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Effect of dust on the performance characteristics of different modules technologies

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ABSTRACT: In this article, we have studied the variation of the electrical performance characteristics of photovoltaic modules under the effect of dust. We have installed four modules of different technologies on the CERER site (Centre for Study and Research on Renewable Energies) for a year without being cleaned and each month we note their characteristics. The four technologies used are mono crystalline, polycrystalline, amorphous and thin film CdTe.
The results showed that dust has more impact on thin film technology with a degradation of 68% of its power and less impact on amorphous which experienced a 29% loss in power.

KEYWORDS: Dust, electric, photovoltaic module, mono crystalline, polycrystalline, amorphous, thin, film, CdTe.

1 INTRODUCTION

Nowadays, energy-related aspects become extremely important. They concern, for example, the environmental impact linked to the emission of pollutants and the consumption of non-renewable resources. For these reasons, there is growing global interest in sustainable energy production. Among the technologies that could play a role in the production of sustainable and sustained energy, interesting solutions are represented by photovoltaic (PV) cells, wind turbines, biomass power plants and fuel cells. In particular, photovoltaic systems can be considered as one of the most widespread solutions with significant improvement margins while ensuring the production of energy with low environmental impact [1], [2], [3].

The solar photovoltaic (PV) system uses solar cells to convert energy from solar radiation into electricity.

A photovoltaic module has angular losses related to its nominal behavior. There are several factors: direct radiation, diffuse radiation, angle of incidence of the radiation, geographical location and dirt (dust). This last factor has a variable influence on the PV module (depending on whether it is moderate or high) and can greatly affect its performance, especially in desert areas [4], [5]. Such installation areas have the disadvantage of accelerating the phenomena of fouling by sand and dust [6], [7].

The accumulation of dust on the surface of a PV module varies from place to place and depends on environmental conditions such as solar irradiation, temperature, ambient speed, humidity, precipitation and wind [8]. Therefore, the degradation of PV module parameters caused by dust is not uniform for each region of the world [9].

Several studies have been conducted on the impact of dust around the world, albeit in different contexts, environments and time frames.

Studies by Nimmo and Seid [10] indicate that a dust layer of 4mm (thickness) per square meter decreases solar energy conversion by 40% over six months. Deposit rates are even higher in the Middle East, Australia and India. Hottel and Woertz [11] were among the pioneers in the investigation of the impact of dust on photovoltaic systems. The parameters of the modules reduce rapidly with the accumulation of dust on the surface of the photovoltaic panels.

However, there are blocking factors such as dust deposits on the modules which could deteriorate their components, consequently inducing a drop in performance of photovoltaic installations. Thus, an experimental platform has been set up which allows us to measure the performance characteristics of the modules in dust deposit. Solar panels of four different technologies were tested: solar cell modules based on cadmium tellurium (CdTe), monocrystalline silicon, amorphous silicon and polycrystalline silicon. These panels were exposed to the open air for a period of twelve months without being cleaned. The electrical performances of the modules such as the maximum power (Pmax), the short-circuit current (Icc) and the open-circuit voltage (Voc) obtained after each measurement were compared with those of initial in order to calculate their rates of degradation.

The problem posed in this work is then to have a better understanding of the functioning of the modules on a field of experimentation and to study the parameters which govern their functioning. Better control of these parameters made it possible to properly design their installation in order to meet demand and also to achieve energy efficiency which would be an asset for sustainable development.

2 Presentation Of The Experimental Power Plant

2.1 The Test Modules

The experimental platform is installed at CERER (Center for Studies and Research on Renewable Energies) from April 20, 2016 to April 20, 2017.

It consists of the following components:

- 01 monocrystalline module (FST-240);
- 01 polycrystalline module (ND-E230A2);
- 01 amorphous module (NA-901WQ);
- 01 Cadmium Tellurium CdTe thin film module;
- 01 DSS (ESL-Solar data acquisition system)

All the tested modules are in new condition, of different technology and manufacturer, and are mounted on supports oriented with respect to the latitude of the location. After having characterized them; the modules are exposed to the open air on the experimental site without being cleaned for a period of twelve months (one year) and connected to the Data Acquisition System (DSS). Thus, each month, the data of the I-V and P-V characteristics and the electrical characteristics of each module in the STCs are recorded and presented by the SAD throughout the experimental session.

The following table presents the technical sheet given by the manufacturer, of the different PV modules that make up our platform.

Table 1. Electrical characteristics of PV modules exposed at the measurement site

	Photovoltaïcs modules			
Characteristics	**FST-240**	**ND-E230A2**	**NA-901WQ**	**CX3-67**
I_{cc} (mA)	8,46A	8,6A	2,11A	1,79
V_{oc} (V)	37,3V	37,2V	65,2V	60,9
P_{max} (W)	240W	235W	90W	67,5
Temperature coefficient of I_{cc} (% /°C)	0,060	0,053	0,070	0,02
Temperature coefficient of V_{oc} (%/°C)	- 0,350	- 0,360	- 0,300	-0, 24
Temperature coefficient of P_{mp} (%/°C)	- 0,450	- 0,485	- 0,240	-0,25

The experiment took place in the CERER site in real and natural operation.

In this study, we have neither specified the type of dust considered nor studied their size.

The modules are exposed to the open air under the conditions described above and we will record their characteristics in time steps of one month.

As shown in the photo, the environment is surrounded by trees on either side. Our experimental site is located near a football field, and next to a mechanical manufacturing workshop; on a sandy and dusty driveway, where the passage of vehicles is too frequent, which are factors that can favor the dusting of the place.

Fig. 1. Test modules bed

2.2 THE DATA ACQUISITION SYSTEM

The ESL-Solar 5000 electronic load has been specially developed to test crystalline modules and thin layers or chains of modules up to 5kW. All essential electrical load tests can be performed with ESL-Solar. All necessary accessories; the computer, the cable and the sensor are placed inside the portable box. ESL-Solar is useful for the installation of a solar power station, the maintenance service of measurement and control of individual solar modules [12].

Fig. 2. Data Acquisition System

The data acquired by the MMP Track or Scan can be read on the interfaces. Voltage, current and power are visualized on the laptop screen. In order to obtain an exact power curve, voltage and current are measured simultaneously.

Its technical specifications are given in the following table (2).

Table 2. Characteristics given by the manufacturer of the DSS

Reference	Maximum Rating	Values
ESL-Solar 5000	Measurement Light Intensity	0 to1200W/m^2
	Measurement temperature	-20°C to+80°C
	Power (max3s)	5000 W
	Input voltage	0 to 800 V DC
	Current	0 to 20 A DC

Charging can be performed via E-Solar software on the built-in laptop. With the E-Solar software, the I-V (Current-Voltage) curves can be digitized, the module parameter data will be used to bring the estimated values back to the standard test conditions (STC).

This system not only makes it possible to acquire the measurements in real time, to display them on the computer screen but also to record them in order to constitute a database for subsequent processing.

3 Results

3.1 Degradation Of Performance Characteristics Due To Dust

The readings of the I-V characteristics of the various photovoltaic modules tested were carried out during the twelve months of the year from April 2016 to April 2017. Four parameters are measured and recorded during the reading of the I-V characteristic of each module by our DSS: (1) module voltage, (2) module current, (3) solar irradiance received at the module surface, and (4) ambient temperature.

Figures 3, 4 and 5 give us the variations of the electrical characteristics of the power, of the short-circuit current and of the open-circuit voltage of the various test modules which remained twelve months without cleaning.

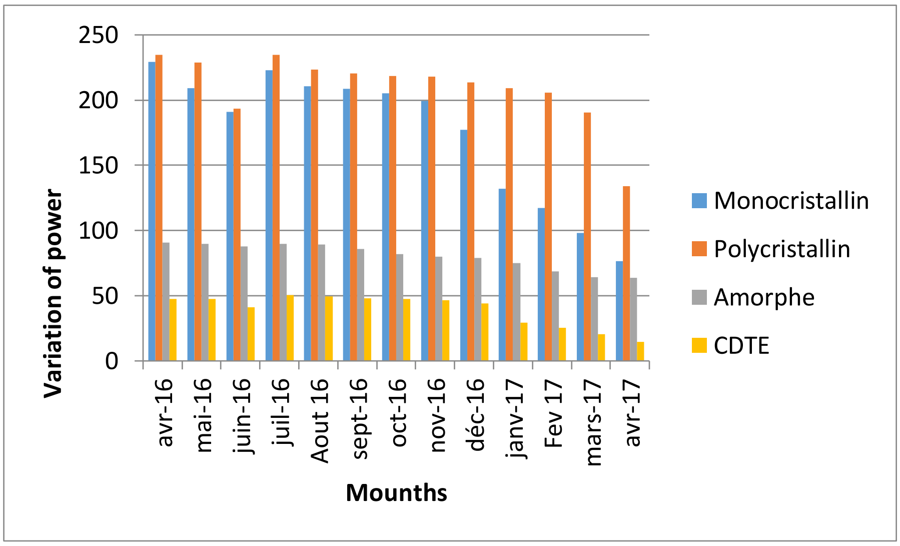

Fig. 3. Variation of the maximum power of the test modules

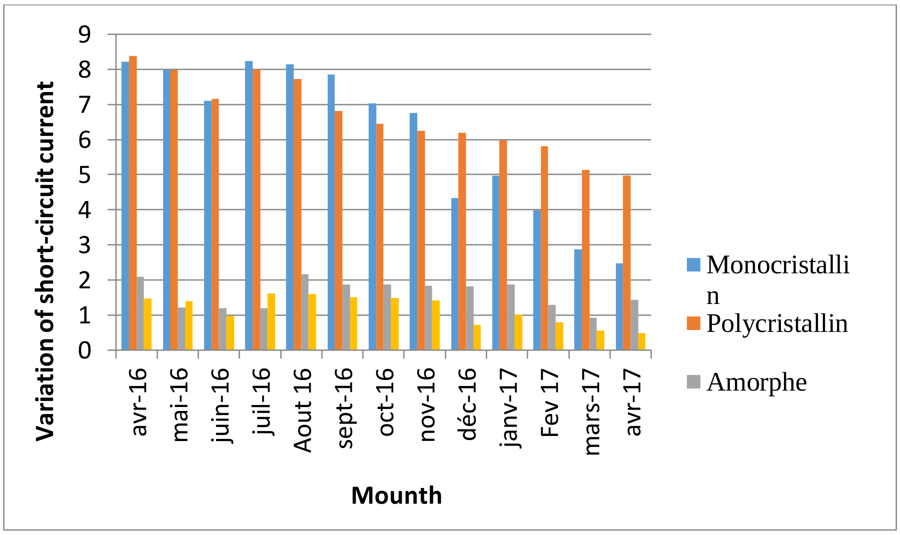

Fig. 4. Variation of the short circuit current of the test modules

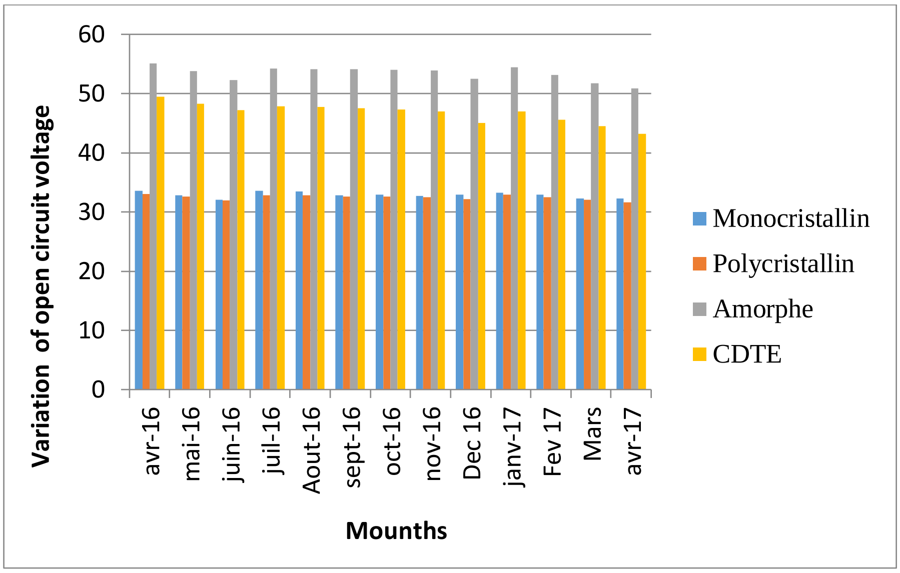

Fig. 5. Variation of the open circuit voltage of the test modules

Over a period of twelve months without cleaning, variations in the performance characteristics of the modules are recorded at monthly intervals under standard test conditions using our data acquisition system.

A color code is provided to distinguish the different technologies used.

The analysis of these figures shows the degradation of the electrical characteristics of the modules under the accumulation of dust over time except for the months July, August and September which coincide with the rainy season where we observe that an improvement in performance rather than a degradation. During this period, the PV modules benefit from self-cleaning by rain.

3.2 Variation In The Rate Of Degradation Of The Electrical Characteristics Of The Modules Under The Effect Of Dust

In order to quantify the RD degradation rate of the short-circuit current, the open-circuit voltage and the maximum power of the various technologies exposed for twelve months in the experimental field without being cleaned; the standardized values measured are compared with the reference values provided by the manufacturer of the PV module. The percentage difference represents the reduction in the parameter. The parameter degradation rate is given by equation (1) [13], [14], [15], [8].

$$R_D (Z) (\%) = \left(\frac{Z0-Z}{Z0}\right) \times 100 \quad (1)$$

With:

Z0: the electrical parameter of the module in the initial state

Z: the electrical parameter of the module in the current state

The table below gives us a summary of this quantity for each technology.

Table 3. Degradation rate of electrical parameters of PV modules

Technologies	Monocristallin	Poly cristallin	Amorphe	CdTe
Overall degradation rate of electrical characteristics R_D (%)	P_{max} = 66 % I_{CC} =69 % V_{OC} = 3.86 %	P_{max} =43 % I_{CC} = 40 % V_{OC} = 4.19 %	P_{max} =29.63% I_{CC} =32 % V_{OC} = 9 %	P_{max} = 68 % I_{CC} = 67 % V_{OC} = 12.68 %

The table above summarizes the degradation rates of the electrical characteristics obtained for the various modules. It is clear that the effect of the dust reduced the performance of the modules and this contributed to the degradation of the latter.

The following section presents and discusses the most significant degradations detected for the four technologies, as well as the evolutions of the electrical parameters ISC, VOC, Pmax which allow a better understanding of the concept of degradation after a long exposure of twelve months on the site of experimentation without being cleaned.

This degradation of the electrical performance of Pmax, Isc and Voc over time is illustrated by figures 6, 7 and 8.

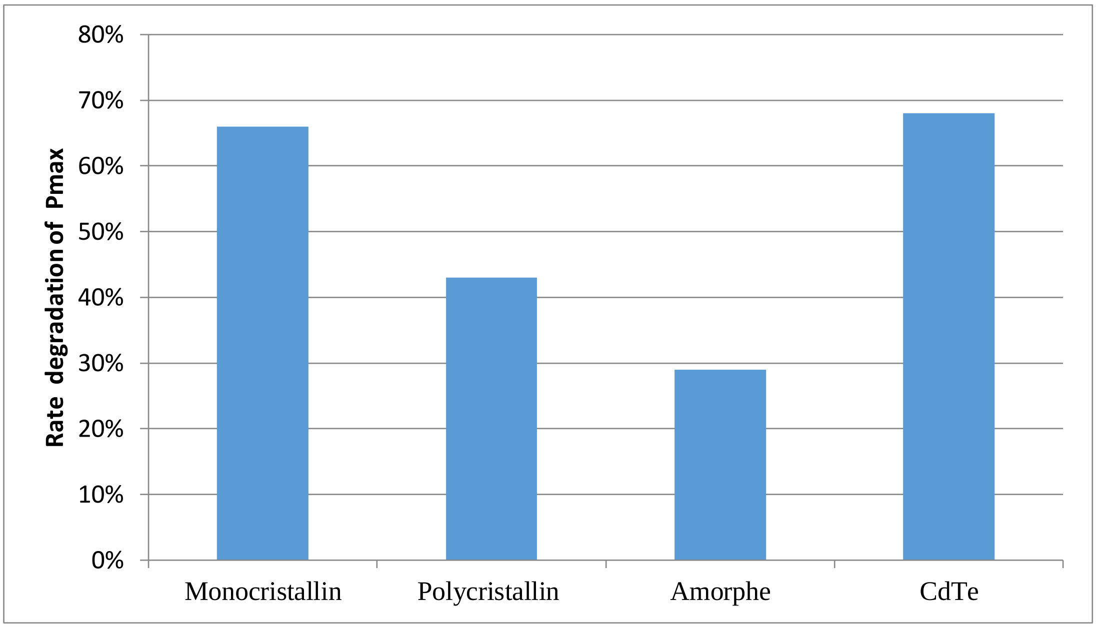

Fig. 6. Variation in the rate of degradation of the maximum power of the modules left one year without cleaning

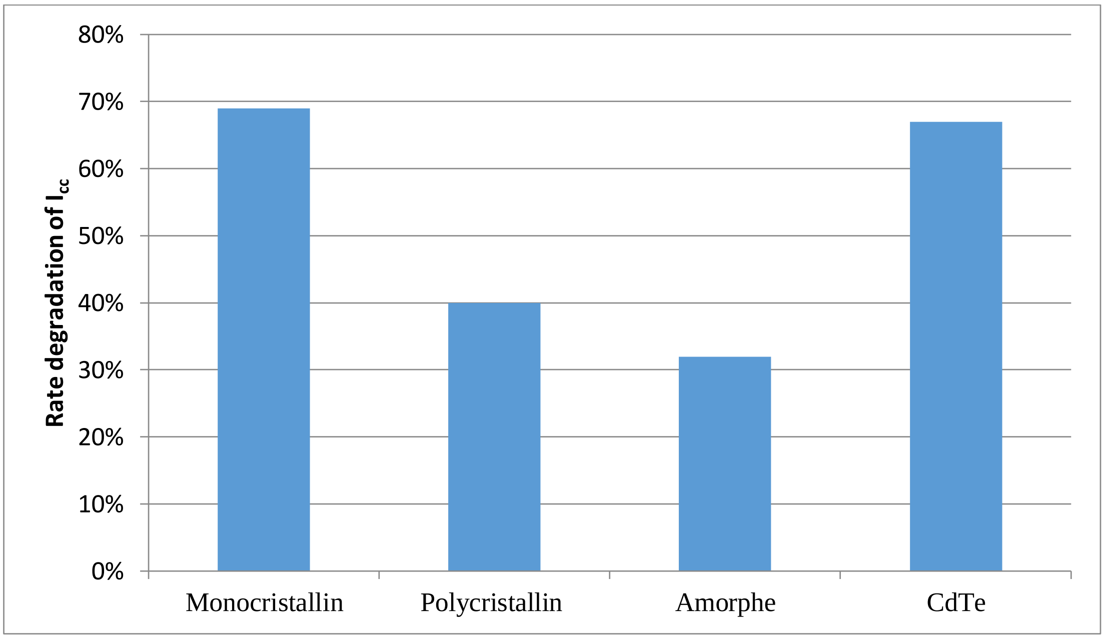

Fig. 7. Variation in the degradation rate of the short-circuit current of the modules that have remained one year without cleaning

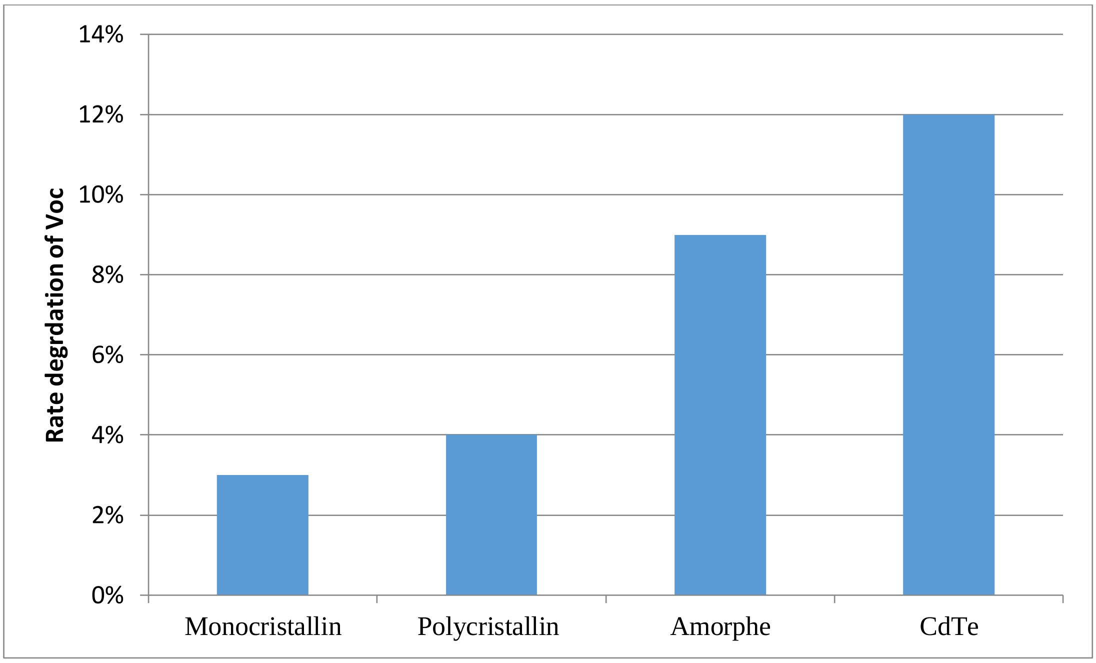

Fig. 8. Variation in the open-circuit voltage degradation rate of modules that have remained one year without cleaning

4 Analysis Of Results And Interpretation

The figures above summarize histograms of the degradation rates of the electrical characteristics of the monocrystalline, polycrystalline, amorphous and CdTe module exposed over a year without being cleaned on the CERER experimental site. This compilation of degradation rates results from the work carried out during this study.

The performance of the modules was monitored monthly. I-V characteristics were performed when irradiance levels were above 800W/m2. The measurements were corrected for temperature at 25°C, using measured temperature coefficients of the modules, and normalized to an irradiance of 1000W/m2.

By analyzing the values contained in table 3, it can be seen that the accumulation of dust for twelve months on the surface of the PV modules leads to a degradation of the electrical performance characteristics, in particular for Pmax, ISC, VOC. However, we see that this degradation depends on the technology used. There is a degradation of Pmax, ISC, VOC, with respectively 66%, 69% 3.86% for monocrystalline technology, 43%, 40%, 4.19% for polycrystalline technology, 29.63%, 32%, 9% for amorphous technology and 68%, 67%, 12.68% for CdTe thin film technology; which causes the histograms to drop.

A small degradation of the short-circuit current is observed while the open-circuit voltage shows no significant variation. The most observed major degradation after the accumulation of dust on the surface of exposed PV modules is that of the maximum power. The level of degradation depends on the technology of the PV module.

Of all the technologies least affected by soiling is amorphous silicon with a degradation rate of 29% of its maximum power; on the other hand, the highest degradation felt on the four modules is the CdTe thin film technology with a drop of 68% in its power.

This finding can partly be explained by the fact that the amorphous silicon module, due to its better performance in low light conditions, showed much smaller degradation rates than the crystalline and thin-film silicon modules.

These histograms are remarkably similar to the degradation rate distribution reported by Alain Tossa in his studies carried out in Burkina Faso on crystalline and thin-film modules exposed at their site for one year without cleaning. The study revealed however, that the micromorph technology is more affected to dust with a degradation rate of 65% [16].

Similar results were found by Raghuraman et al. who studied mono-Si, multi-Si and a-Si module technologies from eight different manufacturers. Amorphous Si modules showed better performance dispersion [17].

Osterwald et al. reported a direct module-to-module comparison for different technologies in the same climate for 17 different modules [18]. Most mono-Si modules showed degradation rates below 1%/year, while thin-film technologies showed degradation rates above 1%/year.

Variations in the electrical characteristics of the modules can be influenced by other parameters such as temperature and UV radiation. Indeed, these parameters vary according to the climatic conditions such as the season, the weather, the place, etc. Added to this is the type of dust that settles on the surface of the modules and their technology.

Jordan et al. compared more than 44 modules of different technologies side by side [19]. Technology and date of installation were found to be the most important factors determining degradation rates

In practice, the performance of the modules decreases from month to month depending on the accumulation of dust. Thus, the dust accumulated on the surface of the modules has a negative effect on their production. The decrease in power that occurs is due to a decrease in the nominal current intensity.

Indeed, the dust induces a generally non-uniform shading on the surface of the PV modules, thus the chains of the photovoltaic cells no longer receive the same intensity of sunshine. However, this drop in power and short-circuit current is explained by the fact that the modules do not receive the maximum sunlight on their surface. These results are explained by the fact that the dust particles deposited on the surfaces of the modules are not identical and modify their parameters differently. It can therefore be said that the degradation of the modules due to dust does not only depend on the quantity but also on the type, the distribution and also on the manufacturing technology.

To discuss the difference in degradation noted on the different technologies, we will go back to their properties. One of the particularities of amorphous silicon is that it continues to produce electricity at very low levels of illumination unlike other technologies. And another specificity is that an amorphous silicon cell has a loss of 0.2%/°C in average power, for an operating temperature above 25°C. As for the crystalline cells, they are protected by one (or more) bypass diodes. Thin-film cells, for their part, do not include a bypass diode simply because of their shape; unlike crystalline silicon therefore easy to shade. Thin film cells have the same wavelength as the module and it is highly unlikely that one cell will be fully shaded without the others being shaded as well. So, the effect of dust on a thin-film module will be totally different from the effect of dust on a crystalline module. However, we note that of all the technologies, the thin-film module experienced a strong degradation of its generated power (68%) under the effect of dust.

5 CONCLUSION

This experimental study allowed us to highlight the impact of dust on the characteristics of electrical performance. The results obtained were compared with other studies. It should be noted that the performance of the modules decreases according to the accumulation of dust but also according to the type of dust and the manufacturing technology of the module. Thus, the results showed that the impact of dust is greater on thin film and monocrystalline technologies than on polycrystalline and amorphous technologies. We can retain through this study that when the PV module is cleaned it recovers its lost power whereas if it is left to accumulate dust its electrical performance parameters will degrade over time.

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