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Study of the influence of dust deposits on photovoltaic solar panels: Case of Nouakchott

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ABSTRACT

Degradation performance of photovoltaic (PV) modules by real weather conditions has become increasingly problematic. In the desert climate, dust accumulation is one of the main concerns that may cause a significant deterioration of PV efficiency. In the present work, experimental investigations were carried out to understand the effect of dust on the electrical performance of PV modules under Toujounine, Nouakchott, Mauritania weather conditions. The measurements were performed with an I-V tracer ftv200. The measured parameters were I-V and P-V curves, open-circuit voltage (Voc), short-circuit current (Isc), current and voltage at maximum power (Imp and Vmp) and maximum power (Pmax); as well as the measurement of temperature of panels and Irradiation. The study was carried out according to the following cleaning scenarios: panels cleaned before each measurement (Clean panels 01), panels undergoing systematic cleaning with the central unit (Clean panels 02) and chains undergoing no cleaning (Dusty panels 03). Then, the modeling of reliability as a function of maximum power by Weibull's law, for clean and dusty panels is evaluated. According to the experimental results, disturbances in I-V and P-V curves for dusty panels were noticed. Also, a decrease in the Isc and the Imp for dusty panels compared to clean panels was found. These results are explained by the effect of dust accumulation on the module's surface, which blocks the solar radiation and thus reduces the conversion efficiency of PV modules. Again, dust reduces the output power of photovoltaic modules by 21.57% for dusty panels per clean panels. Finally, a low reliability for dusty panels compared to clean panels was found, due to the loss in the output power under the dust effect. These results clearly show the importance of properly maintaining and servicing the photovoltaic modules to avoid their degradation by dust deposits.

Introduction

The subject of PV system performance degradation due to dust deposition has become a major concern (Chen et al., 2019; Zhang et al., 2019). The accumulation of dust on photovoltaic (PV) cells has a negative impact on covering glass, which decreases the spectral transmittance and PV power generation efficiency (Lu et al., 2020). Dust accumulation for a long time damages the layer of the panel, resulting in less output and decreasing lifespan (Chanchangi et al., 2020; Gupta et al., 2019a). Dust accumulation effect on the PV performance exposed to outdoor conditions at various sites was widely experimented (Hachicha et al., 2019). Tropical regions such as the Indian subcontinent, the Middle-East, Saharan Africa and the southwestern United States are particularly vulnerable to the accumulation of dust on the surface of photovoltaic systems (Appels et al., 2013; Rao et al., 2014). Mauritania is a country characterized by Saharan north and Sahelian south weathers. The climate is mostly hot and dry. Nouakchott, which is the capital of Mauritania, is located at *18°1′* latitude North and *15°95′* longitude West. The solar radiation of Nouakchott is 5 kWh/m^2/day and the average annual ambient temperature is 26.2 °C. The average annual humidity is 47.6% and the annual wind speed is 5.47 m/s. The dominant wind in Nouakchott is monsoon. Energy is an important challenge for the socio-economic development of the population. As opposed to fossil fuels, the solar resource is renewable and inexhaustible. In Mauritania, the energy situation remains dominated by the use of fossil fuels. Despite the abundance of solar and wind resources, the use of renewable energy is very limited. Today, the installed renewable energy capacity is 169.17 MW, of which 90 MW is the part of solar photovoltaic. With the increase in installed capacity, the search for more efficient PV cells with higher yields has become more and more problematic, especially in regions with harsh climatic conditions. The study of dust effects

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on PV performance is an important issue for the development of this technology. However, several factors and a large number of environmental parameters are behind the degradation and reduce the performance of PV solar modules (Gupta et al., 2019b; Mustafa et al., 2020) such as, high temperature, humidity, angle of incident irradiation, solar radiation spectrum, ageing, dust, mechanical impact, as well as shadows, snow, wind speed, air pollution, dirt, bird pollen and sea salt … etc. The accumulated dust in PV modules is one of the parameters that influence the energy conversion and it can be significant in many regions (Styszko et al., 2019). Most of the world's deserts are areas where the deposits of dust on PV modules should be considered an important aspect (Mizanur et al., 2012). The deposition of dust on photovoltaic (PV) solar panels would significantly reduce the efficiency of PV production, especially in dusty areas (Zhang et al., 2019). The dust deposited on the surface of the solar panel can reduce the solar irradiation incident on the PV cell (Du et al., 2019). The rate of power reduction caused by dust shows a great variety in the different regions (Chen et al., 2020). There are three main factors leading to the deterioration of photovoltaic efficiency: characteristics of dust (chemical compositions), dust particle size and density of dust deposit on the board (depending on the parameters of the two first factors). The authors of Kazem and Chaichan (2016) showed that dust with higher moisture content has the greatest negative impact on the performance of PV panels. Hachicha et al. (2019) reported that the short circuit current is significantly reduced at higher dust density under Sharjah, UAE weather conditions. Also, they found that after 5 months of exposure, the power loss of the PV module is 12.7% and the dust density increased by 5.44 g/m^2. Mustafa et al. (2020) found a reduction in output power of 12.47% and in efficiency of 11.86%, after three weeks, in the Jordanian southern province of Al Karak. They explained that these reductions in power and efficiency were caused by decreasing the short circuit current of the PV module under the effect of dust accumulation; also, they noted that the dust particles disperse the sun rays falling on the PV module surface, resulting in reducing of power output. The authors of Said et al. (2014) found that the transmission factor was reduced to 20% and the corresponding dust deposit was approximately 5 g/m^2 after 45 days of outdoor exposure in Dhahran-Saudi Arabia. They reported that increasing inclination angle reduces the amount of dust accumulation as well as glass transmittance reduction. The authors of Styszko et al. (2019) studied the effect of dust deposition on the PV front cover glass during the non-heating season in one of the most polluted European cities, Kraków. They reported that the dust particles reduce and scatter the intensity of the total radiation incident on the PV modules, which leads to a decreasing in the conversion efficiency. Mohandes et al. (2009) found a maximum power reduction of about 10% in 5 weeks due to dust accumulation, of PV system in UAE. According to Gupta et al. (2019a), dust accumulation on the PV module blocks the solar radiation to enter directly on the solar cell, which leads to the loss in the output power of the modules. They showed the importance of cleaning technique and protecting system for PV module against the environmental conditions of the installation site. Jiang et al. (2011) studied the degradation of PV module efficiency caused by dust deposition, in the laboratory with a sun simulator and a test chamber and onto different types of solar PV modules. They found that the reduction of efficiency has a linear relationship with the dust deposition density, and the difference caused by cell types was not obvious. The dust deposition density was increasing from 0 to 22 g m^2, and the reduction of PV output efficiency grew from 0 to 26%.

The aim of this work is to investigate the dust effect on the performance of PV modules under Toujounine, Nouakchott, Mauritania weather conditions. The electrical parameters measured are (I-V) and P-V curves, Voc, Icc, Impp, Vmpp and Pmax, as well as the measurement of the temperature of the PV solar panels and the Irradiation. The measurements were obtained by using the I-V Tracer ftv200 and according to the following cleaning scenarios: panels that were cleaned before each measurement (Clean panels 01), other panels undergoing systematic cleaning with the central unit (Clean panels 02) and chains undergoing no cleaning (Dusty panels 03). Then, using to the experimental results of maximum power obtained, the curves of the probability of survival and probability of failure, according to Weibull's law were evaluated.

Materials and methods

Experimental setup

The experimental set-up was installed by the Mauritanian Electricity Company (SOMELEC), in Toujounine, Nouakchott, Mauritania. The experimental setup is composed of a platform of 36 solar panels arranged in 6 rows in series connected in 3 strings of 12 modules (Fig. 1). The panels are grouped as follows: 12 in series and the 3 chains in parallel. Tilt of the panels is 12° facing south. The experimental study was conducted in a Sahelian climate in Toujounine, Nouakchott North.

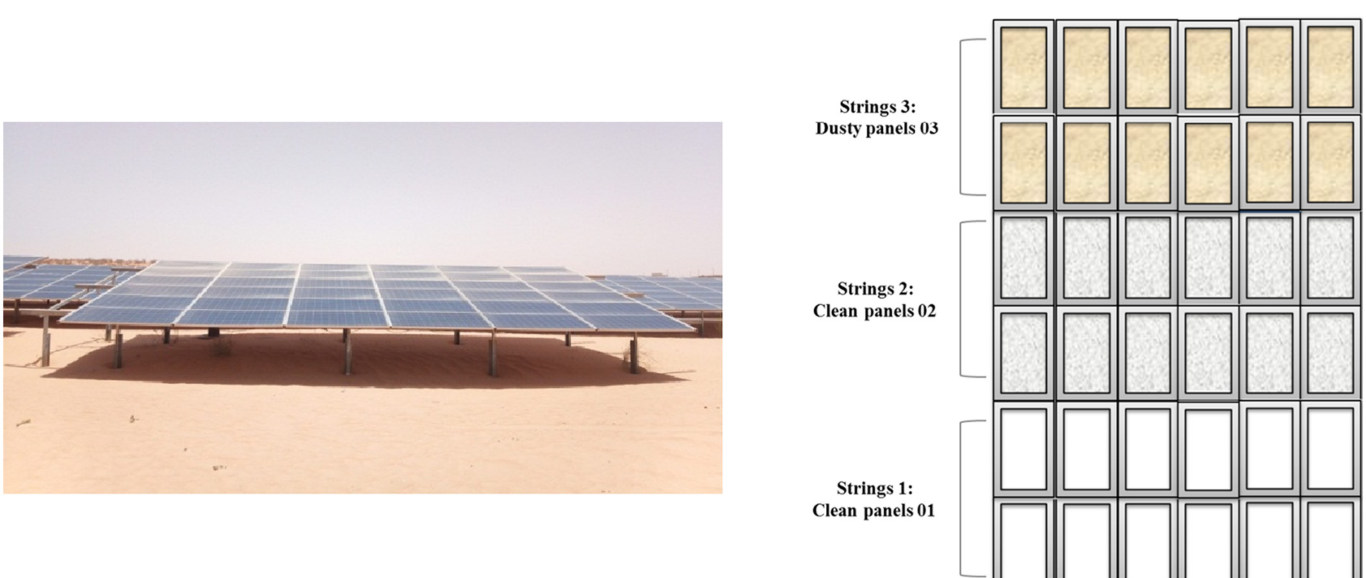


Fig. 1. Experimental set-up.

Fig. 2. Cleaning operation.

Fig. 3. Panels after cleaning.

The degree of power degradation due to the dust accumulation was measured on these test stands according to the following cleaning scenarios:

- Strings 01 of two bottom rows of 12 PV panels (Clean panels 01): these panels are cleaned when measurements are carried out (taken as a measurement reference);
- Strings 02 of two rows in the middle of 12 PV panels (Clean panels 02): these panels undergo systematic cleaning with the power plant;
- Strings 03 of two top rows of 12 PV panels (Dusty panels 03): these panels have never been cleaned.

Cleaning operation

The two types of cleaning operation were done by the staff's hands and were depending on the type of dirt present:

- Dry cleaning in the presence of volatile loads such as dust, sand or leaves.
- Cleaning with water when there are loads such as bird droppings or plant deposits or compact sand/dust layers that cannot be dry removed.

Figs. 2 and 3 show the cleaning operation and the panels after cleaning respectively.

Specifications of the PV panels used

The specifications of the polycrystalline PV panels used for this study are listed in Table 1 below.

Table 1
Panel specifications.

Module type	JKM320PP	
Cell type	Poly-crystalline 156 × 156 mm	
No. of cells	72 (6 × 12)	
Dimensions	1956 × 992 × 40 mm	
Weight	26.5 kg	
Electrical specifications	STC	NOCT
Maximum power (Pmax)	320 W	238 W
Maximum power voltage (Vmp)	37.4 V	34.7 V
Maximum power current (Imp)	8.56 A	6.86 A
Open-circuit current (Voc)	46.4 V	43.7 V
Short-circuit current (Isc)	9.05 A	7.30 A

STC irradiance 1000 W/m^2; cell temperature 25 °C; AM = 1.5.
NOCT irradiance 800 W/m^2; ambient temperature 20 °C; AM = 1.5; wind speed 1 m/s.

Fig. 4. Tracer I-V ftv200.

Fig. 5. Pyranometer DPA/ESR 053.

Fig. 6. Probe PT-100.

Materials used

The JKM320PP PV panel test system consists of a I-V curve plotter *I–V* (Fig. 4), a DPA/ESR 053 Pyranometer, which measures the incident radiation on a horizontal plane (Fig. 5) and a Thermometer: PT-100 probe with 4 wires to measure the ambient temperature (Fig. 6).

Experiment methodology

The I-V curve of PV module was measured by an I-V curve tracer (ftv 200) to characterize PV module's output. The temperature of the module was measured by a Thermometer and the incident radiation was measured by a Pyranometer. The cleaning operation is as follows: 12 modules taken as references were cleaned after each measurement, 12 other modules were cleaned every 10 days with the plant cleaning, and 12 PV panels were never been cleaned. Every week measurements were made.

Results

Power and current-voltage curves under OPC and STC conditions for clean and dusty panels

Fig. 7(a) and (b) describes the power and current-voltage evolution for strings 2 (Clean panels 02) and for strings 3 (Dusty panels 03) respectively, under OPC and STC conditions.

According to the curves in Fig. 7a, the initial current equals a value of 8.19A for STC conditions and a value of 7.63A for OPC conditions, which is normal. Again, the power equals a value of 3.71 KW for STC conditions and a value of 3 KW for OPC conditions.

According to the curves in Fig. 7b, the value of the initial current is 6.28A for STC conditions and is equal to the value of 5.8A for OPC conditions. Also, according to these curves, the power is equal to a value of 3.14 KW for STC conditions and 2.53 KW for OPC conditions.

By comparing the two curves, disturbances in the current-voltage and power-voltage curves for the uncleaned panels were noticed, which clearly shows the effect of dust deposition on the panels' surfaces.

The current-voltage (I-V) characteristics of photovoltaic panels reveal a lot of information to better analyze the degradation of the panels (Rao et al., 2014).

Variation of temperature, irradiance and electrical parameters

Fig. 8a–f shows the curves of the variation of temperature, Irradiance and electrical parameters as a function of time under OPC conditions.

- The curves in Fig. 8(a) show the temperature variation for the three strings studied from 06/04/2019 to 03/06/2019. According to this curves, no change in temperature was observed.
- The curves in Fig. 8(b) show the variation in Irradiance from 06/04/2019 to 03/06/2019. The variation observed on the panels during the day of 19/04/2019, is due to a windstorm.
- The curves in Fig. 8(c) show the variation on the short circuit current Isc. A decrease in the curve of strings 03 compared to strings 02 and strings 03 was observed.
- The curves in Fig. 8(d) show the variation of the open circuit voltage Voc.

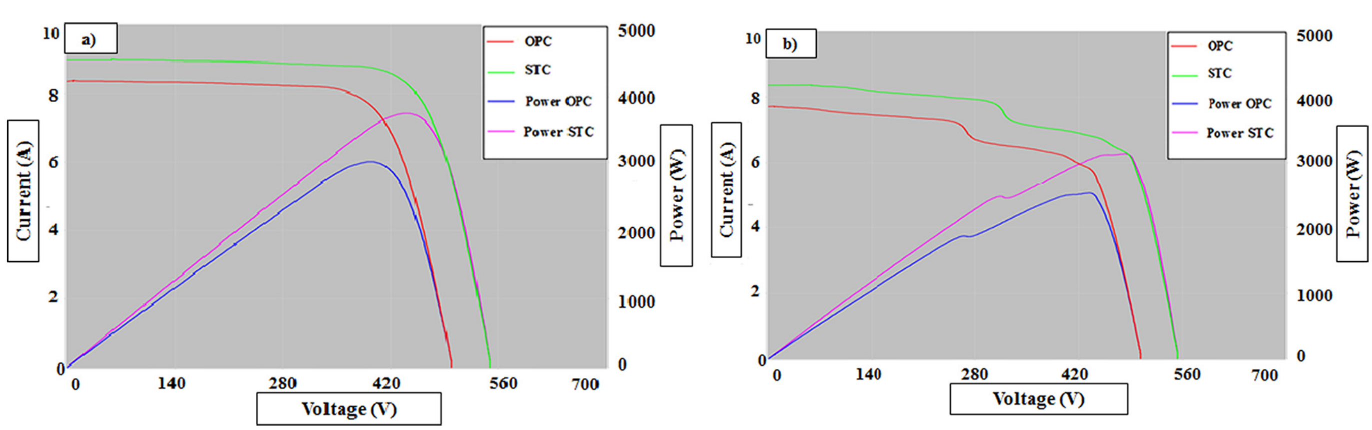
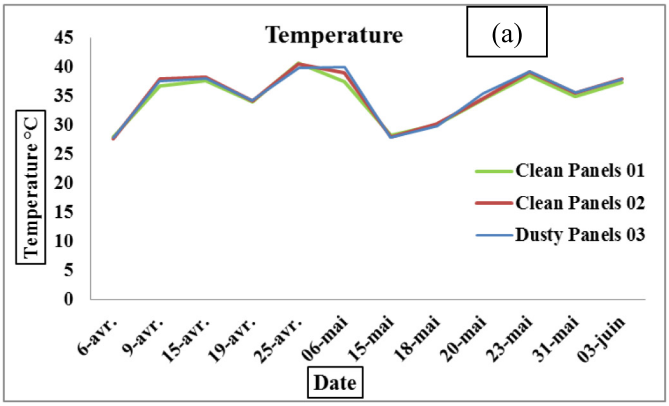
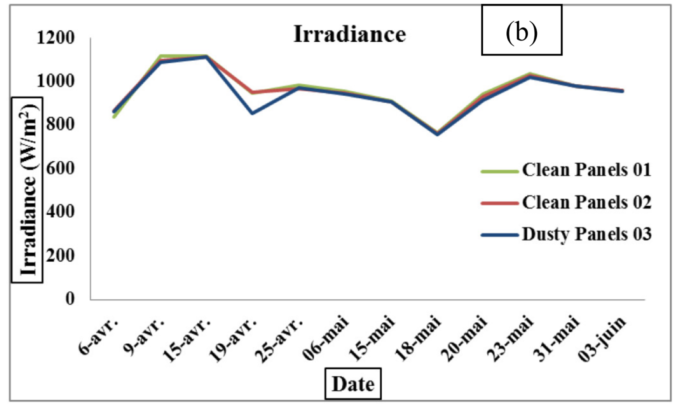


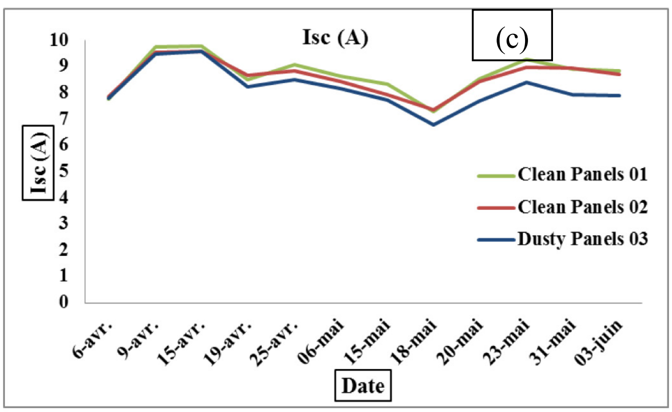
Fig. 7. (a): Evolution of power and current-voltage under OPC and STC conditions for strings 2. (b): Evolution of power and current-voltage under OPC and STC conditions for strings 3.



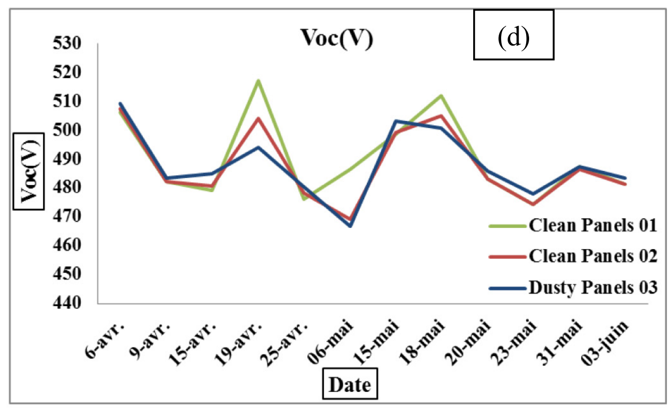
(a): Temperature variation, for strings 1, strings 2 and strings 3



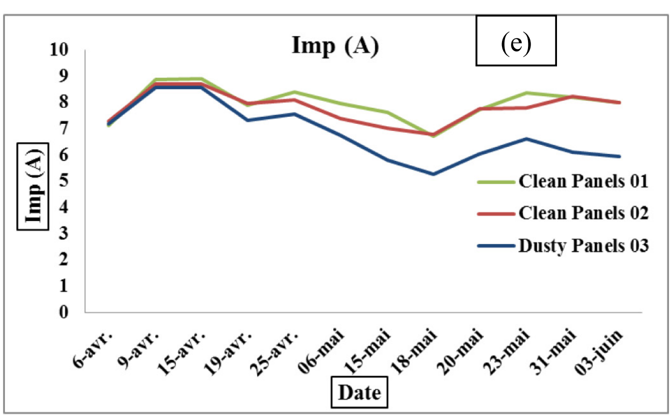
(b): Irradiance variation for strings 1, strings 2 and strings 3



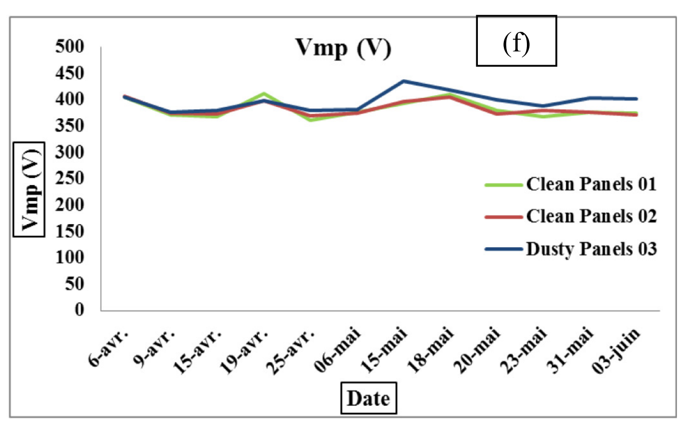
(c): Variation of short-circuit current for strings 1, strings 2 and strings 3



(d): Variation of open circuit voltage (Voc) for strings 1, strings 2 and strings 3



(e): Current at maximum power variation for strings 1, strings 2 and strings 3



(f): Voltage at maximum power variation for strings 1, strings 2 and strings 3

Fig. 8. (a): Temperature variation, for strings 1, strings 2 and strings 3. (b): Irradiance variation for strings 1, strings 2 and strings 3. (c): Variation of short-circuit current for strings 1, strings 2 and strings 3. (d): Variation of open circuit voltage (Voc) for strings 1, strings 2 and strings 3. (e): Current at maximum power variation for strings 1, strings 2 and strings 3. (f): Voltage at maximum power variation for strings 1, strings 2 and strings 3.

- The curves in Fig. 8(e) show that Imp varies almost like Isc. A significant decrease was noted at the level of the uncleaned panels compared to the cleaned panels.
- The curves in Fig. 8(f) show the variation of voltage of the strings Vmp.

Among the experimental results found by Rao et al. (2014), the dust deposit has no noticeable effect on the open circuit voltage of the panels. A slight decrease in the voltage for the dusty panels was observed. Again, under natural sunlight, dust has a slight negative effect on the

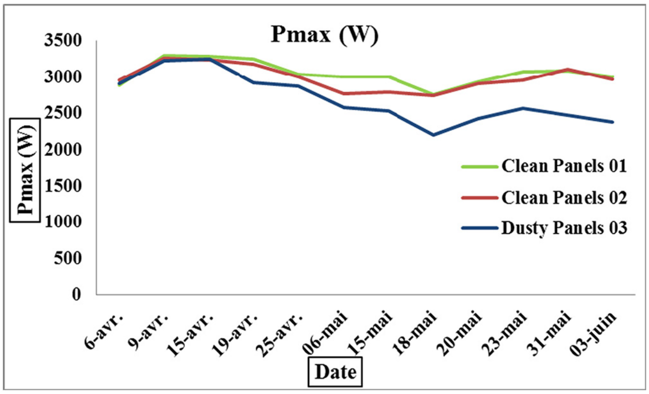


Fig. 9. Power variation over time for the three strings of the studied panels.

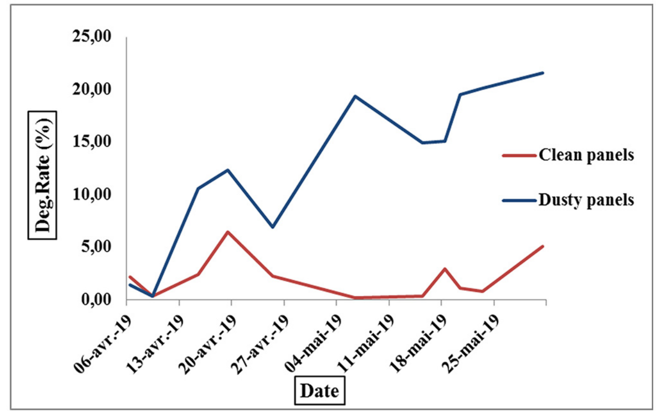


Fig. 10. Degradation percentage of power for cleaned panels compared to uncleaned panels.

short-circuit current produced by the panels. We note that no significant differences in cell operating temperatures were observed.

According to Jiang et al. (2011), the decrease in current found is explained by the dust deposits on the surface of photovoltaic (PV) modules. This leads to a decrease in the transmittance of solar cell glazing and cause a significant degradation of solar conversion efficiency of PV modules - Photovoltaic cell converts the solar light energy into electrical energy (Jacobson & Delucchi, 2011). Dust accumulation on the PV module blocks the solar radiation to enter directly on the solar cell (Gupta et al., 2019a).

Power measurements

The curves in Fig. 9 show the power variation over time, for the three cleaning scenarios studied.

According to the curves in Fig. 9, we found:

- For strings 1 (Clean panels 01), an increase in power at the beginning of the test from the value 2.88 KW to the value of 3.29 KW was found, then an almost constant variation in power was observed;
- For strings 2 (Clean panels 02), an increase at the beginning of the experiment from the value of 2.95 KW to the value of 3.26 KW was found, followed by an increase;
- For strings 3 (Clean panels 03), a remarkable and a progressive drop in power over time was observed. The value reached the end of test 2.47 KW.

The drop in the power Pmax on May 18 for the three strings of panels is due to rain. The value is equal to 2.2 KW for the strings 03; 2.75 KW for the strings 02 and 2.74 KW for the strings 01.

The decrease in power is the main indicator of the degradation of a photovoltaic module.

Degradation rate measurements

The curves in Fig. 10 show the power degradation rate Pmax of cleaned versus uncleaned panels.

According to the curves in Fig. 10, we found a high rate of degradation for uncleaned panels compared to cleaned panels. The degradation rate reaches 21.57% after three months of testing.

The drops and increases in speed observed on the curves in Fig. 10 are explained as follows:

For the day of the 06/04/2019: the two curves of the power variation undergo a decrease due to the rain which has occurred on the 30/03/2019.

For the days from 15/04/2019 to 18/04/2019: the increase of two curves is explained by a very strong wind storm.

According to Goossens and Kerschaever (1999)), wind speeds promote the accumulation of dust on panel surfaces. Ramli et al. (2016) found a 10.8% reduction in the output power of the photovoltaic system, in Indonesia after two weeks of exposure in a dry. They reported also that dust and other particles accumulate rapidly on solar cells and can reduce the efficiency up to 20%. According to the study carried out by Said et al. (2014), the transmission factor was reduced to 20% and the corresponding dust deposit was approximately 5 g/m^2 after 45 days of outdoor exposure in Dhahran-Saudi Arabia. According to Chen et al. (2020), the output power decreases up to 13.9%, after two weeks outdoor exposure for Eastern China. Also, they found that dust accumulates on the surface of photovoltaic modules, in continuous dry weather, will seriously affects the power output.

Modeling survival probability Ps and failure probability Pf

Reliability

The reliability rated R(t) is defined as the probability that a device will perform a required function under given conditions of use and for a given period of time.

To predict the reliability of a material, it is necessary to select the appropriate statistical model for the lifetimes of the test samples. For this, we choose Weibull's law because it is a flexible law that can be adjusted with all kinds of experimental results.

Weibull distribution

The Weibull distribution is generally used to characterize the behavior of systems (mechanical and electronic…etc):

This statistical method is used to determine the relationship between probability of survival (reliability) and maximum power (Eq. (1)):

$$Ps = exp\left(-\left(\frac{\sigma-\sigma_0}{\eta}\right)^M\right) \tag{1}$$

Ps: probability of survival or reliability;
σ: maximum power;
M: shape parameter (Weibull module);
η: scale parameter;
σ_0: position parameter;

The data follow a Weibull distribution, if the points will be linear or nearly linear.

$$ln\left[lnln\left(\frac{1}{Ps}\right)\right] = M(ln\sigma - lnln\,\eta) \tag{2}$$

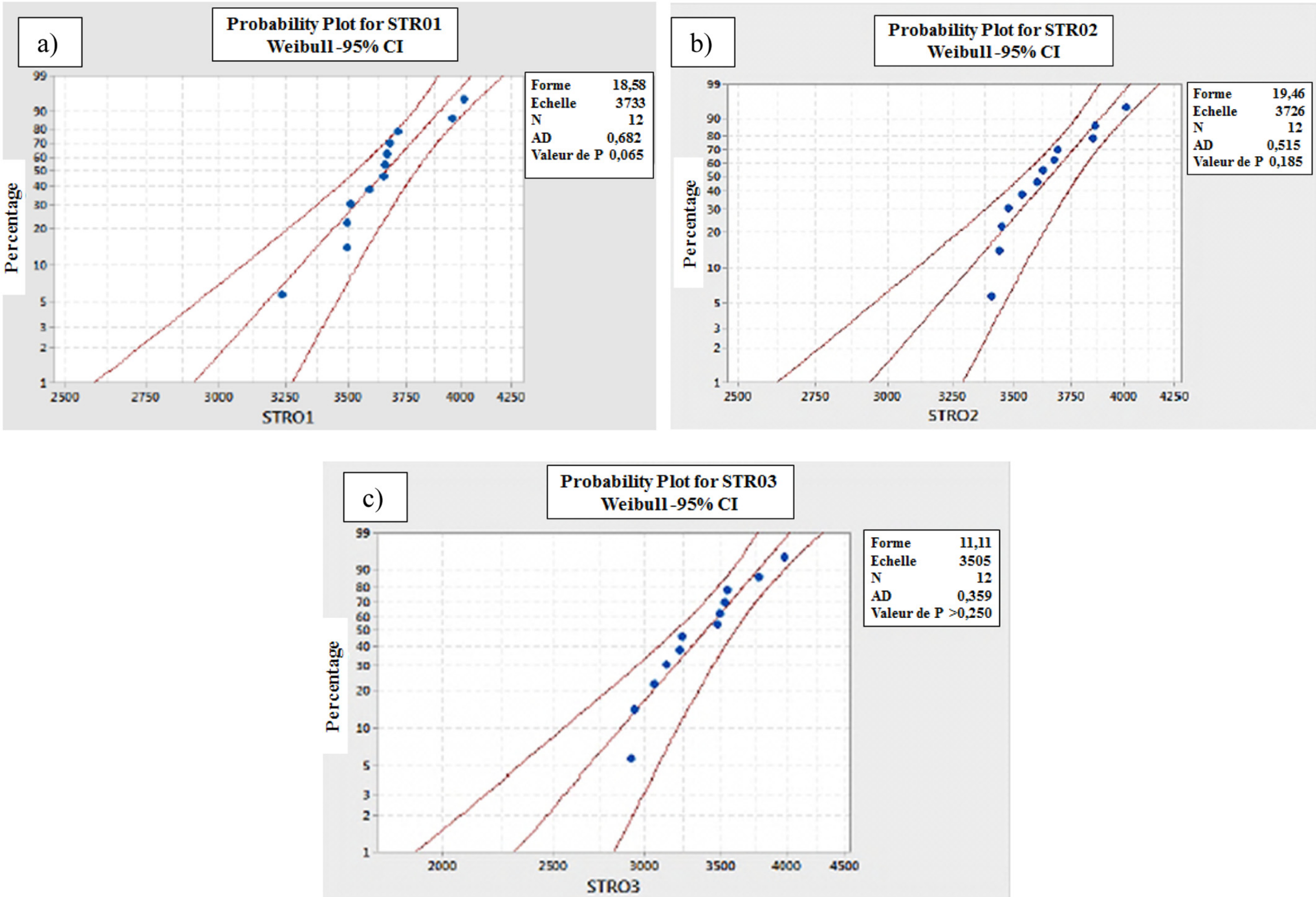


Fig. 11. Determination of the parameters of Weibull's law.

By using the Minitab software and based on Eq. (2), we found the values of the parameters of Weibull's law (Fig. 11) for the three strings STR01, STR02 and STR03.

Reliability modeling as a function of maximum power

The failure F(t) is, contrary to the reliability, the probability that a randomly chosen device will fail before the time t. Thus, it is a complementary value of the reliability (Eq. (3)):

$$F(t) + R(t) = 1 \tag{3}$$

Generally, the variable "time" should be considered as a unit of use. However, in special cases, other units such as kilometers, number of revolutions, … etc., should be considered. In our case, the Maximum Power (Pmax) will be the unit of use. Also, we will replace the symbol F(t) by the probability of failure Pf.

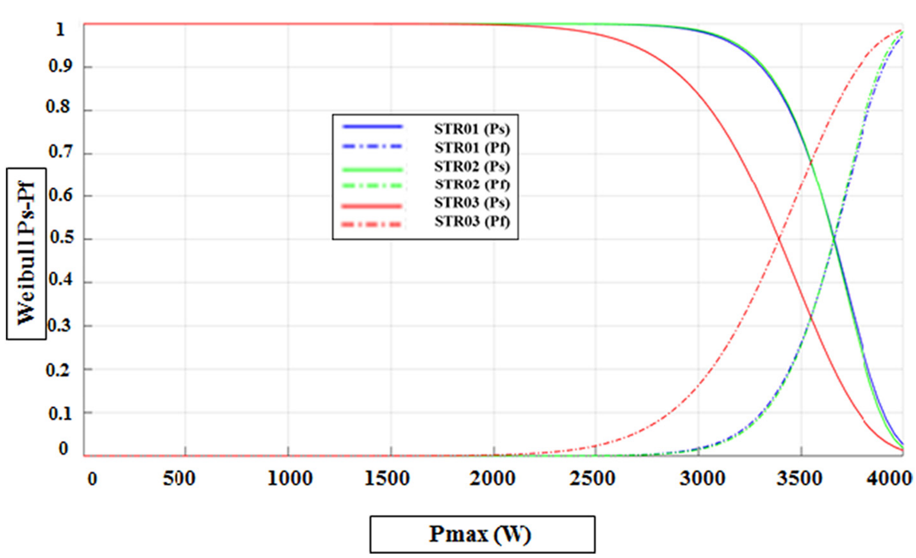


Fig. 12. Curves of survival probability Ps and failure probability Pf.

Fig. 12 shows the curves of survival probability Ps and failure probability Pf (Ps + Pf = 1) for STR01, STR02 and STR03 as a function of maximum power using the first equation (Eq. (1)).

According to Fig. 12, we found that the evolution of the probability of survival (reliability) of uncleaned panels (STR03 or Dusty panels 03) is very low compared to the reliability of the cleaned panels (STR02 and STR01). This decrease in reliability is explained by the decrease in maximum power under the dust effect. On the other hand, we notice that the difference between the reliability curves of the solar panels STR02 and STR01 were very small, which shows the usefulness of systematic cleaning.

Discussions

Salim et al. (1988) found a 32% reduction in performance after eight months due to dust accumulation on a solar PV system in a village near Riyadh, Saudi Arabia (Chanchangi et al., 2020; Ndiaye et al., 2013). Wakim et al. (1981) reported a 17% reduction in PV power due to the accumulation of sand on the panels in Kuwait City after six days. Hussain et al. (2017) confirmed that the smaller particle blocks more sunlight and thus reduces the efficiency of solar panels. Also, they showed that in desert areas and due to dust accumulation the power efficiency of solar panels can be reduced up to 60%. According to Mizanur et al. (2012) dust acts as a barrier between the solar panel and the sun's rays. Also, they found that the value of the short circuit current Isc of a clean panel is higher than the Isc of a dusty panel, and the power decreases with the amount of dust on the surface of panels. According to Rao et al. (2014), the effect of dust on I-V characteristic of panels was studied. They observed that the deposit of dust did not significantly alter the open circuit voltage of PV systems. However, the dust deposits negatively affect the short-circuit current. Again, Rao et al. (2014) found that dust deposition leads to a decrease in generated power and an immense loss in energy produced and the economic loss of a PV power plant. According to Sulaiman et al. (2011), the effect of the presence of dust was studied using artificial dust (mud and talcum), they found a reduction in a peak power generated up to 18% and they found that the differences between the results obtained using mud and talc were generally small (about 6%). They confirmed that a cleaning of the dust on the surface of the PV solar panel is necessary to ensure the best performance. According to the study by Zeshan et al. (2017), the average output power was reduced up to 22% for June, 16% for July and 18% for August due to the accumulation of dust on the surface of the polycrystalline PV modules, exposed to the outdoor operating conditions in Pakistan. They concluded that a regular cleaning of the PV module is necessary to minimize efficiency losses. According to the study by Prasanthi and Jayamadhuri (2015), a reduction of the peak power generated can be up to 30%, under higher irradiation, the effects of dust can be slightly reduced and not negligible. Also, they showed that the power can be improved by using cleaning. An increase in power up to 35% was found. According to Sulaiman et al. (2014), the experiment was done by using a clean panel and a panel covered with talcum, dust, sand and moss. They showed that opaque particles tremendously affect the performance of solar PV. According to Karmouch et al. (2017), the deposition and accumulation of airborne dust significantly reduces the efficiency of solar cells, by reducing the transmission of sunlight. They found approximately 10.4% reduction of efficiency after 16 weeks of exposure for 30° tilted panels and 9.7% for 55° tilted panels. They also recommended using a self-cleaning system product, especially in dusty areas with a low rainfall to prevent dust accumulation and to improve the energy performance module.

Conclusion

The main factor of degrading the generation of PV modules is dust accumulation on the top surface of PV module. Dust accumulation on panel's surface blocks the solar radiation to enter directly on the solar cell, which would decrease the spectral transmittance and PV power generation efficiency. This leads to a decrease in the reliability of the solar PV module. The loss in the output power of the modules can be avoided if modules are cleaned periodically. This study investigated the effect of dust on the electrical performance of PV modules under Toujounine, Nouakchott, Mauritania weather conditions. The study is conducted under three different cleaning scenarios and measurements are taken using an I-V tracer ftv200 as well as the measurement of temperature and irradiation. Also, the modeling of reliability as a function of maximum power by Weibull's law for clean and dusty panels is investigated.

The main results of this investigation are summarized as follows:

- Disturbances in I-V and P-V curves for dusty panels were noticed, due to dust effect.
- A decrease in Isc and Imp for dusty panels compared to clean panels. These results are explained by the effect of dust accumulation on the surface of modules, which acts as a barrier against the sunlight, and thus reduces the conversion efficiency of PV modules.
- Dust accumulation reduced the power output by 21.57% for dusty panels compared to clean panels. Dust accumulation leads to the loss in the output power of the modules.
- The reliability for dusty panels is very low compared to clean panels. This decrease in reliability is explained by the loss in the output power under the dust effect.

This work is an important step in understanding the dust effect on PV performance in Sahelian areas. The results clearly show the great effect of the cleaning operation to obtain the best performances of the PV solar panels.

Abbreviations

STC	Standard Test Conditions
NOCT	Nominal Operating Cell Temperature
OPC	Operational test conditions
Strings 1	Clean panels 01 or STR01
Strings 2	Clean panels 02 or STR02
Strings 3	Dusty panels 03 or STR03
Vmp	Voltage at maximum power
Imp	Current at maximum power
Voc	Open circuit voltage (V)
Isc	Short-circuit current (A)
Pmax	Power measured at the terminals of the PV cell (Watt)
Ps	Probability of survival or reliability
Pf	Probability of failure

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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