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Design of Smart Surface Cleaner for PV Panels and Investigation of The Performance of Cleaning Materials

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Abstract

In this study, a mechanism that automatically detects the contamination on the glass surfaces used in solar cells and collectors and cleans the surfaces has been designed. The performance tests of this automation system were carried out with different pollutants (lime and ash) and the radiation transmittance of the contaminated surfaces was evaluated. It was observed that the radiation transmittance of the glass surface contaminated with lime decreased the most, while the light transmittance of the surface contaminated with ash decreased the least. In addition, the glass surface, which is most polluted with lime, whose radiation transmittance has decreased the most, was cleaned with a felt and microfiber cloth, apart from the well-known rubber wiper and nylon brush. Felt and microfiber fabric used as cleaning material is a new application. As a result; It has been experimentally seen that felt is the best cleaning material.

1. INTRODUCTION

In recent years, PV panels are systems that produce electricity from solar energy and have started to spread rapidly in the world. With the increasing importance of solar energy systems, their efficiency has also gained importance. The natural properties of the semiconductor materials used in these systems limit the efficiency of PV systems by 15-20 % [1]. The installation design of the system (direction, sun exposure, sun tracking) affects the efficiency of the electrical power obtained. However, negligible accumulation of dust, bird droppings, and water spots significantly impair the efficiency of PV panels. Module efficiency in PV panels decreases by 10-25 % due to dustiness of the inverter, conductors and module (ground) [1].

The main factors limiting the widespread use of PV panels are the high initial costs of the panel and electrical equipment and the low conversion efficiency of PV cells [2]. Apart from the sunlight intensity that affects the output of PV panels, there are other parameters that reduce the energy production of PVs by as much as 15 %. The most important of these is the accumulation of dust and soil on the surface of the PV panels [3,4]. Although the dust effect [5,6] in old settlements depends on local conditions such as the presence of air pollution, rain frequency, wind speed, humidity, orientation and slope of the panels [7], it is necessary to determine the effect of dust on the performance of PV panels and draw more general conclusions. Studies have been done [8-10]. With the increase in the use of PV panels in buildings, it has become a special interest to investigate the effect of dust on PV panels in environmental conditions with heavy air pollution [11].

In a study conducted in the laboratory, the electrical output of cells polluted with different dusts on PV panel surfaces was measured under different conditions [5]. They investigated the solar intensity reduction, maximum power; short-circuit current and filling factor parameters in PV cells. They conducted experiments using three types of powder in 5 different sizes, from 5 μm to 80 μm. They stated that both parameters (size and type) play an important role in the reduction of PV cell performance.

In a study on the effects of dust on the transmittance of different materials in a desert environment in India, they observed that dust accumulation decreased with an increase in horizontal slope. The decrease in glass transmittance was recorded as 19.17 % - 13.81 % - 5.67 % for $0^0 – 45^0$ and 90^0, respectively. It was found to be 23 % - 13.98 % and 8.29 % for acrylic at the same angles [12].

The energy production and economic performance of both the artificially polluted surface and the clean surface PV panels were recorded and measured at the same slope and environmental conditions in a region with the highest atmospheric air pollution in the vicinity of Athens in a two-month period. They reported that when the dust accumulation reaches 1 g/m^2, the energy production of the PV panel is reduced by almost 6.5 % compared to the panel with a clean surface, which means a revenue reduction of about 40 E/kWp [13].

Glass transmittance was evaluated in wind conditions where there are storms at regular intervals at different inclination and azimuth angles of a glass surface [14]. They reported that glass transmittance increased from 12.33 % to 52.54 % when dust accumulation decreased from 15.84 g/m^2 to 4.48 g/m^2. They recommended weekly cleaning of the dusty glass surface.

Dust accumulation on the glass of solar collectors used for the supply of clean water from sea water is one of the biggest reasons for the decrease in performance [15]. One month of dust accumulation causes a decrease in the transmittance of the glass between 10-18 % [16]. This decrease in the transmittance of the glass causes great decreases in water production. In the study, they concluded that (in the case of clean glass) the water production decreased from 100% to 40% as the transmittance of the glass decreased from the initial value of 0.98 to 0.6 (for very dirty glass conditions).

Mutluer and Erat in their study; they stated that dusting used in photovoltaic systems affects the efficiency of the panels. For panels to work efficiently, the panel surface must be clean and absorb solar radiation effectively. In the study, a fuzzy logic-based smart cleaning system was designed with an Arduino microcontroller to automatically clean the photovoltaic panel surface and it was seen that the panel efficiency increased by 15-20 % [17].

This work aims to design a cleaning system for the solar PV panels under Medina climatic conditions. This system powered by the PV module itself. Full cleaning system has been designed and tested utilizing a wiper and water jet to remove the accumulated dust and other dirt from solar panels surface. The proposed cleaning system can be worked for long time efficiently. All the strength system components were examined and found to be stable and reliable. Also, the performance of cleaning system evaluated and comparison between the clean and dusty module performance has been conducted. The system performance has been evaluated for both clean and dusty panel at variable inputs of solar radiation. At input power of 805 W/m^2, the efficiency found to be 13.78 % for the cleaning panel and 9 % for dusty panel, whereas at the input power of 460 W/m^2, the estimated efficiency was 12.6 % and 7.3 % for clean and dusty panel respectively. Significant reduction in the efficiency has been reported as 35 % and 42 % for both cases. Therefore, the present work can be considering as a promising and efficient system to solve the problem of poor performance of the photovoltaic cells in areas that experience dusty environment and external pollutants [18]. Al Qdah and his colleagues designed a solar panel cleaning system in Medina, Saudi Arabia, and designed and tested a squeegee and water jet to remove dust and dirt accumulated on the surface of the solar panel. The performance of the system was evaluated for both clean and dusty panel at varying solar radiations. At 805 W/m^2 input power, they achieved approximately 14 % efficiency for the cleaning panel and 9 % for the dusty panel [18].

Gupta et al; they investigated the efficiency of PV panels in Indian climate conditions between December 2019 and April 2021 in a self-cleaning and fixed system consisting of 3 20 W panels each. In the study, the PV system was compared as summer, winter and monsoon seasons. The efficiency of PV panels was 18.3% in summer, 13.3% in winter and 6.4% in monsoon season [19].

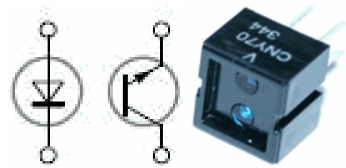
Panat and Varanasi in their study; they stated that with the principle of static electricity, approximately 45 billion liters of water can be saved every year by cleaning the dust from the solar panels in the desert. They also emphasized that the dust accumulated on the panel for a month reduced the panel efficiency by 40 % [20].

In this study, a mechanism that automatically detects the contamination on the glass surfaces used in PV panels and solar collectors and cleans the surfaces has been designed. The performance tests of this automation system were carried out with different pollutants and the radiation transmittance of the contaminated surfaces was examined. Apart from soil and ash among different pollutants, cement used in Konya region due to intense construction and lime from lime quarries and constructions were used. In addition, the glass surface, which is most polluted with lime, whose radiation transmittance has decreased the most, was also cleaned with felt and microfiber cloth, in addition to the known wiper and nylon brush. The use of felt and microfiber cloth as cleaning material is a new application. Felt is a natural, cheap and easily processed material that is widely used for various purposes in the Konya region. Microfiber cloth, on the other hand, is a material that is a bit expensive but effective in sensitive surface cleaning. As a result of the experiments, it has been experimentally seen that the felt is the best cleaning material.

MATERIAL AND METHOD

In PV panels exposed to outdoor conditions over time, some unwanted pollution occurs on the radiant glass material used to protect the semiconductor-based sandwich material (wafer) in the panel against atmospheric conditions. This pollution on the glass panel blocks the light that needs to reach inside the panel. Since the efficiency of PV panels changes with the intensity of radiation, the voltage produced in the panel decreases, which leads to an undesirable decrease in panel efficiency.

In this study, a mechanism that detects the pollution on the PV panel and automatically cleans the PV panel surface has been designed. The mechanism developed to clean the PV Panel is placed on the PV panel and fed from a battery charging circuit that obtains its energy from this panel. Therefore, no extra power source was needed. Here, the most important part of the system is the CNY70 optical sensor, which detects the contamination of the panel, and this sensor is shown in Figure 1.



(a) (b)

Figure 1. CNY70 Optical Sensor a) electrical symbol b) appearance of the sensor

The CNY70 optical sensor has the following features:

- Detection distance: 2 - 9 mm
- Supply: 5 V DC
- Can be used to detect line (black/white) and obstacle
- Output 0-5 V. Microcontroller connection output
- Dimensions: 21 x 11 x 8 mm.

The dimensions of the optical sensor are suitable for easy insertion into the panel. The CNY70 optical sensor consists of a pair of LEDs and receivers, which operate in the infrared band and emit a matching infrared radiation. The output voltage of the sensor kit varies between 0 and 5 V, depending on the amount of infrared radiation on the optical sensor. The block diagram of the system is given in Figure 2. The operation of the system shown in Figure 2 is briefly as follows. The amount of radiation of the glass is continuously detected by the sensor placed on the panel. When the radiation penetration of the glass falls below the value determined by us, the panel glass is detected as dirty and the wiper operates with the water spray of the water pump and the glass of the panel is cleaned. After the glass is cleaned, it is detected that the glass is cleaned with the sensor information coming from the sensor; wiper and water pump are stopped. A small water tank is placed in the automation system for water spraying. It is also an important feature of the infrared sensor that it only detects dirt and does not see darkness as dirt.

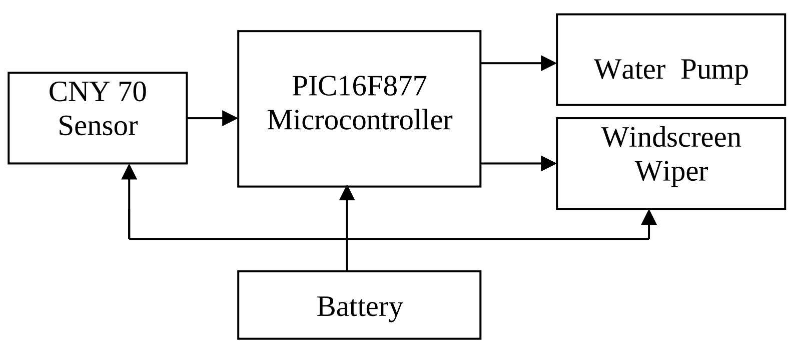


Figure 2. Block diagram of the designed system

Figure 3. Automatic surface cleaner view

The general characteristics of the PV panel on which the designed automatic surface cleaner is applied are given in Table 1.

Table 1. General characteristics of the PV panel used in the system

Bluesun Solar BSM-50M PV module specification	
Solar Cell Type	Mono 125x125
Rated Power (Pmpp)	50 W
Rated Current (Impp)	2.64 A
Rated Voltage (Vmpp)	19 V
Short circuit Current (Isc)	2.96 A
Open circuit Voltage (Voc)	22.6 V
Temp. coefficient (Pmpp)	0.38 %
Max. system Voltage (V)	800 V
Size	700x550x25
Weight (kg)	5

EXPERIMENTS

Various experiments were carried out to determine the level of glass cleaning of the automated system. High performance Perkin Elmer 950 UV/VIS spectrometer device was used as test equipment. This device allows us to measure in the wavelength range of 175-3000 nm (with a tolerance of 0.1 nm). In the spectrometer, the changes in light transmittance were examined by artificially polluting the glass of the solar cell with various dirt. For this purpose, firstly, the glass of the solar cell was polluted with the same amount of substances such as soil, lime, cement and ash found in nature and the permeability of the glass was examined separately. Secondly, after cleaning the panel glass, which was contaminated with 4 different substances, with a rubber wiper, the transmission rates were investigated. Thirdly, different cleaning materials of the glass, which is polluted with lime, which has the lowest permeability, are cleaned and the transmittance rates are discussed. The following cleaning materials were used as cleaning materials.

1-Wiper wiper: Wiper made of soft rubber
2-Felt wiper: 1 cm thick felt made of wool is placed in the wiper mechanism as a cleaning element.
3-Microfiber cloth: Micro fiber cloth was placed in the wiper mechanism and used in the wiping process.
4-Nylon brush: Cleaner created with nylon bristles placed in the holes

RESULTS

When the panel surface is contaminated with soil, cement, lime and ash in the same amount, the transmittance rates are shown in Figure 4.

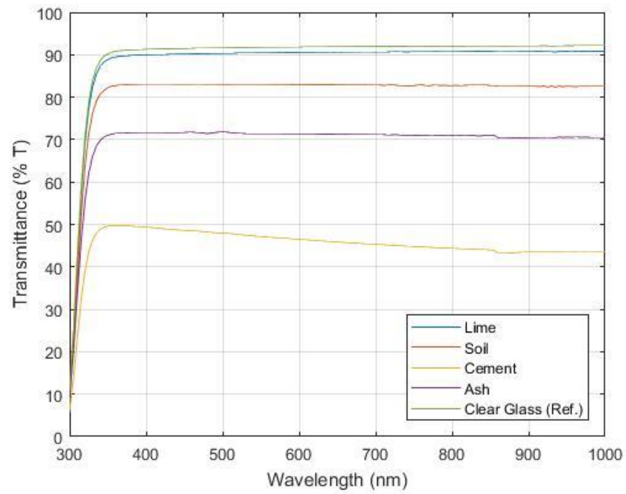


Figure 4. Transmittance rates according to different soil materials

As can be seen from the graph given in Figure 4, the transmittance rate drops to 44% in case the solar cell surface is contaminated with lime. Therefore, it was the contamination of the surface with lime that reduced the electrical output of the panel the most.

Table 2. Light transmission rates of different materials for 400-700 nm

Pollutant	**Transmittance ratio (%)**
Reference glass (clear)	92
Lime	44
Soil	71
Cement	82
Ash	90

The transmittance rate decreases to 71% on the panel surface contaminated with soil. Considering that the permeability rate of lime is the lowest, the cleaning rates of the glass surface contaminated with lime were investigated with different surface cleaning materials. This situation is seen in Figure 5.

Since the permeability rate of the surface contaminated with lime is the lowest, the formula showing the relationship of wavelength and transmittance from the pollution curve of lime was found with the help of MATLAB and is given below:

$$LIME(x) = 54.54\ e^{-x2.532e-04} - 5.627\ 10^{10}\ e^{-x0.06961}$$

The error of the values obtained with this equation according to the real values was calculated as Root Mean Square Error and its value was obtained as 1.033.

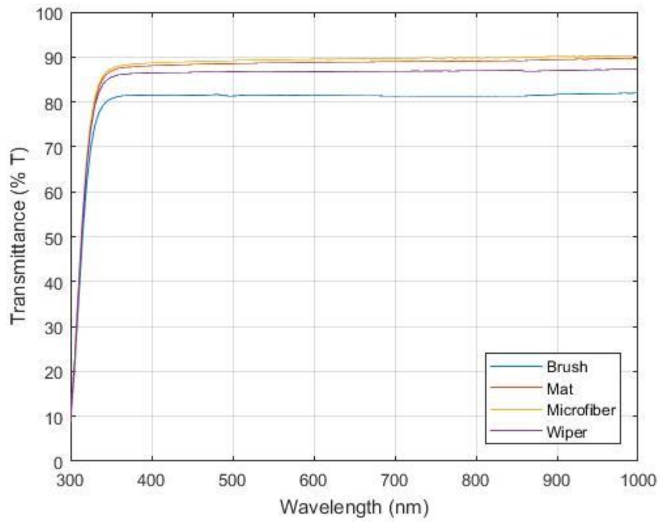


Figure 5. Cleaning curve of lime with different surface cleaning materials

Table 3. The effect on the working performance of the solar cell whose surface is polluted with lime according to the surface cleaning materials

Cleaning material used	Clearance rate (%)	Voc change (Volts)
Brush	81	η. Voc=0,81.22=17,82
Felt	91	η. Voc=0,91.22=20,02
Microfiber material	91	η. Voc=0,91.22=20,02
Wiper	89	η. Voc=0,89.22=19,58

When Table 2 is examined, the highest value with 91% is seen in surface cleaning (44% pollution level) made with felt and microfiber fabric. This value is approximately the initial reference clean glass value (92%). Cleaning with Wiper is approximately 89%. Cleaning with a nylon brush is 81%, 11 points below the reference clean glass value. In addition, the cleaning of the glass surface contaminated with 4 different pollutants in the cleaning automation system with a wiper was also carried out. Graphical figure of the experiment. It is seen in Figure 4.

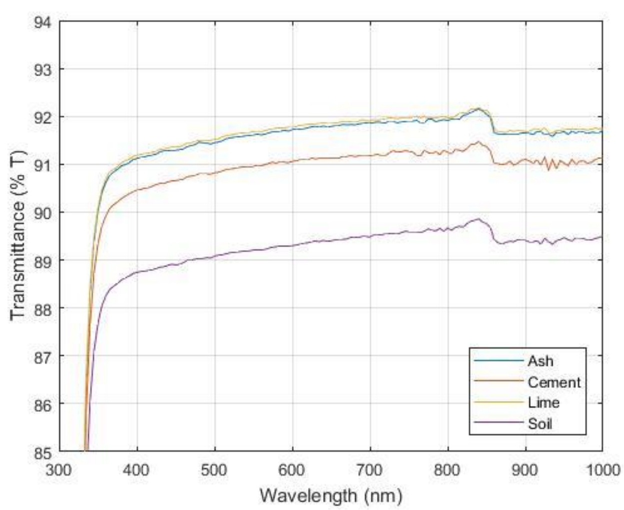


Figure 4. Transmittance rates of the surface contaminated with four different substances in cleaning with wiper

In Figure 4, it was observed that the glass surface, which was contaminated separately with soil, lime, ash and cement, reached a transmittance of approximately 89% - 91% after cleaning with a wiper, which was close to the reference glass value (92%).

CONCLUSION

With the developed automation system, a significant increase in efficiency has been achieved from solar panels. Efficiency also changes with the change of the cleaning apparatus of the automation system. In this study, the changes in the electrical output of the panels were observed in cleaning with different materials with an automatic surface cleaner. Differences occurred in the open circuit voltage of the automatic surface cleaner before contamination and the open circuit voltage after contamination. After the automatic surface cleaner detects and cleans the contamination value, approximate initial permeability rates have been reached. With this system, when cleaning is not done at regular intervals and the surface is dirty, the system will detect this and clean it. If necessary (if the pollution is too much during the day) it will clean several times in the same day. Thus, it will be ensured that the panels are always clean without being dependent on human control. This will increase the annual amount of energy to be produced from the panels. In studies to be carried out on this subject, the best cleaning material should be chosen together with the automatic cleaning system.

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