Study of the Correlation Between the Dust Density Accumulated on Photovoltaic Module's Surface and Their Performance Characteristics Degradation

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Abstract. One of the major constraints related to the operating conditions of photovoltaic systems in the Sahelian environment is relative to the deposits of dust on the surface of the PV modules. Indeed, the Sahel is characterized by frequent and permanent sandstorm that impact on its strong solar potential. However, opinions are still divided on the significant impact of dust on photovoltaic modules production. This paper deals with the correlation between the density of deposited dust on the surface of crystalline silicon photovoltaic modules and the impact on their performances. This study is carried out on two different modules a monocrystalline and a polycrystalline technology. It focuses on the open-circuit voltage (V_{OC}), the short-circuit current (I_{sc}), the fill factor (FF) and more particularly on the maximum power (P_{max}). This paper presents the methodology and the experimental study used to measure the environmental parameters (irradiation, temperature, and humidity), the density of deposited dust and the performance characteristics (I_{SC}, V_{OC}, FF and P_{max}). Finally, the results of the correlation between the density of deposited dust and the performance characteristics of PV modules are presented.

Keywords: Module photovoltaic · Degradation · Dust · Correlation

1 Introduction

Accumulation of dust on the surface of PV module can greatly affect their performance especially in desert areas. However, the desert regions are the most suitable for the production of photovoltaic electricity because of the abundant availability of solar radiation throughout the year. Currently, the idea of setting up large photovoltaic fields in the Sahelian countries with a view of exporting the energy produced to other countries is under discussion [1]. The accumulation of dust on the surface of the PV modules depends on various parameters such as the tilt angle, the type of installation, the humidity.

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Hottel and Woertz were among the first to work on the impact of dust on solar systems [2]. They recorded a maximum performance degradation of 4.7%, with an average incident solar radiation loss of less than 1%. Another study on the accumulation of dust on a photovoltaic system installed in a village near Riyadh showed a 32% reduction in performance after eight months of exposure without cleaning the modules [3]. A reduction of photovoltaic power of 17% on modules installed in Kuwait City was noted after six days without cleaning the modules [4]. In addition, the study also indicated that the influence of dust on PV performance would be higher during the dry seasons. Another study on the effects of dust on PV modules in Palo Alto, California, has shown 2% reduction in the short circuit current Compared to the initial I_{sc} of the module [5, 6]. Shaharin et al. have found that the power reduction due to the deposition of dust on the PV module can be up to 18% [7].

Loss of power due to dust depends on the type of dust; the time since the last rain and the cleaning schedule [8]. Detrick et al. Argue that the average annual power losses of a photovoltaic module ranges from 1% to 4% [9]. In areas where rainfall is frequent, it has been shown that rain can clean the PV modules at a performance restoration point of 1% loss on full power [10]. In a more recent study done in Crete, the average annual losses of power due to dust was 5.86%, with 4% to 5% during the winter and 6% to 7% in the summer [8]. A study was carried out on photovoltaic systems installed in Egypt comparing the energy produced by a clean module, a module that was exposed without being cleaned for a period of one year and a module that was exposed to dust but cleaned every two months. The results showed that the module which remained one year without being cleaned produces 35% less energy than the clean module. The one cleaned every two months produces 25% less compared to the clean module [11].

It would be interesting for photovoltaic system users, to know how often the module needs to be cleaned. If frequent cleaning cannot be done, it will be important to quantify the losses of performance due to dust to take this into account. The study of dust effects on PV modules would also be useful to determine the technology to use, the module types and the implementation. Establishing the correlation between the performance degradation and the density of deposited dust on PV modules allows answer the question concerning the recommended frequency of cleaning the modules.

2 Materials and Methods

2.1 Methodology

This study of the correlation between the density of deposited dust and the variation of the performance characteristics is performed using new solar modules, made by one manufacturer but with different technologies.

After being thoroughly cleaned, the two modules have been characterized before being exposed under natural sunlight within the same conditions (sunshine, temperature, humidity). The measurements are carried out weekly for a period of six weeks. Throughout the week, average environmental parameters such as wind speed, sunshine, ambient temperature and humidity are measured.

By the end of the week, the performance characteristics of the modules are measured under the standard testing conditions with the PV module analyzer (IV-400).

The density of deposited dust on each module is also determined by a method which we present in the following section.

Thus, the value of each parameter is determined, taking into account the reference values of the parameters measured on the clean module at the beginning of the experiment. This normalized value, which reflects the variation of the parameter, is correlated with the density of the deposited dust on each module. The summary of the different stages of the methodology adopted is presented in Fig. 1.

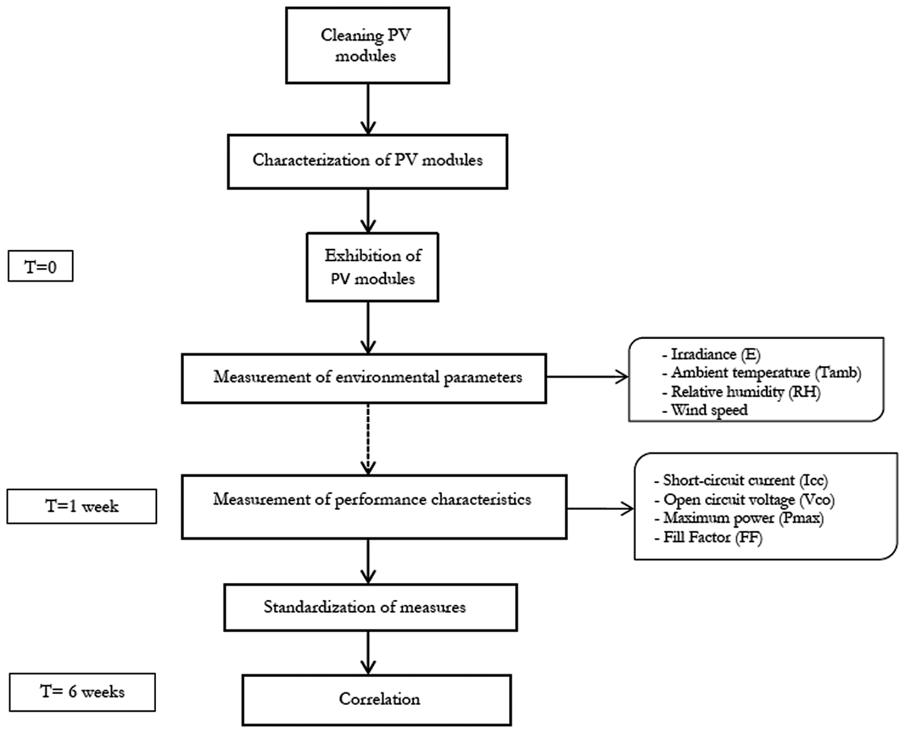

Fig. 1. The proposed methodology.

2.2 Dust Density Determination

Two different options are available to measure the density of the deposited dust on the PV modules. The first is by determining the cleaned module weight at the beginning of the experiment and that of the dusty module at the end of the experiment. The difference between these two measurements gives the amount of deposited dust on the surface of the module. The ratio between the weight of the dust on the surface and the module's area gives the density of the dust deposits [12]. However, this technique requires long-term exposure which would allow collecting a significant amount of measurable dust relative to the weight of the module.

We opted for the second method which consists in using two glass slats of 67 g exposed side by side of each module and with the same inclination as this one. The slats are identical with a surface of 10 cm^2 i.e. 10 cm × 10 cm. At the end of each week, the slats are weighed with a high precision balance. The weight of the deposited dust on the module is obtained by comparing the weight of the slat with dust and the weight of the clean slate. This gives the density of the deposited dust per square centimeter (cm^2).

2.3 Presentation of the Experimental Platform

The technical specifications of the two modules used in this study are given in Table 1. The use of monocrystalline and polycrystalline modules also makes it possible to study the correlation according to the technology.

Table 1. Technical specifications of the modules.

Modules	Technology	Manufacturers	References	Parameters	Values
1	Monocrystalline	TENESOL	TE55-36P	P_{max} (W)	55
				V_{max} (V)	17,79
				I_{max} (A)	3,1
				V_{co} (V)	22
				I_{cc} (A)	3,3
				FF (%)	75
2	Polycrystalline	LORENTZ	LTZ50E	P_{max} (W)	50
				V_{max} (V)	17,1
				I_{max} (A)	2,9
				V_{co} (V)	21,7
				I_{cc} (A)	3,2
				FF (%)	72

The characteristics of the high precision Kern balance used to obtain the dust density are also given in Table 2. This balance has a lid to prevent losses during the quantification of the dust collected with the lamellae.

Table 2. Characteristics of the balance used for the weighing of dust deposits.

Manufacturer	Reference	Range	Precision	Resolution	Specificity
Kern	Kern ABS/ABJ	1 mg–220 g	1 mg	0, 1 mg	Automatic taring

Figure 2 shows the experimental platform including the two modules and the lamellae exposed for dust collection.

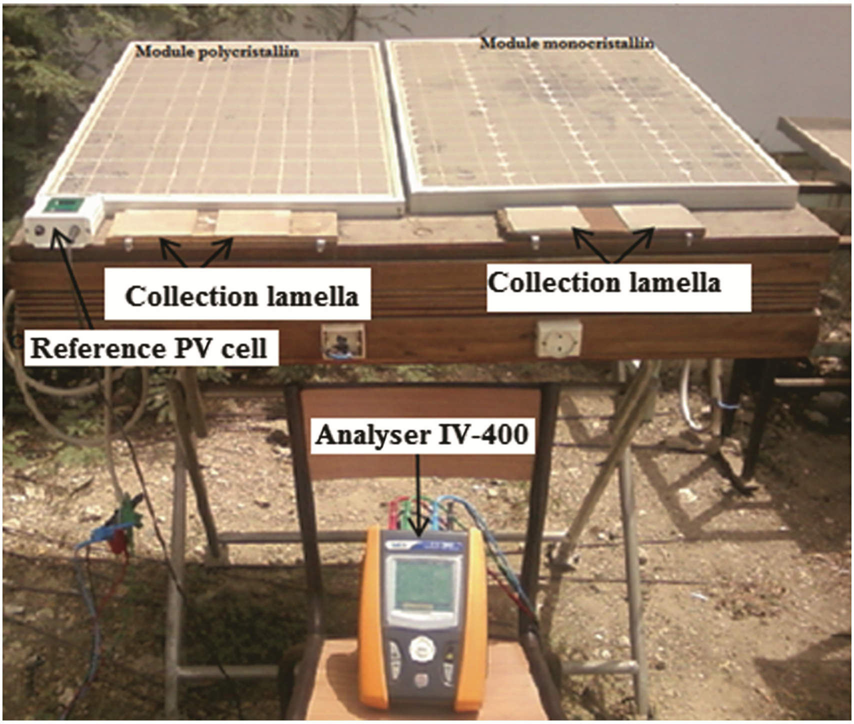

Fig. 2. Experimental platform.

Each module is associated with two glass slides for dust collection. A reference cell is installed on the platform to measure the overall incident solar radiation at the surface of the modules. The PV module analyzer "IV-400" is used to measure the performance characteristics of the modules.

2.4 Environmental Parameters During the Experimental Period

The experiment conducted to study the correlation between the dust density and the performance characteristics of the poly and monocrystalline modules lasted six weeks.

The main environmental parameters measured during this period are presented in Table 3.

For such a study, it is necessary to determine the environmental parameters during the experiment time to analyze and give the interpretation of the correlation results.

Table 3. Characteristic parameters of the six measurement weeks

No. week	Wind speed ($m.s^{-1}$)			Ambient temperature (°C)			Relative humidity (%)			Irradiation ($W.m^{-2}$)	
	moy	max	min	moy	max	min	moy	max	min	moy	Max
1	1,2	4,7	0,2	25,19	37,7	20	73,8	98,9	24,3	632	710
2	1,58	4,9	0,02	26,89	36,1	22,3	70,3	91,4	27,2	710	721
3	1,98	5,3	0,02	27,3	34	23,5	70,8	90	39,8	702	735
4	2,13	5,2	0,1	28	35	24	73	91	35	812	820
5	1,8	4,8	0,3	27	34	23	68	87	40	708	790
6	1,6	4,9	0,02	23	34	27	72	90	39	835	937

3 Results and Discussions

3.1 Evaluation of Dust Density

The amount of dust deposited on each slide is determined at the end of each week. The quantity of dust on each module is given by the mean of the deposits on the two lamellas of ten square centimeters (10 cm^2) associated with it.

We assume that the distribution of dust on the surface of the module is homogeneous.

The following figure (Fig. 3) shows the evolution of the dust density at the surface during the period for each module.

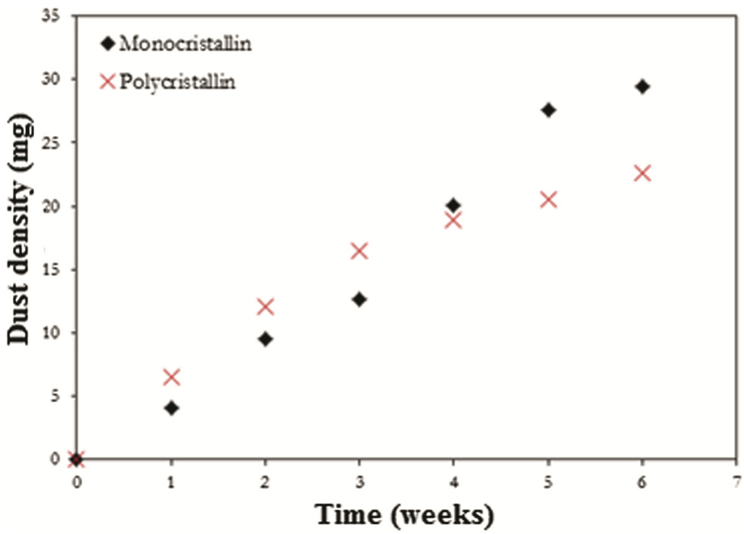

Fig. 3. Variation of the dust density for six weeks.

The accumulation of dust at the surface of the modules induces the increase of its density over time. The evolution of this density is highly dependent on environmental parameters such as wind speed, ambient temperature and humidity.

Correlation between the dust density and the variation of the photovoltaic modules characteristics is studied in the following paragraphs.

3.2 Variation of Performance Characteristics with Dust Density

To study the performance characteristics variation as a function of the dust density, standardized values should be considered. For each parameter, the value measured for the clean module before starting the experiment is taken as a reference in the normalization. The normalized value is given by the ratio between the value relative to the module with a deposit of dust and the one relative to the clean module.

All measurements are recorded under the standard testing conditions using the analyzer.

The standardized variations of the different performance characteristics for the two technologies are presented in the following figures (Figs. 4, 5, 6 and 7).

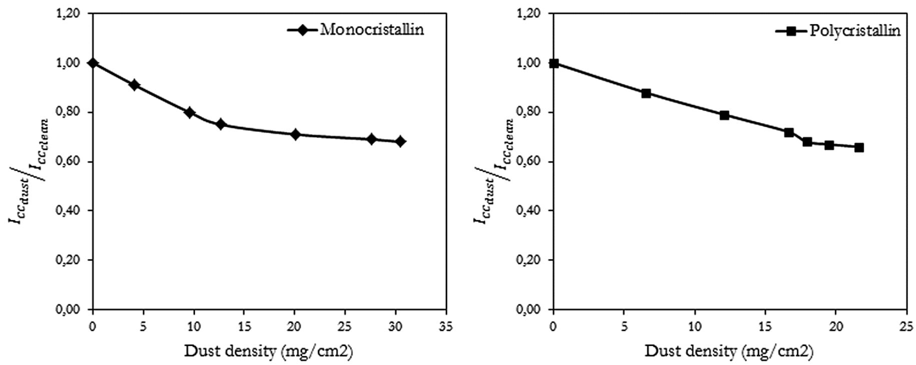

Fig. 4. Variation of the normalized short-circuit current as a function of the dust density.

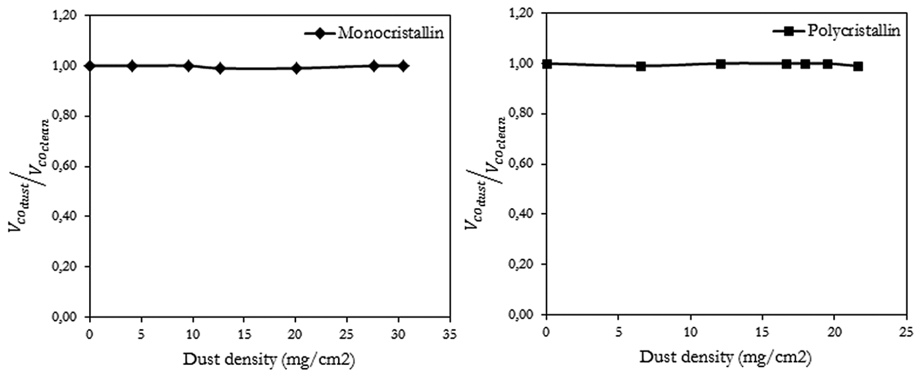

Fig. 5. Variation of the open circuit voltage normalized to the density of dust.

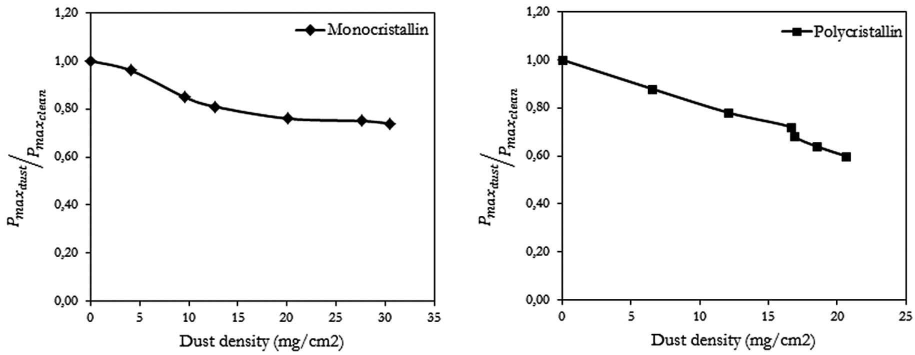

Fig. 6. Variation normalized power as a function of the dust density.

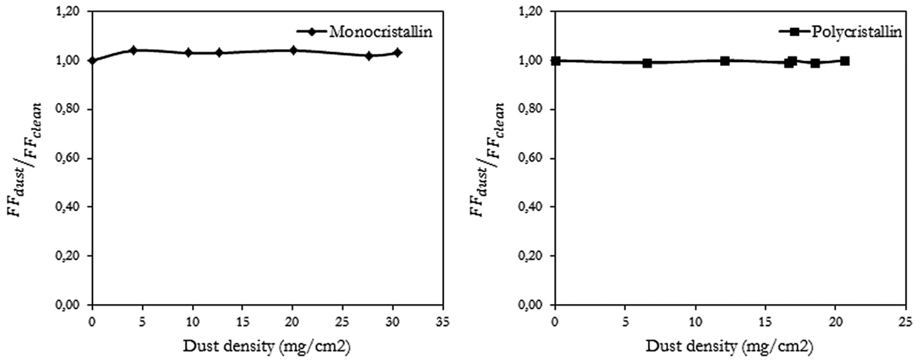

Fig. 7. Variation of standardized fill factor as a function of dust density.

It is noticed that the standardized values of the short-circuit current and the power decrease with the dust density increase for both technologies. This decrease reflects the influence of the dust on the efficiency of photovoltaic modules. We note that this decline progresses quite rapidly, in six weeks of exposure without cleaning the modules:

– The short-circuit current has decreased by 30% for the monocrystalline and 34% for the polycrystalline compared to the clean modules values for a dust density of 30.5 mg/cm^2 and 21.6 mg/cm^2, respectively.
– The maximum power decrease is about 26% for the monocrystalline and 40% for the polycrystalline compared to the clean module characteristics for the same densities of dust.

The open circuit voltage and the fill factor remain constant despite the increase of dust density for both technologies.

This result relative to the open circuit voltage is in phase with those of [10, 13] according to which this is not affected by the accumulation of dust.

We shall hereafter study the link between these variations and the density of deposited dust.

3.3 Correlation Between the Deposited Dust Density and the Modules Characteristics Degradation

We have studied the most appropriate correlations between the modules performance characteristics variation and the density of dust. The Correlation was carried out for all parameters by exponential and polynomial regressions.

Figures 8, 9, 10 and 11 show the different correlations for each characteristic and technology.

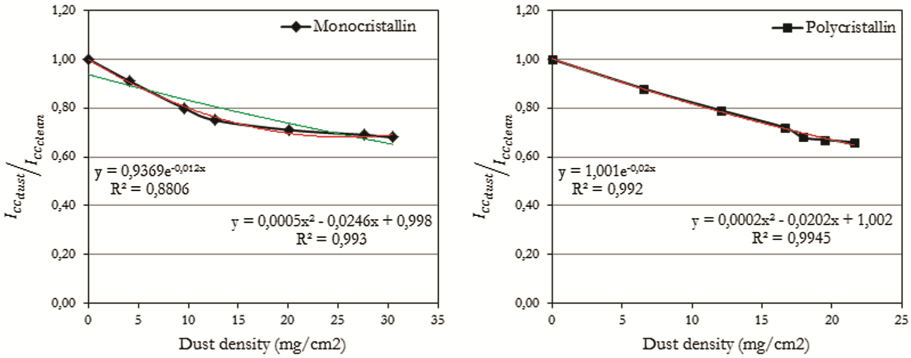

Fig. 8. Correlation between standardized short-circuit current and dust density by exponential and polynomial regressions.

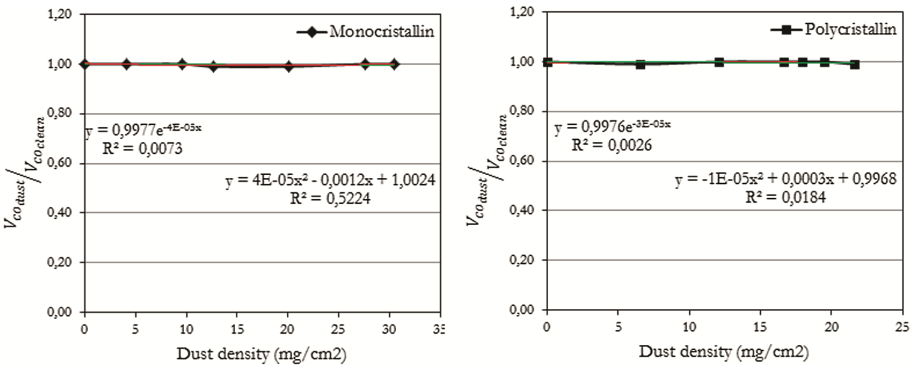

Fig. 9. Correlation between standardized open circuit voltage and dust density by exponential and polynomial regressions.

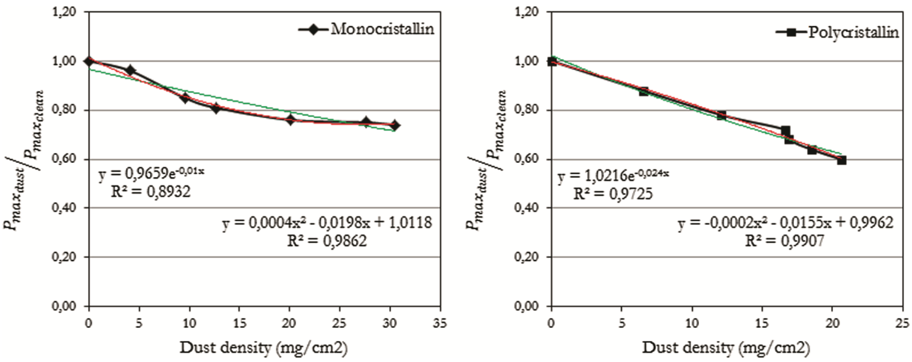

Fig. 10. Correlation between standardized power and dust density by exponential and polynomial regressions.

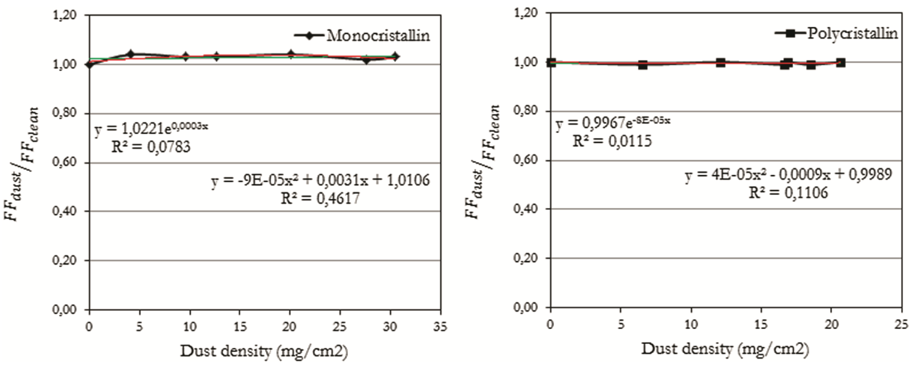

Fig. 11. Correlation between standardized fill factor and dust density by exponential and polynomial regressions.

The objective is to determine the best regression scenario that elucidates more the relationship between the parameter in question and the dust density.

The previous graphs (Figs. 8, 9, 10 and 11) highlight the regression curve, its equation and the determination coefficient for each characteristic related to the two technologies. Table 4 summarizes the main findings of this study.

Table 4. Determination coefficient of exponential and polynomial regressions.

Regressions	Determination coefficient (R^2)							
	Monocrystalline				Polycrystalline			
	$\frac{I_{cc_{dust}}}{I_{cc_{clean}}}$	$\frac{V_{co_{dust}}}{V_{co_{clean}}}$	$\frac{P_{\max_{dust}}}{P_{\max_{clean}}}$	$\frac{FF_{dust}}{FF_{clean}}$	$\frac{I_{cc_{dust}}}{I_{cc_{clean}}}$	$\frac{V_{co_{dust}}}{V_{co_{clean}}}$	$\frac{P_{\max_{dust}}}{P_{\max_{clean}}}$	$\frac{FF_{dust}}{FF_{clean}}$
Exponential	0,880	0,007	0,893	0,078	0,992	0,002	0,972	0,011
Polynomial	0,993	0,522	0,986	0,461	0,995	0,018	0,990	0,110

This experiment allows to propose a relation between the characteristics' variation and the density of dust.

The short-circuit current and the power which are the more sensitive characteristics to the deposition of dust have a determination coefficients very close to one with the polynomial regression as shown in Table 4.

The open circuit voltage and the fill factor have low correlation coefficients for both regressions.

However, the previous study [11] on the impact of dust, with a PV module exposed during one year without being cleaned, showed that the fill factor could be degraded to a maximum of 18% Module. Thus, we may think that six weeks of exposure are too short to detect a change in the fill factor.

4 Conclusion

This paper deals with the experimental study of the correlation between the variation of the performance characteristics of photovoltaic modules and the density of dust. It proposes a method for dust density determination assuming that the distribution of dust on the module's surface is homogeneous.

The correlation establishment showed that the variation of the short-circuit current and the maximum power as a function of the dust density follows a polynomial regression law with a very good coefficient of determination (0.99%) for the Two technologies.

The study carried out in this paper is contribution for PV modules cleaning frequency determination in the study area.

References

1. EPIA: European Photovoltaic Industry Association: Global Market Outlook for Photovoltaics until 2015 (2011)
2. Hottel, M.C., Woertz, B.B.: Performance of flat plate solar heat collectors. ASME Trans. **64**, 91–104 (1942)
3. Salim, A., Huraib, F., Eugenio, N.: PV power-study of system options and optimization. In: Proceedings of the 8th European PV Solar Energy Conference, Florence, Italy (1988)
4. Wakim, F.: Introduction of PV power generation to Kuwait. Kuwait Institute for Scientific Researchers, Kuwait City (1981)
5. Kaldellis, J.K., Kapsali, M.: Simulating the dust effect on the energy performance of photovoltaic generators based on experimental measurements. Energy **36**(8), 5154–5161 (2011)
6. Katz, G.B.: Effect of Dust on Solar Panels (2011). www.gregorybkatz.com/Home/effect-of-dust-on-solar-panels
7. Shaharin, S.A., Haizatul, H.H., Leh, N.S.H.N., Razali, M.S.: Effects of dust on the performance of PV panels. World Acad. Sci. Eng. Technol. **58**, 588–593 (2011)
8. Kymakis, E., Kalykakis, S., Papazoglou, T.M.: Performance analysis of a grid connected photovoltaic park on the Island of Crete. Energy Convers. Manag. **50**(3), 433–438 (2009)
9. Detrick, A., Kimber, A., Mitchell, L.: Performance evaluation standards for photovoltaic modules and systems. In: Proceedings of the 31st IEEE Photovoltaics Specialists Conference, Lake Buena Vista, USA, January 2005, pp. 1581–1586 (2005). ISBN 0-7803-8707-4

10. Ndiaye, A., Kébé, C.M., Ndiaye, P.A., Charki, A., Kobi, A., Sambou, V.: Impact of dust on the PV modules characteristics after an exposition year in Sahelian environment: the case of Senegal. Int. J. Phys. Sci. **8**(21), 1166–1173 (2013). Academic Journals
11. Ibrahim, M., Zinsser, B., El-Sherif, H., Hamouda, E., Makrides, G., Georghiou, G.E., Schubert, M., Werner, J.H.: Advanced photovoltaic test park in Egypt for investigating the performance of different module and cell technologies. In: Proceedings of the 24th Symposium Photovoltaic Solar Energy, Staffelstien, Germany, March 2009
12. El-Shobokshy, M.S., Hussein, F.M.: Effect of dust with different physical properties on the performance of photovoltaic cells. Sol. Energy **51**(6), 505–511 (1993)
13. Ndiaye, A., Kébé, C.M.F., Charki, A., Ndiaye, P.A., Sambou, V., Kobi, A.: Degradation evaluation of crystalline-silicon photovoltaic modules after a few operation years in a tropical environment. Sol. Energy **103**, 70–77 (2014). Elsevier ScienceDirect