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Design of an automated cleaning system for solar panels

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Abstract. This project involves the design of an automated system for solar panel cleaning. The purpose of the design is to reduce the effect of dust on solar PV efficiency. The result is an increase in the efficiency of panel power output by 6.89%. The system is useful in the solar panel field where the system can be operated for a long time without human intervention. It measures and records current, voltage, temperature, radiation, and humidity. The measured data are sent to the designated supervisor.

Introduction

Fossil fuel is commonly used in Saudi Arabia, mostly in power plants, which causes lots of emissions into our air. So, one of the solutions to generating electrical energy and reducing its usage is using renewable energy sources. Solar energy is one of the most important renewable energy sources that use the sun's radiation. It is clean and environmentally friendly. The power produced by photovoltaic cells is mostly determined by the amount of sunlight that reaches them. In fact, many studies concentrate on the design and economic analysis of PV solar systems [1]. Such as using a maximum power point tracker (MPPT) to improve the efficiency of a PV system [2,3], or hybrid systems to improve the performance of a PV system [4]. All of these studies are being conducted in order to increase the efficiency of solar cells. On the other hand, there are many reasons that affect the efficiency and the output power of solar cells, such as solar radiation, Humidity, high temperatures, tilted angle, and the accumulation of dust on solar panels, particularly in desert areas.

Saudi Arabia is a desert area, with high temperatures reaching their peak in summer. The temperature ranges from 40°C to 50°C. Drought and sandstorms are common, especially in Al-HUFUF due to its geographical location near the desert called the Empty Quarter. The issue at hand is the impact of external factors like high temperatures and dust accumulation on the PV panels' surfaces. The efficiency of solar panels is greatly reduced by these two characteristics. As a result, we anticipate that a study of the impact of dust accumulation on PV module output power and efficiency will be required. Dust can also refer to dust storms, which is relevant to this study. To solve this problem, there was a solution to get rid of accumulated dust on the photovoltaic panels using cleaning.

Cleaning solar panels adopted through many stages, starting from traditional cleaning methods are ineffective and detrimental. New techniques are being evolved. Natural forces inclusive of wind and rain will eliminate dust. Mechanical methods, self-cleaning nano-film, and electrostatic gear are employed [5]. Those are referred to as energetic cleaning methods and are applied directly or in a roundabout way to the solar panel [6,7].

The paper is organized as follows. In Section 2, the authors compare the existing cleaning methods of solar panels. Section 3 is devoted to describing the design methodology and the proposed automatic cleaning systems. While Section 4 describes the performance of the designed cleaning system. Finally, section 5 involves the conclusion, recommendations, and future improvement of the design.

Review of Solar Panel Cleaning Techniques

The operation and maintenance of photovoltaic panels should be carried out frequently, not only to improve their efficiency but also to prevent damage caused by dust accumulation due to environmental pollution. A study on several dust removal techniques has been carried out in this work. These methods can be classified as shown in Figure 1. Some of these techniques are discussed below. Their advantages and disadvantages are summarized in Table 1.

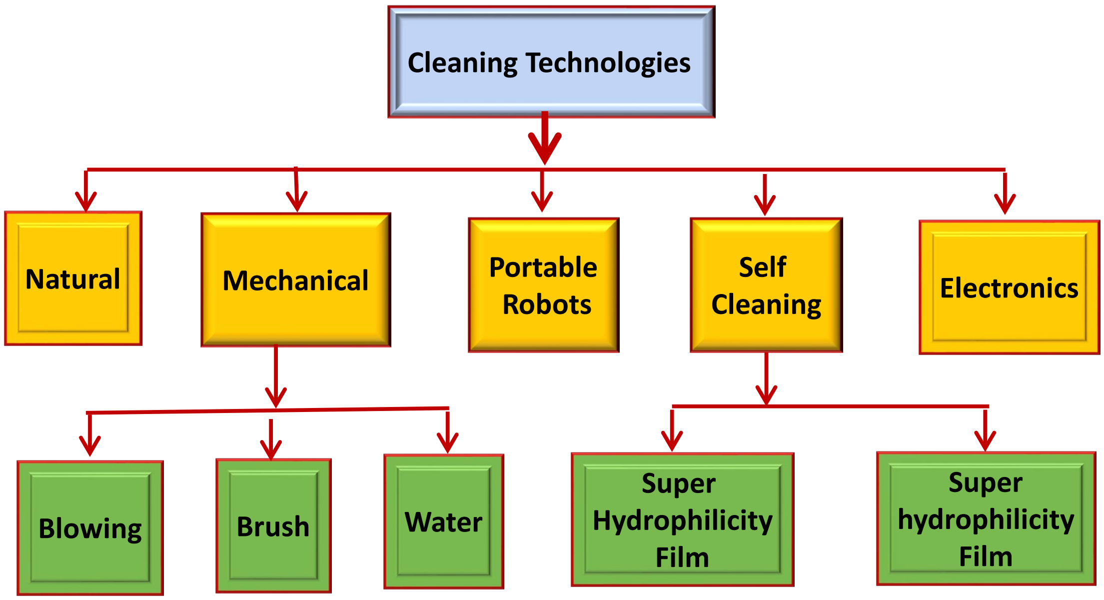

Figure 1. Common Solar PV panel cleaning methods

Dry Robotic Cleaning

Robots can clean solar panels without water. Robots use dry brushes and air pressure to remove dirt. Dry cleaning is generally less effective than wet cleaning. The water involved in wet cleaning removes dust particles since it acts as a medium for the particles to disperse. Despite this, water is not always available everywhere, and this makes it difficult to clean the modules. Therefore, dry cleaning is a great alternative.

Electrostatic Cleaning

Solar panels can be cleaned by means of moving wave electric charge on small particles suspended in liquid [8], allowing dust and similar dirt; except algae to be removed. Dust particles are emitted from the panels when a negative voltage is applied to one electrode and a positive voltage is applied to the other electrode [9,10]. A different mechanism for removing dust involved the distribution of the electric field density to create an electric curtain. By varying the electric field density over the plate, this system forces the dust off the plate [11].

Natural Method

Rain is considered a natural way that cleans PV panels. The amount of rain limits the effectiveness where some countries get rainy less often than others. According to an experimental study [12], accumulated soiling on PV panels for 5 years reduces the generated power by 3%, and the rain could improve the efficiency by only 1% of the full power rating [13]. The results of dry months hint that the output of the PV panel could be reduced by 6%.[14] It is worth noting that light rain might also reduce the efficiency of PV panels and that is due to the dust slides by the rainwater from the upper cells of PV panels onto the lower ones.

Coating Vibration method

Coating Vibration is another method used to prevent dust accumulation by applying a special spray on the surface of PV solar panels and shaking them with a mechanical vibration system. An experimental study was applied to compare the power efficiency of PV panels with different scenarios. According to the experiment PV panel with coating and vibration technique had been reduced by 10% of power efficiency in 6 weeks, while the PV panel with no coating or vibration had been reduced by 10% of power efficiency in 1 week and goes along 33% in 6 weeks [15].

Mechanical Methods

Definition: The mechanical methods remove the dust by brushing, blowing, vibrating, and ultrasonic driving. ` The brushing methods clean the solar cell with something like the broom or brush that was driven by the machine was designed just like a windscreen- wiper. A mechanical method has four techniques to expel the dust which are a robotic method, air-blowing method, water-blowing method, and ultrasonic vibration method.

Wet cleaning

Wet cleansing is completed with ionized distilled water, which is desired for this task. Cleaning PV panels with pure water has massive benefits; it entirely eliminates the contaminating particulates on the surfaces and leaves no residue, which increases the panel output voltage [16,17].

Table 1 Comparison of the forthmentioned cleaning methods

Technique	Approach	Advantages	Demerits
Coating	Water-Free	•High efficiency in humid regions •No electrical power consumption. •Availability of providing other features such as anti-icing, more stability, anti-reflecting, Photocatalysis reaction, and anti-fogging	•Recoating requirement •Treats of realized chemical materials for the environment
Electrostatic charge system	electric curtain	•No water is required •No heavy gears are required	•Needs recharging
Linear Piezoelectric System	Vibration	•Minimum gears required •Lightweight on the surface of the panel	•Comparatively complex system
Manual Cleaning	Water-Based	•Simple with a low cleaning cost •No need for a power supply	•Cleaning efficiency is dependent on the technician's expertise •High water consumption •Restrictions of the floating structure and weight-bearing
Robots	Water-Based and/or Water-free	•Modules can be cleaned every single day with robotic cleaning systems, which is considerably more convenient than manual cleaning.	•This type of cleaning requires a significant investment. This makes it unsuitable for residential use.

		•Compared to manual cleaning, dry cleaning produces more energy because modules are cleaned daily	•Electricity is required to operate these robotic cleaners. That adds to the cost.
Self-Cleaning	Water-Based /Water-Free	•Fully automated •Cooling effect (water-based approach)	•Low efficiency •High consumption of water •High initial power cost
Wet cleaning	Distilled water	•Does not leave a residue •Does not cause corrosion	•High consumption of distilled water

Design methodology and the proposed automatic cleaning systems

The proposed system design will be environmentally friendly and fully automated to clean dust accumulation. The system consists of these main components: Solar panel, Arduino Mega controller, sensors, DC motors, water pump, water tank, and wiper shown in Figure 2. The process of cleaning starts when the system detects a power drop by comparing the PV-measured power P_M and the expected power P_{th} given by:

$$P_M=V_M \times I_M \quad (1)$$

$$P_{th}=E\times A_c\times \%\eta \quad (2)$$

Where

V_M is the measured voltage,
I_M is the measured current
E is the solar radiation at the time of the test
Ac is the area of the solar panel.
η is the solar panel efficiency.

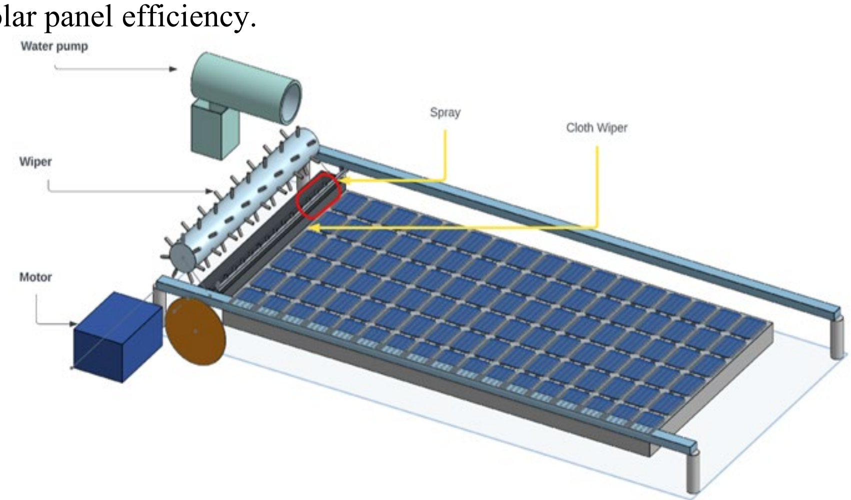

Figure 2: 3D model of the automatic cleaning system.

The control unit is the heart of the cleaning system. It consists of an Arduino Mega unit. It processes all sensor values; it compares the expected power output with the actual output and calls for cleaning. In addition, it sends the data to the transmitter and the display unit. The cleaning unit consists of the DC Motor to move the cleaning mop back and forth. The motor operates at a low speed for effective cleaning. The chosen DC motor has a torque of 2.88 kg.cm at 30.07 rpm. The wiper is chosen in a way such that the weight of the rod and the electric motor are developing a normal force at the PV panel. This normal force creates a frictional one against the movement of the wiper, which will help to clean the cell very effectively.

The water pumping system's main function is to supply the system with adequate water. The principle of operation of this system is to pump water from a low-pressure head to a high pressure to increase the flow rate of the liquid. In addition, a solar radiation sensor is needed to measure the radiation level hitting the solar panel. The output of the sensor is fed to the control unit to decide if the panel power output is as expected or below expected in case of dust accumulation.

The sensor system includes temperature and humidity sensors, a voltage sensor, and a current sensor. The voltage and current sensors are used to calculate the panel power output. The control unit compares it with the expected power output and activates the cleaning process. The following flowchart shows the principles of the automatic cleaning system. The final cleaning system is shown in Figure 3. The prototype performance and benefits are evaluated through field measurements.

Results

The main outcome of the proposed design is improving the solar panel performance by removing the dust settling on the panel. Many cleaning tests have been made. Figures 4 and 5 show the I-V and P_V curves for a 30-Watt solar panel before and after cleaning. The two figures depict that the current and power have increased after removing the dust. The current increased by 9.47% and the maximum power increased by 6.87%.

Conclusion and Future Work

In conclusion, we have looked up factors that affect PV efficiency, and depending on the previous methods and techniques, the combination of water cleaning and nano-spray automated cleaning system is the best method for cleaning dust accumulation.

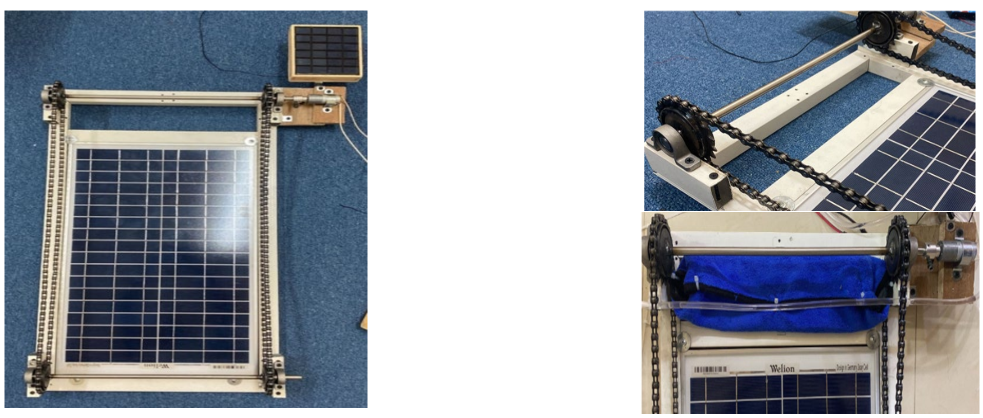

Figure 3: The automatic cleaning system final design

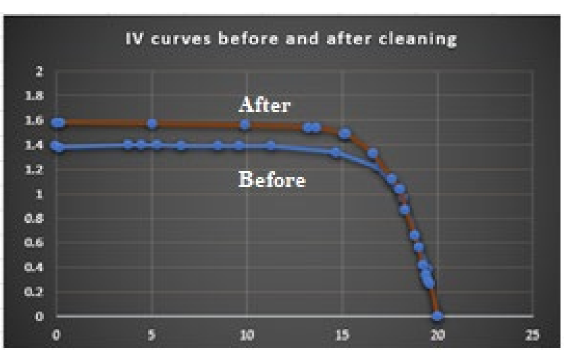

Figure 4 I-V curve for a 30-Watt solar panel before and after cleaning

Figure 5 P-V curve for a 30-Watt solar panel before and after cleaning

Based on the experiments conducted at KFU, the dust effect on PV efficiency was recorded, and cleaning the tested solar panel raises the power efficiency by 6.86%. Our system can be quite useful in the solar panel field where the system can be operated for a long time without human intervention. Also, it is considered green energy and in the line with the future vision of Saudi Arabia. However, power decrease is caused by different natural factors such as (temperature, shadow, dust, etc.) which can be recognized by the control unit.

On the other hand, the system's total energy consumption during the cleaning process is about 66 mWh. The cleaning system will definitely improve the power efficiency by reducing dust accumulation by nano-spray and cleaning the solar panel when the dust starts to affect the power efficiency. Even though a test bed for cleaning solar panels is assembled, the following improvements are needed. These include an automated nano spray, a higher cleaning range (suitable for many solar arrays), and a WiFi-based remote monitoring system.

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