ICIC Express Letters
Part B: Applications
Volume **8**, Number **11**, November **2017**
 ISSN 2185-2766
pp. 1457–1464

DESIGN OF AUTOMATIC CONTROL FOR SURFACE CLEANING SYSTEMS OF PHOTOVOLTAIC PANEL

Syafaruddin[1,*], Faizal Arya Samman[1], Muslimin[2] and Satriani Latief[3]

[1]Department of Electrical Engineering
Universitas Hasanuddin
Jalan Poros Malino Km. 6, Gowa 92171, Indonesia
[*]Corresponding author: syafaruddin@unhas.ac.id

[2]Politeknik Akademi Teknik Industri (ATI) Makassar
Jalan Sunu No. 220, Makassar 90211, Indonesia

[3]Department of Architecture
Universitas Bosowa
Jalan Urip Sumoharjo Km. 4, Makassar 90231, Indonesia

Received May 2017; accepted August 2017

Abstract. *The paper presents experimentally design of a cleaning system for the surface of photovoltaic panel using wiper control mechanism utilizing ATmega16 microcontroller. The proposed cleaning system operates by spraying an amount of water on the PV panel surface and then actuating the wiper using a DC motor. Two limit switches are used to sense the wiper position at the edge of the PV panel. In the experimental test, an amount of dust is deployed on the PV panel surface to test the control power performance. The proposed design is highly effectively used to bring back to the initial efficiency output of the PV panel over the efficiency of dirty panel. The wiper can be managed to work periodically for example five times in a day or can be manually activated using remote control mechanism. The power consumption performances of the proposed system are only about 0.79% and 8.94% under standby and operation conditions, respectively. The low power consumption makes this cleaning system feasible for further product development.*
Keywords: Photovoltaic panel, Cleaning system, Wiper design, ATmega16 microcontroller

1. **Introduction.** Photovoltaic (PV) panels are commonly installed in open-spaced environment which is exposed to sunlight direction in order to maximize the output energy. Consequently, the PV panel performance is susceptible to other obstacles such as shaded objects and dirty problems on the panel surface. In this study, the cleaning system of PV panel surface is discussed in order to gain much output power from the installed PV systems. More discussion focuses on dirty problems on panel surface caused by any disposals including dust and how to clean the surface by automatic control mechanism. The cleaning system is surely necessary to increase the sunlight penetration into the panel surface. Accumulated dust on solar photovoltaic (PV) modules can significantly decrease their energy output in desert environment. Therefore, the cleaning process, dust prevention methods and cleaning schedules are highly required in specific environment of PV system applications, such as in desert environment where extreme weather events may occur [1]. In addition, the expected much power from the giant PV plant in desert area is highly important. For these reasons, the frequency of cleaning based on dust characteristics [2] and cleaning protocol regarding the technical and economic assessments [3] were taken into account to have the trade-off between installation cost and the gain of output power by provision of the cleaning systems.

A photovoltaic panel consists of several cells connected in series, parallel or both. Each photovoltaic cell on the same exemplified by a diode, so the equivalent circuit in the photovoltaic cell structure is a series of diodes arranged in series, parallel or both. Dust or other debris may cause only partially covered diodes, while other diodes continue to receive solar radiation normally. Diodes which receive solar radiation normally would experience forward bias, while the diodes which receive lower solar radiation after covering by dust or other debris would experience reverse bias. Diodes with reverse bias can be a high barrier for the energy transfer which reduces the flow of the forward bias of the other diodes. If this problem continues, the output power of reverse bias diode will drop out due to burning or excessive heat condition [4].

Dirty problems on panel surface contribute significant losses to the output power of PV systems. Experimental study regarding the effects of dust on PV panel has shown the correlation between the grain dust and variation in PV panel performance [5]. The existence of dust on the surface of the panels will reduce the conversion efficiency up to 18%. Hence, a cleaning mechanism to maintain the power performance by removing the dust from the solar panel surfaces is required [6-8]. In addition, there is average increase of 4.4% losses in daily sunlight radiation penetrating the panel surface caused by the dust. This power loss is much increased for the long time operation without raining such as in summer time where the dust accumulation may cause daily losses of 20% [9]. Other pollutants such as ash and bird dropping can also reduce the power performance of solar panels [10]. Moreover, dust disposals which cover continuously solar panel surfaces can damage any cells in a solar module after showing the hot-spot problems [11].

Stacking layers of dust on the panel surface can be cleaned manually. However, this should require human resources and it could lead to the risk of electric shock or falling. In any circumstance, a robot can be used to clean the surface of solar panels. However, the existing robot is still very costly of about $50,000 and should be operated by at least two human operators [9]. To design a robot for cleaning the PV surface, it requires components such as brush, DC motors, and conveyors. However, the idea does not explain in detail how the robot is planned to carry out the cleaning task and no result of robot design has been made [12]. An approach to clean the photovoltaic protective cover on the rotating polycarbonate disk has been designed [13]. However, the mechanical force to remove dust on surface seems too complex in terms of testing and experimental designs and needs extra power to drive the system works. Similar approach of cleaning surface of PV panel by dry cleaning systems has been performed where the proposed system is claimed made of low cost material and highly effective utilization in comparison with robotic cleaning systems [14]. Another approach, such as electrostatic cleaning system has also been demonstrated to remove sand on PV panel surface in desert area application [15]. However, the claim of zero power consumption for electrode circuit is still questionable from the overview of single-phase high voltage connection. Similar design of surface cleaning system on dusty environment with piezoelectric actuator is used to drive the wiper fixed on actuator [16]. However, the piezoelectric material systems are again uncommonly utilized and less-applicable; therefore, the system is much more expensive than our proposed method.

To improve the properties of anti-dust for PV modules, the concept of self-cleaning has also been proposed for many years to overcome the unstable traditional cleaning systems in nature environment. Surface cleaning systems have been significantly concerned in order to gain much output power from the cleaned PV panel surface. Self-cleaning coating systems are the most proposed technique by utilizing, for instance superhydrophobic surface based on Aluminium oxide layer [17], self-cleaning and antireflective properties of hydrophilic nanostructured glass substrates [18], novel super-hydrophilic coating with high stability and corrosion resistance [19] and utilization of TiO_2-SiO_2 nanostructured coatings [20]. However, these proposed methods of self-cleaning systems are very expensive due to exclusive material utilization and very complex chemical compound, and the additional materials are probably contained of dangerous chemical substances and no guarantee of significant increase in efficiency energy conversion.

This paper presents an experimental result of a cleaning system powered by microcontroller. In order to implement the mechanism, wipers can be used to remove dust in the panel surface [21]. The wiper can be actuated by DC motor and activated daily or even per hour or intentionally when the panel surfaces are dusty. The DC motor is then controlled by an electronic control unit with a few number of sensors or limit switches to adjust its forward and reverse rotations. The design steps consist of design phase and testing phase. The design phase includes wiper mechanical setup on the PV panel, electronic hardware design and embedded software development. The testing phase includes testing, measurement and data analysis. Measuring and testing were conducted by spreading dust over the surface of the photovoltaic with different mass volume. Data analysis is made to analyze the output power of photovoltaic during normal day light conditions, dusty conditions and conditions after cleaning with the proposed windshield wiper system.

The outline of the paper is presented as follows. It begins with the importance of the proposed design of cleaning systems in gaining the efficiency conversion of photovoltaic module. Then, problem statement and design objective are presented. Later, the mechanical and control setup designs are specified including the testing design regarding the efficiency improvement and power consumption. The conclusion and outlook of the future design improvement are denoted in the end.

2. **Problem Statement and Design Objective.** Electric energy generated by the photovoltaic is very susceptible to the influence of a layer of dust on the surface of the photovoltaic. Dust layer on the photovoltaic surface can reduce the level of solar radiation accepted by photovoltaic. Thus, it will decrease the energy produced and efficiency of the photovoltaic.

The aims of this research are designing and constructing a wiper system which is able to clean the surface of photovoltaic littered and covered with dust layer. This study also aims to analyze the efficiency conversion and power consumption of photovoltaic during normal day light and dusty conditions. The power performance of the photovoltaic panel is also measured and analyzed after it was cleaned by the wiper system for different amount of dust deployed on the PV panel surface.

3. **Mechanical Design and Control Systems.** In our research work, the mechanical systems of control design can be seen in Figure 1. Three main components are rotary axle (A), photovoltaic panel (B) and wiper axle (C). The rotary and wiper axles are rotated by DC motor with technical specification of input voltage, speed rotation, torque being 6V, 130rpm and 2.3Nm, respectively. The type of photovoltaic module/panel is poly-crystalline Silicon technology with the technical specifications being 100Wp of output power, 17.5V of maximum voltage (V_{MAX}), 5.71A of maximum current (I_{MAX}), while the open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) are 21.5V and 7.02A, respectively. In addition, Figure 1 presents the leg side view of the PV panel setup with the wiper system. The following items present the dimensional specification of the system mechanics.

- The width of the frame: 670mm
- The length of the frame: 1603mm
- The height of the back frame: 655mm
- The height of the front frame: 451mm
- The slope of the frame: 83°

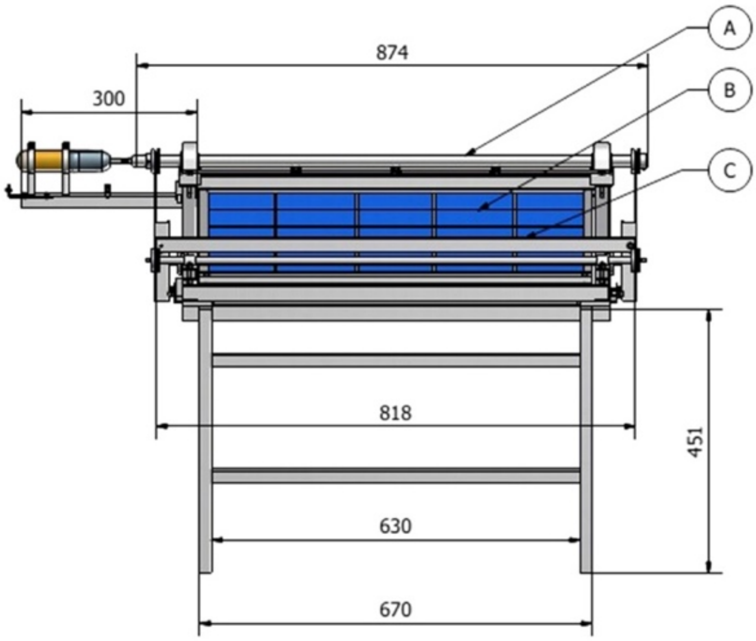

Figure 1. Front side view of mechanical design

3.1. **Mechanical setup.** Several components in the perpective design system denoted in alphabetical order including their functions as shown in Figure 2 are listed as follows: cantilever frame as supporting of mechanical systems (A), upper limit switches to provide signal to reverse the wiper motor rotation (B), fanbelt to attach pulleys on both sides (C), lower limit switch to provide a signal to reverse the upward rotation wiper motor (D), pulley to rotate the fanbelt (E), wiper axle (F), rail as the path for wiper wheel when running for cleaning (G), DC motor (H). In addition, Figure 2 presents the right side view of the photovoltaic (PV) panel with wiper control system. In this experiment, the PV panel top position ascends about 83 relative to the gravitiy axis. The drawing unit shown in the figure is millimeter.

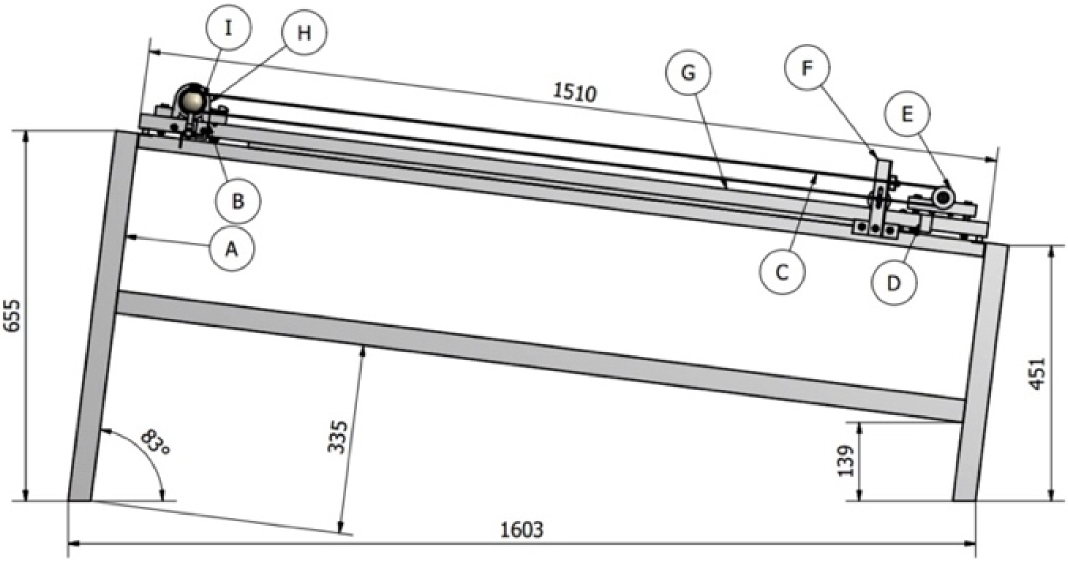

Figure 2. Right side view of mechanical design

3.2. **Control system design.** Figure 3 presents the control system model of the cleaning system in a block diagram. The block C(s) shown in the figure is a multi-input multi-output (MIMO) transfer function model. The microcontroller C(s) is the main electronic control unit, which starts operating cleaning mechanism based on an activation signal set by a real-time clock (RTC) module or from an activation signal from a remote control. When an activation signal is received by the microcontroller, then the microcontroller will start activating the water spraying mechanism for about 10 seconds. Afterwards, the wiper starts moving to clean the surface of the solar panel until it reaches the lower limit switch, and it moves back to its initial position. The lower and upper limit switches are normally closed. Thus, when the wiper touches the limit switches, then they will

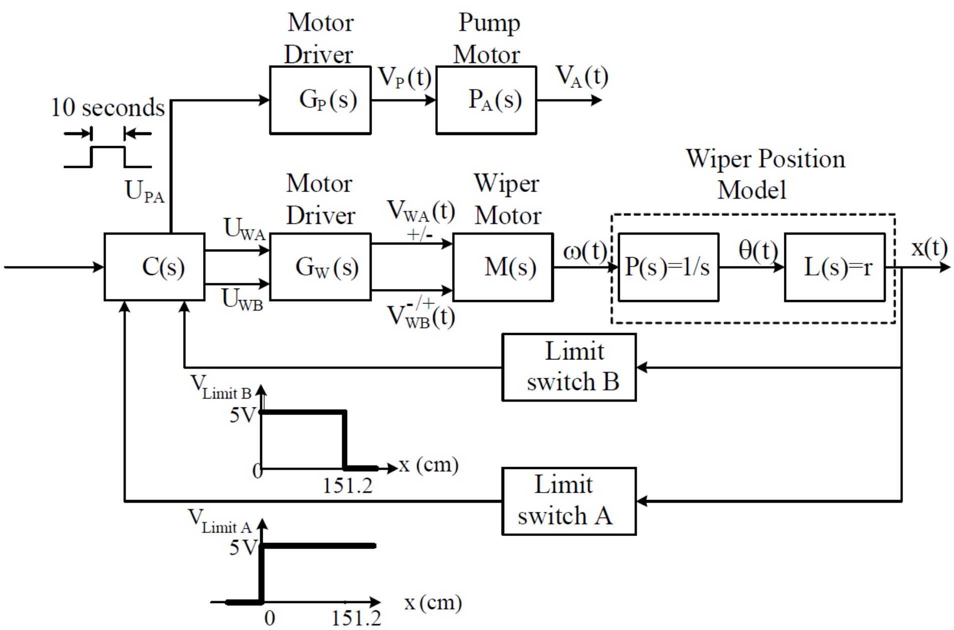

FIGURE 3. Block diagram model of the cleaning control systems

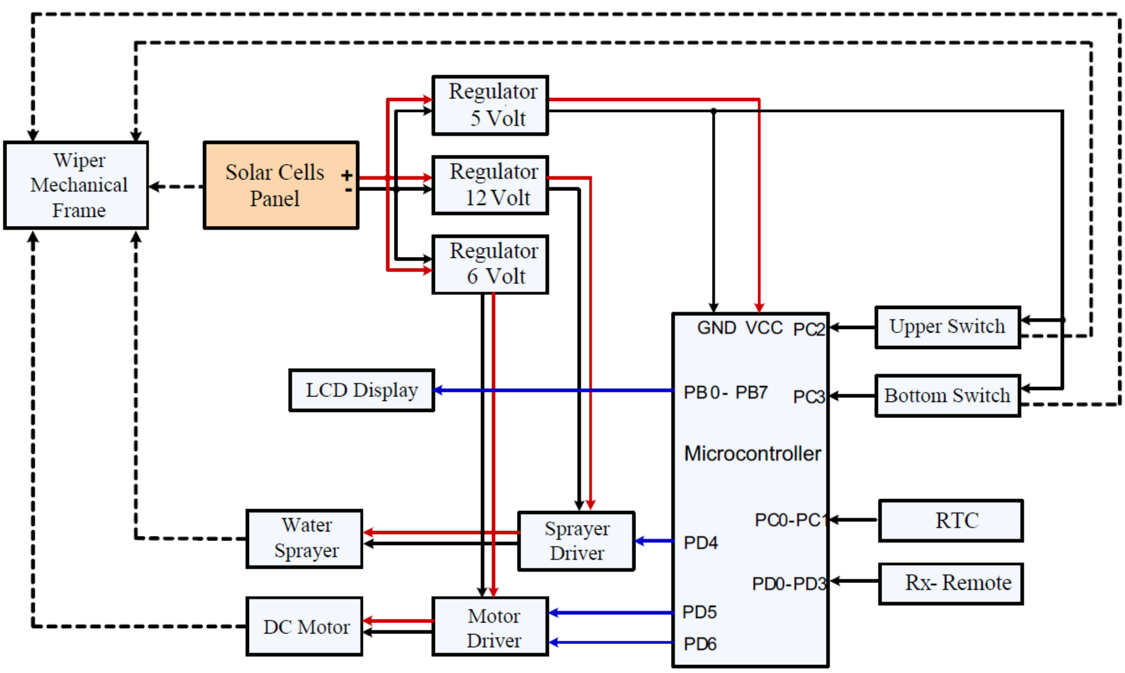

FIGURE 4. Proposed design configuration based on microcontroller circuit

send 5V signal to the microcontroller. In overall design, Figure 4 presents the system configuration of the microcontroller-based wiper system. The actuators (pump or water sprayer and wiper motors) and the microcontroller are supplied with electric power from the solar panel. The microcontroller is supplied with voltage of 5V, the pump motor for water sprayer is with 12V and the DC motor for the wiper is with 6V of voltage supply.

Regarding the wiper control movement, the distance of the wiper movement for one direction is 151.2cm or 1.512m. For a single motor rotation, the wiper movement reaches 12cm since the motor shaft radial is about 1.91cm. Table 1 presents the operating conditions of the wiper motor for different voltage levels. The voltage and current supplied to the wiper motor in order to make a single-direct 151.2cm-linear movement are measured to obtain the power consumption. The time required to move 151.2cm linearly (T_w) is also mesured to achieve the total energy requirement in Joule (J) or Watt-Second. The $x(t)$ is the linear movement equation of the wiper, where each constant represents the movement speed. Also from Table 1, the minimum power and energy consumption to operate the wiper motor are 2.35W and 13.865J, respectively by applying voltage to the motor with 4.9V. It means the actuated motor cannot operate normally when the voltage applying to the wiper motor is lower than 4.9V.

Table 1. Energy and power measurements for different voltages of the wiper motor

Voltage	**Current**	**Power**	$\mathbf{T_w}$	**Energy**	$\boldsymbol{x}$**(t)**
4.9V	0.48A	2.35W	5.9s	13.865J	25.6t
5.6V	0.58A	3.25W	4.8s	15.6J	31.5t
6.2V	0.66A	4.09W	3.9s	15.951 J	38.8t

4. **Testing Design.** Some experiments by deploying a few gram of dust averagely on the surface of the photovoltaic panel are performed. The mass volume of the dust used to test the system was 64.11g. The dust deployment on the panel surface is made to check the capability of the wiper/cleaning system to improve the PV efficiency. Table 2 presents the measurement results and calculations of power and efficiency when an amount of 64.11g dust is used. It seems that the wiper action can improve the PV panel efficiency from about 10.06% upto 17.46% for single wiper repetition, upto 17.50% for twice wiper repetition and upto 17.55% for three times wiper repetition.

The power consumption measurement results in Table 3 show the proposed design of cleaning system consumes very low and stable or similar at all states of standby, wiper

Table 2. Efficiency measurement results for 64.11g mass of dust

Measurement Results						**Calculation Results**					
No.	Mass of Dust (gr)	G_L (Lux)	V_{OC} (V)	I_{SC} (A)	Wiper Repetition	G_W (Watt/m^2)	Power Radiation P_R (Watt)	Fill Factor FF	Power P_m (Watt)	Efficiency (%)	Avg. Efficiency (%)
1	0	84,500	19.83	5.47	0	667.55	499.39	0.81	87.52	17.53%	17.56%
2		84,400	19.81	5.49		666.76	498.80	0.81	87.74	17.59%	
3	64.11	84,200	19.46	3.21	0	665.18	497.62	0.80	50.24	10.10%	10.06%
4		84,200	19.43	3.19		665.18	497.62	0.80	49.84	10.01%	
5		83,600	19.80	5.40	1	660.44	494.08	0.81	86.25	17.46%	17.46%
6		84,200	19.81	5.44		665.18	497.62	0.81	86.94	17.47%	
7		83,900	19.83	5.42	2	662.81	495.85	0.81	86.72	17.49%	17.50%
8		84,100	19.83	5.44		664.39	497.03	0.81	87.04	17.51%	
9		84,200	19.83	5.46	3	665.18	497.62	0.81	87.36	17.56%	17.55%
10		84,500	19.84	5.47		667.55	499.39	0.81	87.57	17.54%	

Table 3. Power consumption measurement of proposed design of cleaning system

States	Time of operation	Clean panel		Dirty panel (64.11g of dust)	
		Output power (W)	Power consumption (W)	Output power (W)	Power consumption (W)
Standby	8 hours	87.74	0.69 (0.79%)	49.84	0.69 (0.79%)
Wiper movement	9.6 sec	87.74	3.94 (4.49%)	49.84	3.94 (4.49%)
Wiper movement with water spray	10 sec	87.74	7.84 (8.94%)	49.84	7.84 (8.94%)

movement and wiper movement with water spray regardless of the panel conditions. Only 0.69W of PV module output is used under standby condition and remained unchanged for 8 hours' operation. This power goes to the microcontroller circuit operation. Meanwhile, only 3.94W and 7.84W are utilized for wiper movement and wiper movement with water spray, respectively. The low power consumption makes this proposed cleaning system feasible for further product development. In comparison, the utilization water volume and energy to discharge water have been considered for cleaning the surface of PV panel in desert area application with the minimum water and energy usages [22].

In addition, the wiper can be managed to work periodically, or can be manually activated using remote control mechanism. The periodical cleaning service is enabled by using a real-time clock (RTC) embedded on the system. The wiper system can be periodically activated for example by five times in a day with a specified schedule. The wiper can also be activated manually using wireless device. Using the standard device, the wiper can be remotely operated in the distance of maximum 27m.

5. **Conclusions.** This paper has presented a wiper equipment used to clean the surface of a photovoltaic panel. Based on the experimental results, the average efficiency of photovoltaic on the initial condition is 17.56%. However, under dusty condition for instance with the mass of dust being 64.11g, the efficiency is decreased to 10.06%. It is a common sense that the increase in dust volume, decreases the efficiency significantly. After cleaning operation was turned on with one wiper movement, the average efficiency increased by 17.46%. Moreover, when the cleaning is made with twice wiper movement, then the average efficiency was 17.50%. Finally, after the cleaning is made three times, the average efficiency was 17.55%. In addition, the percentage of the power consumption of system during standby and operation conditions were 0.79% and 8.94%, respectively. The low power consumption makes this proposed cleaning system feasible for further product development.

6. **Future Study.** Our proposed design system can be improved by addressing the following subjects.

1) An extended or extra rechargeable battery to power the cleaning system could be used. In this respect, the electric energy from the PV panel can be used to charge the battery.
2) The system testing could be made with real-time data logging to achieve better performance analysis.

Acknowledgement. This research is granted by the National Ministry of Research, Technology and Higher Education of Indonesia under the research scheme of Unggulan Perguruan Tinggi (UPT) 2016.

REFERENCES

[1] H. Khonkar, A. Alyahya, M. Aljuwaied, M. Halawani, A. A. Saferan, F. Al-khaldi, F. Alhadlaq and B. A. Wacaser, Importance of cleaning concentrated photovoltaic arrays in a desert environment, *Solar Energy*, vol.110, pp.268-275, 2014.

[2] Y. Jiang, L. Lu and H. Lu, A novel model to estimate the cleaning frequency for dirty solar photovoltaic (PV) modules in desert environment, *Solar Energy*, vol.140, pp.236-240, 2016.

[3] M. Fathi, M. Abderrezek and P. Grana, Technical and economic assessment of cleaning protocol for photovoltaic power plants: Case of Algerian Sahara sites, *Solar Energy*, vol.147, pp.358-367, 2017.

[4] R. Ramaprabha and D. Mathur, Impact of partial shading on solar PV module containing series connected cells, *International Journal of Recent Trends in Engineering*, vol.2, no.7, pp.56-60, 2009.

[5] M. Abderrezek and M. Fathi, Experimental study of the dust effect on photovoltaic panels' energy yield, *Solar Energy*, vol.142, pp.308-320, 2017.

[6] S. A. Sulaiman, H. H. Hussain, N. S. H. N. Leh and M. S. I. Razali, Effects of dust on the performance of PV panels, *World Academy of Science, Engineering and Technology*, vol.58, 2011.

[7] A. Benatiallah, A. M. Ali, F. Abidi, D. Benatiallah, A. Harrouz and A. Mansouri, Experimental study of dust effect in mult-crystal PV solar module, *International Journal of Multidisciplinary Sciences and Engineering (IJMSE)*, vol.3, no.3, pp.1-4, 2012.

[8] J. Casanova, M. Piliougine, J. Carretero, P. Bernaola, P. Carpena, L. Lopez and M. Cardona, Analysis of dust losses in photovoltaic modules, *World Renewable Energy Congress*, Linkoping, Sweden, pp.2985-2992, 2011.

[9] M. Anderson, A. Grandy, J. Hastie, A. Sweezey, R. Ranky, C. Mavroidis and Y. P. Markonpoulos, Robotic device for cleaning photovoltaic panel arrays, *International Conference on Climbing and Walking Robots (CLAWAR)*, pp.1-10, 2009.

[10] J. Kaldellis and P. Fragos, Ash deposition impact on the energy performance of photovoltaic generators, *Journal on Cleaner Production*, vol.19, no.4, pp.311-317, 2011.

[11] E. Kaplani, Degradation effects in Sc-Si PV modules subjected to natural and induced ageing after several years of field operation, *Journal of Engineering Science and Technology Review (Special Issue on Renewable Energy Systems)*, vol.5, no.4, pp.18-23, 2012.

[12] K. Sabah and S. N. Faraj, Self-cleaning solar panels to avoid the effects of accumulated dust on solar panels transmittance, *International Journal of Science and Research*, vol.2, no.9, pp.246-248, 2013.

[13] A. Rifai, N. A. Dheir, B. S. Yilbas and M. Khaled, Mechanics of dust removal from rotating disk in relation to self-cleaning applications of PV protective cover, *Solar Energy*, vol.130, pp.193-206, 2016.

[14] A. A. Shehri, B. Parrott, P. Carrasco, H. A. Saiari and I. Taie, Accelerated testbed for studying the wear, optical and electrical characteristics of dry cleaned PV solar panels, *Solar Energy*, vol.146, pp.8-19, 2017.

[15] H. Kawamoto and T. Shibata, Electrostatic cleaning system for removal of sand from solar panels, *Journal of Electrostatics*, vol.73, pp.65-70, 2015.

[16] X. Lu, Q. Zhang and J. Hu, A linear piezoelectric actuator based solar panel cleaning system, *Energy*, vol.60, pp.401-406, 2013.

[17] S. Sutha, S. Suresh, B. Raj and K. R. Ravi, Transparent alumina based superhydrophobic self-cleaning coatings for solar cell cover glass applications, *Solar Energy Materials and Solar Cells*, vol.165, pp.128-137, 2017.

[18] M. Sakhuja, J. Son, H. Yang, C. S. Bhatia and A. J. Danner, Outdoor performance and durability testing of antireflecting and self-cleaning glass for photovoltaic applications, *Solar Energy*, vol.110, pp.231-238, 2014.

[19] H. Zhong, Y. Hu, Y. Wang and H. Yang, TiO_2/silane coupling agent composed of two layers structure: A super-hydrophilic self-cleaning coating applied in PV panels, *Applied Energy*, 2017.

[20] A. Sokli, M. Tasbihi, M. Kete and U. L. Štangar, Deposition and possible influence of a self-cleaning thin TiO_2/SiO_2 film on a photovoltaic module efficiency, *Catalysis Today*, vol.252, pp.54-60, 2015.

[21] M. Rahman, M. Islam, A. Karim and A. H. Ronee, Effects of natural dust on the performance of PV panels in Bangladesh, *International Journal on Modern Education and Computer Science*, vol.10, pp.26-32, 2012.

[22] K. A. Moharram, M. S. Abd-Elhady, H. A. Kandil and H. El-Sherif, Influence of cleaning using water and surfactants on the performance of photovoltaic panels, *Energy Conversion and Management*, vol.68, pp.266-272, 2013.