Preliminary design and test of a water spray solar panel cleaning system

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Abstract. Solar panels are susceptible to dust accumulation on their surface for long term operation. Scheduled cleaning work is thus important to maintain the efficiency and reliability of the solar panel for producing electricity. The paper presents a preliminary design of the cleaning mechanism for the solar panel surface using a semiautomatic wiper control system. A DC motor is utilized to power the wiper. The amount of water is sprayed over the solar panel surface, while the wiper is moving back and forth. The manual switch buttons are used to control the rotation direction of the DC motor. The experimental tests are conducted to obtain the solar panel performance, namely output voltage, output current, output power, and panel efficiency under clean and dusty conditions. The comparison of both conditions has been made to determine the cleaning effectiveness of the proposed prototype. The test results show that the wiper swept repetition of 10, 20, and 30 times delivers 57.0 percent, 79.1 percent, and 86.7 percent of the performance of the initial clean surface condition, respectively.

1. Introduction

In developed and developing countries, global issues related to the greenhouse effect and limited fossil energy reserves have prompted the governments to make efforts to conserve and diversify fossil fuel-based energy. One way is to use solar energy as an environmentally friendly alternative energy. Solar energy provides a renewable energy source plenty available and free of cost. Indonesia, thanks, has huge solar energy potential equivalent to 112,000 GW_p electrical power capacity with daily average global irradiation of 4.8 $kWh/m^2/day$ [1]. The prospect of deploying photovoltaic (PV) technology is enormous to obtain usable electricity, in addition to another potential like thermal energy.

The PV systems employ solar cells array, which forms solar panels to convert sunlight into electricity directly. Besides, the PV systems consist of the balance of systems encompasses solar charge controller (SCC), inverter, and battery bank and direct current (DC) and alternating current (AC) load systems. The advantages of solar PV systems include non-pollutant, non-noise, compact, reliable, and low maintenance costs [2, 3]. The challenges of PV technology are the low module efficiency ranging from 10-16.2% and expensive installation costs about USD 1,329/kW_p [4].

The PV systems require maintenance works due to their installation in outdoor environments. They are susceptible to changes in local climate conditions and shading by vegetations that grow around. The condition of PV surface cleanliness should also be of concern to the PV owners. Soiling effect, which refers to particulate contamination such as dust accumulation on the PV panel front surface, is one of the significant problems in solar power systems [5-7]. Dust deposition can prevent the penetration of sunlight through the optical surface of the PV module into the solar cells. The process of converting photons of sunlight into electric current is thus inhibited, which ultimately decreases the production of electricity. Solar cells that are blocked by dust, causing reverse-biased on other cells and the resultant effect is a drastic decrease in the PV panel performance [8]. Therefore, the PV panel requires a cleaning mechanism to maintain energy yield performance, even for multiple panel array configurations.

Methods of cleaning to remove dust from the PV panel surface include manual, automatic, and passive processes. The passive method is a self-cleaning process utilizing super hydrophobic and super hydrophilic surface coating treatments. Manual and automatic cleaning with a mechanical process, for instance, by using water must consider water resources available on the site, especially in desert regions [7, 9]. Several researchers reported the automatic mechanical cleaning system of the PV module surface with water spray. Syafaruddin *et al.* experimentally designed an automatic cleaning system based on the ATmega16 microcontroller with a wiper control mechanism and water spray [10]. About a 10% decrease in efficiency is observed under the dusty condition of a dust mass of 64.11 g spreading over the PV panel surface. Their cleaning method can improve module efficiency very close to the initial efficiency of 17.56% under clean conditions applied for a 100W_p rated power module. Alghamdi *et al.* investigated a programmable logic controller (PLC) based automatic cleaning system with a water jet spray for 8kW_p PV carport installed on the campus of King Abdulazis University Saudi Arabia [11]. The cleaning system reduces sand soiling and increases the module's power output by over 27%. Amber *et al.* developed an automatic self-cleaning mechanism for a 50 W_p solar panel and controlled by the ATmega 2560 microcontroller, which equipped by a rain sensor [12]. Their cleaning system increases the electrical output of the PV module by 26-50%.

This paper attempts to describe a preliminary prototype design and performance of a water spray solar panel cleaning system based on a semiautomatic wiper control mechanism. The effects of the cleaning process on the changes in the PV system performance under dusty and clean conditions are compared and analysed. The prototype is developed on a laboratory scale as the first stage to further serving the needs of the PV system maintenance in the community. It can also become a teaching practice material in a renewable energy technology course for students in the Department of Mechanical Engineering, Politeknik Negeri Bali.

2. Methodology

2.1. PV cleaning system design

Figure 1 shows a mechanical design of the PV panel cleaning system. The main components are the PV panel, wiper movement mechanism, mounting frame, and water supply system with nozzle spray. The PV panel is a poly-crystalline type of 120 W_p maximum power, 14.7% of module efficiency, 18.1 V of maximum voltage (V_{mp}), 6.63 A of maximum current (I_{mp}), 21.8 V of open-circuit voltage (V_{oc}), and 7.21 A of open-circuit current (I_{sc}). The PV panel dimension is 0.665 m x 1.225 m. Solar charge controller of 20 A rated current and a 12V/24 Ah of valve-regulated lead-acid (VRLA) battery are wired to the PV module.

The wiper actuator consists of a 12-24 V DC motor driver of 60 W rated power with idling speed of 10,000-15,000 rpm, a wiper, rollers, and rails. The wiper moves horizontally back and forth on the distance of the rail of 1,131 m. The wiper is of 0.61 lengths and mounted overhead of the PV panel by mild steel frames and rollers. The speed of the motor is controlled using a pulse width modulation (PWM) module, and its direction is governed by using two manual push buttons.

The water supply system employs a 12 V DC pump of 4.0 liter per minute (LPM) flow and 3.0 A of rated current. The water storage tank capacity is 10-liter. The pipeline is a flexible plastic hose of 3/8" diameter. The three spray nozzles are attached to the hose line on one side above the wiper motor. The flow measurement uses a rotameter of 2.5 LPM maximum scale. The circulated water is partially flowing back to the water tank due to the wasted water spray flow.

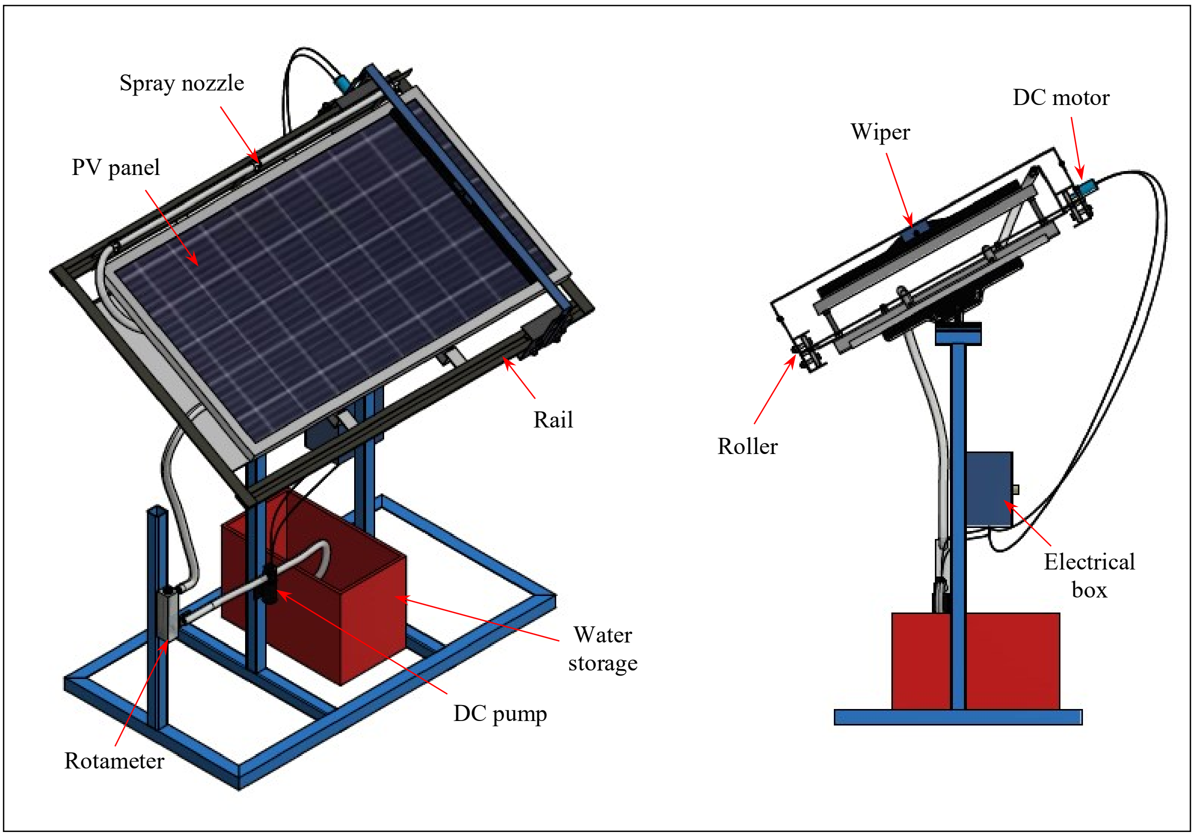


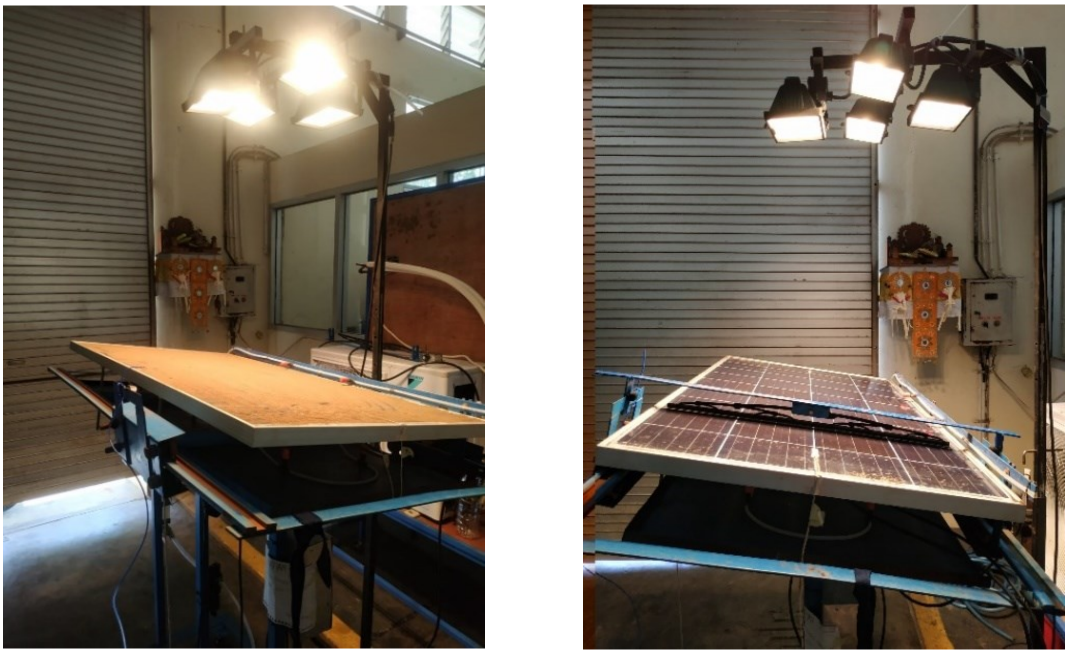
Figure 1. Design of a water spray PV panel cleaning system.

2.2. Experimental setup and procedure

Figure 2 shows the experimental setup and conditions of the PV panel cleaning prototype. The performance test is carried out in the indoor environment using 4 x 500 W of halogen lamps as the light source to replace the sunlight. The light intensity exposed to the PV panel is regulated using a dimmer of 4,000 W. The distance between the lamps and the PV panel surface is set at 0.85 m. The PV panel is tilted at an angle of 8.5^o.

The preliminary test is focused on the performance of the PV panel power output. The data collection includes voltage and current output from the PV panel to the SCC and light intensity capture on the PV panel surface. The PV panel is connected to the SCC and battery during the test. It means that the PV panel is loaded to the battery. The data readings of the voltage and current are monitored on the SCC and taken every 10 minutes for 3 hours. A solar power meter (SM2016 model) is used to measure the light intensity.

The test is conducted to compare the PV panel output performance under dusty and clean panel surface conditions. The dusty surface is simulated by spreading the dust of about 85 g of mass over the PV panel surface. The clean surface is the initial reference condition. The two design of the test has been set up as follows: the light intensity varies for both dusty and clean surface conditions and the wiper movement repetition varies at a constant light intensity of 1000 W/m^2, which then compares to both dusty and clean surface conditions.



(a) **(b)**

Figure 2. Experimental setup, (a) dusty surface, (b) clean surface.

The output power from the PV panel (P_{pv}) in watt is as given by:

$$P_{pv}=V\,x\,I \tag{1}$$

where V is output voltage (volt), and I is output current (ampere). While the panel efficiency (η_p) is given as:

$$\eta_p=\frac{P_{pv}}{I_s\,x\,A_p} \tag{2}$$

where I_s is light intensity (W/m^2) and A_p is panel area (m^2).

3. Results and discussion

Figure 3 shows a comparison of the output voltage and current under dusty and clean surface conditions based on the light intensity variation from 600 W/m^2 to 1000 W/m^2. It is apparent that the output voltage and current increase as the light intensity increases. The output voltage increases by 0.2 V and 0.4 V for every 200 W/m^2 increase in the light intensity for dusty and clean surfaces, respectively. Accordingly, the output current increases from 0.46 A to 0.6 A and from 0.86 A to 1.15 A. The dust deposit of 85 g mass decreases the output current of 44.7-47.8% and the output voltage of about 4%. As can be seen, the changes in the output current are higher than that of the output voltage. It seems that the connection of the PV panel to the SCC maintains the battery charging voltage. The dust layer on the surface of the PV panel causes the light transmittance to decrement from its reference, herewith the clean condition. The light transmittance coefficient linearly decreases with the more dust settled on the PV panel surface. The low transmittance coefficient means that the less light beam passes the optical surface results in low conversion of the light into electricity [13].

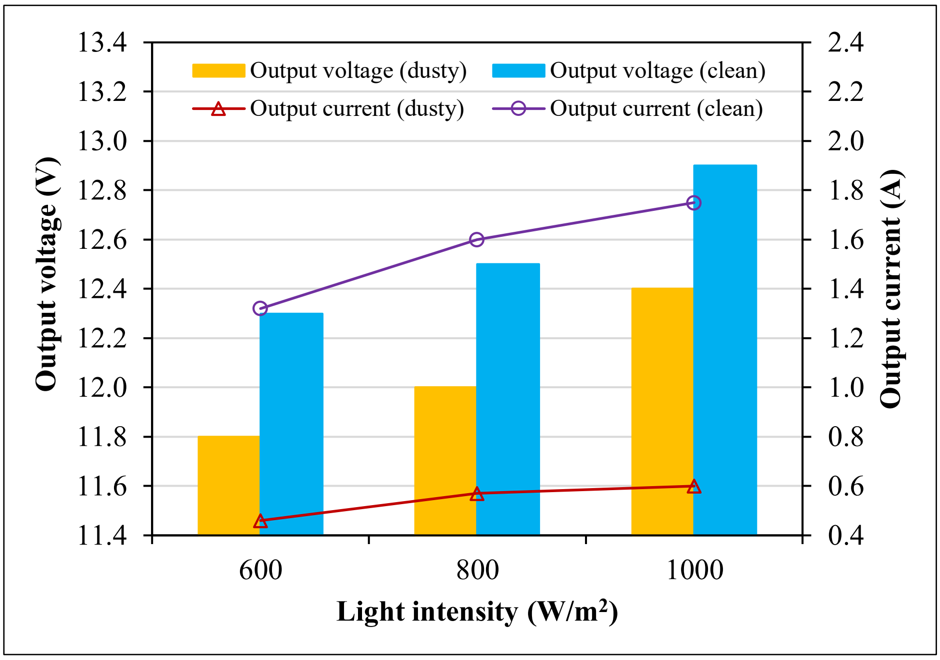


Figure 3. PV output voltage and current for different light intensity.

Figure 4 shows the effect of the wiper movement repetition during the cleaning process on the PV panel output voltage and current as compared to the dusty and clean conditions. The output voltage is 12 V, 12.2 V, and 12.7 V for 10, 20, and 30 times of swept repetition, respectively, while the output voltage is 12 V and 12.9 V for dirty and clean conditions. Accordingly, the increase of output current is significant, which is 0.69A, 0.93A, and 1.03 A, as compared to 0.6 A and 1.15 A for dusty and clean conditions. The increased number of wiper repetition reveals a cleaner panel surface as well as the unobstructed light penetration, thus increasing the PV panel output voltage and current.

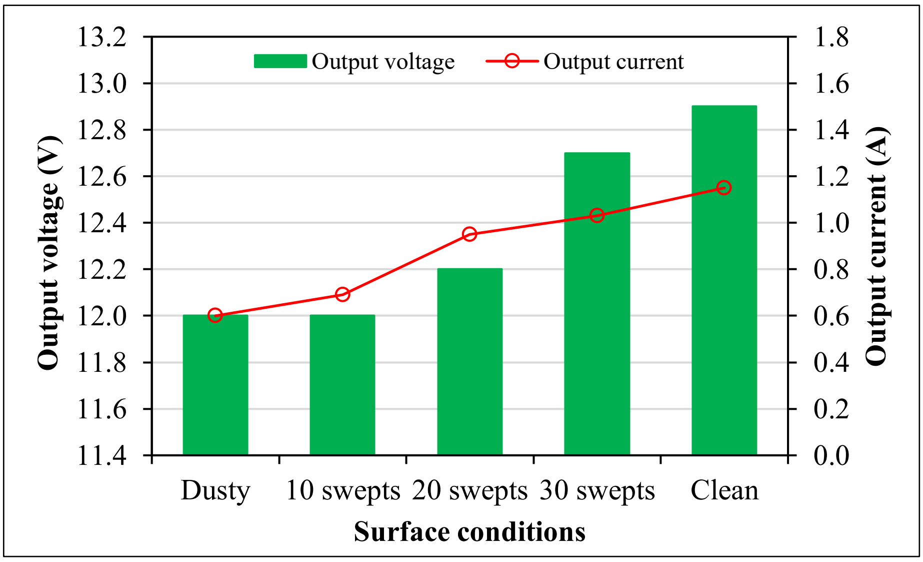


Figure 4. PV surface conditions and wiper movement versus output voltage and current.

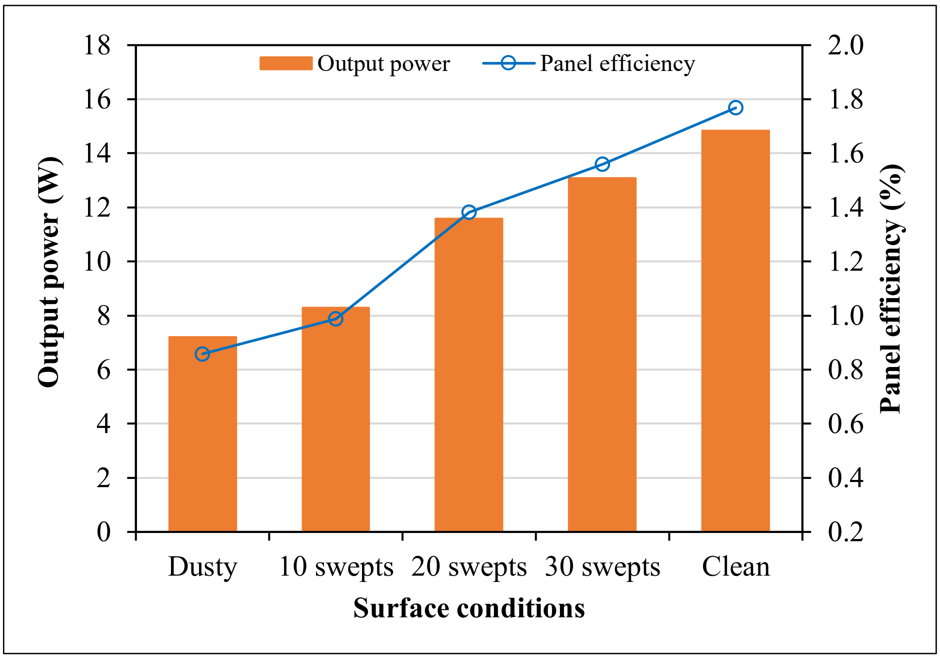


Figure 5. PV surface conditions and wiper movement versus output power and panel efficiency.

Figure 5 shows that the PV panel output power and efficiency increase with the more times of wiper repetition. The output power increases from 8.3W to 13.1W, while the panel efficiency increases from 0.99% to 1.56% for or 10, 20, and 30 times of swept repetition. The dusty and clean conditions reveal 7.2W and 14.8W, 0.86% and 1.77% of the output power and panel efficiency, respectively. As shown in Figure 5, the wiper swept repetition of 10, 20, and 30 times delivers 57.0%, 79.1%, and 86.7% of the performance of the clean surface condition, respectively. Moreover, the output power and the panel efficiency is far lower than the results by [1], which is 87.6W and 17.55% based on a 100W_p panel rated power and under outdoor test. It seems that in our research work, the light of the halogen lamps cannot expose uniformly on the whole of the PV panel surface. The halogen lamp has lower spectral irradiance than that of sunlight in an outdoor environment. As a consequence, more heat is generated due to the low photonic energy transmitted by the halogen lamp, hence decreasing the output power and panel efficiency [14].

4. Conclusions

Dust deposition on the PV panel surface can significantly reduce the output power as well as the panel efficiency. The regular manual or automatic cleaning is fundamentally essential to minimize the soiling effect. In this paper, the cleaning mechanism prototype based on a water spray and semiautomatic operation has been presented. The wiper swept repetition of 10, 20, and 30 times delivers 57.0%, 79.1%, and 86.7% of the performance of the initial clean surface condition, respectively. Further works of the prototype improvements are required to optimize uniform water spray distribution, times of wiper swept repetition, and its capability towards autonomous action using a microcontroller.

5. References

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Acknowledgments
The authors acknowledge the grant from Politeknik Negeri Bali under the research scheme of DIPA Reguler 2019.