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PERFORMANCE DEGRADATION OF PHOTOVOLTAIC MODULES UNDER PARTIAL SHADING CONDITIONS

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Abstract: The utilization of solar energy through photovoltaic (PV) technology has become one of the most sustainable and widely adopted methods of electricity generation globally. Photovoltaic panels, composed of interconnected silicon-based semiconductor cells, operate efficiently when uniformly exposed to sunlight. However, their direct exposure to environmental conditions makes them vulnerable to performance degradation, particularly due to partial shading. Partial shading, often caused by passing clouds, nearby obstacles, or structural interference, disrupts the uniform operation of PV cells, leading to mismatch losses, reduced energy yield, and potential long-term damage. When a cell is shaded, it experiences voltage reversal and excessive heat dissipation, creating hotspots that compromise panel reliability and shorten lifespan. Research has shown that mismatch losses resulting from shading can account for up to 10% of total power losses in PV systems. Furthermore, the type, duration, and pattern of shading play critical roles in determining the extent of its impact on energy output and system efficiency. Given that shading is largely unpredictable and unavoidable, understanding its influence on PV performance is essential for optimizing system design, mitigating energy losses, and enhancing overall reliability. This study investigates the effect of partial shading on photovoltaic panels, highlighting its mechanisms, consequences, and implications for sustainable solar energy generation.

Keywords: Photovoltaic Panels, Partial Shading, Solar Energy Efficiency, Mismatch Losses, Hotspot Effect

INTRODUCTION

The production of electricity by solar energy has become one of the most widely used technologies in the world. This production depends essentially on the sun, and is made through photovoltaic (PV) cells that absorb this energy and transform it into electrical energy. PV cells are wafering a few centimeters in thickness that are usually composed of silicon (Si) semiconductors. These cells must be combined together in series to form a PV panel

(Wang and Hsu, 2011). In order to exploit the energy better, the PV panels are installed in open sky, which exposes them directly to several factors that have a harmful impact on their performance. One of these factors is shading. The PV cells must be identical and benefit from the same operating conditions, however, if any of these cells is shaded, the current through the cell will be very high and voltage across its terminals will be inverted causing a high thermal dissipation on its surface called hotspot (Skomedal et al., 2020; Zhang et al., 2021). Niazi et al., 2019) Partial shading mostly caused by obstacle shadows arising at specific times, and by clouds that move temporarily (Lee et al., 2021), it can be one of the main causes of mismatch losses which are Responsible up to 10% of the total energy generated power (Roy, 2015). Partial shading is not predictable not measurable and unavoidable (Srinivasan et al., 2020). type, duration and pattern of the shade can influence the performance, lifetime, reliability and energy yield of PV modules (Hanifi et al., 2019; Sun et al., 2014; Teo et al., 2018).

Several studies done on partial shading around the world

Rajput et al. (2016) developed a mathematical model to calculate solar cell temperature, hot spot temperature and module efficiency in opaque and semitransparent mono crystalline silicon PV module; calculations of the model estimate the power efficiency of PV models for hot spots (opaque 10.41%, semitransparent 10.62%).

Vargas et al. (2015) found that when number of shaded modules increase small reverse current flows, but when the number of shorted PV modules increases the reverse current increases significantly. Satpathy et al. (2018) studied the effect of partial shading in different grid and sub grid structures; they found that total-cross-tield (TCT) and series-paralell (SP) interconnections have better energy production with reduction in redundancy. In addition, according to Mehedi et al. (2021) the net gain in energy of the micro inverter and power optimizer is significant. when the installation is heavily shaded, but the use of these devices can be counterproductive Ndiaye et al. (2014) showed that the impact of shadow can cause hot spots on the PV module and lead to a degradation of the latter. In addition, partial shadows can create multiple peaks on the P−V curve, thus making it difficult to identify the optimum operating point (Roy, 2015). Faye et al. (2017) investigated the impact of partial shadow on the performance of the PV module installed in a sub-Guinean climate. The different types of shadow transmittance showed that the power loss of the module varies according to the nature of the shadow, the illuminated surface, the study medium and the technology as a function of the transmittance. Gupta et al. (2021) developed an electromagnetic strategy to improve the performance of photovoltaic panels under the effect of partial shading, this strategy consists of replacing the bypass diodes by an electromagnetic relay, which prevents the formation of hot-spot and open-circuit defects. The aim of our work is to study the effect of partial shading on the performance of two types of solar panels; mono-crystalline and polycrystalline.

The idea is to shade a part of PV cell (100, 50 and 20%) with different materials (white paper, transparent paper and tree leaf) of different transmittance level and evaluate the performance of the panels for each shading case. Thus, study the impact of changing the location of the shaded cell on the results obtained.

METHODOLOGY

Exposing PV panels to open sky makes them vulnerable to all kinds of dirt such as dust, bird droppings, and tree leaves. These pollutants deposit on their surface arbitrarily in terms of concentration and location. As a result, the PV cells can be shaded, causing a malfunction of the panel and even a degradation of its performance.

To illustrate the impact of partial shading on the performance of PV panels, we performed an experimental study on a monocrystalline PV module with 72 cells of 16.63 cm×9.97 cm, and a polycrystalline module with 36 cells of 14.80 cm×6.70 cm. The mono-crystalline panel is recently installed, while the polycrystalline panel has been used for 2 years. Both modules contain bypass diodes in their junction boxes (Figure 1 and Table 1).

First, we characterized the different materials used in the experiment by evaluating the light absorption rate for the materials used in the experiment by using a Luxmeter. The experiment is performed in a closed room in the laboratory with constant lighting, the instrument is placed on a work table and the initial value of the light illuminance is measured and noted. Then, one of the materials used for the study is placed on top of the luxmeter while respecting a distance of 15 cm. The new value of the received illumination is measured and noted again.

This experiment is done in the same way for each type of leaf to determine their rate of light absorption. This rate is calculated for each material, using Equation 1.

$$\square = \frac{I_d - I_f}{I_d} \times 100 \qquad (1)$$

where □ the rate of light absorption by a leaf, Id is the initial luminous intensity measured by the luxmeter, and If is the final luminous intensity measured by putting one of the material used for partial shading.

Second, a partial shading experiment of the panels is performed by moving the position of the shaded cell. Thus, for each panel, a part of the cell surface is shaded according to the following proportions: 100, 50 and 20% of the cell with the three types of materials (white sheet, transparent sheet and tree leaf). Before the start of the experiments, the panels were well cleaned and characterized with an IV tracer (IV400).

The study is done on the roof of the building which shelters a part of the laboratory LE3PI of the Polytechnic School of Dakar. Figure 2 shows the flowchart of the experimental procedure. To estimate the loss rate for each electrical parameter of the panels, Equations 2, 3 and 4 are used:

$$\frac{P_{maxi} - P_{maxSTC}}{P_{maxi}} \times 100 \quad \square \quad Pmax= \qquad (2)$$

$$\frac{V_{coi} - V_{coSTC}}{V_{coi}} \times 100 \quad \square \quad Vco= \qquad (3)$$

$$\frac{I_{sci} - I_{scSTC}}{I_{sci}} \times 100 \quad \square \, Icc= \qquad (4)$$

RESULTS AND DISCUSSION

The shadowing of buildings or objects and the deposition of pollutants on the surface of solar panels can cause the phenomenon of partial shading; this phenomenon depends on several factors, including the transmittance of the deposited objects. The rate of light absorption for each type of leaf used is as shown in Figure 3. The light Source: results of my work absorption rate is presented as a function of the amount of light measured in the workroom. The experiment showed that the transparent leaf has a high level of transmittance and is therefore the most transparent leaf followed by the tree leaf and the white leaf, respectively. Each measurement was carried out three times.

The partial shading causes very important degradation rates in the maximum power, short circuit current and open circuit voltage. Figures 4 to 6 show respectively the degradation rate of the power, the open circuit voltage and the short circuit current according to the shading rate of the cell and the technology of solar panels used. The maximum loss rate for the polycrystalline panel is about 60% when the shading is done with the white leaf for a shading rate of 100%.

Figure 1. Mono module under test in partial shade. Source: results of my work

Table 1. Technical characteristics of monocristallin and polycristallin panel in STC.

Panel	Monocrystalline	Polycrystalline
Pmax	245 W	150 W
Imax	8.19 A	8.57 A
Vmax	1000 V	22.5 V
Isc	8.67 A	8.24 A
Voc	36.72 V	18.2 V
Number of cells	72	36
Dimensions (mm)	1663×997×42	1480×670×35

The minimum loss is noted for a shading of 20% of the cell by the transparent sheet with a rate of about 10% loss on the monocrystalline panel.

We find that the degradation rate varies with the shading rate and the leaf used. It increases when the shading rate increases and decreases when the shading rate decreases. Also, the polycristallin module has a more remarkable degradation rate compared to the monocrystalline.

Figures 7 and 8 show, respectively a comparison of the I-V and P-V characteristics of the studied modules operating without partial shading and with partial shading of 100% of the cell using the 3 materials.

Figure 7 shows that the short-circuit current registers a minimum value of 7.2 A when shading by white leaf and a maximum value of 8.3 A for shading by transparent leaf, while the P-V characterization, undergoes the same variation as I-V. The power decreases when the shaded area increases (Figure 8). Moreover, we also notice that drops by 62.51 and 51.51 W, respectively for the monocrystalline and polycrystalline panel, and by 59.55 and

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25.61 W, respectively for the mono-crystalline and polycrystalline panel if the illuminated panel area is 98.62%. This power loss can be reduced by adding a bypass or blocking diode to the PV module (Silvestre et al., 2009).

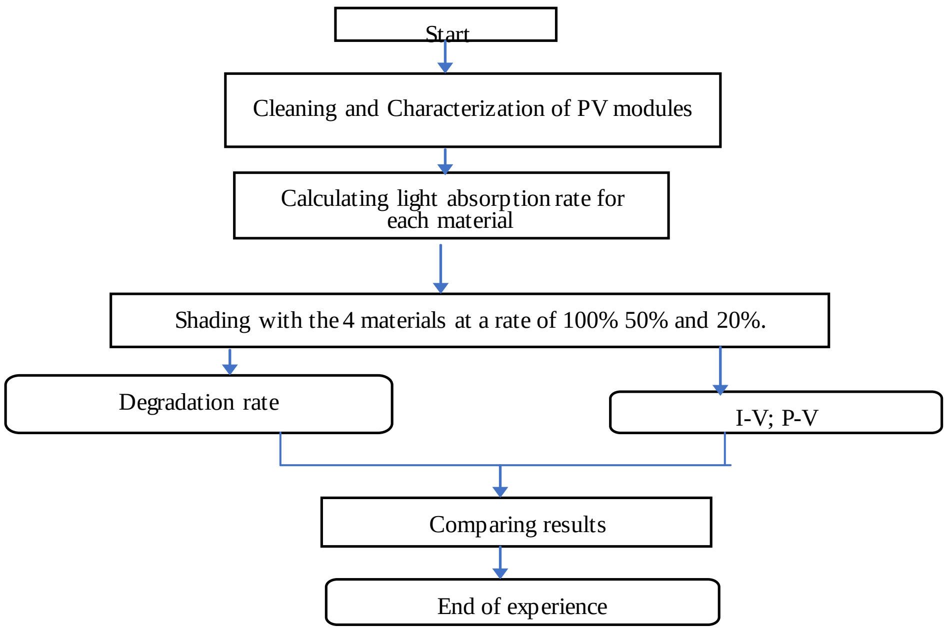

Figure 2. Experiment steps diagram.
Source: results of my work

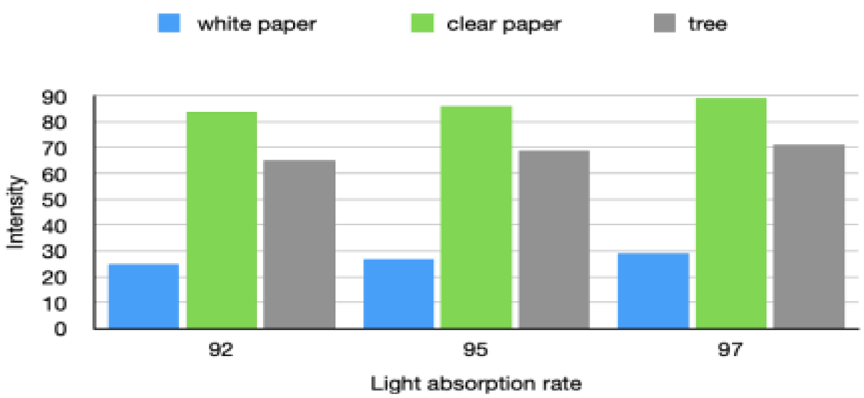

Figure 3. Light absorption rate of each material as a function of intensity. Source: results of my work

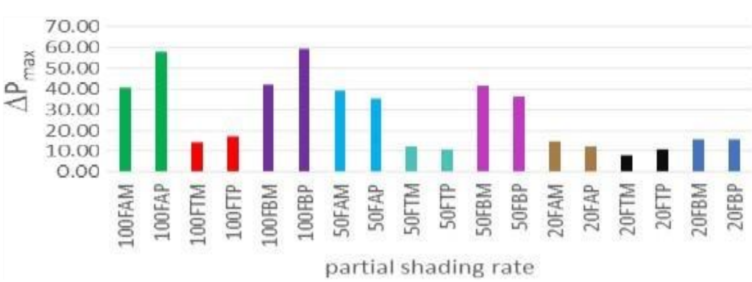

Figure 4. Power loss rate variation as a function of technology and shaded surface of the cell. Source: results of my work

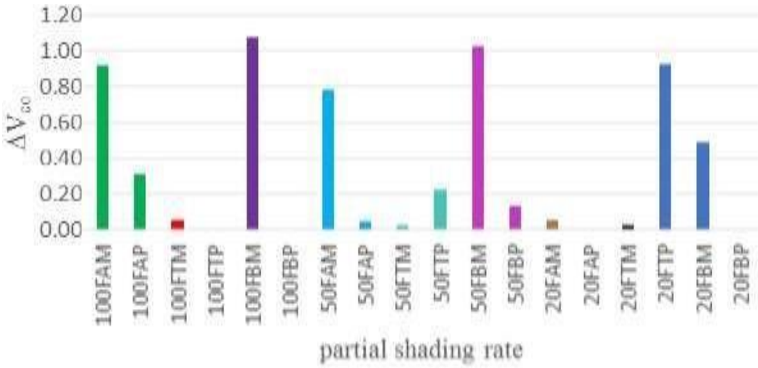

Figure 5. Rate of evolution of the open circuit voltage as a function of technology and shaded surface of the cell
Source: results of my work

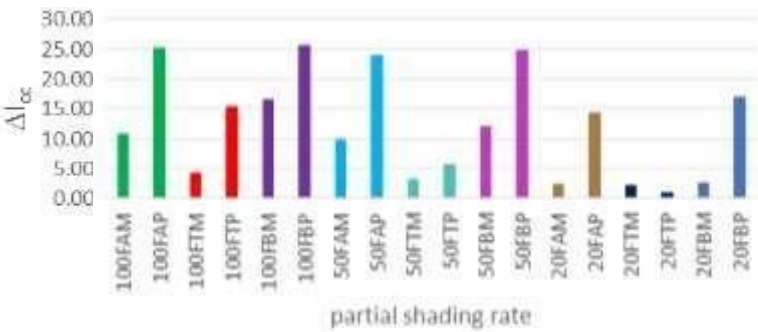

Figure 6. Rate of change of short circuit current as a function of technology and shaded surface of the cell. Source: results of my work

The results of the 50 and 20% partial shading of the cell show the same tendency of variation for each material and for each type of panel technology, shading with transparent sheet gives the best results followed by tree leaf and then white leaf. Table 2 shows the maximum power and short-circuit current results for each type of partial shading.

Source: results of my work

Conclusion

The effect of partial shading on two types of panels, mono-crystalline and polycrystalline PV panels, was studied using three materials and varying the surface area and the shaded cell.

The experiment showed that the power loss of the module depends on the technology of the panel, the nature of shading and the shaded surface, moreover, we found that the polycrystalline module undergoes a higher rate of performance degradation than the mono-crystalline module and the change of the place of the shaded cell does not have an impact on the obtained results.

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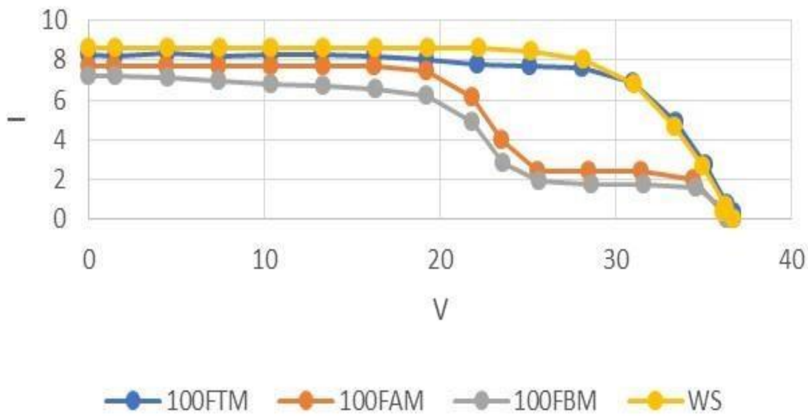

Figure 7. Characteristic of the IV curve of monocrystalline module without shading and with 100% partial shading of the cell by the three materials. Source: results of my work

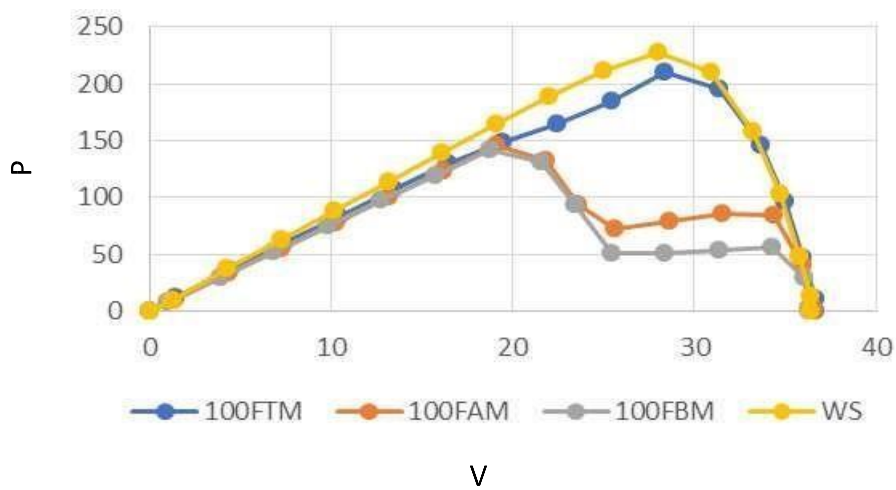

Figure 8. Characteristic of the PV curve of monocrystalline module without shading and with 50% partial shading of the cell by the three materials.

From the results obtained, before implementing a photovoltaic installation, it is necessary to carefully study the site, considering any element causing partial shading.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 2. Shading partial experiment for different panel and material.

Parameter	Pmax (W)	□Pmax (%)	Isc (A)	□Isc (%)

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	0%	Without shading	228.28	6.82	8.61	0.69
	100%	Transparent paper	210.06	14.26	8.36	4.26
		Tree left	145.94	40.68	7.72	10.95
	50%	White paper	141.32	42.06	7.23	16.60
		Transparent paper	214.13	12.60	8.39	3.22
Monocrystalline		Tree left	148.66	39.32	7.82	9.80
		White paper	143.39	41.47	7.62	12.11
		Transparent paper	224.43	7.91	8.48	2.19
	20%	Tree left	209.36	14.67	8.46	2.42
		White paper	206.38	15.89	8.45	2.53
Polycrystalline	0%	Without shading	134,23	10.51	8,52	0.58
	100%	Transparent paper	123.97	17.35	7.43	15.34
		Tree left	61.35	57.86	6.51	25.20
	50%	White paper	60.98	59.34	6.41	25.67
		Transparent paper	133.59	10.94	8.08	5.71
		Tree left	97.16	35.22	6.52	23.92
		White paper	95.09	36.60	6.44	24.85
		Transparent paper	133.89	10.74	8.49	0.93
	20%	Tree left	132.1	12.48	7.34	14.35
		White paper	131.28	15.87	7.11	17.03

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