PV Modules Self-Cleaning Solutions and Transmittance Loss Measurements

Soukaina Medaghri Alaoui, Salima El Ayane, Dounia Dahlioui and Abdelfettah Barhdadi*

Physics of Semiconductors and Solar Energy Research Team (PSES)
Energy Research Center, Ecole Normale Supérieure, Mohammed V University in Rabat, Morocco

* abdelfettah.barhdadi@um5.ac.ma

Abstract - **This paper presents a review of different self-cleaning solutions minimizing the impact of soiling on photovoltaic panels, as well as a study of soiling in order to identify clearly the parameters, which favor the soiling accumulation on solar panels surface. Based on a comprehensive study of exposed solar glass samples within our platform located in Rabat-Morocco, identifying soils deposit evolution has been recently started with a comparison between two samples exposed according to two different angles 0° and 45°. The difference in soiling distribution and transmittance between the two samples was well analyzed by presentation of loss trend due to soiling and which has marked 2.25%.**

Keywords - **Self-cleaning solutions; Soiling; PV Panels; Distribution; Transmittance**

I. Introduction

Global demand for renewable energy is constantly increasing. Several studies have been developed on solar energy because of its efficiency, availability and ease of production. However, the influence of accumulated dust on the surface of photovoltaic modules will allow adopting several research topics. Many studies aim to examine the factors that influence the performance of photovoltaic panels and therefore seek to improve them by different methods. Indeed, the impact of dust accumulation on the performance of photovoltaic panels (soiling), on which many studies have been published, is one of the essential and critical factors in this regard [1]. It decreases the incoming irradiance to the solar cell, obscures solar flux and causes power loss. Studies in dry areas show that these losses could reach up to 15 % of total capacity of generation per day [2]. Fig. 1 shows studies evolution on the impact of dust accumulation on the efficiency of photovoltaic panels [3].

In this work, a detailed review of preventive solutions was presented to lead the work towards solutions that have fewer drawbacks, and therefore guide their effectiveness for sustainable development. The difference between two glass samples at two different angles 0° and 45° (distribution and transmittance) was determined using a Solar-meter. This approach has been performed by measuring the received and transmitted irradiance on six points for each glass sample under the same real conditions during two months of exposure.

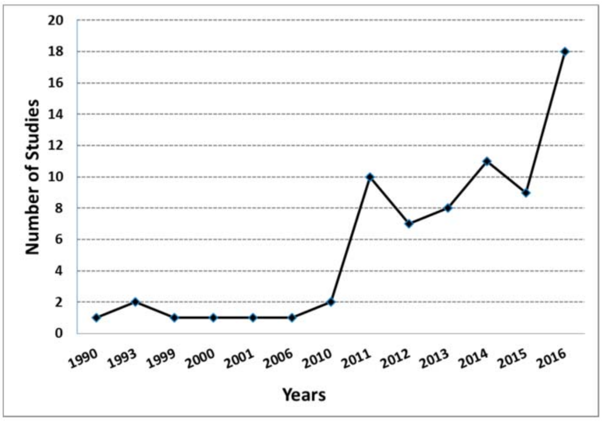

Figure 1. Demonstration of the growing interest of studying the impact of dust accumulation on the performance of PV [3].

II. Anti Soiling Solutions for PV Panels

Many publications related to soiling prevention, inspection and different way to clean PV panels was discussed. There are various passive methods of soiling mitigation and active methods including water-based cleaning techniques, semi-automated mechanized cleaning techniques, manual cleaning, Electro Dynamic Screen (EDS) solutions, Super Hydrophobic Plane (SHOP) and Super Hydrophilic Plane (SHIP). Each of these solutions has advantages as well as disadvantages which change with climate.

A. Electro Dynamic Screen (EDS)

The electrodynamic screen, which is generally placed on a photovoltaic panel, ensures an automatic and continuous removal of dry particles on the panel without using water or a mechanical system to clean. Indeed, this screen contains electrodes supplied with high voltage to generate electromagnetic fields that use an attraction force. Therefore, it helps to remove the charged and the uncharged particles. The electromagnetic fields move particles to the edges of the panel surface, and based on this method, many studies show that the EDS has an efficiency of 90 % [4]. The cleaning panels comparison in several studies has marked the same cleaning index between those cleaned with EDS, and reference panels [5]. A schematic of EDS is clearly presented on Fig. 2, It shows the different electrodes used for ensuring cleaning.

978-1-7281-1182-7/18/$31.00 ©2018 IEEE

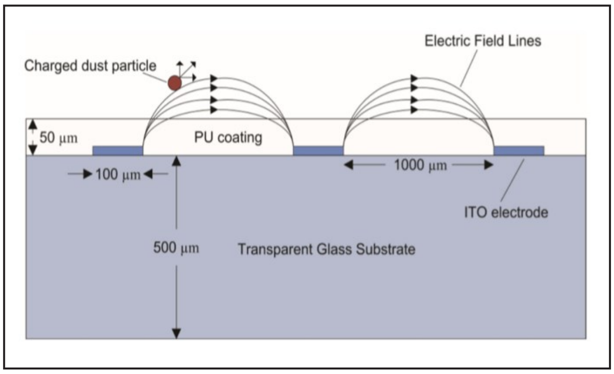

Figure 2. Schematic of Electrodynamic Screen

B. *Super-Hydrophobic Coating (SHOP)*

This anti-soiling coating is inspired by the lotus effect phenomenon, which attract recently the interest of the researchers. Super-hydrophobic surfaces have several properties like (anti-corrosion, anti-icing,...) [6] especially an essential roughness for the construction of SHOP coating [4], thanks to this property which consist on forming barriers against the spreading of the drop water which becomes spherical under the air effect between the barriers and then can carry dust particles as shown in the Fig. 3. Super-hydrophobic coatings are generally deposited by spraying, and formed thin layers of highly transparent silica nanoparticles, which are bonded to the substrate using a polymer binder. Many studies have shown that super-hydrophobic coatings have better durability and more uniform nanostructured surfaces [7].

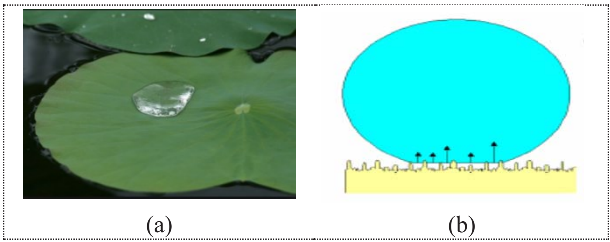

Figure 3. (a) Lotus leaf with hydrophobic properties. (b) Drops of water taking a spherical shape

C. *Super-Hydrophilic Coating (SHIP)*

The super-hydrophilic surface is generally composed of titanium dioxide or silicon dioxide, obtained by nano-patterning of the glass surface. This type of coating has more advantages than hydrophobic coatings due to its ability to decompose chemically dirt under the effect of UV light (the photo catalytic effect) which causes the formation of H_2O and CO_2 [4]. Several studies done on restoring the efficiency of TiO_2 and they have shown that is chemically stable, durable, non-toxic, economical and transparent to visible light [8]. Arabatzis related to UV stability, non-abrasive sand blasting conditions, light transmission, hydrophilicity and photo catalytic effect, investigated other properties. As results these studies have given good conclusions especially for hard climates [8] (figure 3).

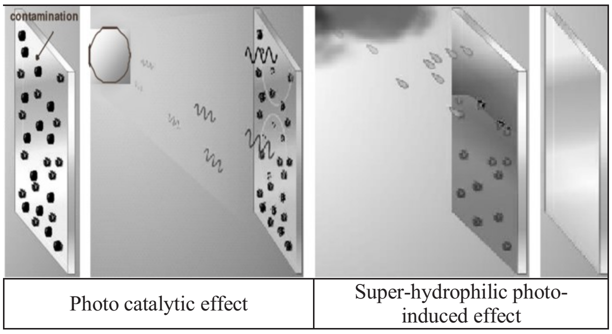

Figure 4. Self cleaning by photocatalytic effect

C. *Synthesis*

Each self-cleaning solution has its advantages and disadvantages, hence the necessity to compare their effectiveness in order to know the favorable climatic conditions for each solution and to develop their efficiency according to specific climatic conditions. The Table 1 presents a comparison between the three types of self-cleaning solutions.

Table 1. Comparison of self-cleaning methods

Anti-soiling solution	Benefits	Drawbacks
EDS	- Quick cleaning. - Less energy consumed. - Automated operation by sensors and controller.	- Degradation of the screen by the UV. - 15% decrease in output power. - Ineffective for wet dust. - Less effective for large particles. - Expensive.
SHIP	- Passive method, does not consume energy. - Breaks up dirt. - Less adhesive to dust. - More efficient than SHOP. - More sustainable (no polymer material).	- Accumulates more of dust after its deterioration.
SHOP	- Less energy consumed.	- Accumulation of dust for a long time. - Cleaning only with water.

III. Soils Distribution and Transmittance Study

The power output delivered from a photovoltaic module highly depends on the amount of irradiance [10], this factor is strongly affected by soils deposition on the solar glass. Therefore, the characterization of this deposition is essential to develop effective mitigation approaches. In this work a study of soils distribution and transmittance study has been recently started to investigate specially the layer bonded directly with the surface of the glass, which contains particles chemically bonded with a high adhesion force [9].

A. *Material and Methodology:*

In our RDI Solar Energy Platform located in ENS of Rabat [10], two samples of solar glass are exposed on tilt test bench following two different angles 0° and 45° during two months in order to compare their transmittance Tr (0°) and Tr (45°) with that of the cleaned sample.

Experimentally, after eighteen days of exposure of 2 samples manufactured by Durasolar P + characterized by low iron pattern ≤ 0.02 % Fe_2O_3 and a thickness of 4 mm, the transmittance Tr (%) for each sample was calculated from the irradiance received G (W/m^2) and the irradiance transmitted G_{moy} (W/m^2) on 6 different points by (1) and (2).

$$\mathrm{moy} = \frac{\sum_{i=1}^{6} G_i}{6} \quad (1)$$

$$T_r = \frac{G_{moy}}{G} \quad (2)$$

The irradiance was measured using a SPM72 Reference Solar-meter. This instrument is EMC compatible and has been tested in accordance with EN 61326 (1997) + A_1 (1998) + A_2 (2001).

This comparison guides us towards the correlation between the dust deposition process and the transmittance loss of solar glass.

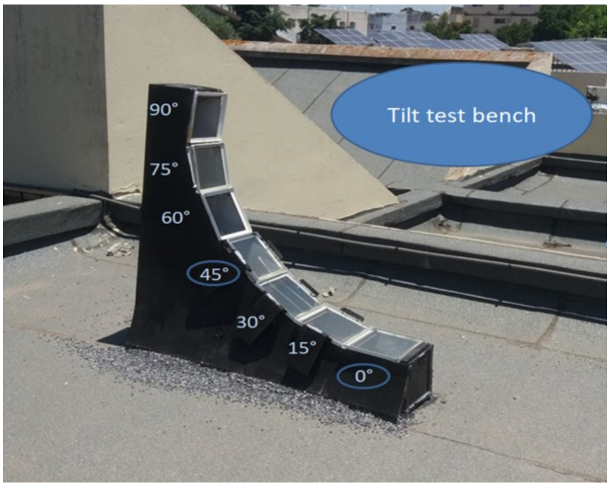

Figure 5. Tilt test bench for exposition of two samples

B. *Results and discussions*

The transmittance measurement has been started after eighteen days of exposure and it lasted two months. We noticed a significant difference in the distribution of the soiling layer, which is mainly affected by moisture and gravity. Consequently, the transmittance difference, which is influenced by the distribution of soils on solar glass surface is marked.

1. *Distribution*

In the Fig. 6, we visualize an important distribution difference between the two different tilt angles 0° and 45°, this later will affect the homogeneity of the soiling layer. The sample exposed at 45° is more homogeneous than the one of 0°. Many areas on the sample glass of 0° contain more soils while others are empty.

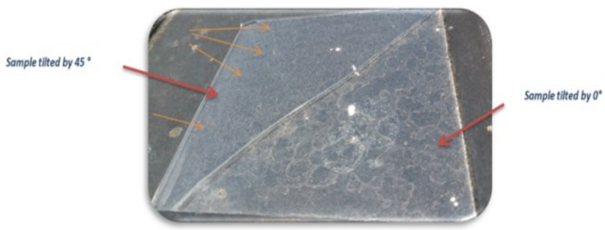

Figure 6. Soiling distribution on the two exposed samples

We explain this difference by the effect of gravity and humidity. For the sample of 45°, the water drops formed by the condensation of water particles under the effect of humidity, they transport dust thanks to the gravity and they leave thereafter traces of their path, which are indicated in the Fig. 6. For the sample of 0°, the water drops deposited by the moisture effect remain on the glass surface and then after drying, the drop circumference presents an obstacle for the soils transported by wind. Which favorite consequently its accumulation.

2. *Transmittance*

To compare the transmittance of the three samples it is essential to calculate the difference between each two pairs of samples. To do this, we compared the results between the sample glass exposed at 45° and the reference (cleaned sample). We present in Fig. 7 the trend of this difference, which presents a loss. Indeed, according to this figure, the trend of transmittance difference between the two samples is increasing. This explains the increase in transmittance loss of the 45° tilted sample due to soiling.

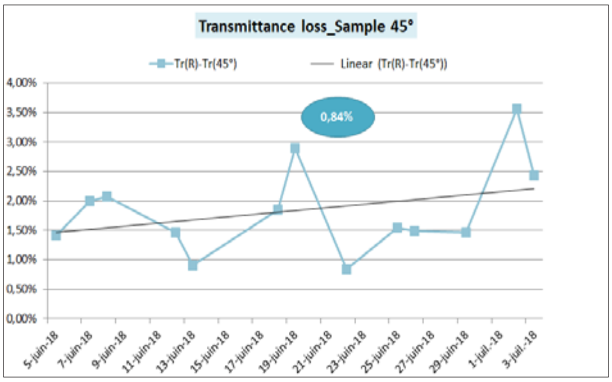

Figure 7. The trend of transmittance difference between samples (45° and reference)

Thereafter, the transmittance difference between sample glass exposed at 0° tilt and the reference was calculated, as shown in Fig. 8. The increase of the loss in transmittance is shown by trend line. This loss is greater than the loss presented in Fig. 7. We validate this remark by the graph presented in Fig. 9.

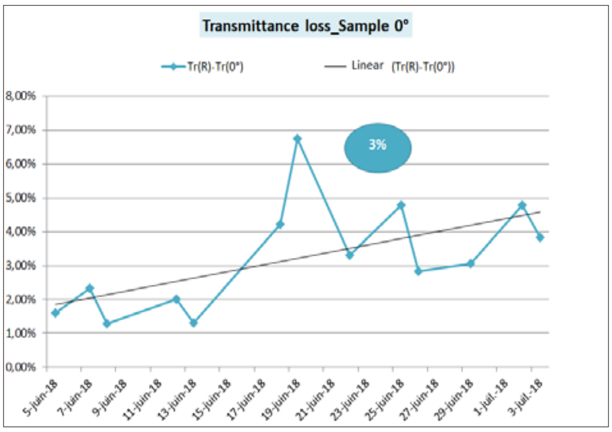

Figure 8. Transmittance difference between samples (0° and Reference)

This study showed a remarkable difference between Tr (0°) and Tr (45°) which reaches 2.25 % and still evolving as shown in Fig. 9. In the rest of this study, we continue taking measurements to show the evolution of soiling during a long period and we aim to visualize the difference between soils distribution of the two samples surface by image-processing visualization techniques,

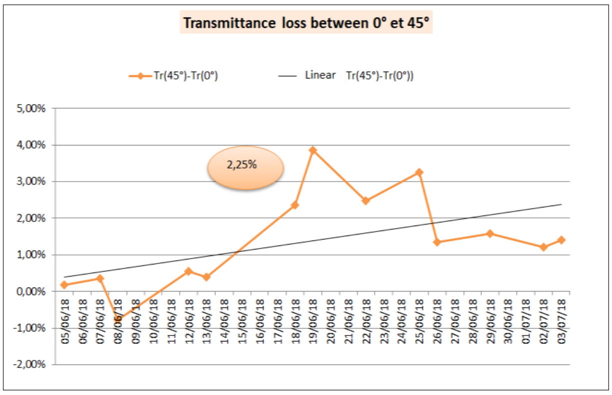

Figure 9. Transmittance difference for samples of 45° and 0°

For all particles that remain on the surface and those that leave by wind and gravity effect.

IV. CONCLUSION

Preventive solutions for self-cleaning against the soiling deposition and a comparison between these advantages and disadvantages were presented, which will be detailed at the end of this work. In order to lead well to several soiling rate mitigation techniques, it is essential to study soils deposition process and how it influences solar glass transmittance.

The experimental study of soiling on two samples of solar glass exposed at two different angles 45° and 0° is presented in this paper, the distribution of soiling on solar glass surface depends on several parameters as it was demonstrated in this study such as the moisture and the gravity. We noticed that the soiling layer is more homogeneous on the 45 ° sample. While the sample exposed at 0° contains more details, which are parts full of soiling and more disordered.

A transmittance study was presented in this work as well were we calculated the transmittance difference between each two samples. The evolution obtained had a trend explained by the decrease of the transmittance in rapid way for the sample exposed at 0° in a quick way.

ACKNOWLEDGMENTS

This work is co-financed by the Moroccan Institute for Research in Solar Energy and New Energies (IRESEN) in the framework of SOLEIL Inno-PV Project. It is also supported by the Moroccan MENFPESFC ministry and the CNRST in the framework of Priority Research Project PPR1 Nr. 14/2016. The authors are thanking all their institutional and industrial partners and collaborators for their valuable contributions.

REFERENCES

[1] K. Menoufi, "Dust Accumulation on the Surface of Photovoltaic Panels: Introducing the Photovoltaic Soiling Index (PVSI)", *Sustainability*, vol. 9, n° 6, p. 963, juin 2017.

[2] K. Kurokawa, K. Komoto, and P. V. D. Vleuten, "Energy from the Desert: Practical Proposals for Very Large Scale Photovoltaic Systems". *Earthscan*, p.252, 2007.

[3] W. J. Jamil, H. Abdul Rahman, S. Shaari, and Z. Salam, "Performance degradation of photovoltaic power system: Review on mitigation methods", *Renew. Sustain. Energy Rev.*, vol. 67, p. 876‑ 891, janv. 2017.

[4] D. Deb et N. L. Brahmbhatt, « Review of yield increase of solar panels through soiling prevention, and a proposed water-free automated cleaning solution », *Renew. Sustain. Energy Rev.*, vol. 82, p. 3306‑ 3313, févr. 2018.

[5] B. Guo, E. Y.-T. Chen, W. Javed, et B. Figgis, "Characterization of an Electrodynamic Dust Shield Device for PV Panel Soiling Mitigation", in ASME 2017 11th International Conference on Energy Sustainability, Charlotte, North Carolina, USA, 2017, p. V001T08A001.

[6] X. Zhao, B. Yu, et J. Zhang, "Transparent and durable superhydrophobic coatings for anti-bioadhesion", *J. Colloid Interface Sci.*, vol. 501, p. 222‑ 230, sept. 2017.

[7] G. Polizos *et al.*, "Transparent superhydrophobic surfaces using a spray coating process", *Sol. Energy Mater. Sol. Cells*, vol. 176, p. 405‑ 410, mars 2018.

[8] I. Arabatzis *et al.*, "Photocatalytic, self-cleaning, antireflective coating for photovoltaic panels: Characterization and monitoring in real conditions ", *Sol. Energy*, vol. 159, p. 251‑ 259, janv. 2018.

[9] G. W. Penney et E. H. Klingler, " Contact potentials and the adhesion of dust ", Trans. Am. Inst. Electr. Eng. Part Commun. Electron., vol. 81, n° 3, p. 200–204, 1962.

[10] A. Barhdadi, "Photovoltaic Technology Platform for Training, Research, Innovation and Electricity Production at Mohammed V University of Rabat", 01-juill-2016.