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Design and Implementation of Solar Cell Cleaning Control System

Mazin N. Ajaweed[1*], Mazin T. Muhssin[2], Abduallah A. Al-Mashhadani[3]

[1]Control and Systems Department, College of Engineering, University of Technology, Baghdad, Iraq
[2] Electrical Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq
[3]Electrical Engineering Department, College of Electronic and Mechanical Engineering, Bristol University, Bristol, UK

[1]https://orcid.org/0000-0001-5078-0269
[2]https://orcid.org/0000-0002-2780-3845
[3]https://orcid.org/0000-0002-1986-7064
[*]Email: mazin.n.ajaweed@uotechnology.edu.iq

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Abstract

The Republic of Iraq, similar to other Gulf countries is affected by the swings in oil costs, which motivates the policy makers to start thinking about integrating renewable energy such as PV power plants into the grid. This study is conducted to provide a solution for the accumulation of dust and dirt on the PV panels which is a problem of national and international significance. The accumulated dust on the panels of solar cells reduces the applied radiation of sunlight and reduces the efficiency of the solar cells. In this paper, a remote cleaning control system is designed and implemented practically to maintain the panels' cleanliness. The control system is implemented on the real solar panel at different times throughout the day and is characterized by a lightweight and tight structure. The results show that there is a noticeable efficiency improvement for the solar panel output when it is cleaned in comparison to when it is heavily and medium dusted. After cleaning the panel, the average dissipated power with different tilt angles is increased by almost 1.75W when power measurement is collected at 9 am and 1.85W when measurement is collected at noon.

Keywords: Photovoltaic panels, solar cell efficiency, cleaning control system, dust accumulation

1. Introduction

The technologies of renewable energy have been increased in the world to meet the needs of sustainable energy [1]-[9]. In this attention using solar energy has been adopted to reduce the damage and cost of fossil fuel sources in the future [10]. Globally, the capacity of solar power is growing by almost 9%, from 480 GW in 2018 to more than 8,000 GW in 2050 [11]. Many environmental factors could influence the operation of the Photovoltaic (PV) [12]. In Middle Eastern countries, dust is considered one of the main drawbacks that could significantly reduce the efficiency of the PVs [13]-[17]. Reference [14] described the characteristics of Iraqi geographic and meteorically as well as the activities of humans that will lead to an increase in the effect of desertification in different areas of Iraq. Consequently, this effect could increase the dust and sand which could cause to deteriorate the energy system performance of PVs panels. This comprehensive study is useful for the engineers, researchers, and companies that will deal with solar energy systems in Iraq.

Kazem et al. [15] investigated specific weather factors such as dust aggregation, humidity, and wind speed and the cleaning methods supplied to reduce the pollution effect on the PV system. Nine approaches have been implemented in different cities to clean PV panels from dust aggregation for 30 days. It has been observed that cleaning using water is enough to wash panels in some cities while not effective in other cities.

Shenouda, et al. [16] studied the dust aggregation effect on the performance of solar panels in North Africa, the Far East region, and the Middle East region. Through this work, several techniques for cleaning purposes were presented including manual and automatic techniques with less use of water and human interference.

Chaichan et al. [17] described the effect of a dust storm that occurred in Baghdad on PV panels for 3 days in terms of voltage current, and efficiency drop. The study suggested dry cleaning such as brushes to enhance the PV performance.

Hussain et al., [18] revealed that the dust and dirt accumulated on the panels could minimize the PVs efficiency by up to 50%.

Al-Hasan [19] explained the impact of the layer of sand on the transmittance of beam light at the PV module surface. Depending on the wavelength, particle size, angle of incidence, and density of particles on the surface, the beam light factor has been calculated.

Kaldellis and Kokala [20] and Mekhilef et al. [21] implemented an actual test for five similar PV panels installed in a severe environment with dust aggregation on the surface. The existence of dust on the panels led to a 40kw loss of energy on an annual basis.

Al-Rasoul[22] collected data on a dust storm that occurred in June 2009 in Baghdad and investigated its impact on the performance of the solar panels. The study ended with a conclusion that cleaning approaches are necessary to improve the performance of the panels

Based on the aforementioned studies on the effect of dust on PVs, it is important to clean the PV panels from time to time to improve their efficiency and performance. Conventionally, the process of cleaning the solar panels was performed manually. Manual cleaning has some drawbacks including motion difficulties, the possibility of panel destruction, the risk of worker accidents, and high cost [17]. The autonomous cleaning process of photovoltaic panels has been used to overcome the problems accompanied by the classical cleaning process.

2. Related Works

Manufacturing of PV panels has grown widely in the world in proportion to the high demand for renewable energy. Thus, the cleaning strategy of the solar panels took possession of many scholars. Removing dust and dirt from the PV panels can be accomplished by washing them using pumped water or by cleaning them with a brush either with water or waterless.

In [23], a local cleaning control system was designed and implemented to clean the solar street lighting panels. The system uses a sensor to sense the dust and clean it through dripping water in a predefined time threshold. The study concluded that this type of control system is useful when placed locally on solar panels, especially on solar street lighting panels.

Another research work considered a cleaning control system with the new mechanical structure to clean the panels in arrays rather than cleaning the panels individually. The system constructs water pipes on the PV frame which cover a large space of PV array. This system monitors the status of the weather and the performance of the PV to activate the cleaning system either automatically or by attributing the utilization of the Internet of Things (IoT) technology [24]-[26].

Some of the other works address the challenge of water consumption especially in deserts. Therefore, waterless methods for dust removal from the PV panels were presented in [27], and [28]. The study used electrostatic induction to provide dry cleaning. This technique of cleaning system applies electrostatic force to bring out the sand from the solar panel surface. High single-phase voltage is given to the electrodes through parallel wires implanted in the transparent glass of the solar panel plate. This technique shows that more than 90% of sand was removed from the panel surface. The main disadvantage of this method is the requirement to change the existing solar panels.

Robotic cleaning systems were also adopted through several studies, where a mechanical frame was designed with a wiper attached and equipped with a motor to control the movement of the wiper to clean the surface of the solar panels [29]-[31].

The contribution of this work can be summarized as I) Unlike the design of most cleaning systems that require add-on extensions to the PV array, the cleaning control system in this work does not interfere with the function of the PV panel's structure, II) The dimensions of the mechanical frame of the whole control system can be adjusted to fit different sizes of panels, III) the cleaning control system is provided with different operational modes based remote control, IV) The dissipated power is calculated with different tilt angles, before and after cleaning the panel with two dust levels.

3. Methodology

An automatic cleaning control system is implemented for PV panels with the following specifications: 50W output power, 12V rated output voltage, 36 cells, and 775x680x28mm in dimension. The structure of the whole system is designed in such a way that it is flexible and easy to work practically. The proposed control system aimed to save the cost and effort of the workers who are responsible for panel cleaning. The block diagram representation of the whole cleaning control system is presented in Fig.1. Movable rail with a brush is connected underneath the solar panel. The panel can be cleaned as long as the cleaning brush moves on its surface. The rail is attached with two wheels driven by stepper motors at both sides of the rail. The initialization of the cleaning process starts when the end-users press the switching buttons on the wireless panel. The Nano Arduino receives two signals, i.e. from the wireless panel and the directional sensors. The directional sensors sense the direction of the rail and send the information to the Arduino. The Arduino in its turn, sends the data of both the wireless and rail's direction to the PIC-16F88 microcontroller. The microcontroller is programmed by flow-code software to make the control decision based on its inputs so as to adjust the stepper motors and turn the wheels of the rail. Hence, the rail moves left and right to clean the panel. Note that the PIC-16F88 microcontroller is used as it is small in size and can easily fit in the rail.

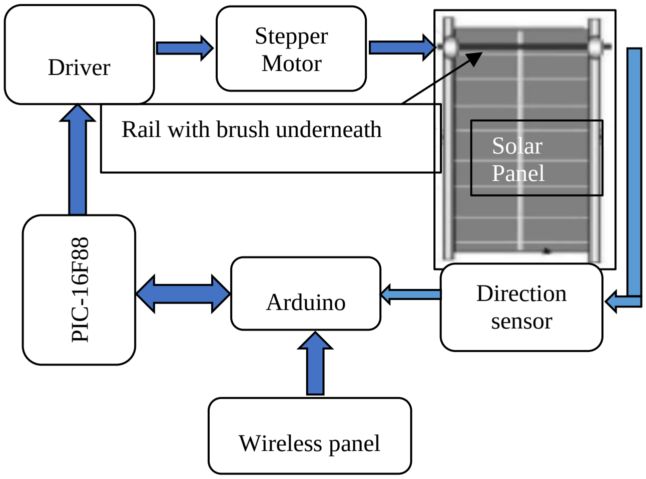


Figure 1. Block diagram of the cleaning control

3.1. Mechanical Part

The aim of this part is to build a mechanical structure of the cleaning system to be suitable for cleaning arrays of panels placed in parallel order, as shown in the terraced panels of Fig.2.

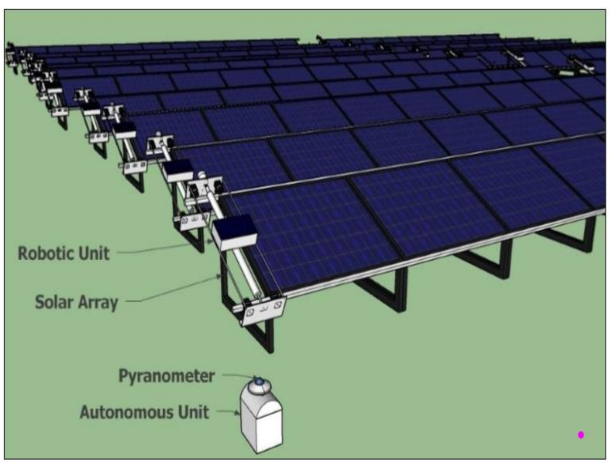


Figure 2. Terraced PV panels with a cleaning robot

The model assumes a structure that does not interfere with the function of the PV panel's structure. That is, the structure of the PV panels will stay the same as constructed by the manufacturers or by the PV installers. In most situations, the PV panels are installed with pitch angles between 30-45 degrees having free ends. For this reason, a 50-watt solar cell on adjustable arms that can be rotated at a suitable pitch angle is installed, and hence the ends of the panel are kept free to imitate the real situation of terraced PVs as shown in Fig.3. As shown in Fig.4, The mechanical structure of the cleaning system consists of movable rail with brush underneath. The rail ends are connected with a very precise wheel system for left and right motions. That is, each of the ends of the rail is connected from the top by two wheels running over the board, and from the side is linked to a ball bearing running on the side of the PV board to maintain the balance of the rail. In terms of cost saving and flexibility, the mechanical structure of the cleaning system is designed to not only be fixed with one array of panels but also can be removed and attached to another array of panels. Thus, avoiding the cost of a large number of cleaning systems at one PV farm. In other words, the rail can be removed from the PV panel whenever required and can be used to clean another solar cell array.

Figure 3. Free ends PV panel installed on an adjustable arm

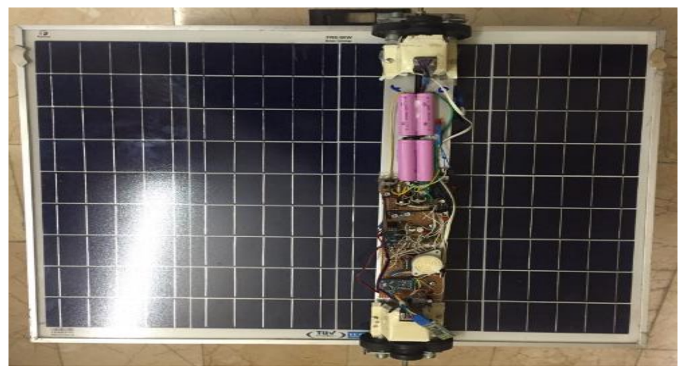


Figure 4. The structure of the rail

3.2. Electrical Part and the Operation of Cleaning Control System

The implementation of the electric circuit of the cleaning control system is shown in Fig.5. The Electrical control system is integrated into this model to control the direction of the rail. The electrical components are placed on the rail (See Fig.4) and then covered with a plastic box. Fig.6 shows the block diagram of the main parts of the electrical part. The hardware contains a driver for two stepper motors on both sides of the rail used to drive the wiper from end to end of the solar panel. The stepper motors are used as they have low cost, reasonable torque, high reliability, and accuracy at low speeds. These two motors are fixed at each end of the rail to soften its movement. These motors receive instructions from a microcontroller based on the sensor readings. Each motor is integrated with three rubber wheels to make the wiper slide well on the surface of the solar panel. The second component of the electrical part is the Arduino Nano microcontroller which collects the readings of sensors and sends them to PIC-16F88. The Nano microcontroller is the small, complete, friendly board used in this project to make the control board design much smaller. The operation of the Arduino, in this paper, is essential because of its ability to communicate with other components such as Bluetooth cards and sensors. The third component is the PIC-

16F88 which represents the middle stage between the Arduino and motors and is programmed to make decisions after receiving the readings from the Arduino. PIC-16F88 instead of other types of microcontrollers was used as it is easy to program. The other component is the Bluetooth card that is used to transmit the signals between the electronic board and the remote-control panel to execute the orders of the user. The last components are the two magnetic sensors that are fixed at both edges of the solar panel to provide the control system with information on the movement directions of the rail. The magnetic sensors are used instead of other sensors such as ultrasonic, infrared, and RFID sensors because of their accuracy, and range, and it is easy to install in such control systems.

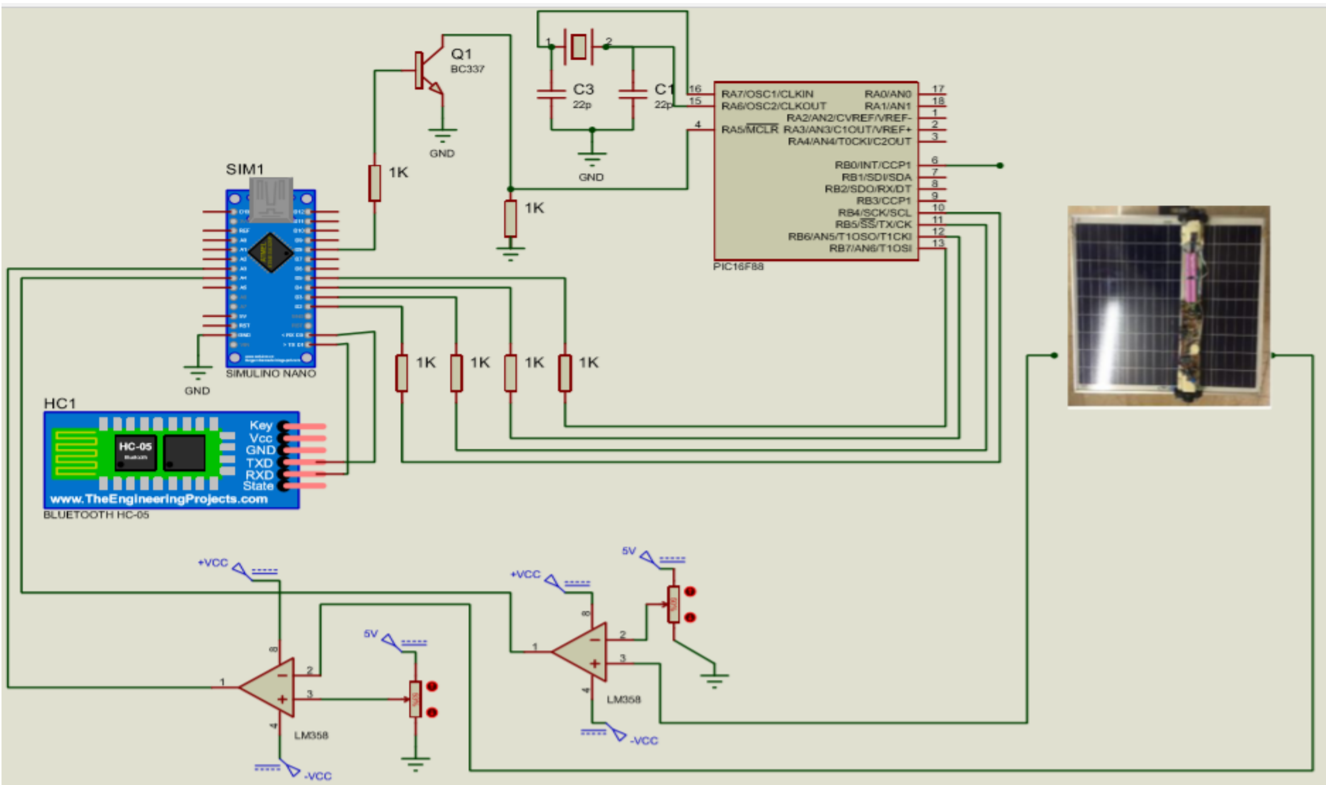


Figure 5. The electronic circuit of the cleaning control system

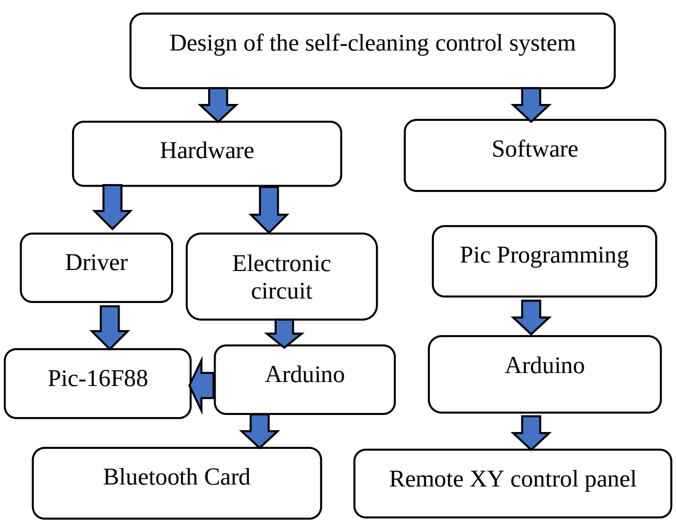


Figure 6. Block diagram of main components of the electrical part of the cleaning control system

The remote control system was used to control the angle of the stepper motors, and hence the directions of the rail through the Remote- XY application. This application is installed on Android or IOS systems (users can add more modes of operation based on many factors, such as the weather, and the number of cycles).

The users can use this application on their mobile and/or tablet to send the instructions to the Bluetooth card to perform many tasks. For example, to run the cleaning process for a certain period of time, to control the number of cleaning cycles, and to terminate the cleaning process. In this paper, four modes for the operation of the cleaning process were conducted as shown in Fig.7(a) that are operated based on the flowchart presented in Fig.7(b). The first mode is for continuous cleaning, the second mode is to clean for 1 minute, the third mode is for 5 minutes, and the fourth mode is for 10 minutes. The cleaning process could be terminated at any time by pressing the Termination button. The initialization signal can be sent to the Arduino from the wireless panel via the Bluetooth card, where the user can choose the cleaning mode presented. The Bluetooth chip (HC-05) is connected to the Nano Arduino via the transmitting and receiving pins. The Bluetooth chip receives. The operation modes from the users and send it to the Nano Arduino. The Arduino sends the fourth operations modes to the Pic-16F88 through pins 10, 11, 12, and 13. Pic-16F88 is programmed by using flow code software to control the direction of the movable rail according to the fourth operation mode. Two comparators (LM358) were used to measure the distance between the rail and the magnetic sensors fixed at the left and right edges of the panel. The operation of the comparators is presented in equations (1) and (2).

$$V_1 = V_{ms1} - V_{ref} \quad (1)$$

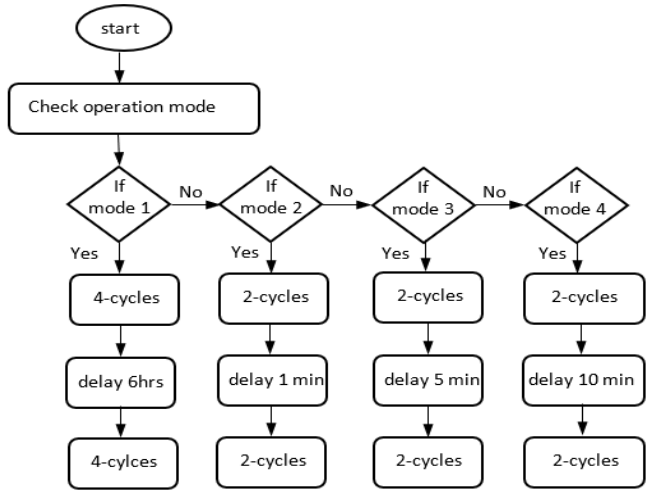
$$V_2 = V_{ms2} - V_{ref} \quad (2)$$

Where V_{ms1} (in volt) is the voltage at the magnetic sensor placed on the right side of the panel, which indicates the distance between the rail and the right edge of the panel. V_{ms2} (in volts) is the voltage at the magnetic sensor placed on the left side of the panel, which indicates the distance between the rail and the left edge of the panel. The direction of the moving rail is controlled based on equations (1) and (2) and is presented in Table 1. When the rail moves toward the right side of the panel, the V_{ms1} increases and V_{ms2} decreases. Thus, when the rail gets closer to the right edge, V_{ms1} becomes greater than V_{ref}, and the rail stops and turns back to the left side. Conversely, when the rail gets closer to the left edge, V_{ms2} becomes greater than V_{ref}, and the rail stops and turns back to the right side. However, if $V_{ms1}<V_{ref}$ and $V_{ms2}<V_{ref}$, this means that the rail is moving and does not reach the edges.

Table 1. The direction of rail-based on V_1 and V_2

V_{ms1}	V_{ms2}	V_1	V_2	Direction of rail
$\geq V_{ref}$	$<V_{ref}$	positive	negative	Change to right
$<V_{ref}$	$\geq V_{ref}$	negative	positive	Change to left
$<V_{ref}$	$<V_{ref}$	negative	negative	Continuous moving

(a)



(b)

Figure 7. (a) Modes of Operation using mobile (b) flowchart of the operation of this mode

4. Results and Discussion

After the implementation of the practical system using the methods and steps explained in the methodology section, this section focuses on the results before and after using the PV cleaning system. Results of the current and voltage outputs are obtained by using a Digital Multimeter. The angles of the PV in which it is placed are set up manually using a protractor. Practical results were collected on the basis of two case studies. The first case study was implemented at 9 AM. Fig.8 shows the output power curve with different tilt angles of the PV panel before and after the cleaning process with medium and high dust applied to the panels. It can be noticed that the value of output power increased after applying the cleaning process.

However, it is not clear if the dust has considerable concern when there is intense sun radiation. Hence, once again another case study was implemented to investigate the potential of the cleaning process at 12 PM, as the solar intensity is high. Fig.9 shows the output power versus tilt angles curves for three scenarios with high dust applied, medium dust applied, and after cleaning. It is very noticeable the negative impact of dust on the power output of PVs even when the sun's light is intense.

The output power of PV panels was improved, thanks to the cleaning control system. The dissipated power P_{dis} is calculated using Equation (3), where $P_{clean\ pv}$ is the output power of clean PV, and $P_{dusted\ pv}$ is the output power of dusted PV.

$$P_{dis} = P_{clean\ pv} - P_{dusted\ pv} \quad (3)$$

Tables 2 and 3 show the values of P_{dis}, v.s different tilt angles, before and after cleaning of dust at times 9 am and 12 pm, respectively. It can be noticed that P_{dis} varies according to the tilt angle and the sun's light. The P_{dis} is lower when the measurement is collected at 12 pm, and it decreases also when the tilt angle tends to be between (30-40) degrees.

Table (2) reveals the output power of the PV at 9 am according to three categories; Medium Dust, High Dust, and After Cleaning. It can be shown that at zero degrees, the PV power is equal to 22.75W and 22W based on medium and high dust respectively. While after cleaning, the output power is improved to 24W (Max P_{dis} is equal to 2W). At 40 degrees, the output power is equal to 23.5W and 22.75W based on medium and high dust respectively. However, after cleaning, the output power is improved to 24.5W (Max P_{dis} is equal to 1.75W).

Table (3) shows the output power of the PV at 12 pm according to three categories; Medium Dust, High Dust, and After Cleaning. It can be seen that at zero degrees, the PV power is equal to 24.25W and 23.25W based on medium and high dust respectively. While after cleaning, the output power is improved to 25W (Max P_{dis} is equal to 1.75W). At 40 degrees, the output power is equal to 25.25W and 24.375W based on medium and high dust respectively. However, after cleaning, the output power is improved to 26W (Max P_{dis} is equal to 1.625W).

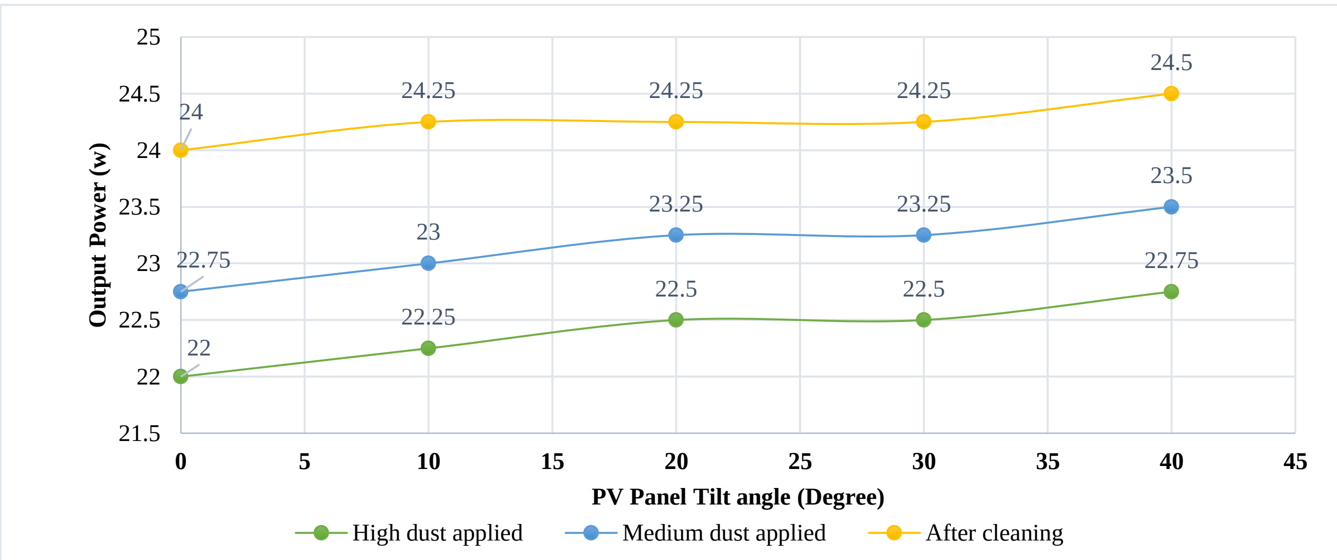


Figure 8. The output power curves with different tilt angles of the PV panel at time 9 am

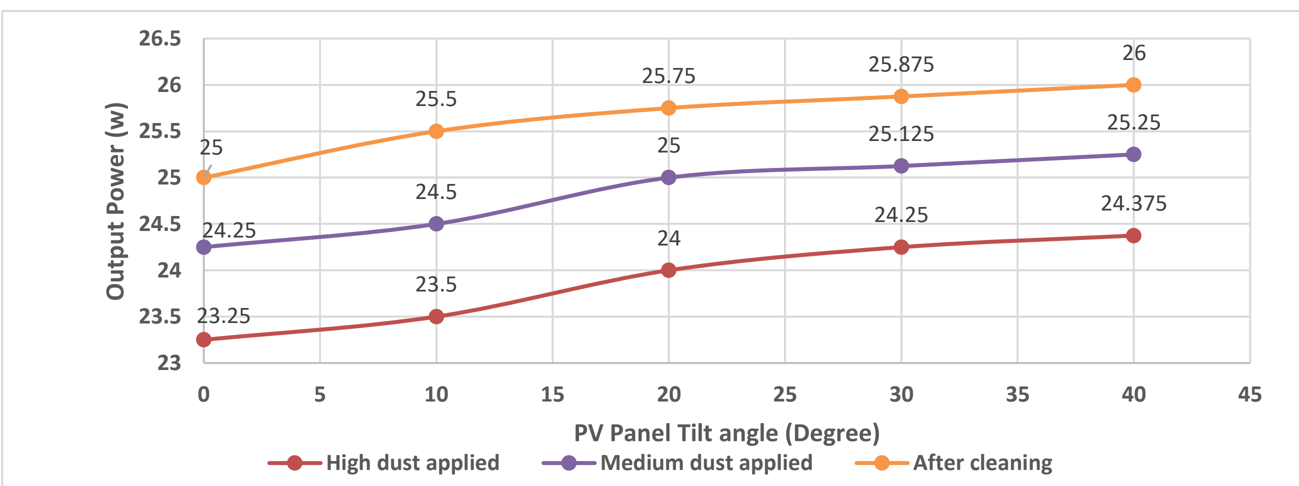


Figure 9. The output power curves with different tilt angles of the PV panel at time 12 pm

Table 2. The value of P_{dis} at 9 am

High Dust		**Medium Dust**		**After Cleaning**		**P_{dis} (w)**	**P_{dis} (w)**
Degree	Power (w)	Degree	Power (w)	Degree	Power (w)	based on high dust	based on medium dust
0	22	0	22.75	0	24	2	1.25
10	22.25	10	23	10	24.25	2	1.25
20	22.5	20	23.25	20	24.25	1.75	1
30	22.5	30	23.25	30	24.25	1.75	1
40	22.75	40	23.5	40	24.5	1.75	1

Table 3. The value of P_{dis} at 12 pm

High Dust		**Medium Dust**		**After Cleaning**		**P_{dis} (w)**	**P_{dis} (w)**
Degree	Power (w)	Degree	Power (w)	Degree	Power (w)	based on high dust	based on medium dust
0	23.25	0	24.25	0	25	1.75	0.75
10	23.5	10	24.5	10	25.5	2	1
20	24	20	25	20	25.75	1.75	0.75
30	24.25	30	25.125	30	25.875	1.625	0.75
40	24.375	40	25.25	40	26	1.625	0.75

5. Conclusions

This paper proposed the design of a control system to address the problem of the accumulated dust on solar cell panels. The control system has mechanical and Electrical parts. In the mechanical part, the rail and brush are fixed together and integrated into the panels of PV panels in a movable way. In the Electrical part, the wheels of the rail are driven by two stepper motors. A control model was designed to control the directions of the motors. Finally, the model was equipped with a mobile control system for the provision of remote control. The whole control system does not undermine the normal structure of the panels, i.e. when the PV panels are installed in reality in a parallel order. The cleaning control system presented in this paper provides considerable improvement to the output power of the PV panels. The measurements of P_{dis} seem to be small when cleaning a single PV panel. However, future work should be conducted to investigate the dissipated power on a large number of PVs.

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Author Contribution Statement: All authors conducted the work equally.

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