# Investigation of Solar Photovoltaic Performance Via Cooling-Light Concentrating And Cleaning System Using Robotic Arduino Approach

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***Abstract***— **This paper proposes two solar photovoltaic (PV) systems; a PV system integrated with multiple fixed concentrating mirrors and cooling system, and a PV system embedded with an improved panel robot cleaning system. The main contribution of the first system is the increasing of irradiance absorption without overheating the PV panel. This can be achieved by placing three mirrors around the solar panel with specific angles and a water hose at the top-end of the panel to allow water running on the surface of the panel in which it is controlled by Arduino program. On the other hand, the main advantage of the second system is the improvement of power output generated by PV panel with the help of simple cleaning robot construction to clean depositions of impurities on the panel's surface. This is done by designing a robot on the PV panel and subsequently creating the circuits to be operated by an Arduino microcontroller. The cleaning robot works based on the amount of voltage received by PV panel from the sunlight. Data Acquisition Interface LVDAC is used to record the output power from PV panel of both systems. The first system shows increment in the output power which indicates that the concentrating mirrors and cooling system proposed is viable to enhance the performance of PV system. For the second system, it is found that there is improvement of about 70% to 80% in the output power of PV panel after cleaning process.**

***Keywords—Arduino; multiple fixed concentrating mirrors; Photovoltaic; Data Acquisition Interface***

## I. INTRODUCTION

Renewable energy is the energy obtained from natural resources that can be replenished, such as solar energy, wind energy, biomass, geothermal and ocean energy [1]. Solar energy is one of the most important sources among the renewable energies. Generally, solar system can be classified into two categories. First, thermal system which converts solar energy into heat; meanwhile the other one is the photovoltaic (PV) system which converts solar energy into electricity [1]. The characteristic of PV as a semi-conductor material allows it to convert solar energy to electrical energy [2-3]. However, PV system is claimed to have a problem in its energy conversion efficiency that is reducing in time due to increasing temperature by 4-17% during its operational period [1, 4].

The performance of PV system is depending on input of irradiance from the sunlight. The irradiance absorption itself is affected by several factors such as weather, tilt angle and shading. Solar panel must absorb maximum amount of solar irradiance in order to increase the electrical efficiency of PV cell [5, 6]. One of the ways to increase the amount of irradiance is by using concentrating mirror, where it can receive and direct sunlight to the solar panel.

One of the methods found from previous study is using light reflection method. The solar panel is attached with multiple fixed directed mirrors that act as reflectors [6]. The function of the mirrors is to direct sunlight onto the solar panel. For maximum radiation absorption, the solar panel must be perpendicular to the light source. The presence of mirror will increase the efficiency of PV cell especially during the afternoon. Study in [7] shows that the efficiency of solar panel increased up to 20% when reflecting mirrors are used. However, the use of reflecting mirrors has its own negative impact to PV cell, which is the increase in solar panel temperature [1]. Solar irradiance that can be absorbed by PV cell is not converted into electricity completely. Some of the solar irradiance is transformed into thermal energy, causing the electrical efficiency of PV cell to decrease [4]. To overcome the increasing temperature problem, cooling system is installed to PV system.

Power generation from PV cell will decrease when the surface temperature of the solar cell increases [8]. Overheated of PV panel must be cooled down in order to avoid decreasing in efficiency [9]. The first cooling system is by using water immersion technique [10]. In the experiment, the temperature of PV panel is controlled by immersing the panel into a container that contain water. Water acts as heat dissipater which will maintain the panel's temperature. The depth of the solar panel is varied from 0 cm to 6 cm in order to get the best result. However, the method resulted in reduction of light reflection due to lower refraction index of the water and the absence of the thermal drift. Therefore, this type of cooling system may not be a good solution in improving the output power while reducing the PV panel temperature.

The second cooling method is using water circulation [1, 10, 11, 12]. In this technique, the water is sprayed at the top end of solar panel and flows on the surface panel to lower the temperature. Water pump, tank, temperature sensor and Arduino microcontroller are needed in this method. When the temperature sensor senses the panel surface temperature at

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certain level, it will send the information to the Arduino. The Arduino will power up the water pump and water will circulate on the surface of the solar panel for a certain time. Authors in [11], found that the decrement of PV temperature by 8$^{o}$C will increase the panel efficiency by 3%. Thus, proving that combination of PV panel with cooling system will lower the surface temperature and boost up the efficiency of PV cell.

Besides, the power produced by PV system is also influenced by the deposition of any unnecessary impurities on the PV surface [15]. Several experimental studies have been conducted where solar panel has been implemented with different cleaning methods to overcome performance degradation of PV panel due to deposition of impurities on its surface. The approaches presented are the electrode wires [16], air flow method from air conditioning system [17], water cleaning agent [18], surfactant cleaning agent and fully portable robot systems [19, 20, 21].

The electrode wires approach is one of the methods that connect the solar panel with the electrode wires with a gap between each wire [16]. The concept of transporting particles using electrostatic is claimed as one of the effective ways to remove particles [22]. The solar panel is placed in 20° inclination to facilitate the movement of dust [15]. As the system operates, cover glass in the solar panel with the electrode wire will cause sand that approaches the solar panel to repel. However, this method is not an efficient method to clean the PV panel surface since it continues to operate even when the PV system is not in use.

Using water as cleaning agent cannot remove completely the accumulated dust after a long period of time [23]. Although cleaning process can be better if the water pressure is increased, however, that approach will lead to a huge amount of cost [24]. The use of surfactant as cleaning agent can literally avoid the deposition of sand on the solar panel surface in a long period of time [25]. Nevertheless, the cleaning process requires manpower to refill the surfactant tank and thus making this method less efficient to clean PV panel surface.

The fully portable robot system is the other new method of cleaning PV panel. The portable robotic cleaning device is developed and features a versatile platform which travels the entire length of a panel [19]. The robot is symmetrical, so the weight of the robot is distributed uniformly, hence, increasing the stability of the robot on the PV panel [20]. The robot is operated by the microcontroller and battery control. Sensors are installed on both sides of the robot to send signals indicating it has reach the panel edge, a point at which the robot has to return back to the starting point to make a second cleaning pass [21].

In this paper, the cooling-light reflection method is designed and integrated into conventional PV system with the aim of enhancing its performance in terms output power. Concentrated mirrors are used to direct more solar irradiance onto the panel's surface and water circulation cooling system is implemented to reduce the panel's temperature caused by the mirrors. A robot cleaning system is also designed and tested at various panel surface conditions to analyze the condition's effect on PV system's performance.

## II. METHODOLOGY

### A. *Cooling-Concentrated PV System*

Fig. 1 shows the experimental setup of the cooling-concentrated PV system. There are two main parts of the system's construction which are the concentrating mirrors and the cooling system. Factors that have to be considered in preparing the concentrating mirrors are the size, tilt angle as well as mirror position.

In the system, three mirrors are attached to the left, right and top side of the panel respectively and each of them has the same dimension as the PV panel to ensure full coverage of sunlight reflection on the panel. Studies in [6] and [13] stated that the best tilt angle for the mirror is between 50$^{o}$ – 60$^{o}$ inclinations. It is important to determine the tilt angle of the mirror correctly because it ensures sunlight reflection to directly hit the surface of PV panel [14]. In this experiment, the mirrors are attached to the PV panel with tilt angle of 60$^{o}$ inclination.

Second part of the system's construction is the cooling system which is designed to help reduce PV panel's temperature. As PV panel gets heated, it needs to be cooled down for a better performance because high temperature will affect its efficiency [9]. Water is used as cooling agent because it has high specific heat capacity and readily available [1]. In this part, the main components are Arduino microcontroller, water pump and temperature sensor.


Fig. 1. Experimental Setup for Cooling-Concentrated PV System

Both the cooling-concentrated PV system and conventional PV system are placed under the sunlight simultaneously. Fig. 2 shows the overall process of the cooling-concentrated PV system. The temperature sensor is placed on the surface of the PV panel and it is connected to Arduino board where the board is powered by a laptop. If the temperature sensor senses the panel's temperature is exceeding 50 °C, it will send signal to the Arduino board and trigger the water pump to start operate for 30 seconds. Water will flow on the surface of PV panel to cool down its temperature. The sensor will keep on sensing the temperature of PV panel. If the temperature is still above 50°C, the pump will continue to operate for another 30 seconds. The output of the PV panel is connected to 228.57 Ω load resistor and then, connected to Data Acquisition Interface LVDAC for data collection in terms of temperature, output voltage, output current and output power. The output data of the two PV systems are analyzed and compared. The experiment is set to begin from 11am until 1.27pm.

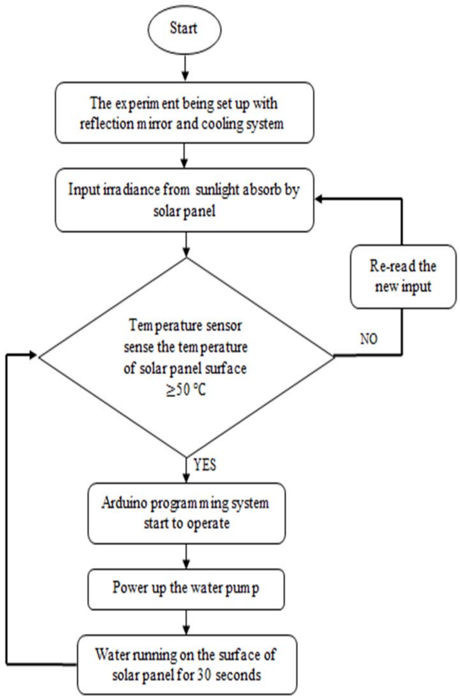


Fig. 2. Process Flowchart for Cooling-Concentrated PV System

### *B. Conventional PV System with Photovoltaic cleaning system*

The PV cleaning system experiment is designed to investigate power improvement in three different surface conditions of panel. The three surface conditions are as follow:

- PV panel with clean surface.
- PV panel with moss on the surface.
- PV panel with sand on the surface.

The electrical and physical characteristics of the PV panel are shown in Table 1.

TABLE I. ELECTRICAL AND PHYSICAL CHARACTERISTICS OF THE PV

| Electrical characteristics | |
|---|---|
| Model no. | PVM-10 |
| Maximum Power (Pmax) | 10W |
| Voltage at Pmax (Vmp) | 18 V |
| Current at Pmax (Imp) | 0.55A |
| Open-circuit Voltage (Voc) | 21.6V |
| Short-circuit Current (Isc) | 0.61 A |
| Power Tolerance | ±3% |
| **Physical characteristics** | |
| Panel dimensions (mm x mm x mm) | 350 x 290x 15 |
| Weight | 1.1kg |

The cleaning robot is attached to the PV panels. The operation of the robot depends on the conditions that have been programmed in the Arduino microcontroller. Each panel is connected to resistors which act as load to the system. It is then connected to data acquisition and LVDAC software for output data collection in terms of voltage, current and power for every one minute for two hours. A more detail illustration of the system can be seen in Fig. 3.

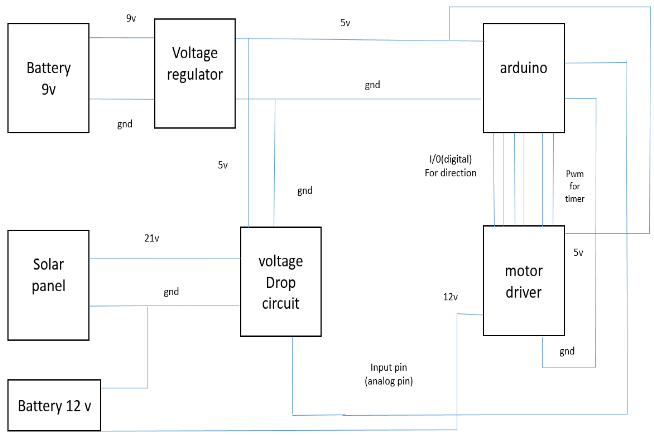


Fig. 3. Circuit Construction for Photovoltaic cleaning system

The motor driver which is powered by a 12V battery is responsible in controlling the movement of motor in two directions (forward and reverse). In this work, an integrated circuit, IC L293 is used as the main coordinator of the motor. The PV panel also becomes the source of the circuit to operate. The panel can produce up to 21 volt and it is connected to the voltage drop circuit. Voltage from the panel is then transferred to the voltage drop circuit. Arduino microcontroller analyzed changes in the voltage for the cleaning robot to operate according to conditions set.

The cleaning robot will only operate when the LDR, which is also installed in the system receives high intensity of light. In this case, 1.7V is set as the minimum value for the robot to work. The microcontroller will send disabling signal to the motor driver when the LDR receive voltage below that 1.7V. This is to avoid any robot operation, especially during cloud effect or during the night. On the other hand, the voltage drop circuit is used to detect input voltage to the panel. If the voltage is less than 5V, the cleaning robot will start to clean the PV panel surface. The experiment is set to begin from 9am until 11am where the LVDAC will record the output data at the same time.

## III. RESULTS AND DISCUSSIONS

### *A. Concentrated (Light Reflection) PV System*

Analysis on the concentrated solar system experiment is performed based on the output voltage, output current and power produced by the solar panel. The results are then compared with the output voltage, output current and power produced by a conventional solar system, which has no concentrating mirror. Fig. 4 shows the output voltage and output current of both concentrated and conventional solar system. It can be seen that the voltage curve of the concentrated PV system (red line) is slightly higher than the voltage curve produced from conventional solar panel (blue line) with the highest voltage value of 19.99V. The figure also depicts larger red area compared to the blue area. This actually indicates that the output current from the concentrated solar system (red area) is larger than the conventional system (blue area), thus, proving that the solar system with concentrating mirror is better in terms of performance compared to the conventional system.

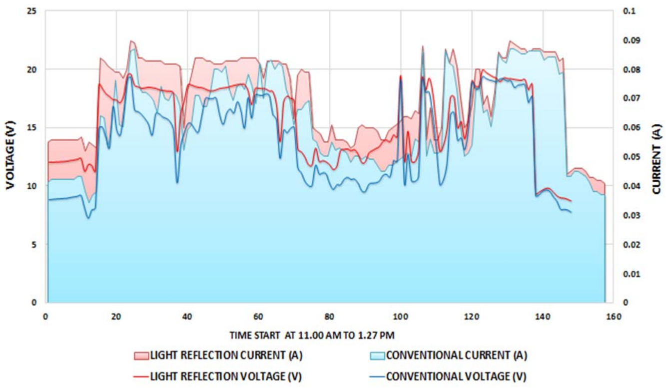


Fig. 4. Voltage and Current Output of Light Reflection vs Conventional Solar Panel

Fig. 5 illustrates the output power generated from the concentrated and conventional solar panel respectively. Generally, it can be seen that the power produced by concentrated PV system (red line) is higher than the conventional PV system (green line). The highest power generated by the concentrated system is 1.799W while the conventional system generated only about 1.693W of power. This shows that the irradiance concentrating method is improving the solar panel performance in generating power.

However, there are moments that the unreliability of the system may occur, specifically when it is unable to meet the load. A loss of load occurs whenever the system load exceeds the available generating capacity. From the experiment conducted, the highest power output gained from the concentrating mirror method is only 1.799 W, an amount that is required to power the load

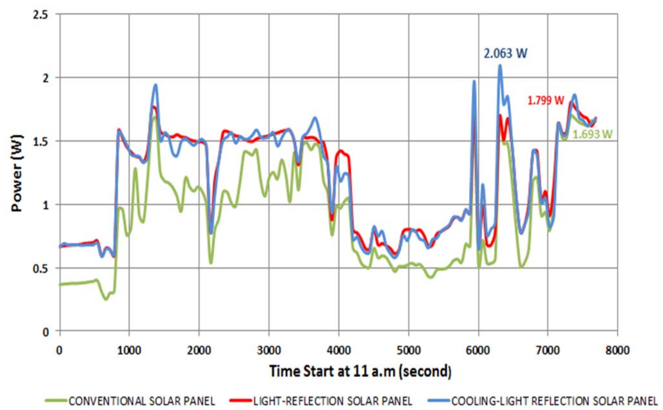


Fig. 5. Power Comparison Between Light-Reflection and Cooling-Light Reflection with the Conventional Solar Panel.

Since the power produced comes from an intermittent source, there are certain times when the load cannot be fulfilled. For instance, at times 4500 second, 5000 seconds and 5500 seconds, the power produced by the concentrated PV panel is less than required, causing the loss of load. At the three particular seconds, the load is loss since the power generated is 0.614W insufficient.

Finally, the percentage of the maximum power output produced from a 10W PV panel can be obtained by dividing the highest power output from the experiment to 10W and then, multiply with 100. As the result, the percentage of maximum power (1.799W) produced by the PV panel from the experiment is about 17.99% of the actual PV panel rated power. Therefore, the used of concentrating mirror on the PV panels can improve the output power when compared to the conventional power which generates only 16.93% of maximum rated power.

The concentrating mirrors installed to the solar system proposed in this project proved as an efficient method in enhancing PV panel performance because the output voltage, current and power produced are higher in values compared to the conventional system. However, the method itself had caused increment in the temperature of the PV panel. Due to this, the PV panel may not operate at its best performance.

Fig. 6 illustrates the temperature graph between the light-reflection PV system (concentrated system) and the conventional PV system. The temperature of concentrated solar panel (red line) is higher than temperature of conventional solar panel (blue line). This is because in the concentrated PV system, not only the mirror directs more irradiance, but it also concentrates heat to the surface of solar panel. Therefore, to overcome the overheating PV system, a cooling system is introduced in this work.

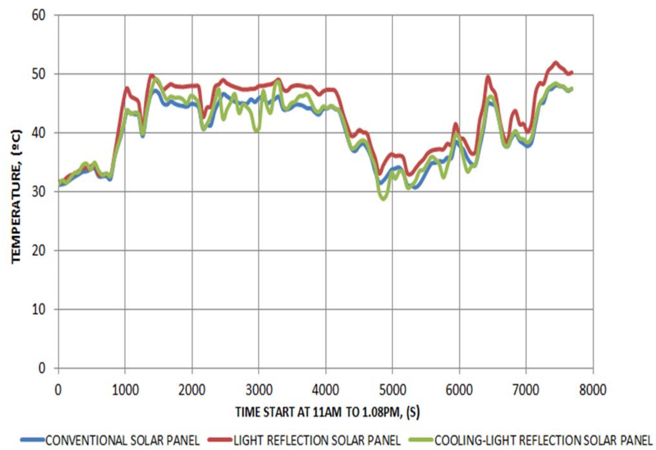


Fig. 6. Temperature Compared Graph of Cooling-Light Reflection and Light Reflection with the Conventional Solar Panels.

### *B. Cooling-Concentrated (Light Reflection) PV System*

The cooling system is implemented to help reducing the temperature of solar panel. The green line in Fig. 6 shows the temperature curve obtained after a cooling system in installed to the concentrated PV panel. The cooling system is set to operate as soon as the solar panel temperature reaches 50°C. Water will flow on the surface of the panel to cool down its temperature.

From Fig. 6, temperature of the concentrated solar panel (red line) is the highest amongst the three cases, which indicates that the concentrating mirror is overheating the solar panel surface. The figure also shows that the temperature from the cooling-concentrated system is within the temperature range of conventional solar panel. Hence, the performance of solar panel can be maintained at a good level with the use of cooling system since the temperature produced by the cooling-concentrated system is more stable and controllable compared to the concentrated solar panel.

Besides that, the maximum output power produced from the cooling-concentrated method is 2.063W which is the highest value compared to both concentrated and conventional solar panels with just 1.799W and 1.693W respectively as shown in Fig. 5. The performance of the solar panel increased in terms of output power generated and temperature which indicates that the cooling-concentrated method is an efficient approach to improve performance of the PV system.

### C. *Conventional PV System with Photovoltaic cleaning system and Different Surface Conditions*

The performance of conventional PV with cleaning system is analysed with different panel surface condition which are clean surface, moss covered and sand covered conditions. The PV panel with each condition is connected to the data acquisition with LVDAC software. The performance is analysed in terms of output voltage and output power of the PV system. For the moss covered and sand covered panels, the amount of moss and sand placed on the panel surfaces is initially small and then after a few minutes, the amount is added to observe their effect on the voltage and power. The results are then compared to the clean surface of PV panel.

Figs. 7 and 8 show the PV panel with a clean surface, PV panels with moss and sand on the surface respectively. Fig. 9 illustrates the voltage of three different surface conditions of PV and the effect of cleaning process on the voltage. The data are taken in the morning from 9am to 11am on 12 May 2016. The nonuniform pattern of output voltage in each condition is caused by cloud movements and shadings. It can also be seen in the figure that the output voltage from a clean PV surface has higher magnitude compared to the output voltage from moss covered and sand covered PV panel.

Fig. 7. PV panel with a clean surface

(a) (b)

Fig. 8 Deposition of (a) moss and (b) sand on PV Panel

As more amount of moss and sand are added on their respective panel surface, the voltages in both conditions drop down drastically. These are shown at 720s, 1020s, 1560s and 2820s. The figure also shows that after 720s, 1020s, 1560s and 2820s, the output voltage of both moss covered and sand covered PV panels increased rapidly. This is because, the cleaning robot is set to operate as soon as the voltages drop down to below than 5V. Since the voltages at each time drops below 5V, the cleaning process took place and thus, improving the performance of the panels.

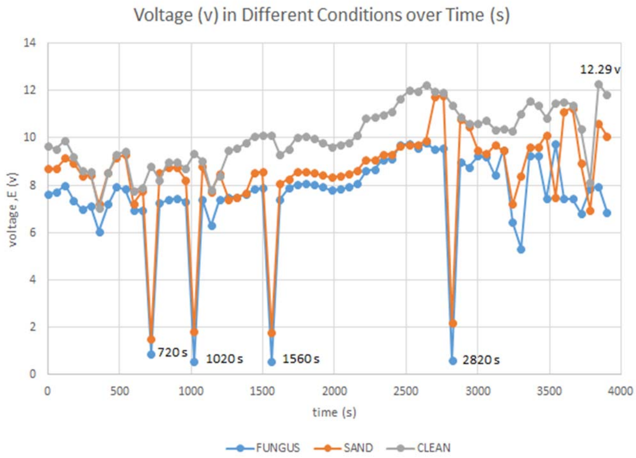


Fig. 9 Voltage of all conditions versus Time

Fig. 10 depicts the output power of each PV panel condition at different time of operation. It shows that panels covered with moss (blue line) and sand (orange line) has smaller output power than the clean PV panel (grey line). This proves that the presence of moss and sand on panel surfaces is a hindrance to maximum PV panel performance. Similar to the output voltage trends, the nonuniform pattern of output power occurred due to cloud movements and shadings. At 720s, 1020s, 1560s and 2820s, the output power drops drastically as more moss and sand are added on their respective panel surfaces. The amount then increased rapidly after cleaning process take place.

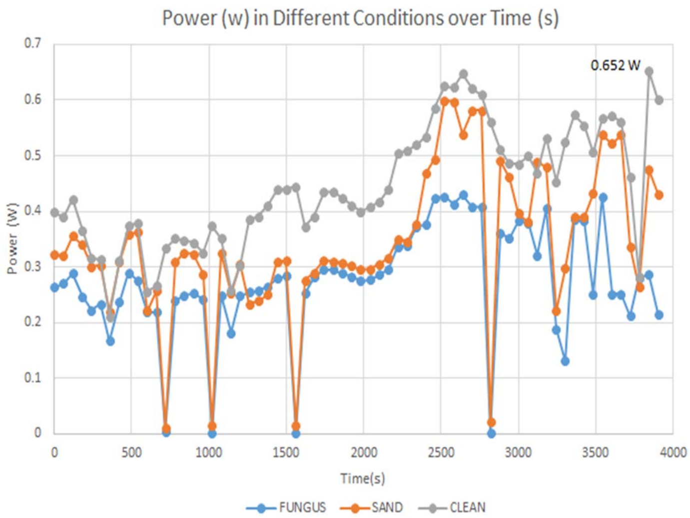


Fig. 10 Power of all conditions versus Time

Finally, the percentage of the maximum power output produced from a 10W rating PV panel can be gained by dividing the highest power output from the experiment with 10W of PV panel and then, multiplied with 100. In this case, the maximum power produced by PV panel during clean condition is 0.652W. Thus, the percentage of maximum power output can be calculated by dividing 0.652W with 10W and then multiplied with 100, resulting in 6.52% of the actual panel rating.

## IV. CONCLUSION

The performance of PV panel is improved by installing concentrated mirrors and cooling system on the panel. By using multiple fixed directed mirrors as reflectors, the output power of the panel increased. However, this method caused the surface temperature of the panel to increase too and affected the performance of PV panel. Therefore, cooling system is introduced to decrease the surface temperature. By allowing water to flow on the surface of the panel, the temperature of the PV panel reduced and its performance increased.

A PV cleaning system with an intelligent method was designed to clean the deposition of impurities on the PV panel surface. This system utilizes a robotic approach with the proper circuit to control the robot operation. The sensitivity of Light Dependent Resistor (LDR) which senses the presence of light becomes one of the main components that allow the cleaning robot to work. With the deposition of two types of impurities (moss and sand), the robot starts to clean the PV panel surface as soon as it receives voltage below than 5V. Each panel's output power obtained through the LVDAC software shows that the panel cannot performs at its best when there are impurities of the surface of the panel.

The future research will try to combine both proposed method to enhance the PV performance, either for short term (concentrated mirrors and cooling system) and long term (PV cleaning system).

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