

# Effects of the Shading Rate on the Electrical Parameters of CIGS-Based Solar Modules

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## Abstract

The aim of this article is to study the effects of the shading rate on the electrical performance parameters of CIGS PV modules. The study concerns a new flexible CIGS type photovoltaic module with a power of 90 W, manufactured by the company Shenzhen Shine Solar Co., Ltd. This module, reference SN-CIGS90, is tested under the initial conditions to ensure its correct operation and to determine the initial values of the electrical parameters before shading. After this characterization test, the module is exposed under the actual operating conditions of the Renewable Energies Study and Research Center (CERER), located in Dakar, then 4 types of shading are performed with the same mask: partial shading 25% partial shading, 50% partial shading, 75% partial shading, and 100% full shading. The variation rates obtained on the experimental values of the 4 types of shading carried out determine that the shading phenomenon constitutes a factor that influences negatively on the electrical parameters of a CIGS-based PV module. Indeed, for 25% of the surface of the shaded module, there is a reduction of 58.139% of the maximum power and of 60.507% of the efficiency and for shading of 100%, the module loses 84.436% of its maximum power and 84.135% of its performance.

## Keywords

Modulus, Shading Rate, Electrical Parameters, Mask

## 1. Introduction

When new, a PV module is characterized by its electrical parameters such as short-circuit current; the open-circuit voltage, efficiency and the maximum

power it delivers. These data vary overtime when the module is exposed to sunlight with the actual operating conditions of the installation site [1].

This variation can be due to several factors, among which we can quote the shading. Studies have shown that the output power of photovoltaic panels is sometimes lowered due to the appearance of shadow on them [2] [3]. In one of their studies, Zaihidee *et al.* [4] showed that on only 2% of the shaded area of the module, the performance loss was 70%.

Shadows can be caused by trees, buildings, but also by mounting structures of some modules on others, droppings falling on the modules as well as leaves from trees and others...

When a module is shaded in a series-connected module system, bypass diodes can prevent the shaded module from being reverse biased. If the bypass diodes open, the shaded module is indeed shorted. And if the bypass diodes fail or are ineffective, the shaded module may experience reverse bias stress, which is very dangerous for the module [5].

It has been observed that CIGS modules, subjected to the stresses of reverse polarizations, develop white characteristics similar to worms visible under the glass which have been associated with hot spots [6]. The presence of hot spots in CIGS modules is a key factor in the failure of these modules due to shading [7] [8].

The use of protective diodes to protect against power loss and reverse bias is difficult in thin-film modules [9].

In our study, we showed the impact of shading on the electrical parameters of CIGS-type photovoltaic modules installed in a Sahelian environment. The analysis of the various rates obtained on the experimental values of 4 types of shading is the object of this study.

## 2. Experimental Study

### 2.1. Description of the Experimental Material

#### 1) The flexible CIGS module

To carry out this experimental study of the effect of the shading rate on the electrical parameters of CIGS-based solar modules, we bought a new flexible CIGS type module. **Table 1** shows the construction data of the module.

**Figure 1** shows the module in a new condition.

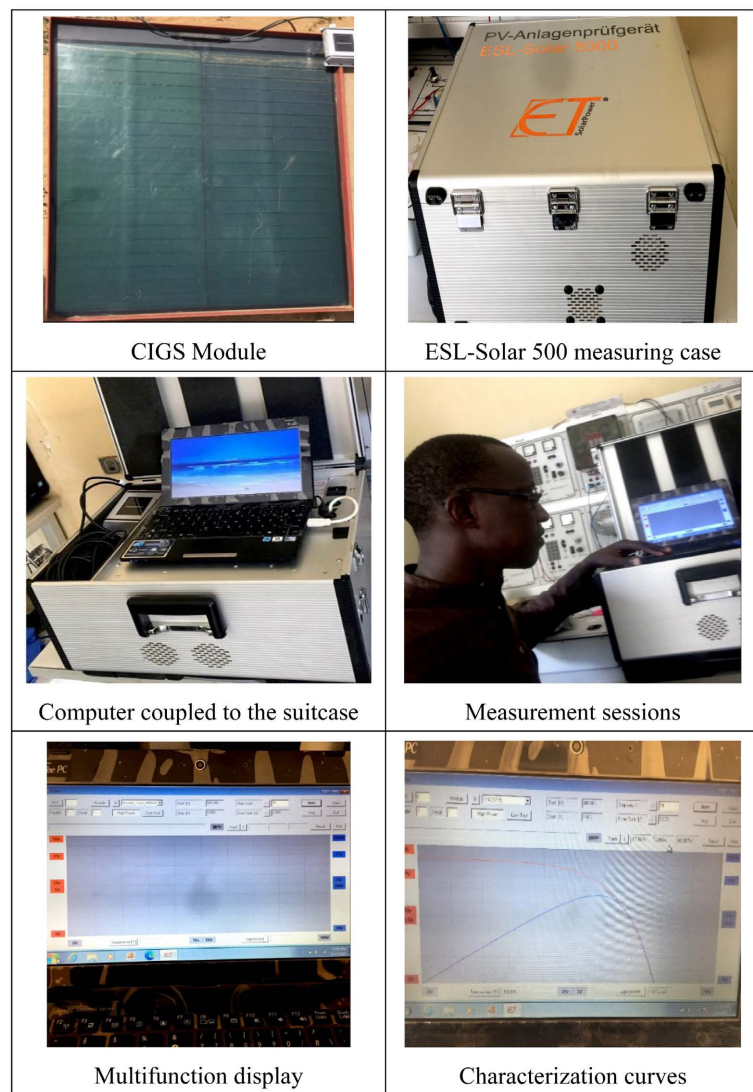
#### 2) The measurement platform

The work was carried out on the site of the Center for Study and Research on Renewable Energies of the Cheikh Anta DIOP University of Dakar (CERER) where the flexible CIGS type module was exposed. The measurement platform also includes the electronic analyzer ESL-Solar 500 which is an electronic case specially designed for testing solar cells and modules of all technologies. It measures the short-circuit current, the open-circuit voltage, the maximum current, the maximum voltage, the form factor, the maximum power, the efficiency, the temperature of the module, the irradiation... All these functions are dis-

played on the clear multifunction screen of a computer coupled to the suitcase. **Figure 2** shows the device for experimental measurements.



**Figure 1.** CIGS module in new condition.



**Figure 2.** Characterization tests and determination of initial values.

**Table 1.** Construction data of the module.

Technology	Reference	$V_{co}$ (V)	$I_{cc}$ (A)	$P_{max}$ (W)	$\eta$ (%)
CIGS	SN-CIGS 90	4.890	25.600	90.00	14

## 2.2. Experimental study

After this test, the module is exposed on the CERER site and underwent 4 types of shading:

- Partial shading at 25%, corresponding to a quarter of the surface of the module.
- Partial shading at 50%, corresponding to half of the surface of the module.
- Partial shade at 75%, corresponding to three quarters of the surface of the module.
- Total shading at 100%, corresponding to the total surface of the module.

**Figure 3** illustrates this.

## 3. Results and Discussions

Using an “ESL-SOLAR-500” analyzer, we sought to determine the effect of the shading rate on the electrical performance parameters of the CIGS module. The study is carried out at the Renewable Energies Study and Research Center (CERER), located in Dakar. The results obtained are presented in **Table 2**.

In our experimental studies below, we need to determine the rates of absolute and relative variations between the initial parameters and those obtained after the study. For this, we used the following equations:

$$\text{TVA} = V_F - V_I \quad (1)$$

$$\text{TVR} = \frac{V_F - V_I}{V_I} \times 100 \quad (2)$$

VAT, the absolute rate of change, TVR, the relative rate of change;

$V_f$ , the final value of the parameter and  $V_i$ , the initial value of the parameter.

**Table 3** shows the results obtained as a function of the shading rate.

We observe in this study a strong decrease of all the electrical parameters which increases with the shading rate, except the open-circuit voltage  $V_{co}$ , which presents a slight decrease.

Indeed, for 25% shading, the module loses 58.139% of its maximum power ( $P_{max}$ ), 60.507% of its efficiency ( $\eta$ ), 35.035% of short-circuit current ( $I_{sc}$ ) and only 1.269% of the voltage open circuit ( $V_{co}$ ). For 50% of the surface of the shaded module, the loss is 73.866% of  $P_{max}$ , 60.293% of  $\eta$ , 39.648% of  $I_{sc}$  and 4.612% of  $V_{co}$ . For 75% of the surface of the shaded module, the loss is 82.153% of  $P_{max}$ , 75.352% of  $\eta$ , 74.122% of  $I_{sc}$  and 9.678%  $V_{co}$ . For total shading, the module loses 84.436% of its maximum power, 84.135% of its efficiency, 82.482% of short-circuit current and 11.086% of the voltage open circuit.

These results obtained only like all thin-film technologies, for which shading constitutes a phenomenon that severely reduces the efficiency of CIGS-based

**Table 2.** The different electrical parameters obtained for the 4 types of shading.

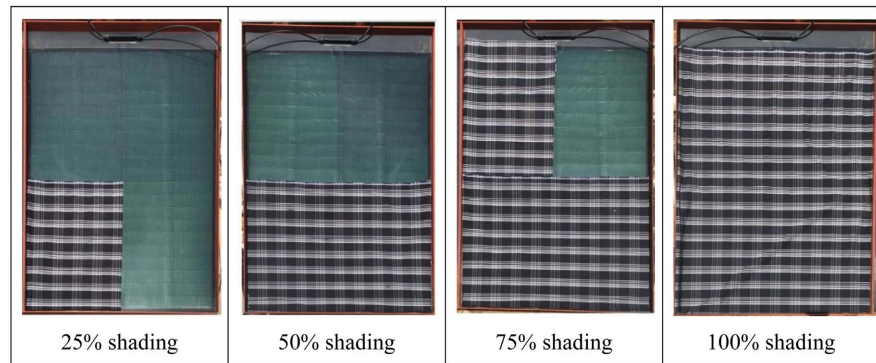
Module (SN-CIGS90)	Experimentals Conditions					
					<ul style="list-style-type: none"> <li>• Illuminance (W/m<sup>2</sup>) 825: Initial measurement (before shading)</li> <li>• Illuminance (W/m<sup>2</sup>) 837: First measurement (25% shading)</li> <li>• Illuminance (W/m<sup>2</sup>) 835: Second measurement (50% shading)</li> <li>• Illuminance (W/m<sup>2</sup>) 838: Third measurement (75% shading)</li> <li>• Illuminance (W/m<sup>2</sup>) 830: Fourth measurement (100% shading)</li> <li>• Temperature (°C) 57: Initial measurement (characterization test)</li> <li>• Temperature (°C) 52.9: First measurement (25% shading)</li> <li>• Temperature (°C) 55: Second measurement (50% shading)</li> <li>• Temperature (°C) 50.5: Third measurement (75% shade)</li> <li>• Temperature (°C) 55.0: Fourth measurement (100% shading)</li> </ul>	
		Parameters	$I_{cc}$ (A)	$V_{oc}$ (V)	$P_{max}$ (W)	$\eta$ (%)
		Initial values before shading	4.270	23.092	60.917	13.048
		Values obtained for 25% shade.	2.774	22.799	25.500	5.153
		Values obtained for 50% shade.	2.658	22.027	15.920	5.181
		Values obtained for 75% shade.	1.105	21.685	10.872	3.216
		Values obtained for 100% shade.	0.748	20.532	9.481	2.070

**Table 3.** Results on the shaded module, (a) 25% shading, (b) 50% shading, (c) 75% shading, (d) 100% shading.

Moduls	Parameters	The absolute rate of change	The relative rate of change
(a) 25% shading	$P_{max}$ (W)	-35.417	-58.139%
	$V_{oc}$ (V)	-0.293	-1.269%
	$I_{cc}$ (A)	-1.496	-35.035%
	$\eta$ (%)	-7.895	-60.507%
(b) 50% shading	$P_{max}$ (W)	-44.997	-73.866%
	$V_{oc}$ (V)	-1.065	4.612%
	$I_{cc}$ (A)	-1.693	-39.648%
	$\eta$ (%)	-7.867	-60.293%
(c) 75% shading	$P_{max}$ (W)	-50.045	-82.153%
	$V_{oc}$ (V)	-2.235	-9.678%
	$I_{cc}$ (A)	-3.165	-74.122%
	$\eta$ (%)	-9.832	-75.352%
(d) 100% shading	$P_{max}$ (W)	-51436	-84.436%
	$V_{oc}$ (V)	-2.560	-11.086%
	$I_{cc}$ (A)	-3.522	-82.482%
	$\eta$ (%)	-10.978	-84.135%

solar panels, even at new condition. This reduction depends on the area of the shaded module.

We have also observed that the loss of performance linked to the effect of shading depends on the nature and the thickness of the mask.



**Figure 3.** Different types of shading.

In fact, in these experimental research works, we also used masks of different types and thicknesses, to perform total shading on the same module under the same experimental conditions, and we obtained different results.

**Figure 4** illustrates this.

The results obtained on the variation of the electrical parameters for each type of mask are shown in **Table 4**.

The analysis of these experimental results above allows us to say that the decrease in electrical parameters depends on the nature but also on the thickness of the mask used. Indeed, the loss of power is estimated at 39.910% for the total shading with a blue plastic tarpaulin as a mask, a little transparent, 84.436%, for the total shading with a simple cotton fabric mask (75% cotton) and at the end, 87.905% for total shading with a lab coat (100% cotton) used as a mask. **Figure 5** shows the characteristic curves of the module as the function of shading rate.

The general shape of I (V) and P (V) curves shows that the shading causes significant deformations in I - V and P - V characteristics of CIGS-based photovoltaic modules. These deformations are more visible in the case of partial shading at 25% and 50% and we note in these two cases a non-uniformity of the curves.

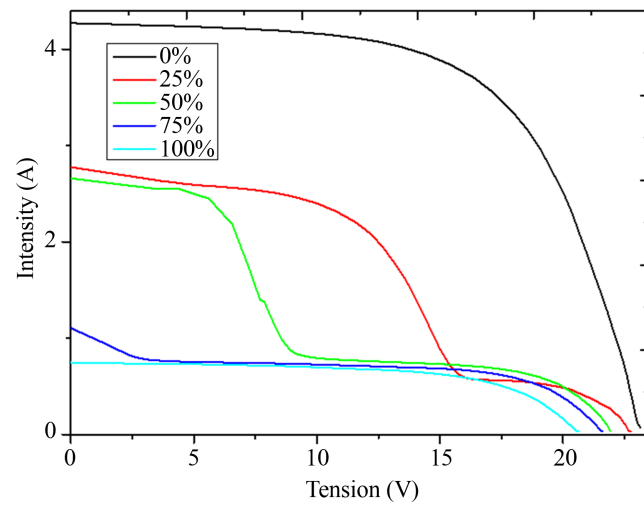
We also observed a sharp decrease in the short-circuit current caused by shading. This reduction is obvious, insofar as the mask blocks the arrival of solar radiation on the surface of the module, which leads to a reduction in the charge carriers generated by the module and consequently a reduction in the short-circuit current depending on the module.

Studies have shown that for a cell with a high shunt resistance, the effect on the distortion of I - V characteristic will be less severe [10]. Another effect of shading is that of shifting the point of maximum power to lower voltage values. Indeed, the smallest shading rate (25%) performed on the module, generates a power reduction of around 58.139% which is dissipated in the form of heat. In short, the shading effect can cause poor operation of the photovoltaic system, which is why the solar panels must be protected by bypass diodes and the system must be connected to an inverter following the maximum power point (MPP) in order to be able to carry out permanent monitoring of the system.

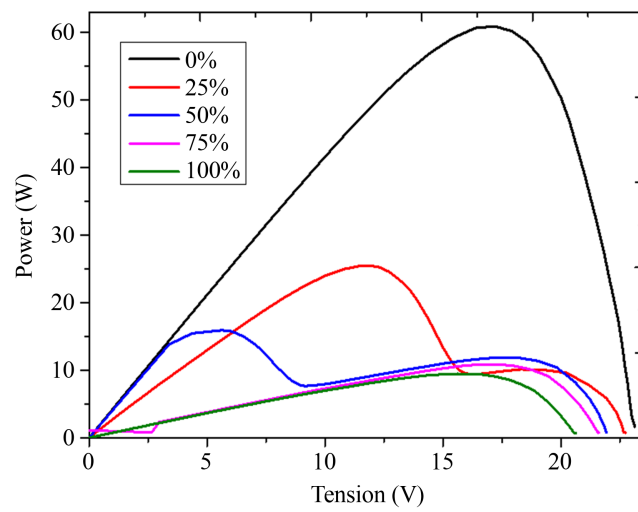




**Figure 4.** Full shading with different masks.



(a)



(b)

**Figure 5.** I - V and P - V characteristic curves of the module as a function of the shading rate, where: (a) represents I - V and (b) represents P - V.

**Table 4.** Results obtained for total shading with different masks.

Experimental conditions	<ul style="list-style-type: none"> <li>• Illumination (W/m<sup>2</sup>) 830</li> <li>• Temperature (°C) 55:</li> </ul>			
Parameters	$I_{cc}$ (A)	$V_{oc}$ (V)	$P_{max}$ (W)	$\eta$ (%)
Initial values before shading	4.270	23.092	60.917	13.048
Values obtained for total shading with a slightly transparent plastic cover	2.604	22.935	36.605	7.877
Values obtained for full shade with a single cotton fabric of (75% cotton)	0.748	20.532	9.481	2.070
Values obtained for total shade with a lab coat (100% cotton)	0.680	20.669	7.368	1.618

## 4. Conclusion

Our study focused on the analysis of variations in the electrical parameters of a CIGS-based photovoltaic module under shading conditions. The evolution of the electrical parameters describing the operation of the module as well as the I - V and P - V characteristics with the shading rate were obtained for four occultation configurations. The objective was to study the impact of the shading rate on the electrical parameters of the module in question. The data collected indicate that the shading causes a sharp decrease in the electrical parameters of the CIGS modules. Apart from the open-circuit voltage, which is not too much influenced by the shading phenomenon because it shows a slight decrease, all the other parameters show a strong decrease, the value of which increases with the percentage of the shaded area of the module but also the nature and thickness of the mask used.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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