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A New Method to Reduce Soiling Effect on Performance of a Solar PV Module

*Akram Abdulameer Abbood Al-Khazzar**

ABSTRACT

In spite of many advantages behind the dependence on the photovoltaic (PV) systems butthe efficiency level of the PV module still not satisfying. The fuel of the PV modules is the amount of sun light absorbedby the module and that depends on many factors such as front surface reflectivity, solar beam incidence angle and the most important is the transmissivity of the front surface. Soiling and dust accumulation reduce the transmissivity. This article presents a review for the studies about the impact of dust accumulation on solar PV module performance and a discussion for some solutions or cleaning techniques implemented in the previous studies. Also in this work, a new method is introduced to reduce the soiling. The method can briefly described as a moving cover with a cotton cloth attached firmly to the backside of the cover. At sunset, the module should be covered and the cloth wipes down part of the dust and the opposite happens at the sunrise. The results showed that a 9.22% gain in power produced by covered module than the uncovered module. Also, the covered module output was very close to the module after it was cleaned.

Keywords: *Photovoltaic System; Soiling Effect; Dust Effect; Cleaning Method; Iraq.*

1.0 Introduction

Photovoltaic (PV) power systems are one of the renewable – solar energy sources that expected to play a promising role in fulfilling the electricity requirements in the future [1]. Solar PV systems in opposite to the conventional thermal power plants work under uncontrolled environment such as solar radiation variation, ambient temperature and deposition of air pollutants such as dust and dirt accumulation on the PV modules or arrays where the last one represents a troublesome problem especially for a location of desert nature which is characterized with the greatest amount of solar radiation on the globe [2].

For a PV module, Dust accumulation causes a gradual decrease of output power of PV module. The drop in power output is due to the reduction in transmittance of the front layer to the incident solar radiation

Till now, the literature could not provide a clear vision about the dust effect on the PV systems performance because of many factors which are specific for each location such as the period of PV module exposure without cleaning, rain probability, tilt angle of the module, wind speed, humidity, nature of the location, etc. therefore it is hard to give a suitable correlation or mathematical model that control the effect of dust on the reduction of the absorbed solar radiation.

Mani & Pillai [3], Sarver et al. [4] and Sayyah et al. [5] presented the most comprehensive review articles so far about this problem. Those articles include most of the studies about the impact of dust and dirt accumulation on the solar PV systems in several regions of the world. Also those articles provided an analysis of the advantages of different cleaning approaches.

The Middle East and North Africa, receiving high amounts of insolation, face their own sets of atmospheric challenges— namely, heat and dust. This topic studied mainly in this region which is quite similar to Iraqi environment, these studies are well discussed and presented in the aforementioned review articles.

1.1 Soiling composition

Soiling includes not only dust accumulation, but also combustion products, salt deposits from non-distilled water, soot, ash, bird droppings, and growth of organic species. Dust particles are defined as any particulate matter less than 500 μm in diameter which is nearly about 10 times the diameter of a human hair [4]. The most common composition can include

**Department of Energy Engineering, College of Engineering, University of Baghdad, Iraq*
(E-mail: akramabdulameer@gmail.com)

organic minerals from geomorphic fallout such as sand, clay, or eroded limestone. The chemical composition of dust varies from geographical region-to-region, with the silicon-oxide based sand particles typically dominating in the desert regions of the Middle East [3]. Bird dropping is one of the important problems that affect the performance of PV modules. Bird droppings are a good example of that as they are much more opaque than other soiling content like dirt. Moreover, it is hard for the rainfalls to wash the bird droppings off the module surface [6-7].

1.2 Dust settlement factors

Dust settlement mainly relies on three primary factors the dust properties (chemical properties, size, shape, weight, biological and electrostatic property, etc.) as well as on the local environmental conditions (site-specific factors, environmental features and weather conditions, surface finish, tilt angle, humidity and wind speed also affect the dust settlement) [3], [8-9]. Also, the exposed surface properties, roughness has strong effect on the value of particles adhesion force [3], [10].

Rain fall is the most effective natural way to remove the dust from the PV module. The high relative humidity or light rain contribute to the adherence of the dust particles on the module surface and trap fine dust particles converting it to lumps of clay stuck to the surface and hard to be removed. The wind acts in two opposite ways in the settlement process of dust, the first is bad action because the wind carries the dust particle as well as it could by the reason behind rousing the dust or sand from the uncultivated or arid nature locations. However, the wind causes removal of the deposited dust especially at high tilt angles. Usually, solar energy applications (modules, collectors…) are not installed vertically or horizontally but at a certain angle with the horizon called the tilt angle to increase the amount of radiation. Daily optimum tilt angle depends on the local latitude and the time during the year and other criteria. While the annual optimum tilt angle assumed to be equal to the local latitude [11-12]. Tilt angle of the PV modules is a strong influential factor on dust deposition, and studied by many authors [7], [13-19].

1.3 Minimizing and removing the dust layer

There are several methods implemented to reduce the dust layer over the solar module surface. These methods can be classified into mechanical method, electromechanical method, the electrostatic method and the physical-chemical method [20-21]. Definitely, if the modules are cleaned periodically, thepower losses in the modules can be avoided. But, these techniques and methods are costlydepending on the type of the cleaning system.Moreover, if the modulesare cleaned with water that would made them more expensive because of the water scarcity especially in some regions. Solar PV panels' cleaners usually charge per number of modules, which means large PV arrays cost a lot of money to get cleaned [22].

Washing the modules with clean and clear water is the most common way for cleaning PV modules in small PV installations [23-25]. For nearly horizontal positions, light rainfall which includes soluble salt usually leaves undesirable water spots. After a period of exposure time, these dusty spots build up as residues, forming strongly adhering dust layers that cannot be removed without mechanical detergent scrubbing [26]. For large PV plants, jets of high-pressure water had been presented in many investigations [27-28]. Mohamed and Hasan [24] stated that each module consumes about 5 liters of water for perfect clean.

Several authors proposed a cooling technique to reduce the operating temperature of the PV module by running a continuous thin film of water over the upper surface of the module [29-31],this method was proved to be very effective in cooling the PV module.In addition to the cooling effect, the method provides a cleaning effect by removing the dust layer deposited over the front surface of the module. The major problem is the consumption of water which is not preferable plus the power consumed by the pumping system. However, Rasham et al. [32] suggested an intermittent flow which reduces the amount of water needed.

Numerous attempts have been introduced using mechanical cleaning devices to minimize water consumption in washing and keep PV module surface as clean as possible. Tejwani and Solanki [33] designed and tested a single axis sun tracking system where the module surface becomes perpendicular to the ground twice a day.

At these times, a brush fitted on a sliding rod cleans the system. Kasim et al. [34] applied a solar tracking system with two-axis, at the sunsets the tilt angle of the solar module changed by a tracking system to become more than 90º. Zhang et al. [35] proposed a robotic vehicle supplied with brushes. Rahman et al. [36] proposed a cleaning system consists of a wiper that used to remove dust and rain from the windscreen or windshield in almost all cars and vehicles with assistance of a water spray. Sabah and Faraj [37] exploited an auto-cleaning robot for self-cleaning the solar module.

The electrostatic dust removal is another method of dust removal. When the array surface is charged, the modules will attract particles of opposite charge, and repel particles of the same charge. The method has been enhanced and advocated by researchers for removing dust from solar modules in future space exploration missions [38-42]. Coating the module surface with a material has waterrepellent properties, such as TiO2 or ZnO makes the cleaning process using water more efficient and effective [43-44].

2.0 Climate Characteristics and Solar Applications in Iraq

The Climate of Iraq is described by its high temperatures in summer and high intensity of solar energy.In last two decades, Iraq suffers from repeated dust storms and gust which reduce the visibility to very low levels, see Fig.1.In addition to its dusty environment the average rainy days in the year is less than 50 days. In south of Iraq near the Arabian Gulf, a high humidity weather is the normal condition along the year. This must be taken into consideration to build a PV power plant.

Fig 1: Photographs taken in Baghdad During Dust Gusts [45]

3.0 Methodology

This work presents measurements of power losses due to the accumulation of dust. The experiment has been carried out at the roof of a normal house in a residential area in south of Baghdad - Iraq. The location is a residential area, surrounded by open fields. And several unpaved sandy roads.

A pair of identical mono-crystalline silicon solar modules oriented due to the south and tilted from the horizon with the annual optimum tilt angle for Baghdad city which is equal to its latitude 33.3º.

The electrical specifications of the PV module at Standard Test Conditions STC (solar radiation of 1000W/m2, air mass AM 1.5, cell temperature 25°C) are given in Table 1.

Table 1: Electrical Specifications of the PV Module at

Open circuit voltage [V]	22
Short circuit current [A]	3.1
Voltage at maximum power point [V]	17.5
Current at maximum power point [A]	2.9
Power at maximum power point [W]	50
Number of cells	36
Area of the module [m2]	0.45
Weight [kg]	5.47

The period of experiment did not witness any rainfall at all except very light shower on 27 September. A heavy dust storm, was on the 14thSeptember and started at 2:00AM for about 5 hours and the visibility was about 2.7km as provided by online Baghdad airport weather Information [46].

A stronger dust storm occurred on 3thOctober (unfortunately not included in this study), the storm started at 12:30AM and last for more the 16 hours where the visibility was 0.3 km at the beginning and ended with 2.4km.

3.1 Method description and experiment procedure

The modulesnever been cleaned during the period of the experiment. The method applied in this study to reduce the dust layer accumulated on a PV module can simply described by a cover with rectangular shape of a hard cardboard slightly wider than the width of the PV module.

On the rear surface of the cover, a cotton cloth was fixed firmly as shown in Fig.2.The cloth acts as a wiper or scrubber when the cover slides down.

It is found that some of the dust stuck to the fiber of the cotton cloth and hardly to fall and spread again on the PV module. Therefore, for long periods the cloth must be replaced with another clean one. At sunset, the cover slips downs over the module allowing the cloth to wipe some of the dust downward and it is noticed that the dust is falling down on the lower edge of the module and on the floor and, and the opposite thing happens at sunrise.

Fig 2: Cardboard Cover with a Cotton Cloth

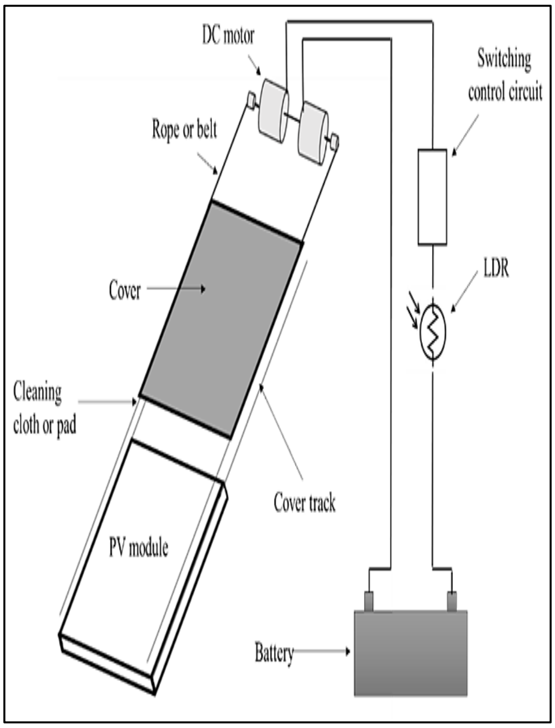
Two tests were done in this experiment; the first test was doneon three arbitrary selected dates during the exposure period were selected 10th and 20thof September and 1stof October to examine the effect of the method. Short circuit current ( ) and open circuit voltage ( ) were recorded simultaneously using two multi-meters every hour from 6:00AM to 6:00PM. The second test were done for every five days and the same measurements were recorded at the noon 12:00 PM.

3.2 Proposed automated system

For future work, it is recommended to develop an automated system to achieve the desired goal (Fig.3). The proposed system consists of a cover plate (made from wood or aluminium sheet with cotton cloth) slips down and up on a simple track. Two DC electric stepper motors must be installed on the top of the cover to drag and drop the cover by a conveyer belt or a rope. The movement of the cover is controlled by a switching control circuit and the input signal to the control circuit is from a light dependent resistor (LDR). LDR is used widely in streets/gardens lighting and some small applications. The motors are powered by a storage battery. Economically, each PV system is usually accompanied with a storage system (battery) in off-grid stand-alone PV system around the world, so most of the cost is from the DC motors and the switching control circuit.

This cost may be less than the periodic cleaning with water. Even though the cost of the proposed system is relatively high, the proposed system reduces the needfor clean water to wash the PV modules, which is a good advantage especially in the regions where there is a lack of water.

Fig 3: Scheme for the Proposed System for Future Work



4.0 Results and Discussion

Maximum power output from a PV module can be found from the power-voltage curve generated from changing the load on the PV module from zero (short circuit) to infinity (open circuit). As illustrated in Fig.4, Fill Factor (FF) is the ratio of the maximum power output to the product of short circuit current and open circuit voltage and it is an indicator for the non-idealities and the internal resistances already exist in the PV module. Fill Factor is little dependent on the effecting factors such as solar radiation and operating temperature. Therefore in this study, the maximum power output determined by assuming constant Fill Factor (=0.75) [47-48]:

$$P_{max} = FF \cdot V_{oc} \cdot I_{sc}$$

Fig 4: Characteristic Curves I-V and P-V of a Typical Mono-Crystalline Silicon Solar Cell

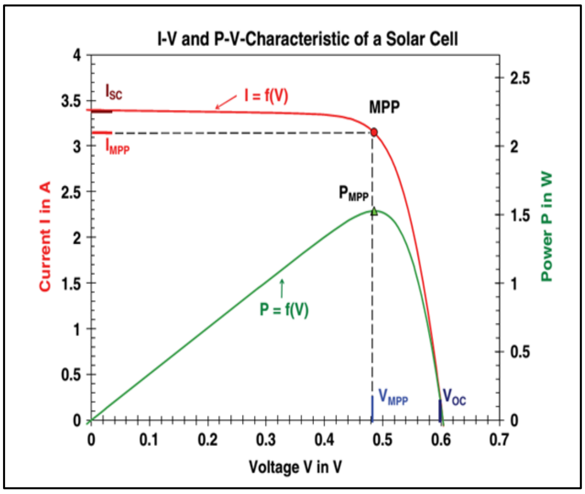
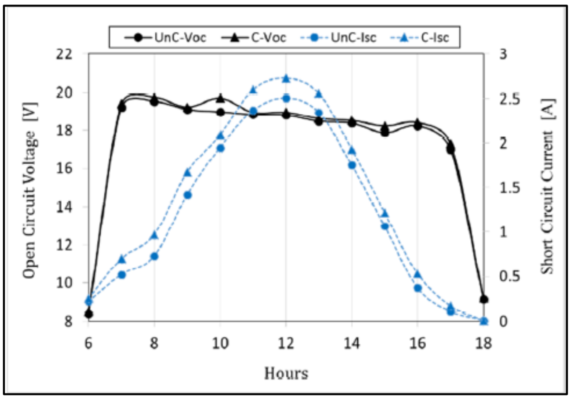


Figure 5 shows the results of the first test. As V_{oc} has a logarithmic relationship with solar radiation, at high radiation the voltage nearly constant and this is noticed in figure 5 where the V_{oc} does not influenced by dust deposition. On the other hand, short circuit current has a linear relationship with the solar radiation and increased as the layer of dust decreased.

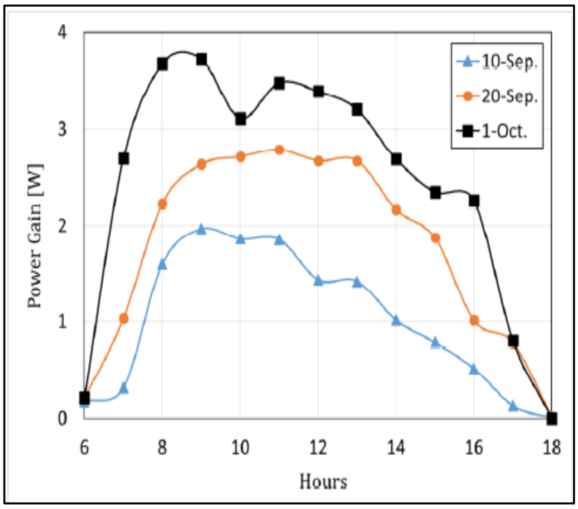
Fig 5: First Test Results, Hourly Measured Open Circuit Voltage and Short Circuit Current for 1st October



In Fig.6 the power gain is the difference between P_{max} of the covered module and P_{max} of the uncovered module, where P_{max} is calculated from equation (1). After 10 days of exposure (10th of September), the covered module had about 2W more power than the uncovered module while this profit reached 3.5W after a month.

It has been noticed that the effect of dust is increased with increasing the amount of incident solar radiation, i.e. when the sun rays are normal to the plane of module.

Fig 6: First Test Results, Hourly Power Gain for Three Dates

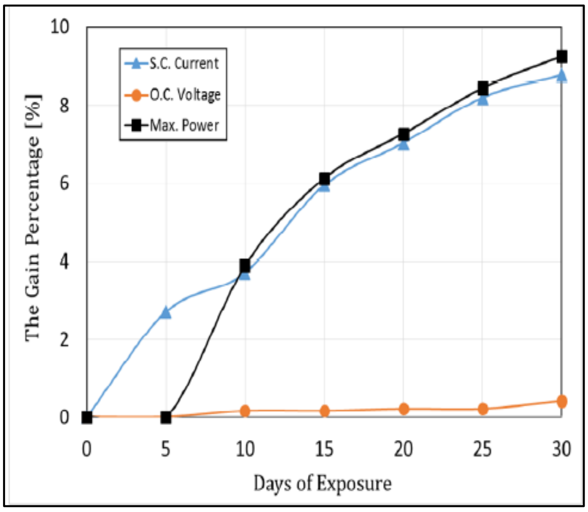


In the second test, the gain of X (where X is I_{sc}, V_{oc} or P_{max}) is found by:

$$Gain\ \% = \frac{X_{covered} - X_{uncovered}}{X_{uncovered}} \times 100 \qquad (2)$$

The gain is plotted against days of exposure in Fig.7. We can see that V_{oc} is nearly constant and independent on dust deposition with small gain at the end of the month with only 0.425%. The I_{sc} increased noticeably and the covered module reached 8.76% more than the uncovered module. Maximum power showed the same pattern of I_{sc} and the gain from covering the module was 9.22%.

Fig 7: Second test results, gain percentage of the short circuit current, open circuit voltage and maximum power along the test period



At the end of the experiment period it was possible to make a comparison between the covered module, uncovered module and perfectly cleaned module. Firstly the measurements V_{oc} of and I_{sc} were taken then very fast cleaning to the covered module was done by wet cloth, then V_{oc} and I_{sc} recorded as fast as possible to ensure that the solar radiation did not change. The results are tabulated in Table 2.

Fig 8: Photographs of the tested PV module After 30 days, from left to right uncovered, covered and cleaned module respectively

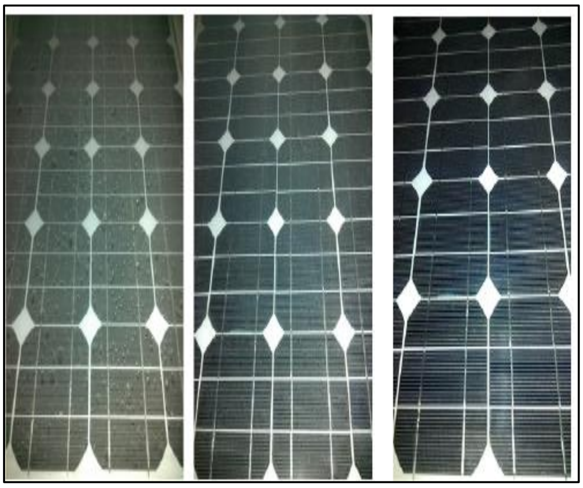


Table 2: Comparison between clean, covered and uncovered modules at 1st of October.

	Clean	Covered	Uncovered
Open circuit voltage [V]	18.34	18.34	18.15
Short circuit current [A]	2.15	2.14	1.95
Maximum power [W]	29.57	29.43	26.54

5.0 Conclusion

This study presents a new method to reduce the soiling and accumulation of dust on the surface of PV module. The method can briefly described by a moving cover with a cotton cloth attached firmly to the backside of the cover. At sunset, the module should be covered and the cloth wipes down part of the dust and the opposite happens at the sunrise. This method ensures that the exposure time of the covered module is reduced to less than half the time of the uncovered module, wiping the module surface two times a day, reduce water consumption for cleaning, less complicated than robotic systems and can be designed for a large panel or long string of modules. Experimental measurements were taken and the results showed that after 30 days the covered module produced about 9.22% greater than the uncovered module. At the end, the covered module was cleaned for comparison and the output power was very close to the power before cleaning.

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