Reduction in soiling loss of PV module using hydrophobic coating with different water contact angle

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Abstract

The deposition of dust particles on Photovoltaic (PV) surfaces is a well-known problem affecting solar panels' performance by reducing their efficiency. Dust and other soiling agents hinder the absorption of solar energy by photovoltaic cells. Consequently, this decreases energy generation, resulting in considerable losses to the PV industry. Hydrophobic coatings are known to reduce soil deposition on any surface. The objective of the present study is to compare the soiling loss of PV modules with and without hydrophobic coatings. Hydrophobic coatings with varying water contact angles (WCA) were applied to PV modules. Uncoated and coated mini-modules were kept for dust deposition in a simulated soiling chamber at different tilt angles to mimic real-world conditions. The soil deposition on coated PV mini-module is significantly less than on uncoated mini-module, leading to lower soiling loss. It indicates that applying hydrophobic coatings is an effective way to reduce the impact of soiling.

Keywords: Hydrophobic, Photovoltaic, Water contact angle, and soiling loss.

1. Introduction

The Photovoltaic (PV) module, used to generate electricity from the sun, must be used efficiently to minimize the current global energy crisis. PV modules comprise glass that prevents the solar cell from storms and dust. The wind carries the dust, and dirt settles on the PV cover glass, reducing the optimum solar irradiance that must reach the solar cell. It has been found that 4 g/m² of dust layer on the solar panel decreased the output power of the solar panel by 40% [1][2][3]. Hence, frequent cleaning is needed, which adds to the maintenance cost. However, the frequency of such a cleaning process can be reduced significantly by applying anti-soiling coatings on the PV cover glass. The anti-soiling coatings can be categorized as hydrophobic surfaces and super hydrophilic surfaces. However, hydrophobic anti-soiling coatings can also reduce the dust deposition rate on the surface of the PV modules [4][5].

Factors responsible for dust settlement are PV system tilt-angle and orientation, ambient temperature and humidity, site characteristics, dust properties, wind velocity, and glazing characteristics [3]. Different experimental conditions may result in varying dust deposition behaviors [6]. Further investigations are pivotal in unraveling the roles of roughness and surface energy on dust deposition, especially considering complications arising from different environmental conditions. In addition, the correlation between surface wettability and dust deposition remains an unsolved issue.

Several studies have demonstrated the effectiveness of hydrophobic, super hydrophilic, and super hydrophobic coatings for PV application [7][8]. However, none of the studies discussed the desired water contact angle (WCA) of the layer required for solar panels installed at different tilt angles. This study aims to quantify the losses on soiled PV modules at different tilt angles and with different surface wettability of PV modules. This study will help to determine the optimum water contact angle for hydrophobic coating needed to reduce the soiling loss of the solar panel. In addition, the dust coverage on PV modules with different surface wettability is quantified through an image-based method.

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2. Experimentation

An artificial soiling chamber is a chamber that is used to accelerate the process of dust deposition, as it can take days in field conditions. The chamber is a 55 x 45 x 45 cm^3 cuboidal box made of 6 mm thick acrylic sheets shown in Figure 1, which creates a cloud of dust, and after some time, dust settles to form a uniform deposition over the exposed surface as shown in Figure 2. The dust used in experiments has been extracted from PV module placed at a real-time outdoor module monitoring station at IIT Bombay, Mumbai, India. The extracted dust was dried in a hot air oven to remove any moisture content before using it [9].

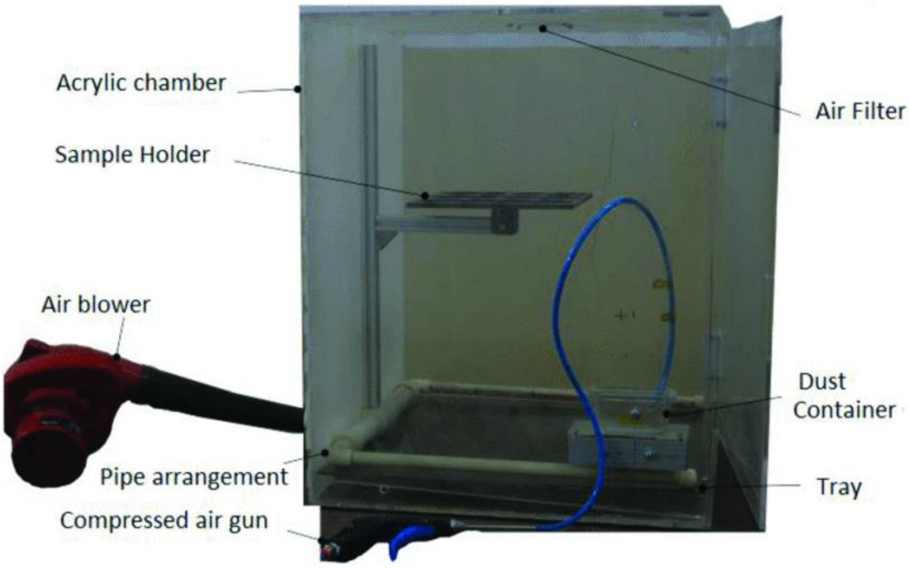

Figure 1. An artificial dry dust deposition system used in the experiment [9]

Hexamethyldisilazane-modified silica coating was developed, and three coating solutions were developed by varying the ratio of HMDS and silica [10]. Three mini-modules were spray-coated with these coating solutions, which resulted in coating with three different water contact angles. Three coated and one uncoated mini-module were kept for soiling in the soiling chamber at two different tilt angles, as shown in Figure 2. I-V characteristics of PV modules were studied before and after soiling. The quantification of dust coverage was studied using optical images and analyzed with ImageJ software.

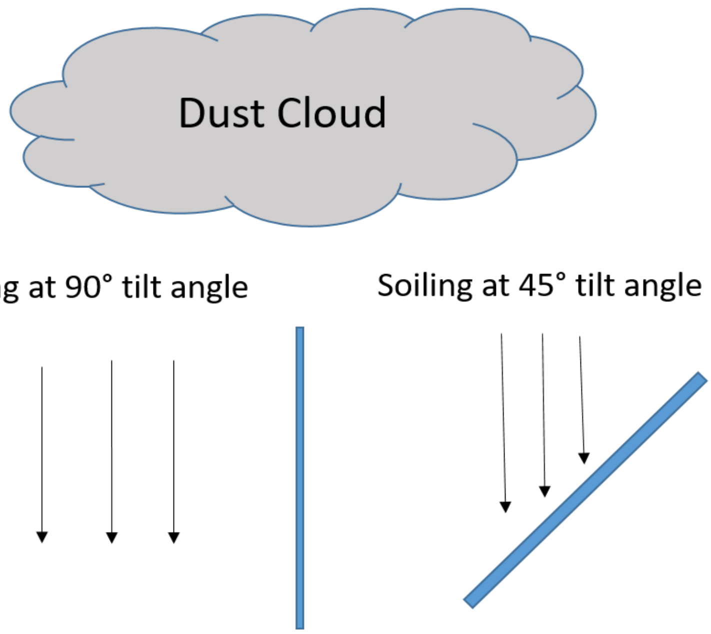

Figure 2. Schematic diagram of soiling setup

3. Results and Discussion

3.1. I-V characteristics of PV mini-module at different conditions

We have analyzed the effect of dust deposition on the output current of coated and not-coated PV mini-modules in indoor conditions. Figure 3 shows the IV curve of the uncoated and coated mini-module before and after soiling at two different tilt conditions at room temperature. When the tilt angle is 90°, the short circuit current (I_{sc}) drop is less than 1% in all cases, as in Table 1. It shows that at 90°, the coating has no significant impact, and very little dust adheres to the surface. At 45° tilt angle, the drop in I_{sc} for an uncoated mini-module is 9.9%, and for a coated mini-module, it is 2.9%, 2.1%, and 1.2% for water contact angles 106°, 114°, and 128° respectively. It shows that at a 45°-soiling condition, more dust adheres to the surface of the uncoated mini-module, i.e., glass, than on the coated mini-module. We can also see that the higher the water contact angle, the lower the drop in I_{sc}.

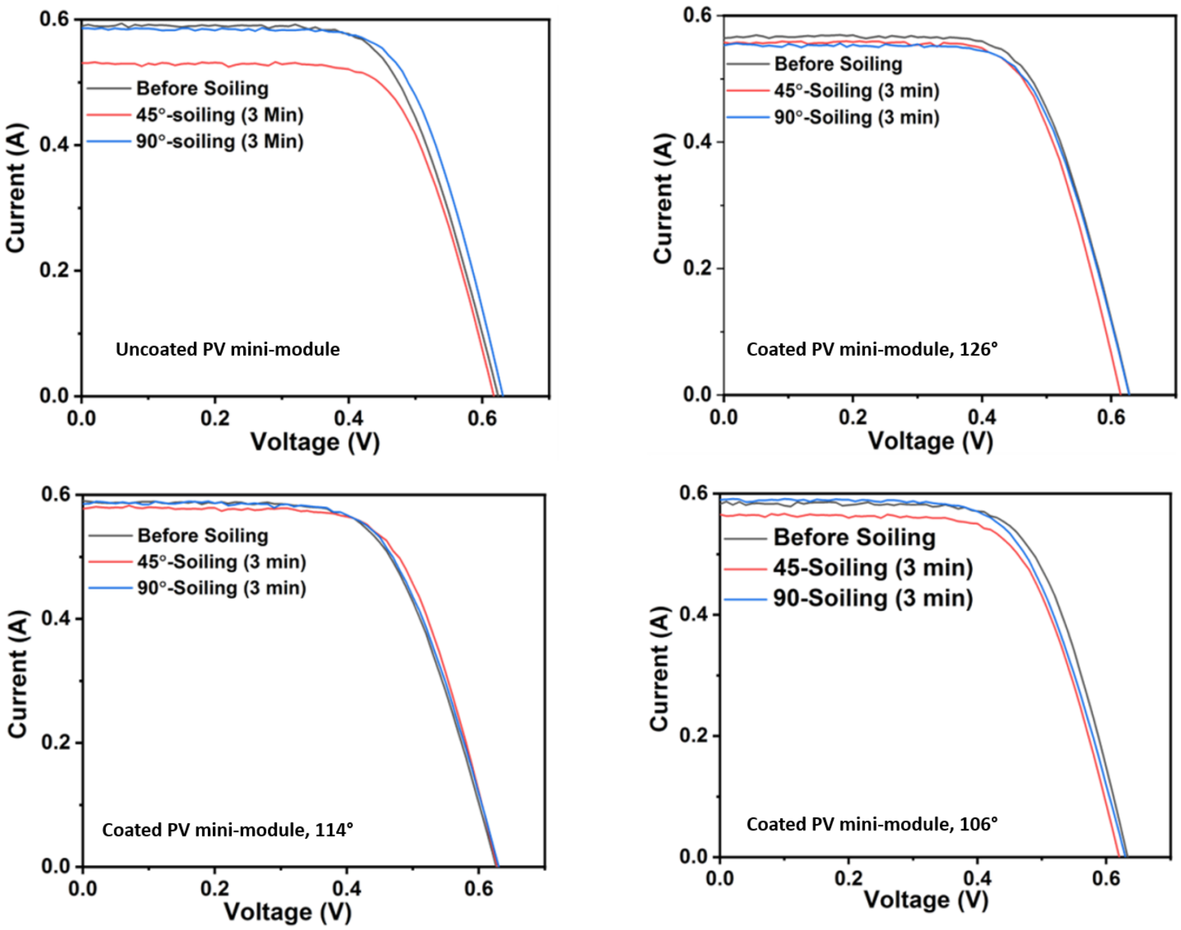

Figure 3. IV curves of the uncoated and coated module before and after soiling at two different tilt conditions at room temperature.

Table 1. Short circuit current of uncoated and coated module before and after soiling and % change

WCA of PV mini-module	Short circuit current (I_{sc}) without soiling	I_{sc} after soiling at 90°	% change after soiling at 90°	I_{sc} after soiling at 45°	% change after soiling at 45°
36°	0.589	0.586	< 1	0.530	9.9
106°	0.582	0.583	< 1	0.565	2.9
114°	0.590	0.585	< 1	0.577	2.1
128°	0.564	0.561	< 1	0.557	1.2

3.2. Quantification of dust coverage area on coated and uncoated PV mini-module

The proposed algorithm is based on four stages: image acquisition, converting the image to 16-bit, setting the threshold, and calculation of area. A digital camera captures the module's image in the visible spectrum, which is then processed to extract the region of interest. Figure 4 shows the soiling surface of coated (106°) and not coated PV mini-modules at a 45° tilt angle. The soiling coverage area was calculated according to the above model, and the effect of the grid was eliminated by subtracting the area of the grid from the total coverage. The area of the grid was measured when the mini-module was clean. It was found that dust particles covered 54% of the area of non-coated surfaces, whereas they covered 19% of the coated surfaces. Even though 54% of the area is covered by dust, it only shows I_{sc} loss of 9.9% because a thin layer of dust is deposited on the surface of the uncoated mini-module, which hinders the light coming to the cell but does not entirely block it. The same observation can be seen in the case of coated mini-module. As discussed, the result complements the I-V characteristic of the coated and not-coated module surfaces.

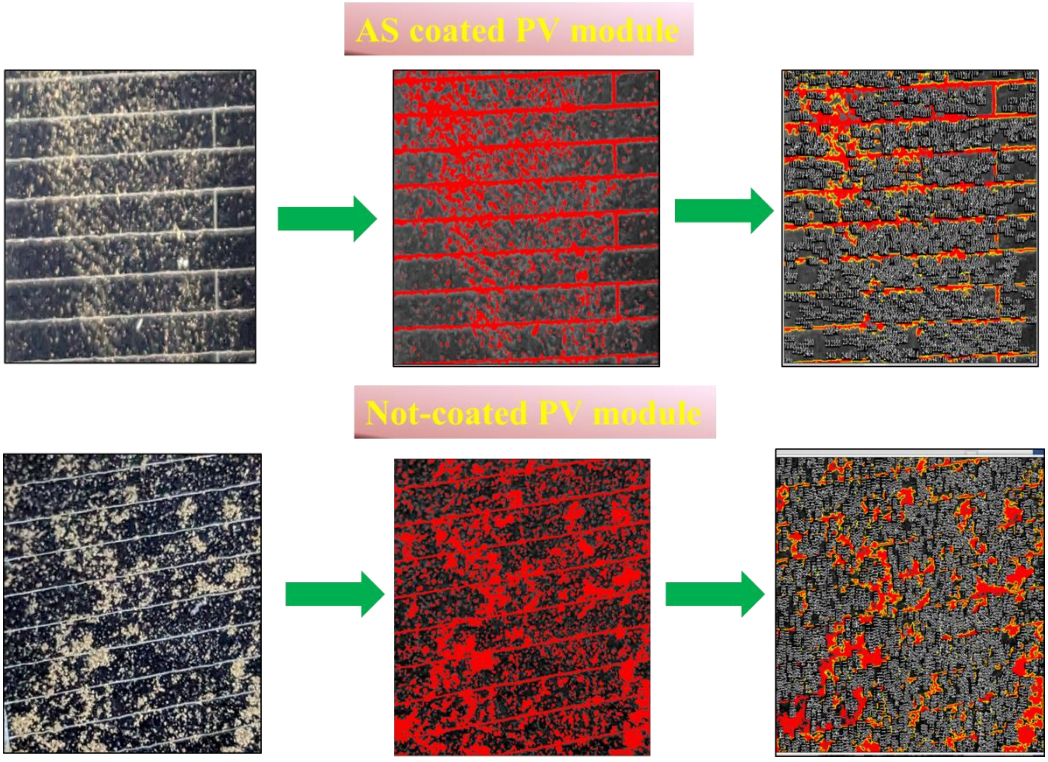

Figure 4. Optical Image of coated and not-coated PV module after soiling and image analysis

4. Conclusion

Coated and uncoated PV modules showed a drop of less than 1% in short circuit current when placed at 90°, which shows negligible soiling of modules. When placed at a 45° tilt angle, the uncoated PV mini-module showed a drop of 9.9%, and the coated PV mini-modules for different WCA of 106°, 114°, and 128° showed a decline of 2.9%, 2.1%, and 1.2% in I_{sc}. It indicates that hydrophobic coating effectively reduces the loss caused by soiling. Higher water contact angle shows lower loss due to soiling by decreasing the adhesion force between dust and surface. An analysis of Optical images of coated and uncoated PV mini-modules also verifies this result.

5. Acknowledgment

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6. References

[1] S. A. Sulaiman, A. K. Singh, M. M. M. Mokhtar, and M. A. Bou-Rabee, "Influence of dirt accumulation on performance of PV panels," *Energy Procedia*, vol. 50, pp. 50–56, 2014, doi: 10.1016/j.egypro.2014.06.006.

[2] M. R. Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad, and S. Hajighorbani, "Power loss due to soiling on solar panel: A review," *Renew. Sustain. Energy Rev.*, vol. 59, pp. 1307–1316, 2016, doi: 10.1016/j.rser.2016.01.044.

[3] M. Mani and R. Pillai, "Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations," *Renew. Sustain. Energy Rev.*, vol. 14, no. 9, pp. 3124–3131, 2010, doi: 10.1016/j.rser.2010.07.065.

[4] G. He, C. Zhou, and Z. Li, "Review of self-cleaning method for solar cell array," *Procedia Eng.*, vol. 16, pp. 640–645, 2011, doi: 10.1016/j.proeng.2011.08.1135.

[5] J. Zhang, W. Wang, S. Zhou, H. Yang, and C. Chen, "Transparent dust removal coatings for solar cell on mars and its Anti-dust mechanism," *Prog. Org. Coatings*, vol. 134, no. March, pp. 312–322, 2019, doi: 10.1016/j.porgcoat.2019.05.028.

[6] F. M. Zaihidee, S. Mekhilef, M. Seyedmahmoudian, and B. Horan, "Dust as an unalterable deteriorative factor affecting PV panel's efficiency: Why and how," *Renew. Sustain. Energy Rev.*, vol. 65, pp. 1267–1278, 2016, doi: 10.1016/j.rser.2016.06.068.

[7] S. Sutha, S. Suresh, B. Raj, and K. R. Ravi, "Transparent alumina based superhydrophobic self–cleaning coatings for solar cell cover glass applications," *Sol. Energy Mater. Sol. Cells*, vol. 165, no. January, pp. 128–137, 2017, doi: 10.1016/j.solmat.2017.02.027.

[8] Z. S. Huang *et al.*, "Experimental investigation of the anti-soiling performances of different wettability of transparent coatings: Superhydrophilic, hydrophilic, hydrophobic and superhydrophobic coatings," *Sol. Energy Mater. Sol. Cells*, vol. 225, no. March, p. 111053, 2021, doi: 10.1016/j.solmat.2021.111053.

[9] L. Fernandes, S. Bhaduri, A. Alath, N. S. Shiradkar and A. Kottantharayil, "Artificial dust deposition chamber for investigation of soiling loss in photovoltaic modules," *2019 IEEE 46th Photovoltaic Specialists Conference (PVSC)*, pp. 2875-2878, doi: 10.1109/PVSC40753.2019.8981343.

[10] S. D. Wang and S. S. Luo, "Fabrication of transparent superhydrophobic silica-based film on a glass substrate," *Appl Surf Sci*, vol. 258, no. 14, pp. 5443–5450, May 2012, doi: 10.1016/j.apsusc.2012.02.032.