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Study of the performance of a system for dry cleaning dust deposited on the surface of solar photovoltaic panels

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This study was carried out at the International Center for Training and Research in Solar Energy (CIFRES) and its main purpose was to study the performance of a solar module cleaning system. To handle this work, a measuring platform consisting of two polycrystalline (pc-Si) PV modules was designed. The modules were connected to a waterless cleaning system on the surface of the solar panels. The platform also contained a temperature sensor on the surface of the module, a pyranometer, shunt resistors (for current measurement), and an acquisition unit. This platform was exposed under real conditions and measurements of the parameters were taken in increments of ten seconds. Only one of the two modules was cleaned daily, and an evaluation of the degradation rate of the short-circuit current (I_{sc}) of the dust module with respect to the cleaned module was carried out. After one month of exposure, the analysis of the results showed a degradation rate of 17.13% of the short circuit current (I_{sc}) of the dirty module compared to the clean module. Compared to the initial conditions under the standard test conditions, a degradation of 10.16 and 24.09%, respectively for the clean module and the dirty module was obtained. This work also showed that a polynomial relation exists between the degradation rate and the dust deposition density with a coefficient of determination of 0.9933.

Key words: Photovoltaic modules, dust, short-circuit current, impact, automatic cleaning without water, degradation.

INTRODUCTION

The development of renewable energy is currently a political requirement. In the short term, an energy deficit from known resources is not predictable, but long-term scenarios already exist that require an overall reduction in the production of pollutants, particularly CO_2. These problems have led to an unbridled race towards new

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forms of energy. The development of renewable energies in Senegal, in this context is a matter of securing the energy supply and the reduction of dependence on imports of fossil fuels. However, the use of these forms of energy has long been marginal, in particular, that of solar photovoltaic whose capacity installed in the year 2000 was 850 KWc. The total installed capacity reached 2.3 MWc in 2005 and was close to 4 MWc in 2010 (0.7% of the total installed capacity) (PANER, 2015). With the advent of a new political alternation in 2012, the implementation of the Emergent Senegal Plan (PSE) has been witnessed, which aims at the country development by 2035. This plan targets the energy sector as an economic development pillar and the reduction of social and territorial inequalities. For example, there has been a proliferation of photovoltaic solar power plants (Bokhole 20 MW, Malicounda 20 MW, Sakal 30 MW and several ongoing projects to validate), which positions the country as a leader in the field at the sub-regional level. However, the development of solar photovoltaic field is encountering a number of difficulties. In terms of operation, solar panels need to be exposed to the open air. Consequently, dust, bird droppings, marine spray, pollen and of course pollution are all external phenomena that can gradually be deposited on the surface of the solar panels. In time, this accumulation of dirt and dust form a thin layer on the photovoltaic cells. This layer, depending on its thickness, can hide the exposure to the sun and thus cause a reduction in the current and voltage generated by the solar panels, greatly reducing the performance of solar panels. This phenomenon is further amplified because the area focused of focus is located in the Sahelian zone characterized by periodic dust storms.

Analysis of the AERONET data at four 4 stations in the Sahel (Dakar, Agoufou, Banizoumbou and Ouagadougou) shows that the Sahel is affected by dust throughout the year (Drame et al., 2013). These dust deposits affect solar photovoltaic installations by causing disturbances in the distribution of energy. Ndiaye et al. (2013) were able to show a maximum power degradation of 18 and 78% for polycrystalline (pc-Si) and monocrystalline (mc-Si), respectively. The phenomenon of dust deposition from surrounding environment on the glazing of PV panels is a major constraint in the cost of maintenance and operating (M & O) for solar plants (Lopez-Garcia et al., 2016). Currently, the panels are cleaned using laborers which is expensive, uses significant amounts of water resources, and often results in mistakes that damage the panels (Al Shehri et al., 2014).

Dry cleaning is one such technology, aiming to mitigate the impact of dust mitigation by removing deposited dust. This solution offers promises in mitigating the impact, but it is important to recognize that synergistic technologies that could actually reduce dust accumulation are also an important topic of research and development (Al Shehri et al., 2017). Figure 1 shows the various methods that can be used to clean the surface of solar panels including natural cleaning, automatic cleaning, manual cleaning, and passive surface cleaning (Sayyah et al., 2014). This paper work presents the system used to clean the solar panels as well as the methodological approach. The degradation over time of the short-circuit current (I_{sc}) of the two modules is evaluated as well as the evolution of the difference between the short-circuit current (I_{sc}) of the two modules as a function of time. The conclusion will deal with the evolution of degradation as a function of the amount of dust on the surface of the modules.

MATERIALS AND METHODS

Dust is generally a term used for any particulate matter that is less than 500 µm in diameter, which compares the size of an optical fiber used for communication or 10 times the diameter of a hair strand (Field et al., 2015). It greatly affects the operation of solar installations. To mitigate this effect, cleaning methods are increasingly developed in order to limit the losses due to dust and dirt. Figures 2a (Ecoppia, 2014) and 2b (Häberlin et al., 2012) show dry cleaning via robots and FWG700 Panel washer, respectively.

Presentation of the system

The study was performed in the laboratory of the International Center for Training and Research in Solar Energy (CIFRES) located at the Polytechnic High School of Cheikh Anta Diop University in Dakar. An experimental platform (Figure 3) was installed on the roof of the building that houses the CIFRES laboratory. It includes sensors to measure the electrical parameters of the photovoltaic modules and environmental parameters, a datalogger and the automatic cleaning system. The platform consists of the following:

(i) Two identical polycrystalline (pc-Si) solar modules inclined at 15° with a power rating of 150 W each, mounted on an aluminum support. Each of the two panels is connected to a waterless cleaning system.
(ii) Shunt resistors to measure the short-circuit current (I_{sc}) of the modules.
(iii) 12-volt AGM battery that powers the cleaning system motor.
(iv) Pyranometer to evaluate the solar radiation at the surface of the modules.
(iv) Hygro-thermometer for measurement of humidity and ambient temperature.
(v) Wind vane and an anemometer to measure the direction and speed of the wind.
(vi) Type K thermocouples to measure the temperature of the modules.

The technical specifications of the modules are given in Table 1. The waterless cleaning system consists of several components including a cleaning brush (wiper blade), cables, DC 12 V motor, scorers to determine the end of travel etc. Data storage is provided in 10 s increments using a Campbell scientific CR800 datalogger.

Presentation of the experimental protocol

The data used in this study were collected in May, 2017. Daily cleaning was carried out on one of the modules while the other was left without any cleaning action during the whole duration of the experiment. The experimental device consisted of a 12 V DC motor

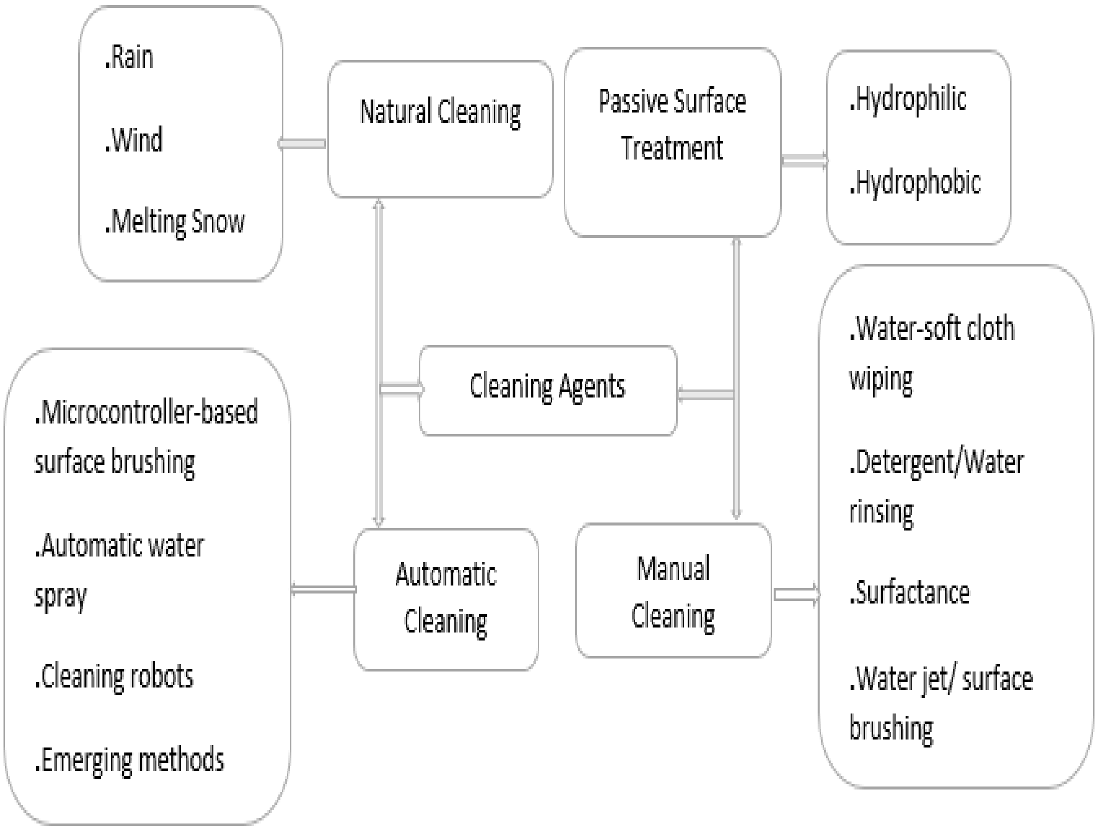

Figure 1. Different cleaning methods for removing dust from solar collectors (Sayyah et al., 2014).

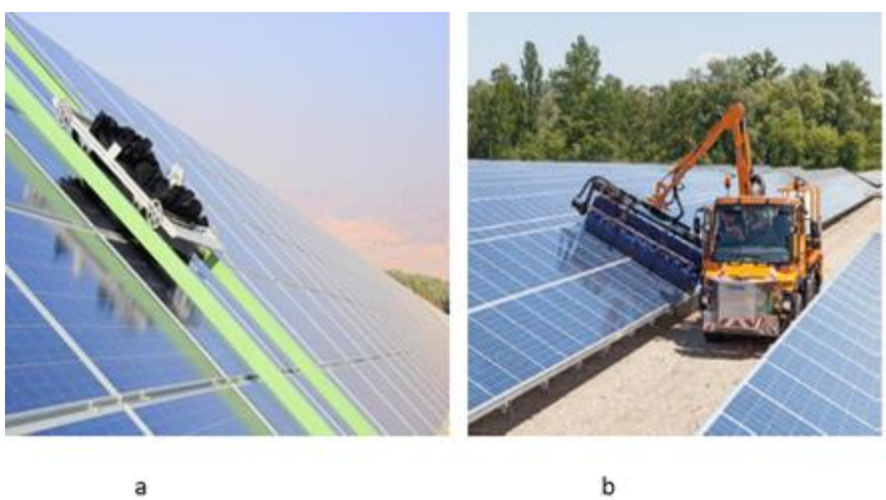

Figure 2. (a) Waterless cleaning of solar panels via robot and b) FWG panel washer.

which drives a brush placed horizontally on the surface of the PV module. The motor is controlled by a microcontroller via an L298 driver which ensures power supply to the motor in both directions of travel. The control signals are supplied by the microcontroller and an end stop detects the moment of reversal of the polarity. The Thomson L298 circuit is an interface reference for DC motors and step by step motors (UIT Nime, 2010). The L298 is a double H-bridge with logic interface that can control two DC motors. These low voltage characteristics, less than 12 V, give it an unquestionable place in integrated power circuits. The H-bridge is an electronic structure used to control the polarity across a receiver. It is composed of four switching elements generally arranged

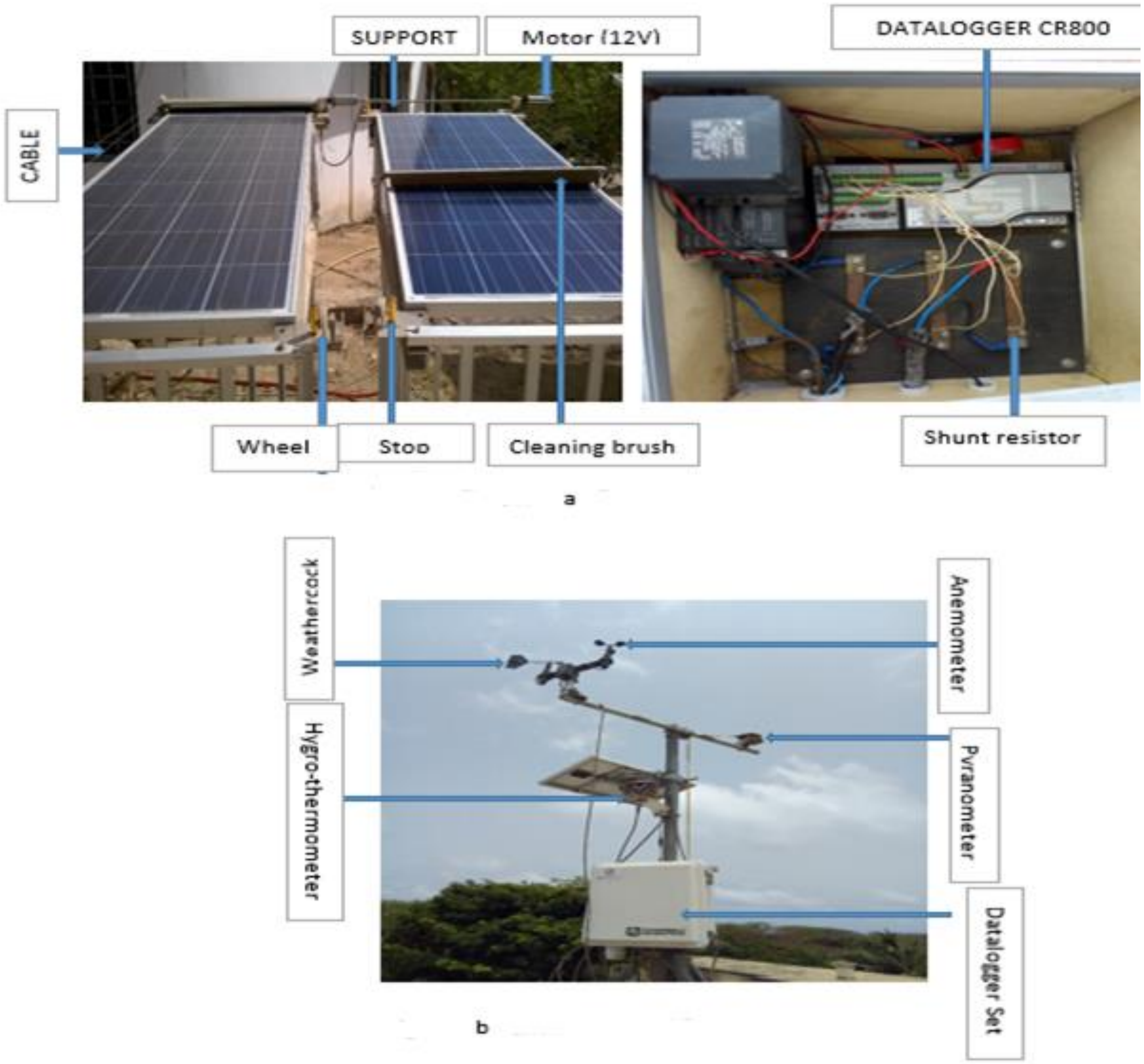

Figure 3. a) Electrical parameters platform and b) environmental parameters platform.

Table 1. Technical specification of photovoltaic modules.

Parameter	Values	Units
P_{max}	150	Watts
(I_{sc})	8.57	Amps
V_{co}	22.5	Volts
I_{max}	8.24	Amps
V_{max}	18.2	Volts
S	99	Cm²
Number of cells (*N*)	36	-
(FF)	0.78	-

schematically in a form of the letter H, hence the name. The switches may be relays, transistors, or other switching elements depending on the intended application. It reverses the direction of rotation of a DC motor. Whether starting or not, the control system depends on the detection voltage. Thus, 10 s after the system detects a voltage, the cleaning is activated. A cleaning cycle is

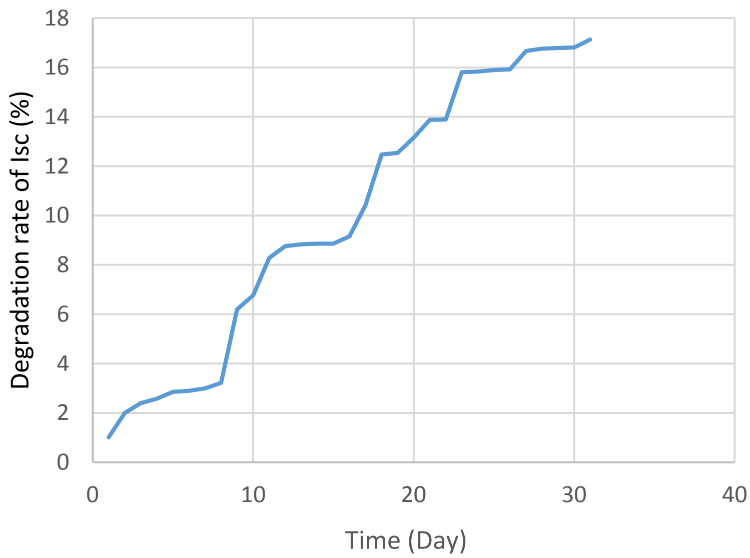

Figure 4. Evolution of the degradation rate over time.

composed of two backward and forward motion periods. When the system starts cleaning and touches the end of stroke after starting (increase of current up to about 2A), it stops because the high resistance causes a rapid increase in motor current. The use of the month of May data was motivated by the fact that this month presents interesting characteristics with strong sunshine, absence of cloud cover and a total absence of rain (Le Sénégal en Mai, 2017). The approach consists of making a comparative study between the short-circuit current of the cleaned module and that of the dirty module. After collecting data at the datalogger level, the measurements were standardized in order to eliminate temperature and sunlight effect according to the model of Equation 1 (Ndiaye et al., 2013):

$$I_{cc,s} = I_{cc;m}\left(\frac{1000}{E}\right) + \alpha\, S\left(T_{ref} - T_{mod}\right) \qquad (1)$$

With $I_{cc,s}$ equal to the standardized short-circuit current (I_{sc}), $I_{cc,m}$ as the measured short-circuit current (I_{sc}), T_{ref} representing the reference temperature, T_{mod} the module temperature, α is the current temperature coefficient, and S is the surface of the modules.

After this step, the rate of degradation of the short-circuit current of the two modules was calculated with respect to their initial conditions using Equation 2 (Ndiaye et al., 2013).

$$\Delta I_{cc} = \frac{I_{cci} - I_{cc,stc}}{I_{cci}} * 100 \qquad (2)$$

With ΔI_{cc} as the rate of degradation of the short-circuit current (I_{sc}) of the modules, I_{cci} which represents the initial short-circuit current and $I_{cc,stc}$ as the one under standard conditions.

According to Paudyal and Shakya (2016) and Al-Hasan and Ghoneim (2005), the degradation evolution is a function of the amount of dust deposition over time. This amount of deposits depends on the exposure site of the panels. Thus, the focus was on the study of the amount of dust that is deposited on the surface of the modules in our work. To do this, glasses with a surface area of 10 cm² and a weight of 96 g are positioned at the same level as the solar panels to collect dust. After a week of deposit, the glasses are weighed using a very high electronic precision balance (1 mg). The weight of the dust is equal to the difference between the weight of the clean glass and that of the glass covered with dust.

RESULTS AND DISCUSSION

Figure 4 represents the evolution of the degradation rate of the dirty module with respect to the specific module over time. The measurements were carried out under the real conditions. It was found that degradation increases over time due to dust accumulation on the surface of the dirty panel. Thus, after one month of exposure, a maximum degradation of 17.13% of the dirty module relative to the clean module was noted. The effect of dust on the long-term performance degradation of PV modules, which had been left without any cleaning procedure, was investigated in a recent (Tanesab et al., 2015) study in Perth, Australia. Although the degradation was mostly due to non-dust related factors such as corrosion, a significant contribution of 16 to 29% was recorded due to dust with a fairly uniform impact on the performance degradation of PV technologies. This degradation of the short circuit current (I_{sc}) of the dirty module with respect to the clean module shows the importance of cleaning the surface of the solar modules.

Figure 5 shows the degradation rates over time of the two modules with respect to their initial values. The short-circuit currents (I_{sc}) collected at the platform was standardized in order to eliminate the effect of sunshine and temperature and was compared to the initial short-circuit current (I_{sc}) (new module). Thus, even if the clean module was cleaned automatically every day, one can still notice some degradation due to other factors different from the dust. Indeed, according to Adelstein and Sekulic

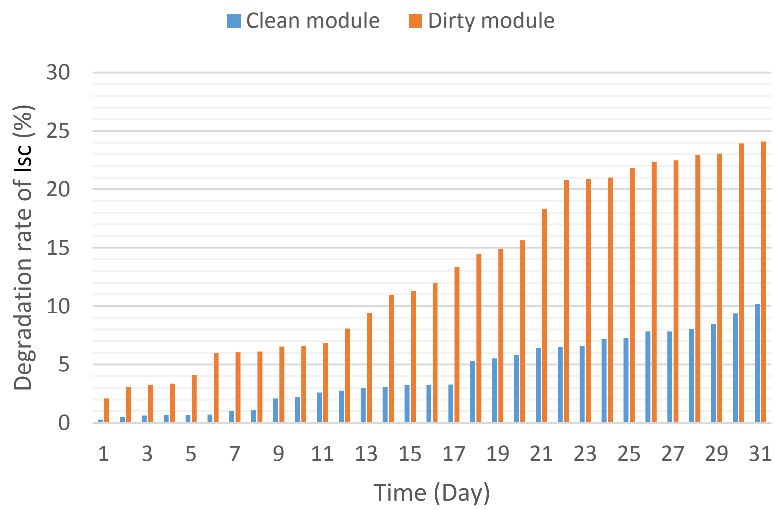

Figure 5. Evolution of the degradation as a function of time for the clean module and the dirty module.

(2005) the electrical parameters of the modules vary according to climatic conditions and gradually degrade over time. This explains the rate of degradation noted at the level of the clean module which reaches the maximum value of 10.16%. However, it should also be noted that the modules had been used about two years before the start of the experiments, which may explain the high value of the degradation. Similarly, the first concern is that dry cleaning may not be as effective as wet cleaning technologies. This is because the water or other chemicals involved in wet cleaning serve as a medium through which dust layers containing salt or similar chemical deposits can be dissolved and the fluid also serves as a medium through which these particles can be transported away from the surface. In dry cleaning, the only method for releasing dried layers of dusty materials is through friction, and air is the only medium through which they can be transported from the surface (Al Shehri et al., 2016).

In Figure 5, there is an increase in the degradation of the short-circuit current (I_{sc}) for the two modules. This degradation is much more significant for the dirty module than for the clean module. Thus the degradation rates can reach maximum values of 10.16 and 24.09% for the clean module and the dirty module, respectively. Indeed, according to Ndiaye et al. (2013), dust induces a generally non-uniform shading on the surface of the PV modules and thus the chains of photovoltaic cells do not receive the same intensity of sunshine. Consequently, they do not have the same behavior and the characteristics of the modules are modified. Some mechanical methods to remove dust from the surface of PV module covers include mechanical wiping, blowing, and the use of removable covers were reviewed. Al Shehri et al. (2016) reviewed different dry cleaning mechanisms that use robotic systems. It was reported that dry cleaning methods using nylon brushes did not affect the optical characteristics of the PV glass surface after equivalent simulation of 20 years.

Williams et al. (2007) reported that the use of mechanical vibration to remove dust resulted in a restoration of 95% of the power-generating capacity of the photovoltaic module. Fernandez et al. (2007) designed a robotic dust wiper supported by a high performance brush to clean surfaces from deposited Martian dust particles. The results showed that the cleaning efficiency was above 93%.

Figure 6 shows the evolution of the degree of degradation of the dirty module as a function of the amount of dust that settles on the surface of the solar panels. After 4 four weeks of collecting dust, we see an increase in the degradation rate of the dirty module depending on the amount of dust that is deposited. Thus, a polynomial regression line is obtained which shows the relationship between degradation and dust deposition density with a regression coefficient of $R^2 = 0.9933$.

Conclusion

The purpose of this study was to suggest a solar photovoltaic solar panel cleaning solution. It was carried out at the Polytechnic Higher School of the University of Dakar and made a comparative study of the short-circuit current of the module cleaned with a waterless cleaning system of the modules and a module without any cleaning action. The month of May that was chosen has very good environmental characteristics. During this study period of 31 days we were able to note a significant rate of degradation of the short circuit current (I_{sc}) of the dirty module.

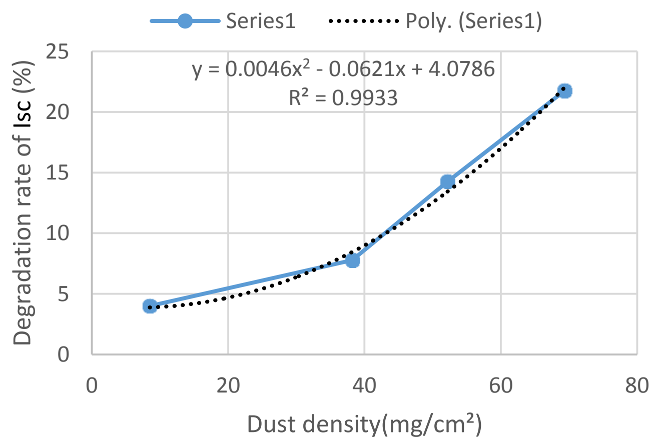

Figure 6. Evolution of degradation as a function of the density of dust deposits.

In this paper the cleaning system and the methodological approach were presented. Interesting results have been found as the proposal of automatic cleaning to limit the effect of dust on the surface of the modules. The following results were thus obtained:

(i) A degradation rate of 17.13% of the dirty module compared to the clean module.
(ii) Degradations of 10.16 and 24.09%, respectively, for the clean module and dirty module.
(iii) A polynomial relation between the degradation and the density of dust deposits on the surface of the modules is determined with a coefficient of determination of 0.9933.

In the continuation of this study, it would be interesting to evaluate the cost of the system to see if the process of cleaning the surface of the modules is profitable or not for the owners and in addition, determine appropriate cleaning frequencies for solar photovoltaic installations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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