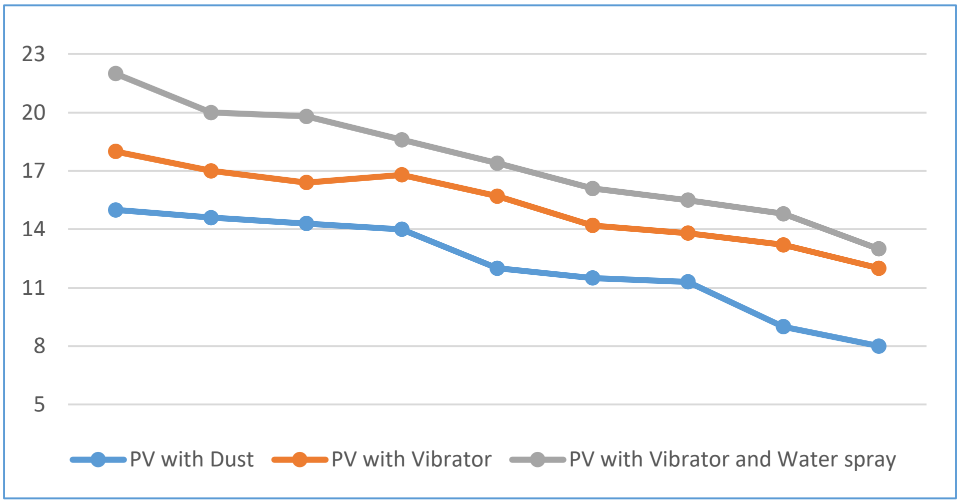

Figure 5. Result of Panel with Dust Accumulation, Vibrator, with Vibrator and Water Spray.

The utilization of panel coatings proves to be a reliable method for mitigating dust deposition and enhancing overall performance. However, the integration of a vibrating setup further amplifies cleaning efficacy. Moreover, adjusting the PV panel's tilt angle can augment dust removal efficiency, as gravity aids in dislodging dust particles, particularly when mixed with water injection. Although increasing the tilt angle beyond the latitude angle may decrease incident irradiance and subsequently reduce energy yield, it concurrently enhances dust shedding capabilities. Thus, there arises a need for additional research to determine the optimal tilt angle for PV panels, striking a balance between effective dust removal and maximizing energy output. This pursuit of optimization holds promise for advancing the efficiency and longevity of PV panel systems in diverse environmental conditions integration.

5. Conclusion

The experimental findings yield several key conclusions

1. Integrating a water spraying system alongside a vibrating system effectively reduces the frequency of required PV panel cleanings from four times per month to three.

2. Maintenance costs are greatly impacted by panel coating: uncoated panels incur double the maintenance expenses compared to coated ones, and when coatings are combined with vibrating systems, maintenance costs escalate to five times higher.

3. Water spraying emerges as a practical dust mitigation technique for solar panel cleaning, which is even more potent in conjunction with vibrating devices.

These conclusions underscore the importance of innovative maintenance strategies in optimizing PV panel performance while also highlighting the cost-effectiveness and efficiency gains achievable through strategic technology.

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