Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2023, 10(5):271-280**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Studies of the performance of CIGS modules under real natural climatic conditions

P.W. Tavares[1,2], H.D. Ndiath[1,2], N. Mbengue[1], D. Gueye[2,3], B. Mbow[1], M.L. Sow[1,2]

[1]Laboratory of Semiconductors and Solar Energy (LASES) Department of Physics, Faculty of Science and Technology, Cheikh Anta Diop University of Dakar, Senegal
[2]Centre for Renewable Energy Studies and Research (CERER) BP 476 Dakar, Cheikh Anta Diop University, Dakar, Senegal
[3]Centre for Renewable Energy Studies and Research (CERER) BP 476 Dakar, Cheikh Anta Diop University, Dakar, Senegal
pierrewilliams.tavares@ucad.edu.sn

Abstract The aim of this work is to study the performance of CIGS (Copper, Indium, Gallium and Selenium) thin-layer photovoltaic modules under real natural climatic conditions. For this, we were able to compare two CIGS photovoltaic modules by exposing them to real weather conditions for three months (January 4 to March 29, 2023). The measurements were made at the Centre for Renewable Energy Studies and Research (CERER). CIGS 1 is cleaned weekly after characterization and CIGS 2 is not cleaned during the three months of study and is characterized weekly. During the study, CIGS 1 lost 23.51% in power, 20.63% in short circuit current and experienced a slight 0.014% increase in open circuit voltage. For CIGS 2, losses are 4.68%, 55.22% and 60.22% for open circuit voltage, short circuit current and maximum power respectively. In addition, the CIGS 2 module lost an average of 20.74% more power than the CIGS 1 module.

Keywords Solar module, thin film, current, voltage, power, performance, CIGS, Senegal

1. Introduction

Today, as fossil fuels are depleted and energy consumption continues to rise, humanity must find ways to produce more energy while ensuring that energy-It can last under any circumstances and that this energy must be in harmony with nature, so that it is not upset. These fossil fuels produce a lot of greenhouse gases that destroy the atmosphere, and they are the main contributors to climate change. To make up for all this, we have to use renewable energies because they are environmentally responsible.

The sun emits radiation that can be transformed into electricity or heat (solar energy), it generates zones of temperature and unequal pressures at the origin of the wind (wind energy), it generates the water cycle (hydraulic energy), it enables plant growth and biomass generation. So, we can say that solar energy is the source of all energy on earth except nuclear energy, geothermal energy and tidal energy. As for the earth, its internal heat can be recovered from the surface (geothermal energy).

The study focuses on the performance of CIGS modules under natural conditions. Two modules will undergo degradation with one of the modules that will be cleaned weekly to make a comparison between the two. We will present the material that was used to do this work and we will end up presenting the results obtained and discussing them.

2. The influence of some parameters on the cell

The environmental parameters that strongly affect the performance of solar modules are: lighting, temperature, humidity, wind speed, rainfall, ultraviolet (UV) radiation, dust and evaporation. Numerous studies published in the literature show that the performance of photovoltaic modules depends mainly on the technology, the site, the weather conditions and the configuration of the photovoltaic system [1].

2.1. The influence of temperature

Temperature is a very important parameter in the behaviour of solar cells as long as they are exposed to solar radiation and also has consequences on the design of the photovoltaic module. The influence of temperature on the performance of modules and PV systems has been studied in several studies. In the PV module performance analysis, Van Dyk et al found that for a 5°C increase, the open circuit voltage decreases by 6.3% while the short circuit current undergoes a slight increase of 1.2%. As a result, the maximum power is reduced by 5.1% [2]. A solar panel with a temperature above 25% loses up to 0.5% efficiency per additional degree [3]. Photovoltaic conversion is an energy application highly dependent on temperature, in terrestrial applications, solar modules are typically exposed to operating temperatures ranging from 10°C to more than 50°C while solar modules are simulated at 25°C. An increase in temperature above 30°C causes a decrease in the efficiency of this module [4], so the module is temperature sensitive. Parameters such as short circuit current, open circuit voltage, shape factor and efficiency are influenced by temperature. We see that in Figure 1, the voltage of a cell decreases strongly with the increase in temperature, the more the temperature increases the less efficient the cell is. On the other hand, the current increases slightly in intensity [5].

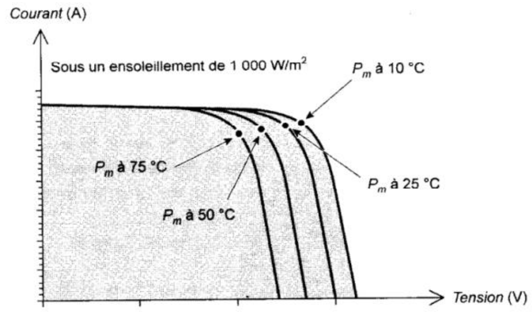

Figure 1: Influence of the temperature (energieplus-lesite.be)

2.2. Influence of dust

As far as dust deposition is concerned, many photovoltaic modules have very low efficiency in contact with dust, significantly reducing the efficiency, but also the performance of the modules. Many parameters such as the property of the dust, the characteristic of the dust including the chemical type, the size of the grains and the form of the dust, influence the deposition of the dust on the surface of the photovoltaic module. In a real environment, the accumulation of dust on solar modules is a natural phenomenon that is very common in desert areas [6]. The research carried out on this issue has shown that this accumulation can produce a fairly significant degradation of the transmittance of glass and consequently, degrade the performance of photovoltaic modules. The literature also reports that dust deposition on CIGS modules leads to a sharp decrease in electrical parameters, except for the open circuit voltage which shows a slight increase, all other parameters show a large variation for the 3 months of exposure without cleaning [7]. Hassan et al studied the effect of airborne dust on the performance of a photovoltaic module and showed that an efficiency decreases of 33.5% to 61.8% was achieved for an exposure of 1 to 6 months respectively [8].

2.3 Presentation of the site

The measurements were carried out at the Renewable Energy Research and Study Centre (CERER) in real and natural operation, located in the DAKAR region more precisely on the route of the geographical service (HB-87) *rue HB-478, HANN BEL AIR. CERER is an institute of the Cheikh Anta Diop University of Dakar (UCAD) which was created by decree no. 80-402 of 28 April 1980.

For 29 years, April 28, 1980, researchers and technicians have not made any headway: the many results developed by its various activities can no longer be counted. Having continued to study meteorological phenomena, to seek and develop processes using all forms of energy, to study and control the radioactivity of air and precipitation, to centralize and disseminate data, to train researchers, the centre has made a real contribution to finding solutions to development problems related to energy and the environment. Today, he has built a solid reputation for expertise in photovoltaic, thermal and thermodynamic conversion, wind energy, energy conservation, biomass upgrading, as well as wastewater treatment, in short, research and development issues.

This region has significant photovoltaic solar energy potential. The climate is of the Sudanese-Sahelian type characterized by the alternation of a dry season from November to May and a rainy season from June to October. Table 1 shows the meteorological data for the study area.

Table 1: Study Area Weather Data

Months	Daily inclined solar radiation (kWh/m²/j)	Humidity (%)	Wind speed (m/s)	Ground temperature (°C)
January	5.54	70.2	5	21.7
February	6.32	74.9	4.9	21.7
March	6.8	78.5	5.4	22.3
April	6.77	83	5.6	23
May	6.3	82.9	5.1	24.8
June	5.74	82.3	4.2	27.4
July	5.25	79.7	3.9	28.3
August	5.16	83	3.7	28.2
September	5.38	84.7	3.4	28.1
October	5.89	81.8	3.9	28.1
November	5.57	73.8	4.6	26.5
December	5.22	68.6	5.2	23.9

3. Materials Used

3.1 The CIGS solar module

Initially, the CIGS solar cell was a simple p-CuInSe/n-Cd/S heterojunction but the structure of the device was mainly configured to substrate formation/Mo/CIGS/CdS/ZnO/AZO/Al; the first CIGS solar cells were developed between 1976 and 1977 through two 100 MW/cm² tungsten halogen lighting modes for 1.2 cm² devices (p-CuInSe2/n-Cd/S) with a 4.5% efficiency by Karzmerski and Al at the University of Maine (USA) [9].

Measurements were made on two (2) thin-film photovoltaic modules. They were oriented to a full south position and a 15° bank relative to the horizontal, that is, to the latitude of the site.

The modules tested are identical CIGS (Copper, Indium, Gallium and Selenium based cell) and 90 W peak power pair, rectangular (960*640) flexible Solar Panel and they are produced in China.

The electrical characteristics of these different photovoltaic modules used in our study are listed in Table 2.

These characteristics are given in STC (Standard test conditions) namely the solar radiation which is 1000 W/m²; the temperature is 25°C and the mass of atmospheric air is AM = 1.5.

Table 2: Characteristics of the modules

Characteristics	CIGS modules
Maximum power (Pmax)	90 W
Short circuit current (Isc)	4.89 A
Open circuit voltage (Voc)	25.60 V
Maximum power voltage (Vmp)	20.60 V
Maximum power current (Imp)	4.37 A
Maximum system voltage	600 V DC
Size	960*640*1 mm

3.2. The test protocols

The two CIGS modules are identical and even, they are exposed to the open air in the same weather conditions, one is cleaned each week after the characteristics are checked and the other is not cleaned. The study is carried out over a period of 3 months (12 weeks).

Before the start of the experiment, the characteristics of the solar modules such as the open circuit voltage, short circuit current, illumination and temperature of the modules were recorded. Various experimental results are obtained from current-voltage and power-voltage measurements according to environmental conditions, namely temperature, illumination, dust deposition etc. For each measurement, almost 50 values are recorded to trace the current-voltage characteristics. Measurements were made during the dry season (January 4 to March 29) between 12h and 13h.

To simplify things, we call the CIGS 1 module as the cleaned module and the CIGS 2 module as the not cleaned module. The objective is to compare the performance of the two CIGS modules (CIGS 1 and CIGS 2) to see the evolution of the performance drop.

Figure 2: Testing platform

3.3. Measuring equipment

To characterize the solar modules and trace the current-voltage characteristics of the photovoltaic panel, we used two identical and pair CIGS modules, a CdTe/CdS module, two multimeters to measure voltage and current, rheostats to play the role of the charge, a Solarimeter model DT 1307 to measure the illumination and a thermometer with thermocouples type K/J to measure the temperature of the photovoltaic panel. To trace the current-voltage characteristic, the data put in Excel are imported into the MATLAB software where we have written programming that allows us to trace the curves.

- For multimeters: two have been used, one acting as an ammeter and the other as a voltmeter. The model used is a CAT IV HT64 digital multimeter with TRMS measurement. It measures electrical current, voltage and resistance over different measurement ranges:

Continuous Voltage (DC) and Alternating Voltage (AC)

Diode test;

Resistance measurement and continuity test;

Hold function, minimum and maximum values and Range function for manual selection of the measurement range;

3½ digits LCD display (maximum 6000 points), decimal separator, automatic polarity indication and backlit.

Technical specifications: uncertainty calculated as [%read + (.dgts number*resolution)] at 18°C: 28°C < 75% HR.

Figure 3: Digital multimeter

- For the thermometer with thermocouple: we used type K/J LCD display (4 digits) double input with a width of 55 mm: for use with thermocouple K and J, temperature display in °C, ° F or Kelvin, double measurement, double display, minimum and maximum measurement, display freeze function, AVG function of the last 10 measurements, automatic extinguishing.

The device specifications

Temperature range:

-200°C~ 1370°C (-328°F~ 2498°F) for type K

-200°C~ 1100°C (-328°F~ 2012°F) for Type J

Thermocouple type K included;

Resolution: 1°C or 1°F/0.1°C or 0.1°F;

Power supply: 1*9 V 6F22 battery (included).

Figure 4: Thermometer with thermocouple

- For the Solarimeter: a model DT 1307 Solarimeter was used to measure the illumination. The model specifications are:

Range: 1999 W/m^2, 634 $BTU/ (ft^2*h)$;

Resolution: 1 W/m^2, 1 $BTU/ (FT^2*h)$;

Accuracy: typically, with +/- 10 W/m^2 [+/- 3 $BTU/ (ft^2*h)$] or +/- 5%;

Sampling time approximately 0.25 second;

Display: 3-1/2 digits LCD with a maximum reading of 1999.

Figure 5: Solarimeter

- For rheostat: three rheostats connected in series were used to play the load roles. The coiled variable resistors are used as means of adjustment of current or alternating voltage (AC) and continuous voltage (DC). Each rheostat has a nominal resistance of 3.3 Ω, the tolerance of resistance is 10%, the permissible permanent load at room temperature is 23°C (10 A), the insulation resistance is greater than 3.10 Ω, the grounding resistance is less than 0.1 Ω, the permissible voltage on the terminals is 600 V maximum, the breaking voltage against the case is greater than 2500 V, the degree of protection is IP 20 and the construction is according to EN 61010-1.

Figure 6: Rheostat

4. Results and Discussion

4.1 Presentation of results

The one-week variation in electrical characteristics of the two modules exposed over three months to actual natural climatic conditions is presented in Table 3:

Table 5: Characteristics of the two CIGS modules

Characteristics	CIGS 1 module					CIGS 2 module				
	Vco (V)	Icc (A)	P (W)	η (%)	FF (%)	Vco (V)	Icc (A)	P (W)	η (%)	FF (%)
W0	23.37	4.26	71.5	13.17	71.72	23.68	4.27	72.22	12.55	71.39
W1	23.74	3.72	63.15	14.00	71.47	24.39	3.87	65.57	13.61	69.45
W2	23.37	3.83	63.79	11.97	71.22	23.96	3.9	64.6	12,00	69.14
W3	23.07	3.66	59.23	13.2	70.05	23.7	2.93	47.01	11.99	67.7
W4	23.84	4.09	68.89	12.67	70.6	24.22	3.77	62.91	11.11	68.75
W5	23.99	3.77	63.86	12.56	64.16	24.48	3.48	58.97	10.44	69.07
W6	23.84	3.152	48.28	10.05	64.21	24.09	2.66	43.69	10.01	68.01
W7	24.34	3.86	66.17	12.71	70.4	24.22	2.97	51.59	10.13	71.53
W8	23.22	3.721	60.69	11.48	70.99	23.5	2.846	45.31	8.26	67.75
W9	23.08	3.102	48.79	9.92	68.15	22.78	2.343	33.82	6.91	64.00
W10	23.58	3.502	48.33	9.41	58.52	23.18	2.314	38.12	6.47	57.81
W11	23.63	4.289	66.26	11.06	65.38	23.87	2.647	28.69	6.53	60.33

The current-voltage and power-voltage characteristics of the two GICS modules studied during the three months of exposure to natural and actual climatic conditions are presented below:

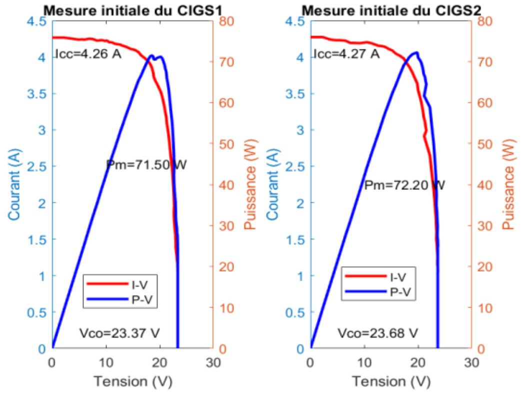

Figure 7: Initial measurement of both CIGS modules

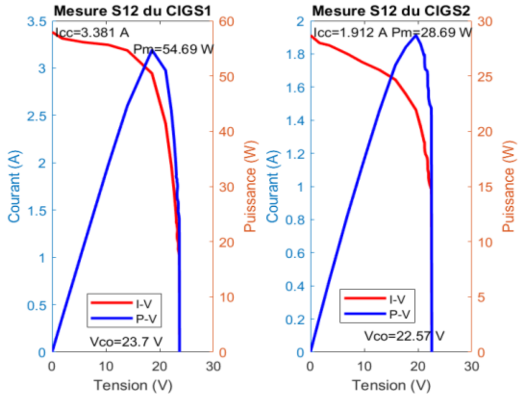

Figure 8: Week 12 measurement for the 2 CIGS

Figures 7 and 8 show the current-voltage (I-V) and power-voltage (P-V) characteristics of the two CIGS modules (CIGS 1 and CIGS 2) of thin film technology and identical manufacturer. They are exposed under different conditions. The CIGS 1 module is cleaned weekly and the CIGS 2 module is left to accumulate dust particles during three months of exposure to natural and real weather conditions.

Both modules were initially characterized, for CIGS 1 the open short voltage is 23.37 V, the short circuit current is 4.26 A, the maximum power is 71.50 W, the efficiency is 13.17% and the form factor is 71.72%.

For CIGS 2, the open circuit voltage is 23.68 V, the short circuit current is 4.27 A, the maximum power is 72.22 W, the efficiency is 12.55% and the form factor is 71.39%.

4.2 Comparison between the two modules

Tables 6 and 7 show the absolute and relative variations in the electrical characteristics of the two CIGS modules.

Table 8 shows the comparison between the relative and absolute variations in the electrical performance of modules exposed for three months without cleaning (CIGS 2) and that with cleaning (CIGS 1).

Table 6: CIGS 1 Weekly Power Loss

Weeks	CIGS 1 Electrical Characteristics									
	Absolute values					Relative values				
	Voc	Icc	Pmax	η	FF	Voc	Icc	Pmax	η	FF
W0	0	0	0	0	0	0%	0%	0%	0%	0%
W1	0.37	-0.54	-8.35	0.83	-0.23	1.58%	-12.67%	-11.67%	6.3%	-0.34%
W2	-0.37	0.11	0.64	-2.03	-0.25	1.56%	2.95%	1.01%	-14.5%	-0.34%
W3	-0.3	-0.17	-4.56	1.23	-1.17	-1.28%	-4.44%	-7.15%	10.27%	-1.64%
W4	0.76	0.43	9.66	-0.53	0.55	3.29%	11.75%	16.3%	-4.01%	0.78%
W5	0.16	-0.32	-5.03	-0.11	-6.44	0.67%	-7.82%	-7.3%	-0.86%	-9.12%
W6	-0.15	-0.62	-15.58	-2.51	0.05	-0.62%	-16.39%	-24.39%	-19.98%	0.07%
W7	0.5	0.708	17.89	2.66	6.19	2.09%	22.46%	37.05%	26.46%	9.64%
W8	-1.12	-0.148	-5.48	-1.23	0.59	-4.6%	-3.83%	-8.28	-9.67%	0.83%
W9	-0.14	-0.62	-11.9	-1.56	-2.84	-0.6%	-16.63%	-19.6%	-13.58%	-4%
W10	0.5	0.4	-0.46	-0.51	-9.63	2.16%	12.89%	-0.94%	-5.14%	-14.13%
W11	0.05	0.787	17.93	1.65	6.86	0.21%	22.47%	37.09%	17.53%	11.71%
W12	0.7	-0.908	-11.57	-0.99	2.88	0.29%	-21.17%	-17.46%	-8.95%	4.4%

Table 7: CIGS 2 Weekly Power Loss

Weeks	CIGS 2 Electrical Characteristics									
	Absolute values					Relative values				
	Voc	Icc	Pmax	η	FF	Voc	Icc	Pmax	η	FF
W0	0	0	0	0	0	0%	0%	0%	0%	0%
W1	0.76	-0.4	-6.65	1.06	-1.94	3.21%	-9.36%	-9.2%	+8 .44%	-2.71%
W2	-0.43	0.03	-0.97	-161	-0.31	-1.76%	0.77%	-1.5%	-11.82%	-0.44%
W3	-0.26	-0.97	-17.59	-0.01	-1.44	-1.08%	-24.87%	-27.23%	-0.08%	-2.08%
W4	0.52	0.84	15.9	-0.88	1.05	2.19%	28.66%	33.82%	-7.33%	1.55%
W5	0.26	-0.29	-3.94	-0.67	0.32	1.07%	-7.69%	-6.26%	-6.03%	0.46%
W6	-0.39	-0.82	-15.28	-0.43	-1.06	-1.59%	-23.56%	-25.91%	-4.12%	-1.53%
W7	0.13	0.31	7.9	0.12	3.52	0.54%	11.65%	18.08%	1.19%	5.17%
W8	-0.72	-0.124	-6.28	-1.87	-3.78	-2.97%	-4.17%	-12.17%	-18.46%	-5.28%
W9	-0.72	-0.5	-11.15	-1.35	-3.75	-3.06%	-17.67%	-24.6%	-16.34%	-5.53%
W10	0.4	-0.029	-0.34	-0.44	-6.19	1.75%	-1.23%	-0.99%	-6.36%	-9.67%
W11	0.69	0.333	4.3	0.06	2.52	2.97%	14.39%	12.71%	0.92%	4.35%
W12	-1.3	-0.735	-9.43	-1.19	6.17	-5.44%	-27.76%	-24.73%	-18.22%	10.22%

Table 8: Variation of the electrical parameters of the two CIGS modules

Modules	Characteristics	Absolute values	Relative values
CIGS 1	Voc	+0. 33	0.014%
	Icc	-0.879	-20.63%
	Pmax	-16.81	-23.51%
	η	-3.1	-23.53%
	FF	-3.46	-4.82%
CIGS 2	Voc	-1.11	-4.68%
	Icc	-2.358	-55.22%
	Pmax	-43.53	-60.27%
	η	-7.21	-57.45%
	FF	-4.89	-6.84%

4.3. Discussion

Tables 6 and 7 show that, in general, the electrical characteristics of the two CIGS modules are modified according to their conditions (clean or dusty). But the effect is more pronounced on the CIGS 2 module than on the CIGS 1 module because the CIGS 2 module is more affected by environmental parameters than the CIGS 1 module. In practice, the performance of the CIGS 2 module decreases from one week to the next depending on environmental parameters such as dust deposition on the module surface.

In the true state of the CIGS 2 module, the short circuit current was worth 4.27 A, the maximum power was 72.22 W and the efficiency 12.55%. With the accumulation of dust particles on the surface of the module, the maximum power, the short circuit current and efficiency are 28.69 W, 1.912 A and 5.34% respectively.

These results alone, like the other technologies, the accumulation of dust and the decrease of the illumination, are the environmental factors which most affect the maximum power and the short-current CIGS-based thin-film solar panel circuit.

Table 8 shows that environmental parameters such as dust deposition, illumination and temperature lead to a sharp decrease in electrical characteristics, except for the open circuit voltage (Voc) which shows a slight increase of 0.014% for CIGS 1. All other characteristics show a large variation for the three months of exposure to real natural climatic conditions without cleaning, with a rate of variation of -60.27% for maximum power, -55.22% for short circuit current, -6.84% for form factor and -57.45% for yield. Note also that the degradation of these characteristics is detected with lower rates of variation on the CIGS 1 module: -23.51% maximum power, -20.63% short circuit current, -4.82% form factor and -23.53% efficiency.

However, this decrease in power and short-current circuit is applied by the fact that the CIGS 1 module receives the maximum amount of sunlight on its surface while the CIGS 2 module receives less and this causes the difference in efficiency of these two thin-layer solar modules based on CIGS.

The comparison of these results shows that, like other technologies, Environmental parameters such as dust deposition and reduced illumination are the most important factors influencing the electrical characteristics of a CIGS-based thin-film solar module.

The difference between the variations obtained on the CIGS 1 and CIGS 2 modules is very large. For example, for maximum power, the difference is 36.74%, which shows that the module exposed for three months without cleaning loses 36.74% more of its power than the module exposed with cleaning.

5. Conclusion

In this work, we presented the results of the experimental study implemented to implement the impact of environmental parameters on the evolution of electrical characteristics of the CIGS-based thin-film solar modules used.

We also compared two CIGS solar modules (clean and dusty) during three months of exposure to real natural weather conditions to see their power drop. We have seen that the performance of solar modules decreases according to environmental parameters such as the accumulation of dust particles on the surface of the modules, the decrease in illumination and the increase in temperature. During the three months of exposure to real natural weather conditions without cleaning, the CIGS module loses an average of 20.74% power.

References

[1]. G. Mohand Kaci, A. Mahrane, M. Chikh, et A. Oulebsir, Etude comparative des performances de modules photovoltaïques de différentes technologies dans un climat méditerranéen. J. Ren, énergies, volume 17 non 2, page 291-300, Juin

[2]. Van dyk et al, Mnotiring current- voltage characteristics and energy output of silicon photovoltaic modules. Renewable Energy, 30(3): 399-411. 2005

[3]. https://www.otovo.fr consulté le 28 Février 2023

[4]. Ahrizi, Roqiya, Baouandji, Warda, Mostefaoui, Mohammed, et. L'influence du changement climatique sur les performances des modules photovoltaïques. 2017. Thèse de doctorat. Université Ahmed Draia-ADRAR.

[5]. www.energieplus-lesite.be consulté le 15/09/2022 à 18h 24 min

[6]. Sayyah et al, Energy yield loss caused by dust deposition on photovoltaic panels Solar Energy, 107: 576-604, 2014.

[7]. Thileli, Djellout et Sarah, Makour. Etude de l'effet de la température et de l'éclairement sur les performances des modules photovoltaïques à base de silicium amorphe. 2017. Thèse de doctorat. Université Mouloud Mammeri.

[8]. Mani M, Pallai R. Impact de la poussière sur les performances solaires photovoltaïque: état de la recherche, défis et recommandation.

[9]. Erteza Tawsif and Md Meganur Rhaman and Al. A review of primary technologies of thin-film solar cells; Engineering Research Express, 2021, https://doi.org/10.1088/2631-8695/ac2353.