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EXPERIMENTAL STUDY OF DUST ACCUMULATION EFFECT ON PHOTOVOLTAIQUE SOLAR MODULE PERFORMANCE IN ZIGUINCHOR, SENEGAL

A. Sidibba[1*], D. Ndiaye[1], D. Kobor[2], E. Menny[3]

[1]Laboratoire d'Electronique Informatique Télécommunications et Energies Renouvelables, (UGB), Saint-Louis, Sénégal

[2]Laboratoire de Chimie et de Physique des Matériaux (LCPM), Université Assane Seck de Ziguinchor, Ziguinchor, Sénégal

[3]Unité Energies Renouvelables, Département physique, Université de Nouakchott Al-Aasriya, Nouakchott, Mauritanie

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ABSTRACT

The present work focuses on a study of dust accumulation effect on a photovoltaic solar module performance in the environment of Ziguinchor, Senegal. Two polycrystalline photovoltaic modules 0.75 W were exposed to the outdoor environment on rooftop of the Chemistry and Materials Physics Laboratory (LCPM) at Assane Seck University, Ziguinchor, Senegal (12 ° 34 N, 16 ° 16 E). The two PV panels were exposed for 70 days to the outdoor environment from March 20, 2018 until May 30, 2018, where, the dusty PV panel was left without cleaning for natural dust accumulation, and the reference PV panel was cleaned daily. The results showed that after 70 days of outdoor exposure without rain, the dust surface density ranged from 0 (g/m^2) at the beginning to 13.84 (g/m^2) at the end of the experiment; which resulted in a 92.3 (%) reduction in the reference module efficiency.

Keywords: Photovoltaic, Dust accumulation, Efficiency reduction.

Author Correspondence, e-mail: sidiabaahmed@gmail.com

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1. INTRODUCTION

Fossil fuel reserves are declining rapidly due to the increased use of thermal power plants and air pollution associated with the burning of fossil fuels. Generally, the main objective of research concerning photovoltaic (PV) systems is to improve their performance so that they can produce more electricity with higher efficiency and in an environmentally friendly way [1,2]. Thus, in order to use efficiently and economically photovoltaic solar systems, it is necessary to take into account the environmental aspects that can have a negative impact on its performance. However, one of these aspects is related to the dust accumulation on the surface of the photovoltaic modules. The dust particles accumulation on the surface PV module greatly affects the performance of photovoltaic solar systems, especially in desert areas. The study of dust accumulation effect has been the subject of several studies. Abdou Latif Bonkaney et al. [3] studied the impact of climate parameters on the photovoltaic solar module performance in Niamey. They showed that the accumulation of dust reduced energy production by 15.29% after 23 days of exposure, the temperature decreased the power output and conversion efficiency of the photovoltaic module by 2.6% and 0.49% respectively and the relative humidity also reduced energy production by 4.3 Wh / m2 / day. Ali, H. M et al [4] studied the effect of dust deposited on the surface of two different types of photovoltaic modules (monocrystalline silicon and polycrystalline silicon). They used two modules of each type and one module from each pair was left exposed to the natural environment for three winter months in Taxila, Pakistan. They showed that dust deposits have a strong impact on the photovoltaic module performance. The monocrystalline and polycrystalline modules show a decrease in the average output power of about 20% and 16%, respectively, compared with clean modules of the same type, and the density of the dust deposited on the surface of the modules was 0.9867 mg/cm^2 at the end of the study. Ndiaye et al [5] studied the impact of dust on the current-voltage (IV) and power-voltage (PV) characteristics of the PV modules (mc-Si and pc-Si) installed at the University of Dakar and monitored for one year of operation without cleaning. They showed that the maximum power loss (P_{max}) is 18 to 78% for the polycrystalline module (pc-Si) and the monocrystalline module (mc-si) respectively, the loss in I_{max} ranged from 23 to 80% for modules respectively pc-Si and mc-Si and the fill factor (FF) can go from 2% for the pc-Si module to 17% for the mc-Si module. Gholami et al [6] studied the impact of dust accumulation on PV performance in Tehran, Iran. After a rain-free 70-day experiment, started on May 9, 2017, at the Shahid Beheshty University Renewable Energy Laboratory, they showed that 6.0986 (g/m^2) of dust was accumulated on the surface, which resulted in a power reduction of 21.47%. Menoufi et al [7] examined the impact of dust accumulation on the electrical performance of photovoltaic solar modules after exposing two 10-watt multicristallin PV modules to the outdoor environment in the Nile East Bank region (Beni-Suef, Egypt). They allowed the dust to accumulate naturally for three months on the surface of one of the modules and the other was cleaned regularly. They showed a significant reduction in the voltage, current and total power of the dusty photovoltaic panel, where it was found that its total power dropped by more than half compared to the reference PV panel. Adinoyi et al [8] studied the effect of dust accumulation on the power of photovoltaic solar modules in the eastern province of Saudi Arabia. They indicated that the power can decrease up to 50% for solar PV modules left without cleaning for more than six months. Rajput et al [9] studied the effect of dust accumulation on the photovoltaic solar modules performance in the central region of India. They showed that dust significantly reduces electricity production by 92.11% and efficiency by 89%. Paudyal et al [10] studied the effect of dust accumulation on the photovoltaic solar modules efficiency in the Kathmandu region of Nepal. They showed that during the 5-month study period, the efficiency of the dusty solar module left to the natural phenomena of dust deposition decreased by 29.76% compared to the module that was cleaned daily and the deposition density of dust on the PV module represented 9.6711 g / m^2 during the study period. Saidan et al [11] studied the impact of dust accumulation on solar photovoltaic modules in the city of Baghdad in Iraq. They showed that the average degradation rate of solar module yields exposed to dust is 6.24%, 11.8% and 18.74% calculated for exposure periods of one day, one week and a month.

For a better use and a good follow-up and maintenance of a photovoltaic system installed in the zone West Africa, it is essential to clean the PV modules periodically. This periodicity depends on both the region and the season. Indeed, regions of Africa near the desert or having two seasons are often subject to impact months of dust and aerosols whose accumulation is harmful to the performance of PV modules. It is therefore important to know how often the module should be cleaned in order to minimize maintenance costs. In the case where frequent cleaning is not possible, it is important to know the performance loss due to the dust to take into account. This study focuses on the evaluation of the dust accumulation effect on a photovoltaic solar module performance in Ziguinchor, Senegal.

2. METHODOLOGY AND EXPERIMENTAL SETUP

The experimental study was conducted at the Laboratory of Chemistry and Materials Physics (LCPM) at Assane Seck University in Ziguinchor, Senegal. Senegal is located in the extreme western Africa between 12.5 ° and 16.5 ° north latitude and 12 ° and 17 ° west longitude. It present a dry tropical climate characterized by two seasons: a dry season from November to June and a rainy season from July to October [12]. Senegal has a significant solar potential with annual average radiation duration of about 3000 h and an exposure rate of 5.7 kWh/m2/day. This radiation varies between the northern part more sunlit (5.8 kWh/m2/day in Dakar) and the southern part richest in terms of precipitation (4.3 kWh/m2/day in Ziguinchor) [13]. The temperature varies from 16°C around Dakar (January) to 38°C in the South (October). The rainfall increases from North to South with an annual average of 300 mm in the extreme North and 1500 mm in the extreme South [12]. The relative humidity varies between 75 and 95% [14]. Two polycrystalline photovoltaic modules 0.75 W were exposed to the outdoor environment on rooftop of the Chemistry and Materials Physics Laboratory (LCPM) at Assane Seck University, Ziguinchor, Senegal (12 ° 34 N, 16 ° 16 E). The experiment has been conducted during 70 days from March 20, 2018 to May 30, 2018 (figure 1), where the specifications of the modules are shown in Table 1, according to the manufacturer's data. Both modules were tested before performing the experiment (open circuit voltage (V_{oc}), and short-circuit current (I_{sc})) to ensure that both panels produce exactly the same voltage and the same output current. One of the modules was left for a continuous accumulation of dust without cleaning and the other module was cleaned daily. The dust density was measured by weighing the dust deposited on the dusty module using the scale with the error of 0.0001 g (figure 2). The open circuit voltage (V_{oc}) and the short-circuit current (I_{sc}) of each module were measured simultaneously and the solar intensity (W/m^2), the ambient temperature T_a ºC and the modules temperature (T_c ºC) on the other hand. The specification of the measuring instruments in the experiment are shown in Table 2. The data were recorded daily during the whole experiment at 9, 13 and 17 hours.

Table 1. The electrical specifications of the two PV modules used in the experiment, according to the manufacturer

Parameters	**Specifications**
Peak power P_m (Wc)	0.75
Open circuit voltage V_{oc}(V)	3,3
Short circuit current I_{sc}(mA)	275
Module efficiency (%)	15
Fill factor (FF)	0.82
Weight (g)	36
Dimensions (mm)	62 X 120 X 3

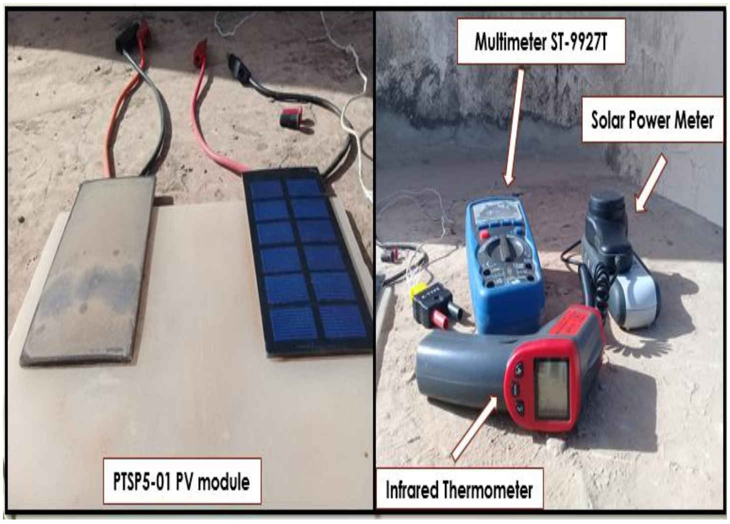

Fig.1. The dusty PV module (left) and the reference PV module (right) used in the experiment

Fig.2. Digital scale to weigh the dust density

Table 2. Specification of measurement instruments used in the experiment

Name of instruments	Make and model	Ratings	Accuracy	Applications
Solar Power Meter	PYR 1307	0 – 1999 W/m^2	$\pm 10\ W/m^2$	Solar radiation intensity
Type of solar module	Item no 11 04 56	V_{oc} = 0-3,3V I_{sc} = 0-275mA	Power tolerance +3%	PV module characteristics
Infrared Thermometer	TY 600 (china)	-32-600	$\pm 0{,}1\%$	PV module temperature
Multimeter	ST-9927T	T , 0-760 °C V, 0-1000V I, 0-10A	Volatge $\pm 0{,}09\%$, Curent $\pm 0{,}1\%$, Temperature $\pm 0{,}3\%$	Output Current, PV Module Voltage, Temperature

The output power was calculated using the following expression:

$$P_m = V_{oc} \cdot I_{sc} \cdot FF$$

The following relationship was used for calculating the module efficiency.

$$\eta = \frac{P_m}{G \cdot A}$$

Where,

V_{oc}: Open circuit voltage produced (V)

I_{sc} : Short-circuit current produced by the photovoltaic solar module (A)

FF : Fill factor

A: PV module surface

G: Solar radiation Intensity (W/m^2)

Power and efficiency losses caused by dust accumulation were calculated according to the following equations:

$$\Delta P = \frac{P_{clean} - P_{dirty}}{P_{clean}} \cdot 100$$

$$\Delta\eta = \frac{\eta_{clean} - \eta_{dirty}}{\eta_{clean}} \cdot 100$$

3. RESULTS AND DISCUSSION

The idea of the present work is to evaluate the effect of dust accumulation on a photovoltaic solar module performance in the environment of Ziguinchor, Senegal. This test is performed for 70 days from March 20, 2018 until May 30, 2018. The amount of dust depositions on a surface are strongly depended on the weather conditions and phenomena during the measurement period.

The average solar radiation intensity at the end of each week of the experiment is illustrated in Figure 3. The average solar radiation intensity varies between 427.8 and 548.2 W / m2, showing the significant and stable solar energy potential of this part of Senegal, which is in perfect agreement with the meteorological data.

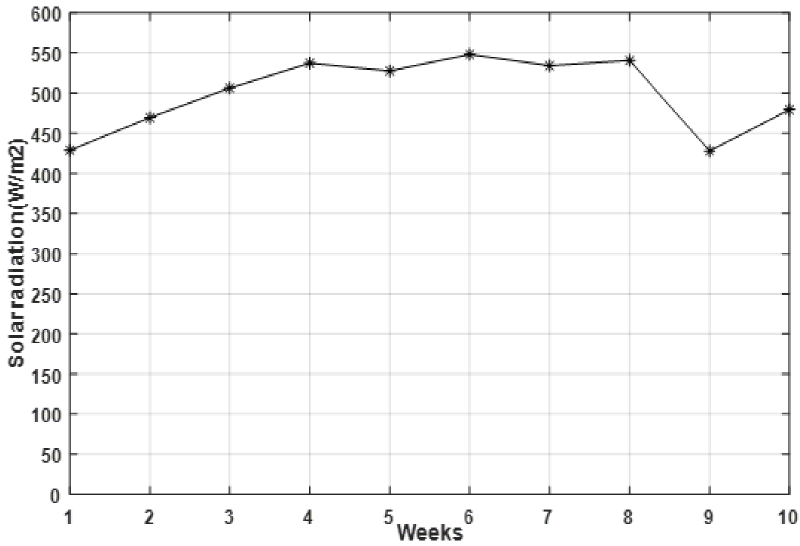

Fig.3. Average solar radiation intensity versus time at the end of each week

Figure 4 shows the average ambient temperature at the end of each week of the experiment. The minimum and maximum average ambient temperature is between 27.58 and 38.52 ° C for weeks 1 and 6 respectively. This curve shows us that the variation of the temperature during this period is around 10 ° C. This does not have too much effect on the performance of polycrystalline silicon photovoltaic cells. On the other hand, this temperature remains quite far from the operating limit temperature of the polycrystalline silicon PV modules.

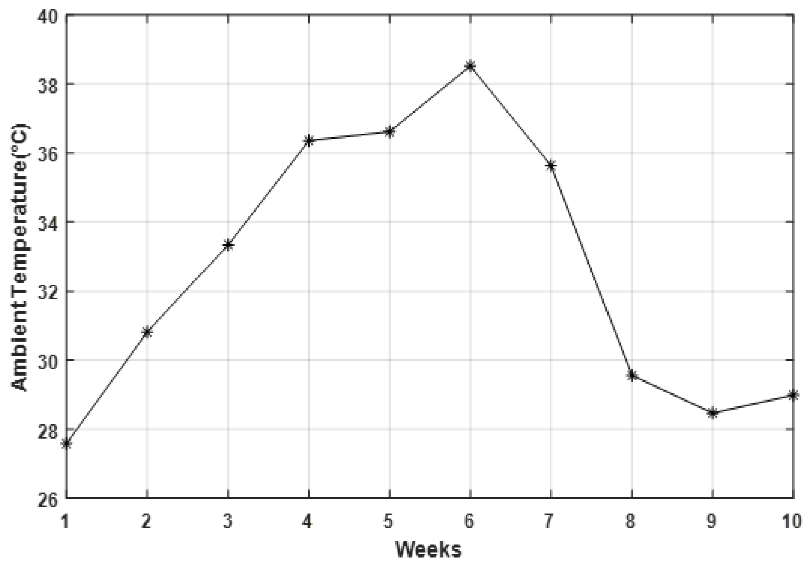

Fig.4. Average ambient temperature versus time at the end of each week

Figure 5 shows the average dust surface density at the end of each week through the experiment. It is clear that according to Figure 5, the level of dust on the surface increases with time, the rate was not constant during the test period. Dust deposition on the surface was faster at the beginning of the experiment, and it slowed down eventually. This could be explained by the presence of dust in the atmosphere more important during the months of March and April that during the month of May when we are at the start of the rainy season in this region. We note that the dust surface density during the test varies from 0 (g/m^2) at the beginning of the experiment (for the clean module) to 13.84 (g/m^2) at the end of the experiment.

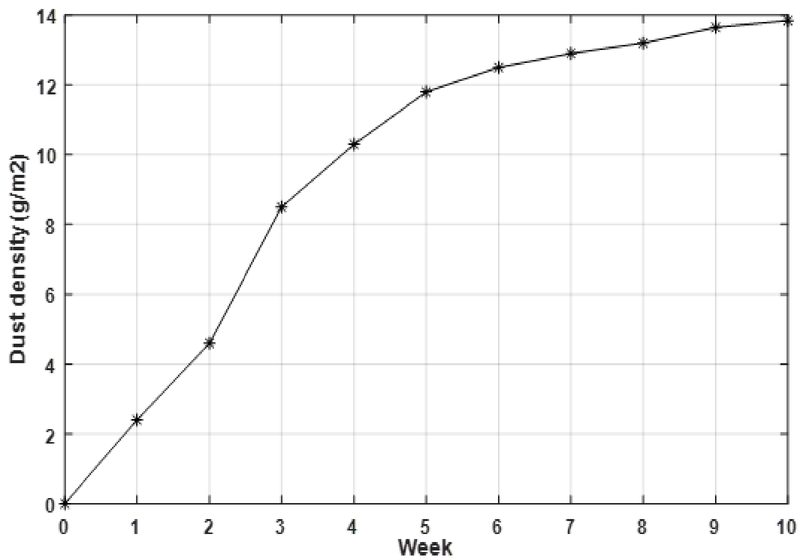

Fig.5. Average dust surface density versus time at the end of each week

Figure 6 shows the variation of the average output power of clean and dusty PV modules as a function of time at the end of each week. Power fluctuations, due to weather conditions and solar irradiation throughout the day. At the beginning, after a week, both modules (clean and dusty) showed a small difference in power output. Over time, the output power of the dusty module has gradually decreased relative to the clean module due to the deposition of dust on its surface.

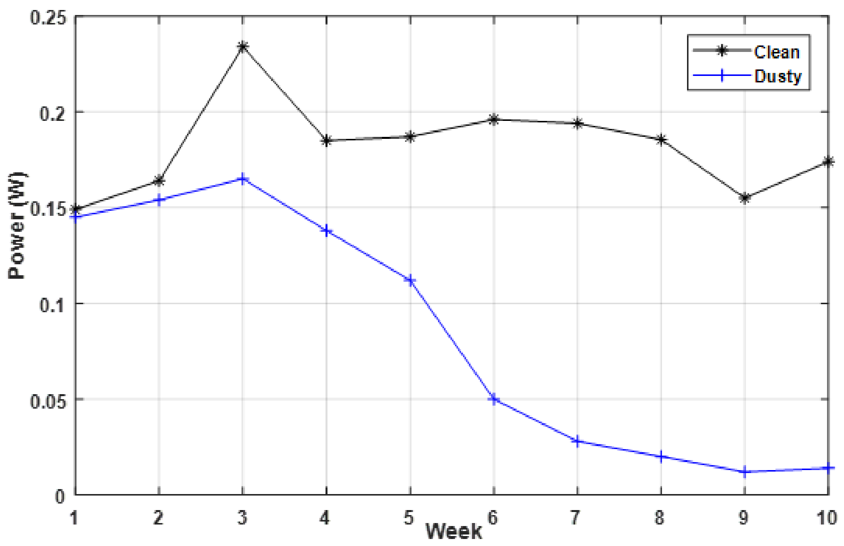

Fig.6. Average output power versus time at the end of each week

The reduction of the power produced by the panels, due to the accumulation of dust, has led to losses of efficiency. Figure 7 shows the variation of average efficiency of clean and dusty PV modules as a function of time at the end of each week. We can see that after one to two weeks, both modules (clean and dusty) showed a small difference in efficiency and over time we find that the efficiency of the dusty module has gradually decreased compared to the clean module because of dust accumulation on its surface.

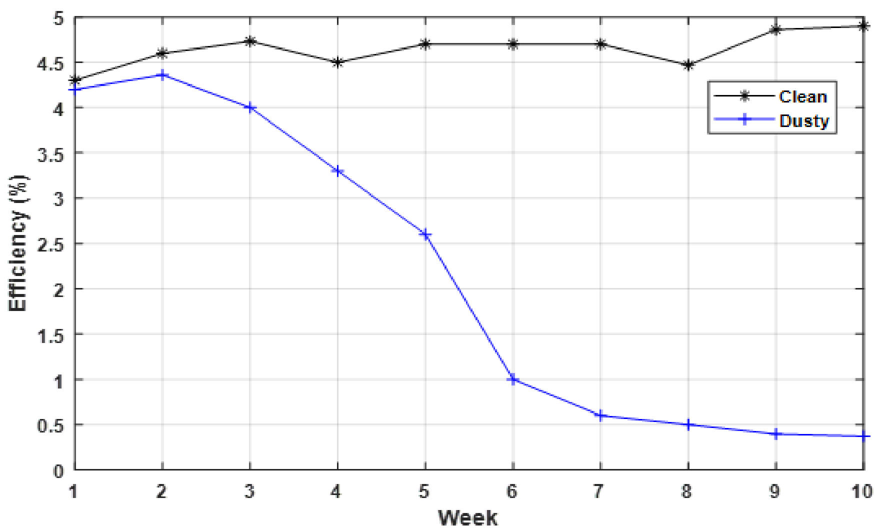

Fig.7. Average efficiency versus time at the end of each week

We can see very well the difference in behavior and the harmful impact of the dust accumulation on the photovoltaic modules.

Figure 8 shows the variation in the average rate of efficiency reduction caused by natural dust accumulation over time at the end of each week. From this figure, it can be seen that the rate of reduction in efficiency increases over time. Indeed, we observe losses about 24% compared to the initial yield and 4.2% after one month of exposure (4 weeks Yield = 3.2%). This value is approximately 45% after 5 weeks of exposure before reaching a stable value around 79% at two and a half months of exposure. The maximum value of yield loss percentages is 92% approximately after ten weeks of exposure outside and seems to reach a top.

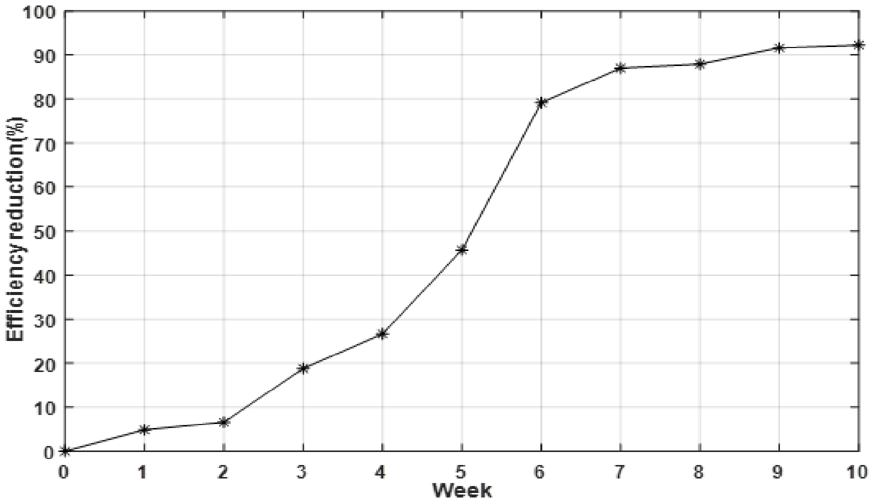

Fig.8. Reduction in efficiency caused by natural dust accumulation versus time at the end of each week

Again, for greater reliability, the results of the average efficiency reduction could be presented compared to the surface density of the dust. Figure 9 illustrates the reduction in efficiency at the end of each week compared to the average density of dust. This figure shows that as the density of the dust surface increases, the efficiency reduction rate first increases with a high rate, but its rate decreases and the power reduction reaches an upper limit. It should also be noted that the surface density of the dust during the test varies from 0 (g/m^2) at the beginning of the experiment (for the clean module) to 13.84 (g/m^2) at the end of the experiment, which resulted in a 92.3 (%) reduction in the efficiency of the reference cells.

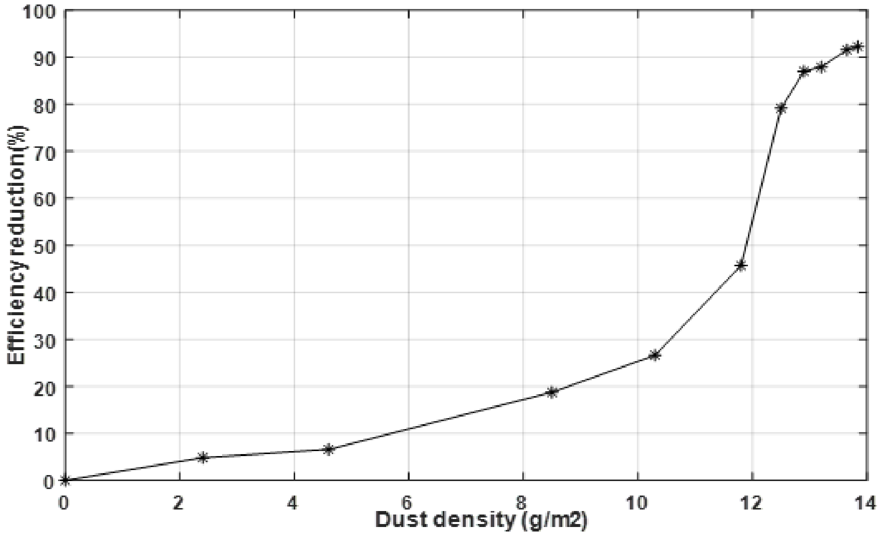

Fig.9. Reduction in efficiency caused by natural dust accumulation versus average dust density at the end of each week

As mentioned previously, the power of the panels depends on both the voltage and the current. For further clarification of the effect of dust accumulation on the behavior of photovoltaic panels, Figures 10-11 are drawn.

Figure 10 illustrates the variation in the reduction of short circuit current and open circuit voltage versus the average dust density due to dust accumulation at the end of each week. It can be seen in this figure that the dust accumulation on the surface of the panel has a considerable effect on the short-circuit current and that the degradation rate increases to about 92% at the end of the experiment, this Due to the fact that Isc decreases as the surface density of the dust increases. This value is exactly same as that found for the percentage of efficiency losses. We note that this deposit has almost no effect on the open circuit voltage V_{co} and its value varies little despite the significant increase in dust deposition. At the end of the experiment after 70 days of exposure, compared to the short-circuit current, the open circuit voltage decreased by 6.5 (%) for a dust surface density of 13.84 (g / m2).

In conclusion, the main reason for reducing the power of PV modules, due to the dust accumulation, is the degradation of the output current.

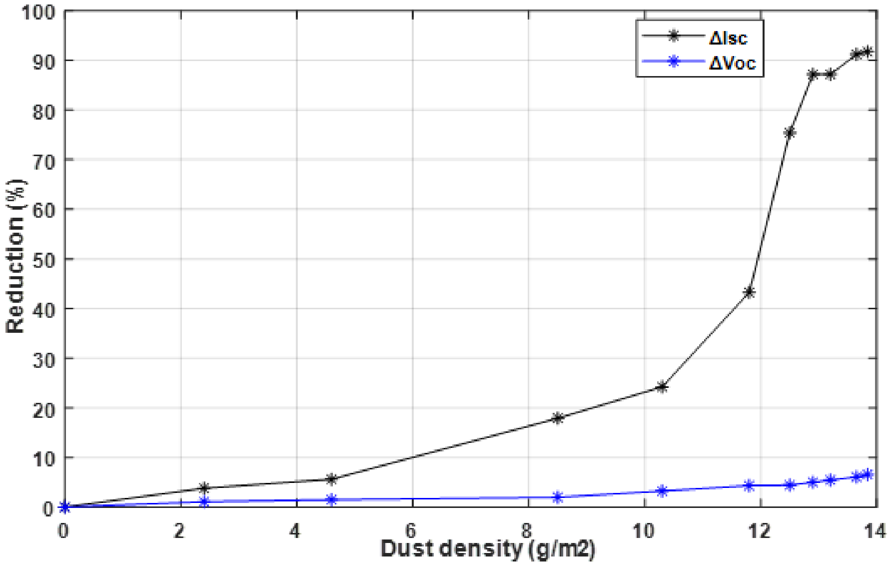

Fig.10. The reduction of short circuit current and open circuit voltage compared to the average dust density due to dust accumulation at the end of each week

Figure 11 shows a comparison of I-V characteristics for clean and dusty reference cells at the end of the experiment. The reported data are obtained at a temperature of 34 ° C and an irradiation of 740 (W/m^2). As can be seen in figure 10 and previously mentioned, the open circuit voltage is weakly influenced by dust accumulation with a 6.5% reduction was observed despite the high surface density of 13.84 (g / m2). In contrast, the short-circuit current decreased significantly for dust cells, resulting in a significant reduction in power.

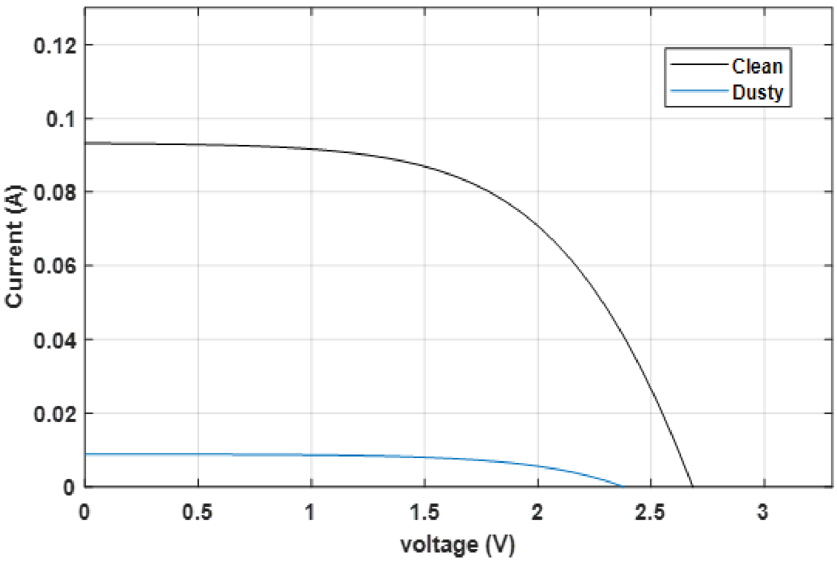

Fig.11. Comparison of I-V characteristics for clean and dusty reference cells at the end of the experiment, under illumination conditions of 34 ° C and 740 (W/m^2)

The effect of dust deposition on the module temperature has been studied. Figure 12 illustrates the variation in the reduction of the module temperature relative to the average surface density of the dust due to the dust accumulation the end of each week. Fluctuations in the reduction of the PV module temperature, due to the weather conditions throughout the day. It can be seen in this figure that the dust accumulation on the panel surface has a considerable effect on the PV modules temperature and that the reduction rate increases to about 10.2% at the end of the experiment. This figure is the best illustration of the dust accumulation effect on PVs in Sahelian regions such as Senegal and the importance of periodic cleaning. However, the temperature variation is small enough to have a real impact on PV performance.

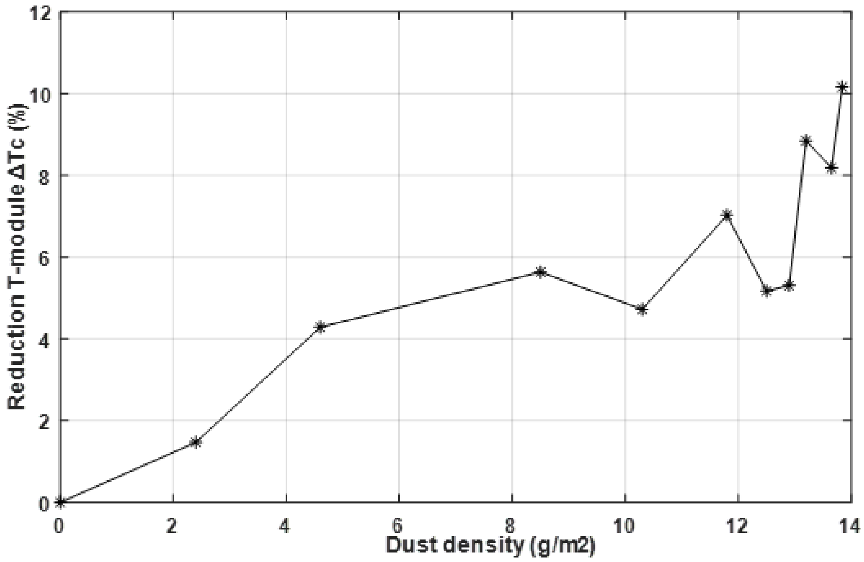

Fig.12. The reduction of the module temperature compared to the average surface density of the dust due to the dust accumulation at the end of each week

4. CONCLUSION AND RECOMMENDATION

The present work focuses on a study of dust accumulation effect on a photovoltaic solar module performance in the environment of Ziguinchor, Senegal. Two polycrystalline PV panels 0.75 W were used for this purpose (the dusty PV panel and the reference PV panel). The two PV panels were exposed for 70 days to the outdoor environment, where the dusty PV panel was left without cleaning for natural dust accumulation, and the reference PV panel was cleaned regularly. The results showed that after ten weeks of exposure to outdoor conditions, it was possible to see that the dust surface density ranged from 0 (g / m2) at the beginning to 13.84 (g / m2) at the end of the experiment, which resulted in a 92 (%) reduction in the reference module efficiency.

Examining the I-V characteristics and comparing the short circuit current and the open circuit voltage for the clean and dusty reference cell, he concluded that dust accumulation reduced both current and voltage. However, the reduction in open circuit voltage is very low (6.5%) compared to the short-circuit current (92%). The main reason for reducing the output power of the cells due to dust accumulation is therefore the reduction of the output current of the cells.

The results also show that the dust accumulation on the panel surface has a considerable effect on modules temperature but rather low on the performance.

The current study, like any other study, needs further researches in some areas to reduce the problems caused by dust accumulation on the surfaces of the solar equipment. Since the experiment for this article was done in a 70-day period, some of the natural phenomena, which could affect dust accumulation density, may not be considered. So a long term experiment should be done to see if it could result in a more accurate correlation. In addition, further studies might be needed to help decide cleaning necessity or optimize the cleaning frequency. However, this study clearly shows that the cleaning frequency of Polycrystalline silicon modules in the Ziguinchor region should not be less than one time per month during the dry season.

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