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Evaluation of the impact of partial shading and its transmittance on the performance of crystalline silicon photovoltaic modules

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This paper presents on the one hand, an evaluation of the impact of partial shading on the performance parameters of two photovoltaic modules respectively in poly and mono. The current-voltage characteristic (I-V), the short-circuit current (Icc), the open-circuit voltage (Vco) and the maximum power (Pmax) were studied. In this work, the measurements were carried out under the standard conditions (STC) in order to make a comparative study of the performance parameters as a function of the illuminated surfaces and the transmittance of the partial shading of two technologies (mono and poly). The results have shown that the power losses under partial shading are much greater for silicon-monocrystalline than for polycrystalline for a transmittance of [0.2 to 1.2] and smaller for [0 to 0.2]. However, the open circuit voltage is not affected for both technologies. On the other hand, the reduction of the short-circuit current is much more important for the polycrystalline.

Key words: Photovoltaic module, photovoltaic (PV) module performance parameter, shading.

INTRODUCTION

With decline of fossil fuel reserves in the world, renewable energies deserve serious studies and are developed on a very large scale. In recent years, these energy sources deserve much more attention. The reduction of photovoltaic production costs and the installation of photovoltaic systems connected to the grid are the main reasons for this trend. During operation, the photovoltaic arrays may be totally or partially shaded, which can lead to a significant decrease in performance. One of the most influential factors on PV power generation is shade (Bai et al., 2015). Intermittent shadows are caused by rapid clouds or built-in obstructions that are more difficult to predict with intermittent impact on losses (Bressan et al., 2015). Full

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Table 1. Characteristics of the two photovoltaic modules: mono and poly.

Cellular technology	Monocrystalline	Polycrystalline
Maximum power (Pmax)	85W	125W
Short circuit current (Isc)	5.15A	7.89A
Open circuit voltage (Voc)	22.2V	22.0V
MPP current	4.80	7.14A
MPP voltage	17.8V	17.5V
Output Tolerance	5%	5%
NOCT	45C	45C
Dimension	1195 mm 541 mm 30 mm	1200 mm 530 mm 35 mm

or partial shading of a PV module directly affects PV system performance (Chao et al., 2015). Also, there are methods capable of detecting module failure and especially partial shading defects (Bressan et al., 2015). Much work has been done in the literature and has shown the effect of shading on the performance of PV modules. This work explored strong correlations between power losses and the geographical location of the environment (Almasoud and Gandayh, 2015). The crystalline solar cells of the modules are forced to work under partial shading with percentages: 25, 50, 75 and 100% on different parts of the module. However, the shading of a cell or group of cells does not have enough impact on the output power of a photovoltaic module (Deline, 2009) as some of the power is dissipated as heat by the shaded cell. The duration of the power drop is related to the type of shadow on the PV dule such as dirt, building environment, leaves, dust etc. The impact of the shadow can cause hot spots on the PV module and lead to a degradation of the latter (Ndiaye et al., 2014). Rajput et al. (2016) showed that, the power efficiency of PV modules has been estimated for hot spot (opaque 10.41%, semitransparent 10.62%). To avoid this phenomenon of dissipation, the manufacturers integrate by-pass diodes at the levels of each 18 cells (Woyte et al., 2003). The main studies presented in the literature have used simulation results without testing experimental data from actual monitoring of photovoltaic systems (Chao et al., 2015). Most of the diagnostic methods are based on the comparison of the controlled data with the simulation results of the photovoltaic systems (Gokmen et al., 2012; Karatepe et al., 2007). In addition, some fault analyzes have compared data with actual measurements; meanwhile, other work is based on statistically analyzed data using learning methods (Díaz-Dor et al., 2010). A sophisticated verification method described in (Kurokawa and Uchida, 1999) also allows checking the shadows on the PV modules. As the performance of the PV module depends on the area, technology and solar irradiation (Pisa et al., 2013), it is indeed, generally impossible to avoid the shadow of clouds, dirt etc . It will be important to investigate the type of shadow (transmittance) and the relative surface area of the shadow (Reinoso et al., 2013). The influence of partial shading on PV modules has been studied by several authors (Wang and Hsu, 2011; Gluchy et al., 2014; Tian et al., 2013). Some have focused on the angle of optimal system configuration under partial shading (Topic et al., 2017). Other work has focused on the position of shading on the module (Woyte et al., 2003). However, most of the works have not attempted to see the relation between transmittance and the relative surface of the shadow on the one hand, and that between the relative surface and the technology. The objective of this work is to characterize the impact of the transmittance of partial shading and its surface depending on the technology and performance parameters of the module.

EXPERIMENTAL STUDY AND METHODOLOGY

The characteristics of the modules used are presented in Table 1. In this work we used two PV modules: 85w mc-Si and 125w pc-Si. The modules are each made up of 36 cells. Currently, the method generally used to reduce power losses from partial shading is to divide the module into several cell groups. The module which is the object of our work is composed of two groups of cells each composed of 18 cells. Each group is protected by a bypass diode (Alonso et al., 2006) which makes two bypass diodes for each module. These are configuration that one finds in the most part on the market.

Presentation of modules

They are two photovoltaic modules, a monocrystalline and a polycrystalline represented in Figure 1. These modules operate under partial shading at illuminated surfaces and different transmittances. The equipment used is composed of an IV-400 analyzer which allows producing the I-V characteristics during a time interval of 5 min with a pyranometer that measures the sunshine. The electrical requirements of the photovoltaic modules are given in Table 1.

Presentation of the "I-V 400 photovoltaic module analyzer"

"I-V 400" performs the measurement of the I-V field main feature of a single module or a module string. The instrument measures together with the characteristic I-V, the temperature of the module and the sunshine in (W/m^2) being tested along with the values of its

Figure 1. Mono and poly under test module in partial shading.

temperature and its incident Irradiation. The acquired data is then processed and then extrapolated to the standard test conditions (STC) in order to compare with the nominal data reported by the module manufacturer, immediately determining whether the chain or module tested meets the characteristics declared by the manufacturer. The current or output voltage of the module is measured with the 4-terminal method, which allows extending the measuring cables that do not require compensation for their resistance, always providing precise measurements. The maximum output voltage is measured at 1000V DC and the maximum output current measurement is 10A DC. The measurement of the solar irradiation (W/m^2) is carried out with a reference cell. The output power and nominal power of the module are also measured. Digital and graphic display of the I-V curve is available. The mechanical inclinometer is integrated to detect the angle of incidence of solar irradiation. This study method comprise measuring the I-V characteristics of each module under different environmental conditions for a time interval of 5 min.

Approach

In order to study the impact of shading according to the technology, we proceeded by using a mc-Si pc-Si and I-V 400 module.

By varying the shading rate of each cell from 25 to 100% for a step of 25% depending on the technology used, the results are stored in a PC machine that collects the data. For the measurement of transmittance, a spectrophotometer was used which measures the transmittance of the various materials used to mask the cells. The performance parameters (curve I-V and P-V, Icc, Voc and Pmax) are measured under the STC conditions. The influence of shading on the characteristic of the PV module can be taken into account by the shading coefficient ηs given by the following relation.

$$\eta_s = \frac{Ps}{Pt\frac{As}{A}} \quad (1)$$

Where, Ps is module power with shading, P_t is module power without shading; As is the illuminated area of the module, and A, the total area of the module. This study will focus on evaluating the parameters Pmax, Icc and Vco on each technology using the partial shading rate according to the following relationships.

$$\Delta Pmax\ (\%) = \frac{PmaxN - Pmax,}{PmaxN} * 100 \quad (2)$$

$$\Delta Vco(\%) = \frac{Voc,N - Voc,stc}{Vco,N} * 100 \quad (3)$$

$$\Delta Icc(\%) = \frac{Isc,N - Isc,stc}{Isc,N} * 100 \quad (4)$$

RESULTS AND DISCUSSION

Impact of partial shading

Impact on transmittance

The dust can be distributed in a non-isotropic manner on a PV module, hence the different shading factors may not be distributed isotropically. This can affect the amplitude of the transmittance of these shading factors as well as the spectral response of different shadows of different transmittances. The various materials used to partially mask the cell includes Silicone noire, Yellow scotch, Ruban tissu béton 2couches, White paper, Yellow card

Figure 2. The mono and poly module under test with the I-V analyzer.

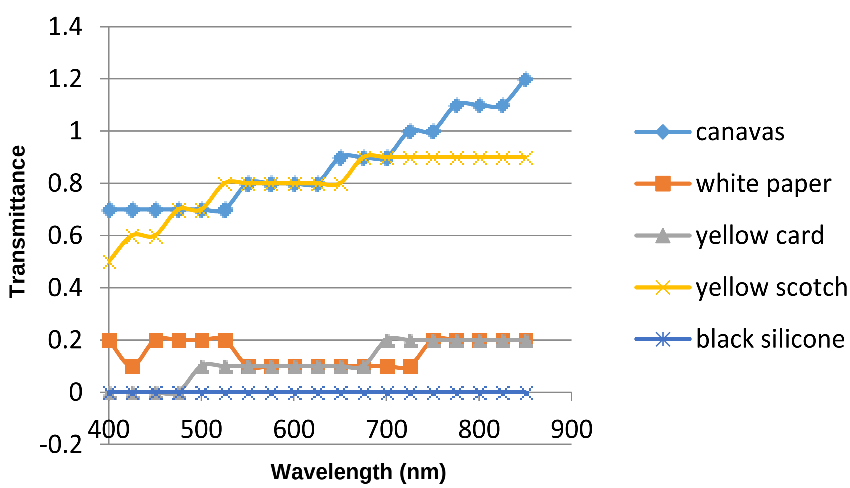

Figure 3. Transmittance of the different materials used as a function of the wavelength in (nanometer).

and Canavas. Figure 2 shows the two modules exposed in field.

The amplitude of transmittance of these different materials as a function of the wavelength is given in Figure 3 with a constant value of the angle of inclination.

Figure 3 shows that the tansmittance of the fabric is much greater than that of the black silicone which has an almost zero transmittance. Partial shading was performed artificially on different technology modules; and the results obtained for different transmittances of light to different technologies are given in Figure 3 showing transmittance of partial shading of two technologies (mono and poly). The results have shown that the power losses under partial shading are much greater for mc-Si than for pc-Si for a tansmittance of [0.2 to 1.2] and smaller for [0 to 0.2]. Experience has shown that this results may be the object of our future. Figure 4 illustrates the rate of power of the two technology as a function of transmittance.

The Δpmax decrease when the transmittance decrease; also, when the transmittance increase the irradiation increase as well as the Pmax. Figures 5 and 6 show respectively the change of short-circuit current and the evolution of open circuit voltage as function of a transmittance.

Impact of partial shading on the I-V and P-V characteristics

Figure 7 shows the I-V and P-V characteristics of the studied modules operating in the normal state and under

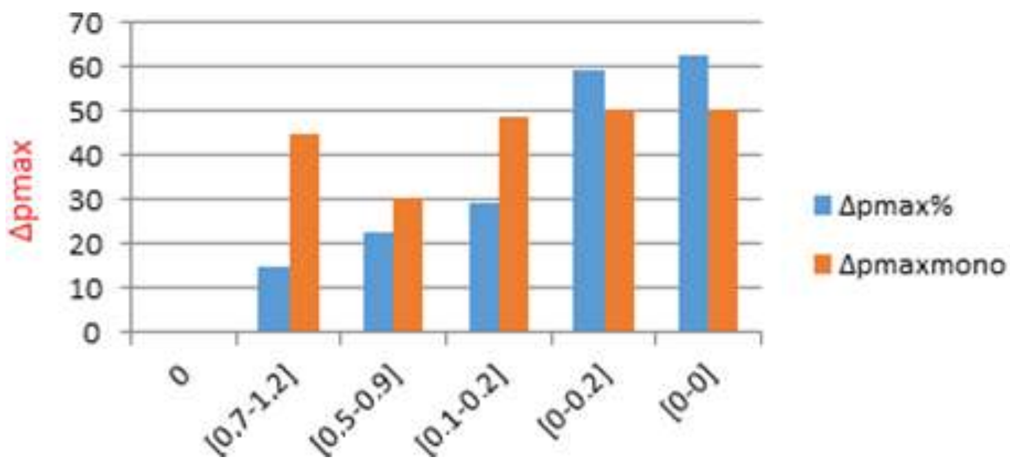

Figure 4. Rate of power loss as a function of transmittance and technology.

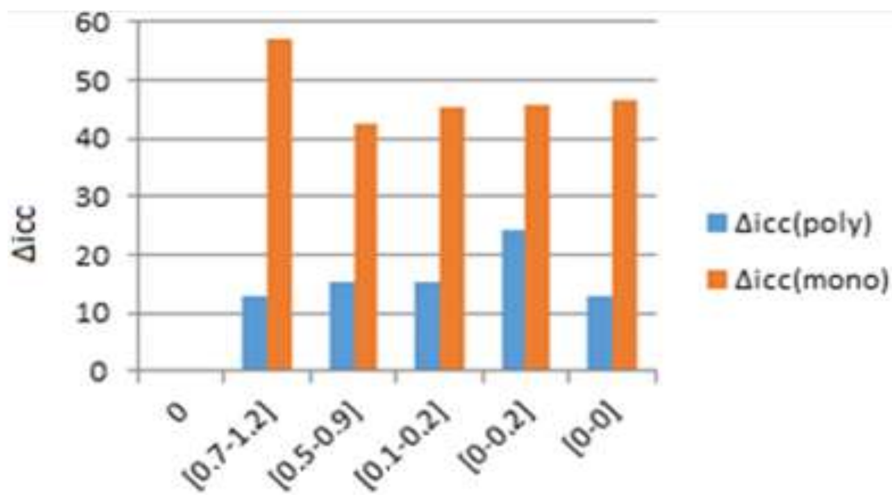

Figure 5. Rate of change of short-circuit current as a function of transmittance and technology.

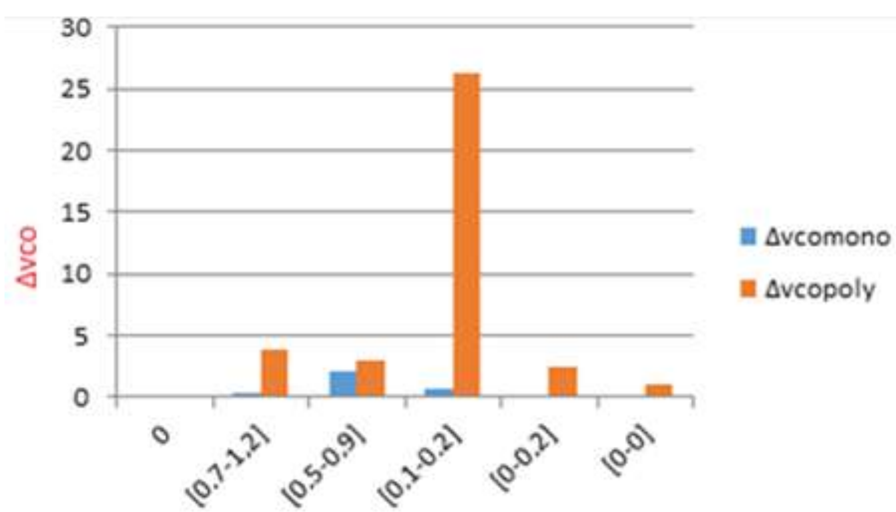

Figure 6. Rate of evolution of the open circuit voltage as a function of transmittance and technology.

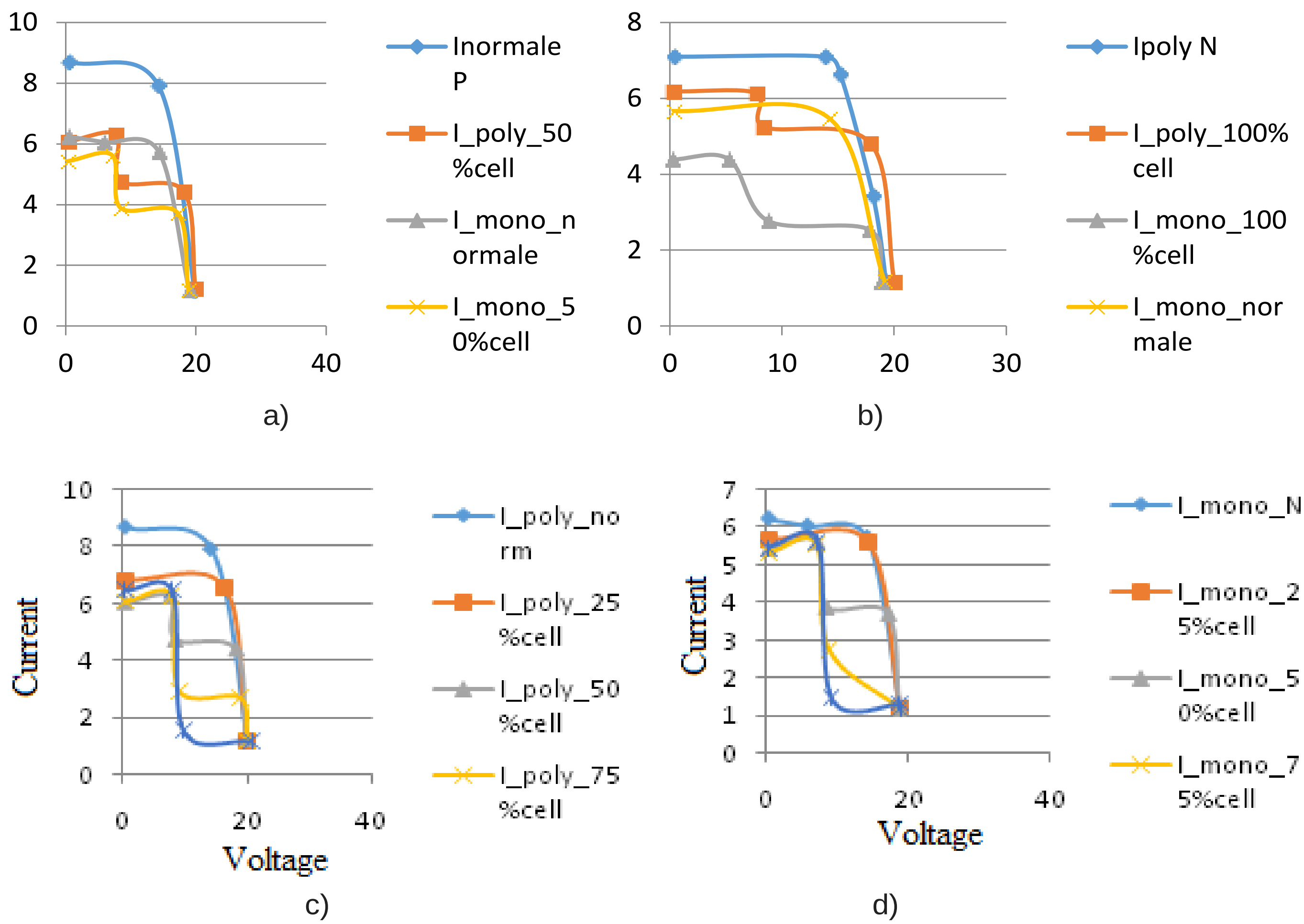

Figure 7. I-V and P-V characteristics of the studied modules operating in the normal state and under partial shading a) I-V normal silicone and 50% cell b) normal I-V and 50% cell masqued [0.7 - 0.12] masked for a transmittance T = 0.

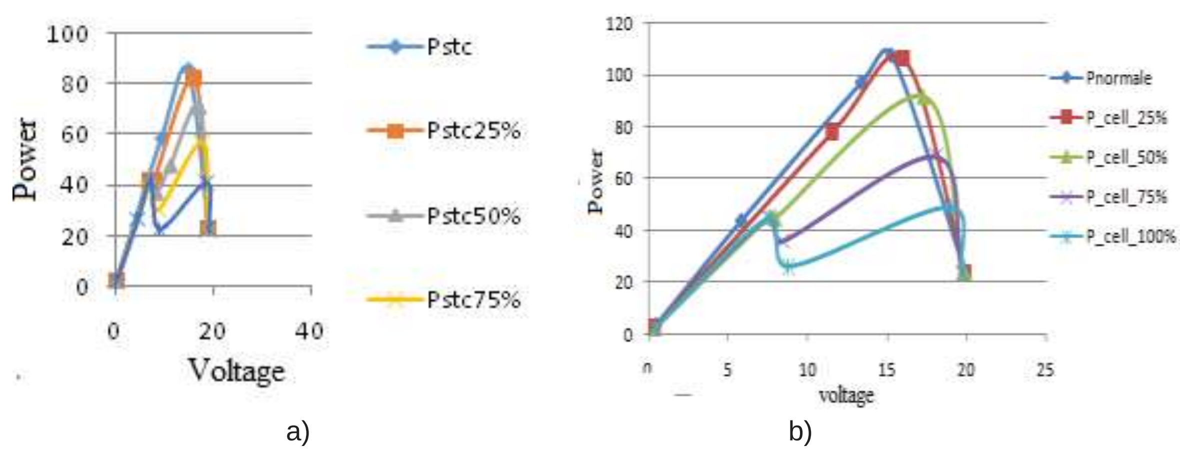

Figure 8. P-V curves with different illuminated surfaces a) White mono sheet b) White sheet poly.

partial shading while Figure 8 shows the P-V curves with different illuminated surfaces. This decrease in the short-circuit current varies as a function of the surface of the shadow on the cell. Figure 9 shows the P-V curves with differents rate and transmittance of mono and poly.

The Pmax of the module varies according to the

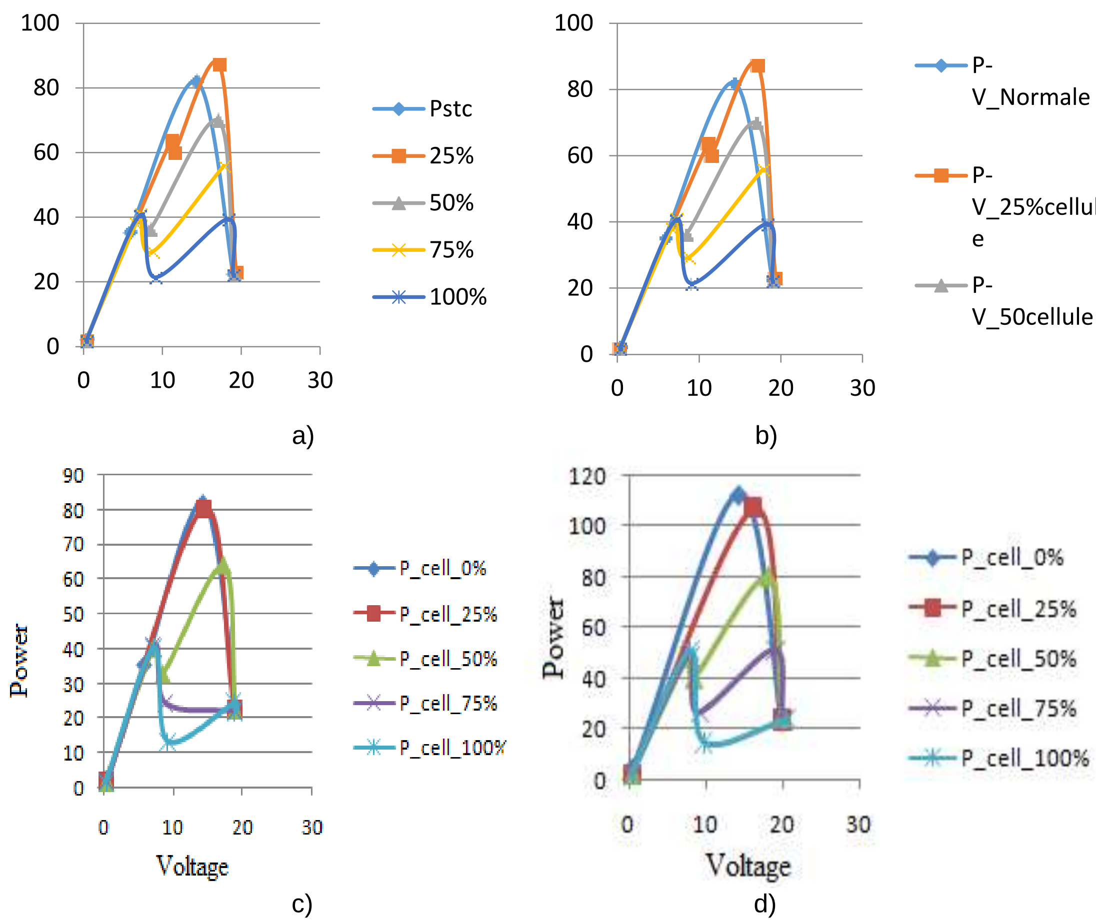

Figure 9. P-V curves with differents rate and transmittance of mono and poly a) yellow card pc-Si b) yellow card mc-Si c) P-V curve silicone mono d) P-V curve silicone poly.

transmittance of the mask and the percentage of surface masked on the cell. For a material with the same percent transmittance of the cell ranging from 0 to 100%, Under STC conditions, the maximum power point (PMPP), STC appears on two peaks following the shading surface. There is the appearance of two points of Pmax as the power has increased from 64.69 to 30.14W. Volquer and Hanitsch (1995) has shown that for a shading rate of 75% of a cell, performance loss is reduced from 70 to 55% by using bypass diodes. A noticeable decrease in the rate of performance degradation is observed for the polycrystalline module. This significant drop in performance was observed by Limmanee et al. (2017). Results showed that for a type of shading (transmittance of the shadow T = 0); On an illuminated surface of 99.31%, the power of the mc-Si module dropped 41.52W and 61.35W for the pc-Si tended only in the case where the illuminated surface 97.23% power drop is 15.93W for the mc-Si and 32.31W for the pc-Si. Power losses are in most cases reduced by adding a bypass diode or blocking diode to the PV module (Silvestre et al., 2009). These results are comparable to those found by Topic et al. (2017) and show that on an illuminated surface of 83.3% of the total area of the module, the output power decreases by 7.1W; which represents 5.7% of the power of the module that is not under the shadow. The results showed that for a transmittance between 0 and 0.2, the power losses are much greater for the poly than for the mono. They rose from 52.15 to 45.20% for poly, and for mono, they went from 45.35 to 33.43% only for a 97.22% illuminated area of the module. For a transmittance between 0.3 and 1.2, the power losses are much more remarkable for the mono module. The Voc has an almost zero degradation rate. The performance losses for the maximum power are estimated at 51.82% for the mc-Si and 52.83% for the pc-Si only for partial shading of 2.78% of the total area of the module.

The loss rate of Pmax, Icc, Vco, and η

Estimation of the power parameters is determined by the Equations (2, 3 and 4) for the performance parameters and by Equation 1 for the shading factor (Figure 10).

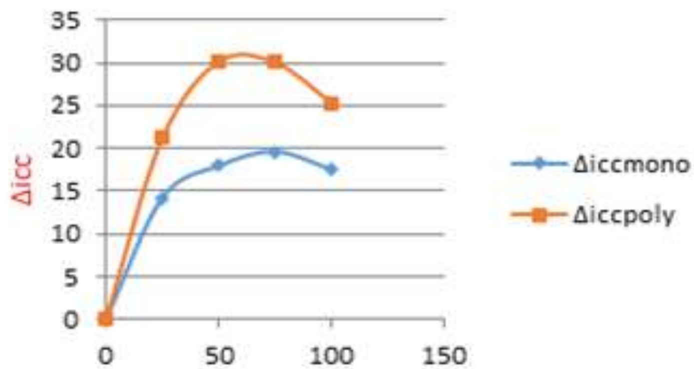

Figure 10. Variation of the short circuit current as a function of the illuminated area and the technology.

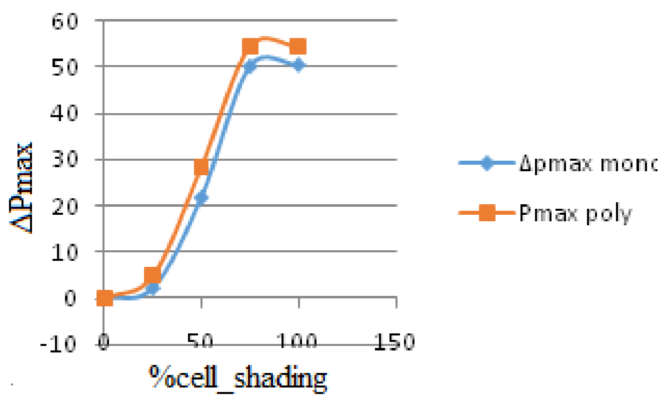

Figure 11. Variation in the rate of loss of power as a function of the technology and of the surface under the shadow of the cell.

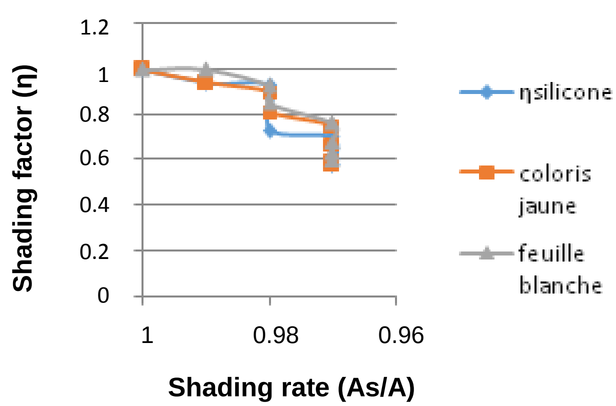

Figure 12. Shading factor as a function of the As / A ratio.

The power losses of the module vary depending on the illuminated surface and the technology. The results showed that pc-Si technology undergoes much more power loss than the mc-Si shading part. Figures 11 and 12 show respectively, the power losses and the shading factor.

The shading factor of Equation 1 along with the calculated values of the shading factor for each step are shown in Figure 13, and represents the ratio between the illuminated part on the total surface of the module.

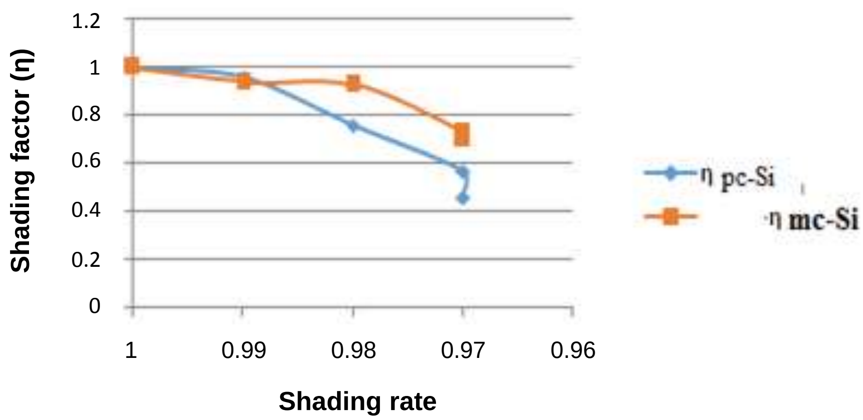

Figure 13. Shading factor as a function of technology.

Conclusion

An experimental study to evaluate the performance, degradation and crystalline technologies under partial shading is presented in this work. The study was carried out in a sub-Guinean climate where the modules are installed in a constant angle. 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. This study will allow the manufacturer to have knowledge on the impact of shading on the modules installed in the field in forest area and allow them to make modules less sensitive to shading.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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