

## A SELF-CLEANING DEVICE FOR POLE MOUNTED SOLAR PHOTOVOLTAIC INSTALLATIONS

by

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*This study aims to develop automatic self-cleaning mechanism (SCM) for pole mounted solar installations and to evaluate its performance. Design and fabrication of device allows the SCM to start cleaning cycle after every 24 hours for a period of 20 seconds. It also restricts the SCM to continue the cleaning process during rain or when the battery voltage level is low. The experiments were done at two identical pairs of photovoltaic (PV) panels tilted at 33° angle, one with SCM and one without, for a period of six weeks in the climatic conditions of Pakistan. Irradiance, dust density and other performance parameters such as maximum power output, short circuit current, open circuit voltage, fill factor and panel efficiency were recorded. The results revealed that with the increasing dust density, the output power, short circuit current, and efficiency decreased dramatically for the PV pair without SCM, i. e. by 85%, 80%, and 86%, respectively. On the other hand, the PV pair having SCM showed fairly a consistent performance due to regular cleaning of the panel surfaces. The proposed SCM is a cost effective mean of removing accumulated dust with a payback period of 2.04 years.*

*Key words: pole mounted solar installation, self-cleaning mechanism, soiling, performance*

### Introduction

Street/road lights consume a considerable amount of electricity on daily basis around the whole world, e. g. in 2010-11, street lightings consumed 1% electricity of India's all electricity consumption [1]. The Clinton Climate Initiative indicated that municipal street lighting can represent from 5% to over 60% of a municipal government's electric bill, depending on the municipality's size, the services it offers, and the efficiency of its public lighting [2]. Similarly, street lightings in Pakistan consumed 441.1 GWh (0.5% of total electricity) in 2015 [3], a country which is currently facing a severe shortage of electricity [4]. In such situation where grid electricity is not available most of the time, alternative energy source such as solar energy can play a vital role in overcoming the on-going energy crises in Pakistan. Fortunately, Pakistan is situated in such a geographical location in Asia where potential for solar energy exists abundant-

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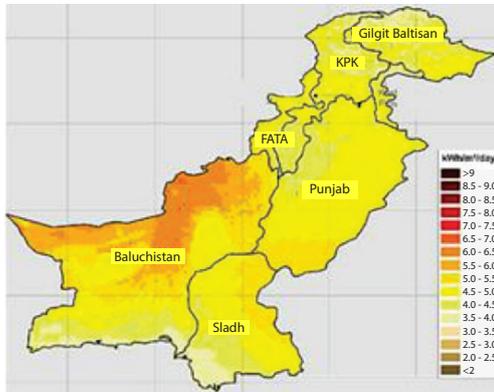


Figure 1. Solar map of Pakistan [6]



Figure 2. Pole mounted solar PV installations on GT road, Mureedkay, Pakistan

ly. Pakistan receives a daily average solar insolation of 5.5 kWh/m<sup>2</sup> with annual mean daily sunshine duration of 8-10 hours throughout the country [5]. Figure 1 shows the solar radiation map of Pakistan [6]. Realizing the on-going electricity shortage, the local governments of different provinces of Pakistan are encouraging the application of solar energy projects. One of such initiatives is the installation of solar street lighting on the major roads of different cities [7]. Pole mounted solar PV installations are generally exposed to airborne dust due to heavy traffic on the roads. This continuous and rapid accumulation of dust reduces the efficiency of such installations by 85% in a single day and in some cases in few hours. Frequent removal of dust is therefore indispensable for such installation which certainly is not possible by manual means. Majority of pole mounted solar lighting are installed on the high speed roads such as grand trunk (GT) Road. Due to high speed traffic, the airborne dust is always there to threaten the performance of these pole mounted solar installations [8]. Figure 2 shows a typical pole mounted PV installation on the GT road in the city of Mureedkay, Pakistan. Manual cleaning of such installations is not

easy. It could be seen that considerable airborne dust has accumulated on the surface of both panels. The process of accumulation of dust on the surface of solar panels is called soiling [9]. A number of researchers from across the world have investigated the effect of soiling and cleaning mechanisms on the performance of the solar panels. The rate at which dust accumulates depends on a number of factors such as climatic conditions, tilt angle, environmental conditions such as humidity, wind speed, dew point temperature, and local conditions (*e. g.* industrial exhaust gases) to which the panels are exposed [10]. Hottel and Woertz [11] were pioneers of investigating impact of soiling on solar thermal collectors tilted at 30° in USA for a period of two months in 1942. They observed 4.7% degradation in performance with 1% average loss in light transmission to collectors. After three decades, Garg [12] investigated the soiling impact at three different tilt angles, *i. e.* 20°, 40°, and 60° for a period of one month. Ali *et al.*, [13] investigated the effect of dust deposition on the performance of monocrystalline and polycrystalline PV modules in Taxila, Pakistan. It was found that monocrystalline and polycrystalline modules showed about 20% and 16% decrease of average output power respectively after 11 weeks of dust deposition. Nahar and Gupta [14] carried out a similar study in India and investigate the soiling phenomenon for the tilt angles 0°, 45°, and 90° during a period of 1.5 years. Merrouni *et al.* [15] investigated the effect of soiling on the glass and aluminum in Morocco for a period of three months (Apr-Jun) and found that horizontal mirrors for both glass and aluminum suffered 45% and 33% cleanliness drop, respectively, 14% each at +45° mirrors and was remained 3% for -45° and 0°. In another study by Pavan *et al.* [16] concluded power production from

PV panels (tilted at 25° angle) on large scale have cleaning dependency. They evaluated 6.9% power loss on sandy soil and 1.1% loss for compact soil. Rao *et al.* [17] had similar research quantifying PV performance losses due to dust accumulation in India. They used two identical panels: one clean and other with 70% dust deposition for each setup. It was observed 30-40% power loss in outdoor test bed and 4-5% power loss for indoor system.

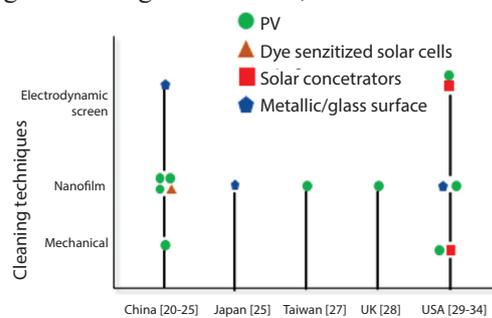
From this extensive literature review of soiling and its effects on solar panels efficiency, regular cleaning of panel surface is crucial for its consistent performance. He *et al.* [18] and Sabah and Faraj [19] reviewed different methods of cleaning and their effectiveness for the surface of solar panels. These methods include natural method, mechanical method, self-cleaning nanofilm method, and electrostatic method. Table 1 summarizes the description, major advantages and disadvantages of these methods.

**Table 1. Description, advantages, and disadvantages of various cleaning methods [18, 19]**

Cleaning method	Description	Advantage	Disadvantage
Natural means	This involves removal of dust by the natural means such as wind and rain	This does not involve any labor and operational cost	Its effectiveness is very low as wind and rain water are not always available
Manual mechanical means	This involves cleaning of solar panel surface with brushes, water <i>etc.</i>	<ul style="list-style-type: none"> <li>– The effectiveness of this method is high.</li> <li>– This helps in physical inspection of panel surface for any possible cracks</li> </ul>	<ul style="list-style-type: none"> <li>– Involves high cost.</li> <li>– Not suitable method for pole mounted PV installation.</li> <li>– Risk of life for the cleaning persons, if pole mounted installation</li> </ul>
Nanofilms	In this method, the surfaces of the solar cell are covered with a pellucid self-cleaning nanofilm	No mechanical cleaning is required	<ul style="list-style-type: none"> <li>– Not suitable for large PV array installations.</li> <li>– High cost.</li> <li>– Yet not matured technology</li> </ul>
Electrostatic removal of dust	This technique helps to lift and transport charged and uncharged dust particles using electrostatic and di-electrophoretic forces	This does not involve any labor cost	This method is not suitable for pole mounted PV installations

A number of researchers [20-34] had investigated the effect of dust deposition on PV panels using different cleaning methods including electromagnetic screens, nanofilm coating and mechanical methods for cleaning purpose.

Figure 3 shows overview of such studies made around the globe. It is apparent that most of the research is limited to USA and China in the areas of electrodynamic screen and nanofilm, respectively, whereas, a limited research has been undertaken on the mechanical cleaning of solar installations. Further, it has been observed that there is very little published literature available for a cleaning mechanism designed specifically for pole mounted PV installations. This clean-



**Figure 3. Overview of solar PV cleaning studies**

ing of pole mounted PV installations is never easy due to their height from the ground level. To address this problem, the need for a SCM for pole mounted solar installations has become indispensable. This research attempts to develop a SCM and to evaluate its performance. This study adds knowledge with original data collected through experiments and would be of high interest for the policy makers, researchers and the operators and owners of solar installation.

## Experimental set-up

### Site selection

Experimental set-up was installed on the roof of Mechanical Engineering Department's building at Mirpur University of Science and Technology in the Mirpur city of AJK, Pakistan. This building was selected as it is very close to a high traffic road, and is in the range of the airborne dust which results from heavy traffic. Mirpur city is situated at  $33.14^\circ$  north latitude and  $73.77^\circ$  east longitude.

This site has high solar insolation and irradiance. Figure 4 shows solar insolation and irradiance levels on a surface tilted at  $33^\circ$  angle facing south-west. It could be seen that solar insolation at this site goes as high as  $7 \text{ kWh/m}^2$  per day during the summer months with an average value of  $4.5\text{-}5 \text{ kWh/m}^2$  per day. Solar irradiance is as high as  $900 \text{ W/m}^2$  during the peak hours daily.

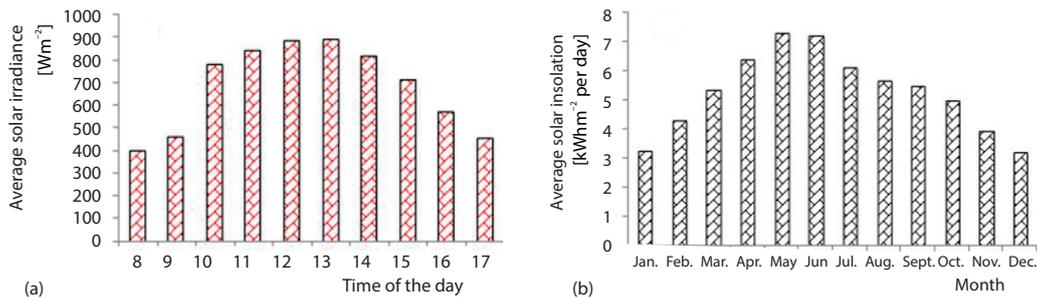


Figure 4. Average hourly solar irradiance (a) and monthly solar insolation (b) in Mirpur AJK [35]

### Technical details of equipment

The proposed SCM consists of two pairs of solar PV panels with moveable mounting structures, a cleaning brush, a DC motor, a rain sensor, a programmable micro-controller, a 12 V rechargeable DC battery and measuring instruments. Details of these components are presented in tab. 2.

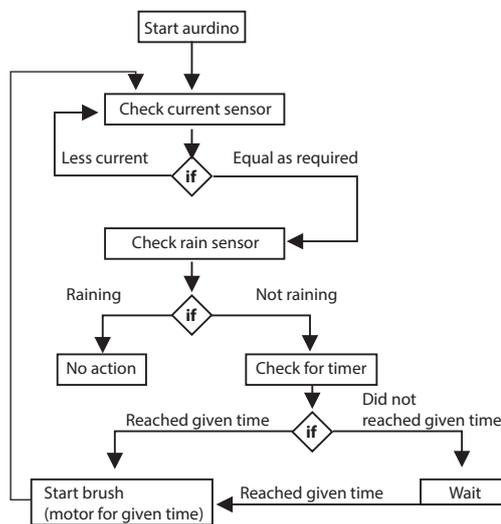
Whole SCM except rain sensor and cleaning brush is installed within a weather proof box ( $140 \times 280 \text{ mm}$ ) and is capable to sustain severe weather conditions. Its addition to the solar module is expected to improve the mechanical strength of the pole and panels against high wind speed.

The micro-controller has been programmed to start cleaning cycle every day at 12 p. m. for a 20 second period. Daily cleaning time, *i. e.* 12 p. m. has been selected because by this time the dew drops congregated on the panel surface would have vaporized. Secondly, by this time solar radiations are getting to their peak value, therefore cleaning the panel surface just before the peak period will certainly provide better conditions for the panel to generate more energy. The cleaning period was set to 20 seconds after a series of experiments in which dust was artificially spread over the panels and time was recorded for a complete cleaning of the surface. It was found that the proposed cleaning brush would

**Table 2: Technical details of equipment**

Equipment/Item	Technical details
Solar PV module	Type: Mono-Crystalline, No. of cells: 12 Cell area: 55 × 60 mm, Rated capacity: 50 W; Short Circuit Current: 2.91 A, Open Circuit Voltage: 22.6 V, Module dimensions: 760 × 540 × 40 mm, Estimated life: 25 years
Mounting structure	Material: Mild Steel, movable along the vertical axis; provides tilt angles between zero and 90°.
Direct current motor	Type: DC Motor, Voltage: 12 V: Rated current: 5 Amperes, Power 60 W, estimated life: 10 years
Cleaning brush	Made of wooden threads/nails screwed to a cast iron strip. The driving end of the brush connects with the shaft of the DC motor. Dimensions: 630 × 40 mm, Estimated life: 2 years
Battery	12V Li-Ion battery – estimated life: 5-6 years
Rain sensor	Model: YL-83 type; operating voltage: 5 V, Dimensions: 50 × 30 mm, estimated life: 3 years
Micro-controller	Type: Arduino mega 2560; Arduino is a microcomputer; it has an internal CPU, RAM, IOS interface, estimated life: 15 years

remove all the dust in 20 seconds. The cleaning time, cleaning period and the cleaning interval, all could be adjusted anytime via re-programming of the micro-controller. Figure 5 shows a flowchart of the SCM cleaning process. Pair of PV panels connected in parallel with complete assembly (front and rear sides) of the proposed SCM is shown in fig. 6.



**Figure 5. Flow chart of SCM cleaning process**



**Figure 6. Experimental set-up of proposed SCM (front and rear side of PV panel pair having SCM)**

Precise equipment was used for the measurement of PV modules parameters. The I-V curve analyzer (Model: PROVA 200A) used for the measurement of output parameters of PV modules including maximum power, short circuit current, efficiency and fill factor. It also traces the I-V and P-V curves. The global solar radiations along the plane of PV modules were mea-

sured using Pyranometer (operating range 150-1500 W/m<sup>2</sup>, accuracy  $\pm 5\%$ ). Dust accumulation on the surface of PV panels was measured by the weight of dust on the glass plates using sensitive digital weight balance. Six glass plates (110  $\times$  60 mm) were placed at same tilt angle (33°) facing south. Weight of each plate was measured in beginning and after every passing week. At the end of 1<sup>st</sup> week, panel number one was removed carefully and its weight was measured. Same procedure was repeated till the sixth week where the dust accumulated on panel number six gave the value of dust density over a period of six week.

#### Calculation of PV panel's performance

Systematic series of measurements were conducted for a period of six weeks. Maximum power depends on the maximum current and voltage for specific time and is given:

$$P_m = V_m I_m \quad (1)$$

where  $P_m$  is the maximum power,  $V_m$  – the maximum voltage, and  $I_m$  represents the maximum current. Percentage efficiency of PV module was calculated using:

$$\eta_{\text{module}} = \left( \frac{P_m}{GA} \right) 100 \quad (2)$$

where  $\eta_{\text{module}}$  represents the module efficiency,  $G$  [Wm<sup>-2</sup>] – the global solar irradiance, and  $A$  – the aperture area of PV module. Fill factor (FF) is a measure of quality of the solar cell. It is calculated by comparing the maximum power to the theoretical power and can be represented:

$$FF = \left( \frac{V_m I_m}{V_{oc} I_{sc}} \right) \quad (3)$$

where  $V_{oc}$  is the open circuit voltage and  $I_{sc}$  is the short circuit current of PV module. The  $V_{oc}$  is the potential difference between two terminals of solar panel when these are not connected to any circuit. Short circuit current,  $I_{sc}$ , is the current value without any resistance in the path of current flow. The I-V and P-V curves were obtained for I-V curve analyser. Readings of all these parameters for both pairs were recorded on daily basis at 12 p. m. All the daily values were then converted to weekly average values for each week in order to compare these with the weekly dust density.

### Results and discussion

Readings were recorded on weekly basis and are shown in tab. 3.

**Table 3. Weekly readings of different parameters**

Week	Dust density [gcm <sup>-2</sup> ]	PV pair with SCM					PV pair without SCM				
		$P_{\text{max}}$ [W]	$I_{\text{sc}}$ [A]	$V_{\text{op}}$ [V]	FF	Eff [%]	$P_{\text{max}}$ [W]	$I_{\text{sc}}$ [A]	$V_{\text{op}}$ [V]	FF	Eff [%]
Week 0	0	70	4.83	19.40	0.73	7.20%	70	4.8	19.15	0.74	7.20%
Week 1	0.58	67	4.26	19.40	0.73	6.69%	67	4.17	19.15	0.74	6.67%
Week 2	1.45	67	4.17	19.38	0.747	6.70%	60	3.75	19.20	0.76	5.99%
Week 3	2.65	63	3.92	19.37	0.715	6.29%	50	3.05	19.07	0.71	5.03%
Week 4	3.87	66	4.08	19.64	0.76	6.63%	43	2.61	19.20	0.75	4.32%
Week 5	5.45	58	3.38	19.59	0.795	5.82%	29	1.63	19.27	0.77	2.86%
Week 6	6.9	58	3.38	19.59	0.75	5.82%	9	0.561	19.20	0.72	0.81%

### Dust accumulation and dust composition

Dust accumulation was measured using digital weight balance for the period of a six week, *i. e.* from September 6, 2016 to October 18, 2016 on weekly basis. Figure 7 shows the dust density ( $\text{mg}/\text{cm}^2$ ) on weekly basis for the period of six week. It is apparent that dust density increased consistently till the end of 6<sup>th</sup> week. No raining was observed during this period. Dust accumulation in the last two weeks was observed higher compared to first four weeks. This is probably because, during the last two weeks, some grinding works in the parking area near this building was carried out which caused a lot of airborne dust in surrounding that ultimately accumulated on the panels. To find the composition of dust, a sample of collected dust was tested using hydrometer method at Soil Test Laboratory of University of Engineering and Technology, Taxila, India. The tests showed that sample dust contains 32% fine sand (diameter  $>0.07$  mm), 60.5% silt (diameter 0.06-0.002 mm) and 7.5% clay (diameter  $<0.002$  mm).

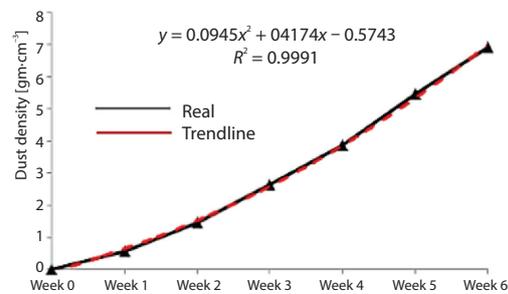


Figure 7. Dust density for six weeks

### Solar PV performance parameters

Figure 8 shows variation of different output parameters of solar modules with respect to variation in the dust density. It is apparent from figs. 8(a)-8(e), that with the increasing dust density, maximum power,  $P_{\text{max}}$ , short circuit current,  $I_{\text{sc}}$ , and efficiency,  $\eta$ , of the PV pair without SCM have identical decreasing trend and were recorded (85%, 80%, and 86%, respectively) lower than that of PV pair having SCM. This confirms that these three parameters *i. e.* maximum power,  $P_{\text{max}}$ , short circuit current,  $I_{\text{sc}}$ , and efficiency,  $\eta$ , are strongly influenced by the soiling effect. As shown in fig. 8(c) variation in open circuit voltage,  $V_{\text{oc}}$ , remained fairly negligible and was recorded between 19.5-20.2 V for both PV pair. This shows that dust density does not affect the  $V_{\text{oc}}$  significantly. From fig. 8(d) it is obvious that dust does not have a significant effect on the FF. However, FF of the PV pair with SCM was observed 4% higher than that without SCM. Overall variation of FF during six week study period was observed 11%. Figures 9(a) and 9(b) show the weekly I-V and P-V curves for the solar panel pair without automatic SCM. It is apparent that with increasing dust density, short circuit current went on decreasing which caused maximum power to drop on weekly basis. Over the six weeks of study period, short circuit current dropped by 80%, *i. e.* from 4.8 A to 0.98 A whereas very little drop in the open circuit voltage,  $V_{\text{oc}}$ , drop was observed. Similarly, peak power consistently dropped during this period. A drop of 80% in maximum power was observed at the end of study period. Figures 10(a) and 10(b) show the weekly I-V and P-V curves for the solar panel pair with automatic SCM. It is apparent that both the short circuit current and power of the panels remained quite consistent during the study period due to regular cleaning of the panel surface.

### Economic analysis

An economic analysis has been done based on the readings collected during six weeks period and on the following assumptions. (a) Same pattern of dust density repeats after every six week period (*i. e.* rain cleans the surface of both panels after every six weeks); (b) Average sunshine hours are 8 during winter months (Nov-Mar) and 12 during summer months (Apr-Oct). (c) Daily electricity consumed by SCM remains constant for all days of the year.

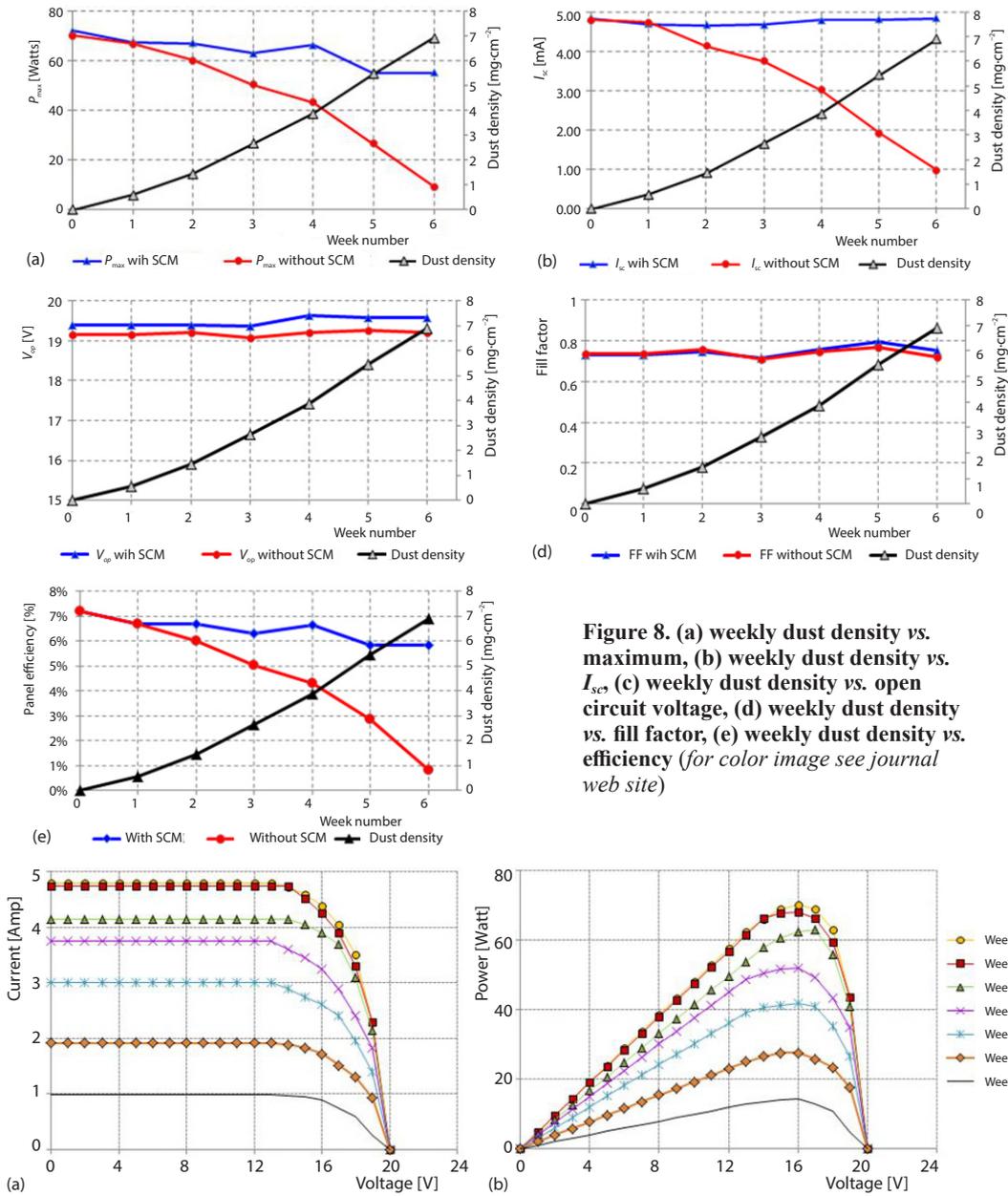
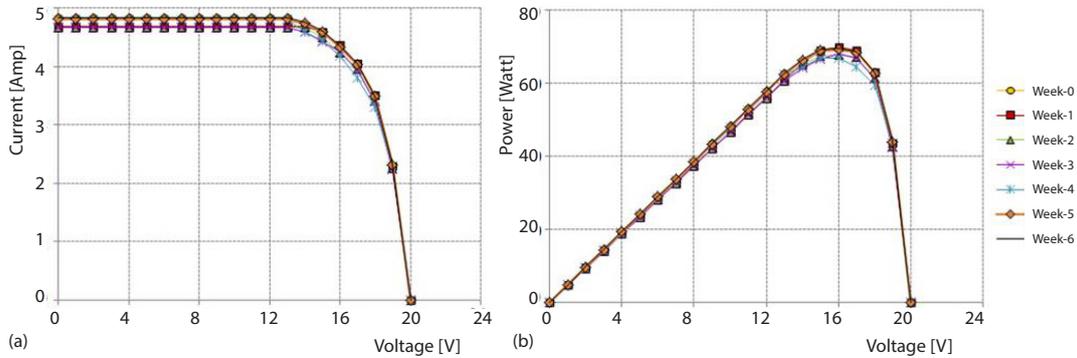


Figure 9. The I-V curves; (a) and P-V curve, (b) for the pair of panels without SCM

Table 4 shows a simple economic analysis whereas fig. 11 shows weekly power generation by PV modules (with and without SCM) based on aforementioned assumptions.

As shown in tab. 4, SCM modules generate 26% higher electricity compared to PV modules without SCM. Under real conditions (*i. e.* PV module installed near a high traffic road), this difference of power generation could be much larger due to frequent and rapid dust accumulation on the PV modules surfaces. Secondly, in summer months, power generation from modules having SCM



**Figure 10. The I-V curves; (a) and P-V curve, (b) for the pair of panels with SCM (for color image see journal web site)**

**Table 4. Economic analysis of proposed SCM for PV modules**

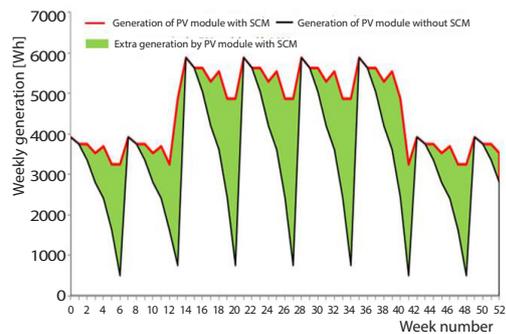
Parameter	PV module with SCM	PV module without SCM	Difference
Weekly power generation [kWh] for winter months and 8 sunshine hours per day	90.4	69	24%
Weekly power generation [kWh] for summer months and 12 sunshine hours per day	151	110	27%
Total annual generation, [kWh]	241	179	26%
Total cost of SCM	PKR. 2800		
Annual savings and Rs. 22/kWh	PKR. 1364		
Simple payback period	2.05 years		

will be much higher than that having no SCM. A difference of 50% in generation from both PV modules (with and without SCM) will result in a payback period of one year.

**Conclusions and recommendations**

Road side pole mounted solar PV installations are exposed to heavily airborne dust which adversely affects the panel’s performance. Manual removal of such accumulated airborne dust is expensive and involves higher maintenance costs. In this study, we have developed an automatic SCM for pole mounted PV installations and have tested its performance. Two PV pairs, one with SCM and the other without SCM, tilted at an angle of 33° were placed on the roof of a building that is very close to a main road for a period of six weeks. Readings of their essential performance parameters were recorded on daily basis. The following conclusions could be drawn from this study.

- Automatic cleaning or regular manual cleaning of panel surface is highly necessary to avoid or minimize the soiling effect.



**Figure 11. Weekly power generation by PV modules**

- Increasing dust density has a significant negative effect on the power, short circuit current and the efficiency of the PV panels, in this case, reduction in the  $P_{\max}$  (85%),  $I_{sc}$  (80%), and efficiency (86%) was observed for the panel pair without SCM.
- Dust density does not increase linearly with respect to time but is somewhat exponential; local conditions may result in a sudden and rapid increase in the soiling effect thus reducing the overall performance of the PV panels.
- Dust accumulation does not affect the FF and  $V_{oc}$ .
- The PV module with proposed SCM could produce 26% to 50% higher electricity compared to a simple PV module.

Finally, it is recommended that the developed SCM should be tested on a road side mounted pole for a longer period in order to evaluate its performance under real conditions.

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### References

- [1] Johnson, A., et al., Energy Savings Potential for Street Lighting in India, Report, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, Cal., USA, 2014
- [2] \*\*\*, CCI (Clinton Climate Initiative), Street Lighting Retrofit Projects: Improving Performance while Reducing Costs and Greenhouse Gas Emissions, Clinton Foundation, 2010, [http://www.dvrpc.org/energyclimate/eetrafficstreetlighting/pdf/CCI\\_EE\\_Streetlighting\\_White\\_Paper.pdf](http://www.dvrpc.org/energyclimate/eetrafficstreetlighting/pdf/CCI_EE_Streetlighting_White_Paper.pdf)
- [3] \*\*\*, Pakistan Energy Year Book 2015, Hydrocarbon Development Institute of Pakistan, 2015
- [4] Khalil, H., B., Zaidi, S., J., H. Energy Crisis and Potential of Solar energy in Pakistan, *Renewable and Sustainable Energy Reviews*, 31 (2014), Mar., pp. 194-201
- [5] Ghafoor, A., et al., Current Status and Overview of Renewable Energy Potential in Pakistan for Continuous Energy Sustainability, *Renewable and Sustainable Energy Reviews*, 60 (2016), July, pp. 1332-1342
- [6] \*\*\*, NREL, National Renewable Energy Laboratory, U. S. Department of Energy, Solar Resource, [http://www.nrel.gov/international/ra\\_pakistan.html](http://www.nrel.gov/international/ra_pakistan.html)
- [7] Mirza, U., K., et al., Status and Outlook of Solar Energy Use in Pakistan, *Renewable and Sustainable Energy Reviews*, 7 (2003), 6, pp. 501-514
- [8] Mafuyai, G. M., et al., Heavy Metals Contamination in Roadside Dust along Major Traffic Roads in JOS Metropolitan Area, Nigeria, *European Journal of Earth and Environment*, 2 (2015), 1, pp. 48-58
- [9] Mastekbayeva, G., Kumar, S., Effect of Dust on the Transmittance of Low Density Polyethylene Glazing in a Tropical Climate, *Solar Energy*, 68 (2000), 2, pp. 135-141
- [10] Sayyah, A., et al., Energy Yield Loss Caused by Dust Deposition on Photovoltaic Panels, *Solar Energy*, 107, (2014), Sept., pp. 576-604
- [11] Hotte, M. C., Woertz B. B., Performance of Flat Plate Solar Heat Collectors, *ASME Trans.*, 64, (1942), Jan., pp. 91-104
- [12] Garg, H., Effect of Dirt on Transparent Covers in Flat-Plate Solar Energy Collectors, *Solar Energy*, 15 (1974), 4, pp. 299-302
- [13] Ali, H. M., et al., Effect of Dust Deposition on the Performance of Photovoltaic Modules in Taxila, Pakistan, *Thermal Science*, 21 (2015), 2, pp. 915-923
- [14] Nahar, N., Gupta, J., Effect of Dust on Transmittance of Glazing Materials for Solar Collectors under Arid Zone Conditions of India, *Solar and Wind Technology*, 7 (1990), 2-3, pp. 237-243
- [15] Merrouni, A. A., et al., Investigation of Soiling Effect on Different Solar Mirror Materials under Moroccan Climate, *Energy Procedia*, 69 (2015), Mar., pp. 1948-1957
- [16] Pavan, A. M., et al., The Effect of Soiling on Energy Production for Large-Scale Photovoltaic Plants, *Solar Energy*, 85 (2011), 5, pp. 1128-1136

- [17] Rao, A., *et al.*, Influence of Dust Deposition on Photovoltaic Panel Performance, *Proceedings*, 4<sup>th</sup> International Conference on Advances in Energy Research, ICAER 2013, *Energy Procedia*, 54 (2014), Dec., pp. 690-700
- [18] He, G., *et al.*, Review of Self-Cleaning Method for Solar Cell Array, *Procedia Engineering*, 16 (2011), Dec., pp. 640-645
- [19] Sabah, K., Faraj, S. N., Self-Cleaning Solar Panels to Avoid the Effects of Accumulated Dust on Solar Panels Transmittance, *International Journal of Science and Research*, 2 (2013), 9, pp. 246-248
- [20] Qi Xia, S., *et al.*, Mechanism of Dust Removal by a Standing Wave Electric Curtain, *Science China Physics, Mechanics & Astronomy*, 55 (2012), 6, pp. 1018-1025
- [21] Wang, E., *et al.*, High-Performance Polymer Heterojunction Solar Cells of a Polysilfluorene Derivative. *Applied Physics Letter*, 92 (2008), 3, 033307
- [22] Pei, J., *et al.*, Efficiency Enhancement of Polymer Solar Cells by Incorporating a Self-Assembled Layer of Silver Nanodisks, *Solar Energy Materials and Solar Cells* 95, (2011), 12, pp. 3281-3286
- [23] Zhao, X. Y. *et al.*, Effects of Damkohler Number of Evaporation on the Morphology of Active Layer and the Performance of Organic Heterojunction Solar Cells Fabricated by Electrospray Method, *Solar Energy Materials and Solar Cells*, 134 (2015), Mar., pp. 140-147
- [24] Liu, J., *et al.*, Stacked Graphene-TiO<sub>2</sub> Photoanode via Electrospray Deposition for Highly Efficient dye-Sensitized Solar Cells, *Organ. Electronhys. Mater. Appl*, 23 (2015), Aug., pp. 158-163
- [25] Ju, F., Fu, X., Research on Impact of Dust on Solar Photovoltaic (PV) Performance, *Proceedings*, 2011 International Conference on Electrical and Control Engineering (ICECE), Yichang, China, 2011 pp. 3601-3606
- [26] Zhang, X. T. *et al.*, Self-Cleaning Particle Coating with Antireflection Properties, *Chem. Mater*, 17 (2005), 3, pp. 696-700
- [27] Chen, F.-C., *et al.*, Plasmonic-Enhanced Polymer Photovoltaic Devices Incorporating Solution-Processable Metal Nanoparticles, *Applied Physics Letter* 95, (2009), 1, 013305-013305-3
- [28] Gray, A., Self-Cleaning Hydrophobic Nano Coating for Solar Panel Glass Generating Great Results for Nanoshell, [http://www.pv-magazine.com/services/press-releases/details/beitrag/self-cleaning-hydrophobic-nano-coating-for-solar-panel-glass-generating-great-results-for-nanoshell\\_100005577/#ixzz3Sr9qqsgv](http://www.pv-magazine.com/services/press-releases/details/beitrag/self-cleaning-hydrophobic-nano-coating-for-solar-panel-glass-generating-great-results-for-nanoshell_100005577/#ixzz3Sr9qqsgv)
- [29] Mazumder, M. K., *et al.*, Self-Cleaning Transparent Dust Shields for Protecting Solar Panels and Other Devices, *Particulate Science and Technology*, 25 (2007), 1, pp. 5-20
- [30] Mazumder, M. K., Self-Cleaning Solar Panels and Concentrators with Transparent Electrodynamic Screens, US Patent 9433336 B2, 2016
- [31] Brenor, L. B., *et al.*, Anti-Reflective and Anti-Soiling Coatings for Self-Cleaning Properties, US Patent 9353268 B2, 2016
- [32] Williams, R. B., *et al.*, Vibration Characterization of Self-Cleaning Solar Panels with Piezoceramic Actuation, Collection of Technical Papers, *Proceedings*, 48<sup>th</sup> AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, Hi., USA, 2007, pp. 512-520
- [33] Blackmon, J., Curcija, M., Heliostat Reflectivity Variations Due to Dust Build up under Desert Conditions, *Proceedings*, Seminar on Testing Solar Energy Materials and Systems, Gaithersburg, Md., USA, 1978, pp. 169-183
- [34] Berg, R. S., *Heliostat Dust Build up and Cleaning Studies*, Sandia Labs, Albuquerque, N. Mex., USA, 1978
- [35] \*\*\*, GPL, Greenstream Publishing Limited, Solar Electricity Hand Book, <http://www.solarelectricity-handbook.com/index.html>