Portable Robot for Cleaning Photovoltaic System

Ensuring consistent and optimal year-round photovoltaic panel performance

Amna Al Baloushi, Maryam Saeed, Shaza Marwan, Shiaikha AlGghafri, and Yacouba Moumouni
Department of Electronics Engineering, The Higher Colleges of Technology, Ras Al Khaimah, United Arab Emirates.
Email: H00257199@hct.ac.ae

Abstract—**With growing costs of electricity and concern for the environmental impact of fossil fuels, implementation of eco-friendly energy sources like solar power are rising. One of the major methods for harnessing solar energy is through the utilization of photovoltaic (PV) panels. However, accumulation of dust and debris on PV panels has the potential to considerably reduce overall efficiency of the system. United Arab Emirates (UAE) is located in the Saharan desert which has an abundance of sunlight and open space appropriate for solar energy applications. The main problem the country faces is dust gust and little rainfall. As a direct consequence, solar panels must be often cleaned because dust reduces the efficiency of PV panels. Current labor-based cleaning methods of photovoltaic arrays are expensive and requires a huge amount of water. This paper proposes a new design and implementation of a Portable PV Cleaning Robot System (PPVCRS). Results showed that with the implementation of the PPVCRS, 1) the overall Solar PV array efficiency has increased; 2) more free and renewable energy was harnessed; 3) overall water usage was cut down; and 4) a significant economic benefits to the country was noticeable because less money was spent on labor and water.**

Keywords—Solar PV Panels, dust, automatic cleaning system, efficiency, UAE

I. Introduction

Dust is the aggregated microscopic solid particles with diameters in the millimeter range. Dust comes from the atmosphere in various ways. The major sources are, but not limited to; wind, pedestrians, automobiles, volcanoes, and pollution [1]. Accumulation of dust from the outdoor environment on the solar photovoltaic (PV) system is a natural phenomenon. It was found from previous studies that accumulated dust on PV surfaces can reduce the overall system's efficiency by 50% [2]. In addition, PV systems built in more arid climates have shown to experience a severe reduction in the long-term power generation. With no significant rain fall it was found in Ref. [3] that the daily energy losses can be as high as 20% or even more. In Ref. [4], the performance of solar PV panels under dusty conditions was investigated. Furthermore, it was found that there is a strong correlation between tilt angle and dust. Other studies, such as Ref. [5] investigated the real effect of dirt and other minute particles on PV cells. In summary, the accumulated tiny particles act like billions of small resistors connected in a series. Thus, the lumped external resistance could reduce the photovoltaic performance by up to 85%.

The focus of this work was to design and implement a solar cleaning robot. This robot is meant to assist solar arrays in delivering energy at its full capacity. An efficient robot can service large scale solar parks. The PPVCRS can not only clean the panels, but can also physically inspect any defects that may reduce the total array output power. This automatic PV cleaning method performs better than human crew and has zero water usage. A complete and periodic cleaning is especially important since the obstruction of a single cell with debris affects the energy generation of the entire array [6]. It is extremely important that all cells operate at peak efficiency, free from any nearby shadow, dust, of bird dropping, since they are all connected in series.

Under the UAE weather conditions, solar panels must be cleaned numerous times a week because even a very little quantity of dust has the potential of reducing the overall efficiency of a PV system. As a result, the proposed solar panel cleaning robot is suggested to be mounted on the PV array in such a way that it frequently cleans the solar panels if any dust or dirt is spontaneously detected. Hence, this paper investigates the best way to maintaining the effectiveness of solar PVs through efficient cleaning schemes when they are exposed to various weather factors, including humidity and dust.

The most important reason for undertaking this project is to improve the life standard of human beings. Also, the study is motivated by the: 1) global trends of designing robots with human appearance, 2) think creatively concept, 3) reduction of greenhouse gas emissions, 4) ever-growing increase in energy cost, 5) need to improve work conditions, and 6) negative human impact on the environment.

This paper is organized as follows. Section II describes the methods used and specifies the design procedures. Section III thoroughly covers the data collection, dust simulation results, and the subsequent analysis of the findings. Finally, Section IV concludes the article.

II. Methods

It is very important to remove dust form the solar cells for the aforementioned reasons. This solar cleaning robot is an object-based sensor design that can remove dust from solar cells in order to maximize solar PV output connected to the utility grid or in islanding mode. This PV cleaning system is not only cheap, but it also minimizes the negative ecological impact of manual and water-based cleaning. The robot is designed to be pragmatic and efficient, thus procuring a year round dust-free PV panels in this harsh and arid conditions. The solar panels cleaning robot is composed of a cleaning brush that moves across the panels by a motor. The latter rides along the top and the bottom of each panel; it then vertically moves through the whole array. This design was selected because of its simplicity, modularity, and expandability. It is easier to move the cleaning head around on the array while providing the lowest risk of scratching the panels because the entire drive system rests on the frame rather than the cover glass. The expandability of this design allows acceptable continuous functionality on a wide range of array dimensions. Although not all panels or arrays are of the same size, this system can adapt easily by interchanging the belts depending on the number of panels in a row. The panel columns have a continuous travel distance since the robot can easily cross the side edges between the panel frames.

The solar panel cleaning robot is a unique water-free robotic cleaning device. It combines a powerful, soft microfiber cleaning system with controlled airflow that removing 99% of the daily dust. It also keeps the panels at their optimal production rates. Fully autonomous and energy-independent, the robot has its own embedded solar panel and energy storage. With a control unit and sensors that drive the system along each row, the robot is easily and remotely managed, monitored, and controlled. Each row of the solar array is equipped with one solar panel cleaning robot attached to it.

The Robot mainly consists of: 1) a battery recharged by a separate solar panel; 2) brushes on the extreme ends; 3) four wheels; 4) three stepper motors; 5) a hell sensors; and 6) a controller system. Two motor are installed on each side of the robot frame. The first motor is for both horizontal and vertical movements. The second motor is used to spin the microfiber brush. The connecting rods and brushes can be modified to fit the same driving system. Some auxiliary, but with equal importance components are: 1) an anemometer for wind speed measurement; 2) a temperature and humidity sensor; 3) an Arduino Mega 2560; 4) an optical dust sensor; 5) a hall effect magnetic sensor; 6) a 2H Micro-step driver; 7) pulleys and belts system; 8) a 3.5" colored TFT touchscreen breakout for outputs display purposes; and 9) a battery charger.

Figure 1. describes the robot cleaning operation steps. Initially, the robot is stationed at the end of the panel. The dust sensor is positioned in such a way that it can detect the tiny particles in the air. Once the sensor detects the dust, a signal is sent to the brushes (via motor) to start rolling. The robot will then start moving in forward or backward direction while cleaning the panel. During this operation, the robot keeps moving at a constant speed until the sensor's signal reaches the panel edge. At that point, the robot slows down and stops. Then, the PPVCRS changes direction.

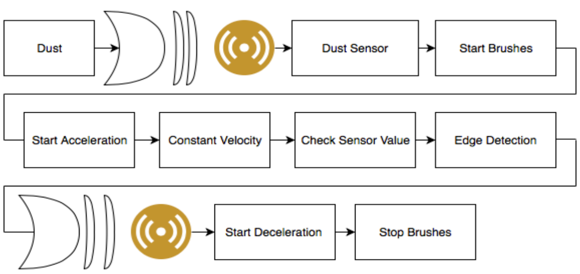

Fig. 1. Solar Panel Cleaning Robot Diagram

III. Results and Analysis

A. Anemometer

The anemometer measures the horizontal wind speed. This parameter is crucial for any wind site assessment. Cup anemometers are the general standard type of anemometer [7]. They are robust and resistant to turbulence and skew winds caused by masts and traverses.

Table 1. shows the testing results of the wind speed sensor in different wind conditions versus the subsequent output voltages. These measurements were shown to be consistent. The maximum wind speed recorded was 4.99 m/s and the minimum speed was as low as 0 m/s.

Moreover, Fig. 2 illustrates the aforementioned results, i.e., the voltage and the wind speed, for clarity purposes. Therefore, owing to the fact that airflow due to wind is able to effect the dust accumulation or dissipation at particular places of the solar panel, measuring the wind speed at a solar site is very important. It can be remarked that powerful swirling wind affects the solar panel generation. In cases where a wind gust is taking place at the site, the PV panel's efficiency is drastically reduced [8]. Thus, the recommendation is that it is worthless cleaning the panels in such a windy weather. Likewise, the decision to leave the robot in a stand-by mode may generate some economic benefits because this significantly cuts down the operation and maintenance costs.

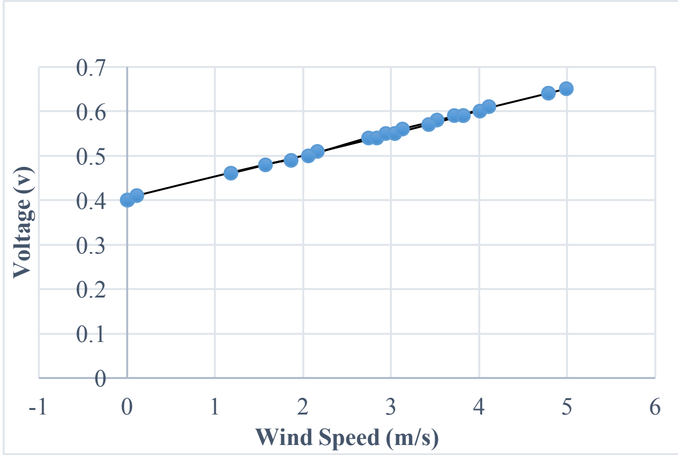

Fig. 2. Wind speed characteristics.

TABLE I. WIND SPEED RESULTS ON A WINDY WEATHER

	Measurements	
	Wind speed (m/s)	Voltage (v)
Test 1	0	0.4
Test 2	1.86	0.49
Test 3	2.94	0.55
Test 4	3.82	0.59
Test 5	4.79	0.64
Test 6	4.99	0.69

B. DHT22 Temperature-Humidity Sensor

The DHT22 is a basic, low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on a data pin. For simplicity in the approach, temperature distribution patterns is portrayed in Fig. 3, both in degrees Celsius and Fahrenheit. Instant temperature variations are noticeable by breathing onto the sensor (like you would fog up a window), thus the humidity increases.

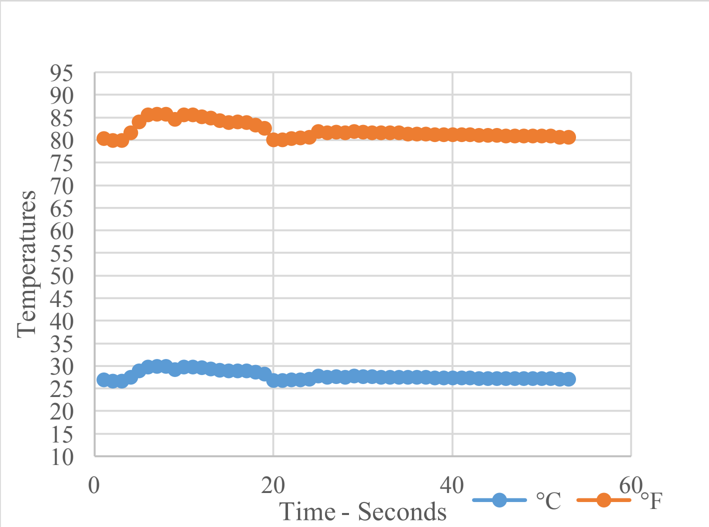

Fig. 3. Temperature characteristic.

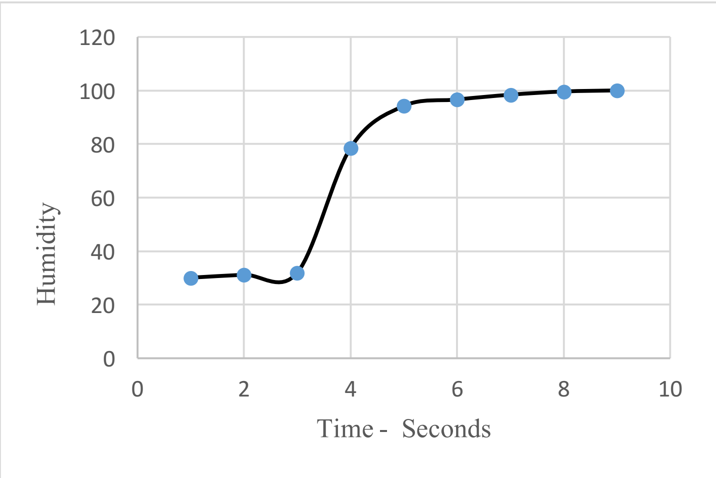

Fig. 4. Humidity characteristic.

TABLE II. RESULT OF HUMIDITY TEST

	Measurements	
	Time – Second	***Humidity – %***
Test 1	1	00.0
Tesr 2	3	31.8
Test 3	5	94.1
Test 4	7	98.3
Test 5	9	99.9

Hence, it can be clearly seen (Fig. 3) that 56 temperature samples were collected, both in ℃ and °F, respectively. The maximum temperature was 85.64 °F and the minimum 79.88 °F. In contrast, Fig. 4 shows humidity which has the following extremes: minimum is 30.00% and the maximum is 99.9%.

The open-circuit voltage of solar cells are mostly affected by temperature changes, which in turn affects the power output. Solar modules work best in certain weather conditions, but since the weather is always changing, most solar photovoltaic modules do not operate under normal operating conditions. The performance of a PV system depends, not only on its basic characteristics, but also on the environmental parameters. Consequently, the ambient temperature plays an important role in the photovoltaic conversion process.

Then how is humidity fits in this study? The high summer temperature in Gulf is often associated with a high humidity content alongside the east and west coasts. Humidity affects solar PV in ways comparable to dust accumulation. Water vapor particles might reduce the irradiance level of sunlight that is required for PV panels to reach high efficiency. PV surface could be moist and light is scattered either by refraction, reflection or diffraction when it hits water droplets [9].

C. Optical Dust Sensor (GPY1010AU0F)

Sharp GP2Y1010AU0F is an optical air quality sensor designed to bond dust particles. The infrared and light emitting diodes in this device are encoded to allow it to detect reflected light in the air. It is particularly effective in detecting very fine particles.

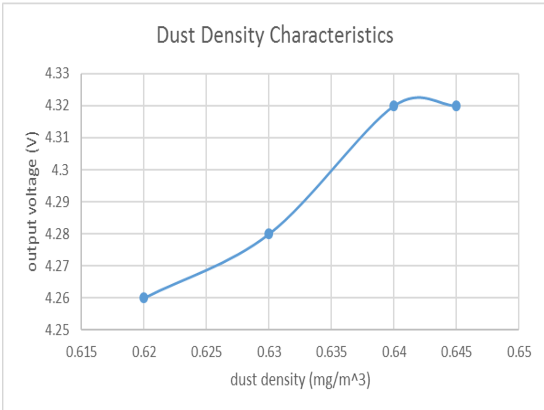

Figure 5. Dust characteristics

TABLE III. OPTICAL DUST SENSOR TESTING

	PV Module	
	Dust Density	*Raw Signal Value (0-1023)*
Test 1	0.62	4.26
Test 2	0.63	4.28
Test 3	0.64	4.32
Test 4	0.645	4.32

Figure 5. shows the optical dust sensor test results on a normal day. Again, for ease in the approach, Table III indicates the dust density contents under various test conditions. It shows the dust density variations from 0.62mg/m^3 to 0.645 mg/m^3, with an output voltage ranging from 4.26V to 4.32V, respectively. By comparing the data to existing once, the robot knows the right time to begin the solar panels cleaning process.

D. 3.5" Colored TFT Touchscreen

To monitor a set of solar panels in a large field, more electronics and power electronics components are needed to detect which of the PVs are subjected to faults. The TFT touchscreen breakout is merely utilized to display the results. Typical fault causes include, but not limited to, severe weather, such as wind and heat. Furthermore, to obtain early warning of faults and creeping changes, monitoring and control of a PV power plant via a central unit is indispensable. In this way, the operator can undertake repairs and maintenance measures at an early stage and thus, avoid costly downtimes. An advanced control can help reduce operating costs and increase solar plant performance [10].

E. Research Implications

The PPVCRS help reduce operating costs and increase solar plant performance. Some of the main advantages and benefits of this project are:

- The robot assists PV panels to work efficiently at their maximum capacity.
- A high cleaning capacity is investigated and has proved to be much faster than a human hand.
- Increasing safety in the work environment because the risky roof access is no longer necessary.
- A thorough cleaning can be achieved in a timely manner through the rotating brushes.
- The design can helps save freshwater in the UAE.
- The design can help reduce PV panel aluminum strip damage due to longtime dust accumulation.
- The lifespan of the solar cells are expected to reach the predicted years.
- The research paves the way to a future research and development niche and collaboration area for policy makers and investors in the region.

IV. CONCLUSION

A reliable, cost-effective, and automatic PV cleaning robot was designed and implemented in the United Arabs Emirates. Its main purpose is to clean solar panels from dust and perform a physical inspection. Dust accumulation can significantly reduce the power output on the PV panels. While the Gulf countries in general and especially the UAE are rich in solar energy, the desert condition is quite an unfavorable factor due to the high concentration of minute particles in the air (dusty). This is shown to undermine the throughput of solar PV systems installed in the region. The robotic system proposed in this research is a simple way to effectively tackle the challenges.

Finally, the research intentions are not only to solve solar panels' dust accumulation issues, but also through this robot, the quality and performance of PV cells are improved. Thus the system helps to cut down labor cost and high water usage in this dry environment.

ACKNOWLEDGMENT

One of the authors would like to express his special gratitude to: (1) the Higher Colleges of Technology, Ras Al Khaimah Women's Campus (RKWC); (2) the program chair, Dr. Ahmed Khodary and Mr. Adrian Miu; and (3) her colleagues for their invaluable contributions during this project.

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