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Analysis of thin film photovoltaic modules under outdoor long term exposure in semi-arid climate conditions

Ali Tahri[a], Santiago Silvestre[b,*], Fatima Tahri[c], Soumia Benlebna[a], Aissa Chouder[d]

[a] Electrical Engineering Faculty of the University of Science and Technology of Oran, Mohamed Boudiaf USTO-MB, BP 1505 El M'naouer, Oran, 31000, Algeria

[b] MNT Group, Electronic Engineering Department, Universitat Politécnica de Catalunya (UPC) BarcelonaTech, C/Jordi Girona 1-3, Campus Nord UPC, 08034 Barcelona, Spain

[c] High School of Electrical Engineering and Energetics of Oran, ESGEE, BP 64 CH2 ACHABA HANIFI-USTO-ORAN, Algeria

[d] Electrical Engineering Laboratory (LGE), University Mohamed Boudiaf of M'sila, BP 166, 28000, 6, Algeria

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ABSTRACT

The aim of this paper is to present an analysis of long term outdoor exposure of two thin film photovoltaic (TFPV) module technologies deployed in semi-arid climate in Saida city located in Algeria. The TFPV modules are: a-Si:H/μc-Si:H (micromorph) and copper indium selenide (CIS). The TFPV modules were characterised by measuring their I-V curves during three years under the same outdoor climate conditions, where the measurement of weather parameters were also performed. The goal of the analysis is to evaluate the degradation rates of the TFPV modules in semi-arid climate. The analysis is based on two techniques, the effective peak power of PV module and power irradiance technique. It was found that TFPV modules CIS and micromorph exhibit a degradation rate of −2.34%/year and −1.73%/year respectively. The calculated degradation rate for CIS technology is higher than those reported in the literature for locations in Europe and lower than those for locations with hot and humid conditions. In the opposite the degradation rate of the micromorph was lower than those given in the literature.

1. Introduction

The exponential growth of the Photovoltaic (PV) market has been maintained from more than a decade. The global PV installed capacity in 2015 total is 228 GW and it is expected to follow its growth in the next years because of the trends observed in China, Japan and the United States (USA) among other countries (IEA, 2016).

Global PV module production is clearly dominated by crystalline silicon PV and in second place by thin-film (TF) PV. It is estimated that 3.6 GW of TFPV modules were produced in 2015, accounting for 6% of total PV module production (IEA, 2016). Despite TFPV modules have reduced its market share in a 4% from 2014, its annual production as increased in 1.2 GW last two years (Institute for Solar Energy Systems, 2016).

TFPV modules present lower production costs and lower temperature coefficients relative to the crystalline (c-Si) and polycrystalline silicon PV modules (Virtuani et al., 2010; Tossa et al., 2016). Therefore, TFPV modules are especially attractive in applications where high ambient temperatures are reached.

The most common materials used in the production of TFPV modules are copper indium gallium selenide sulphide (Cu(In,Ga)Se2, CIGS), cadmium telluride (CdTe), and amorphous silicon (a-Si). These PV technologies present lower efficiencies than c-Si based PV modules. However, the efficiency of TFPV modules has significantly improved. CIGS and $CuInSe_2$ (CIS)-based PV modules passed from 14.2% conversion efficiency (Kushiya, 2014) to 17.5% (Institute for Solar Energy Systems, 2016) and First Solar has achieved 22.1% of conversion efficiency in CdTe TFPV modules in the laboratory (IEA, 2016). Moreover, the theoretical conversion efficiency limit for CdTe TFPV modules is 29% due to their band gap of 1.45 eV (Muñoz-García et al., 2012).

However, TFPV modules present degradation phenomena when exposed outdoor (Meyer and van Dyk, 2003; Mendoza-Pérez et al., 2009; Muñoz-García et al., 2012; Jordan and Kurtz, 2013). Staebler-Wronski effect (SWE) causes light induced degradation (LID) that strongly affects hydrogenated amorphous silicon (a_Si:H) and it also has effects, although more reduced in amorphous silicon/hydrogenated microcrystalline silicon heterojunction (a-Si:H/μc-Si:H), also called micromorph TFPV modules (Staebler and Wronski, 1977; Yamawaki et al., 1997; Van Dyk et al., 2007).

Several studies of TFPV modules were recently presented in the literature including, life cycle assessment (Chatzisideris et al., 2016), effects of irradiance change on the values of model parameters of a_Si:J

* Corresponding author.
E-mail addresses: alitahri.dz@gmail.com (A. Tahri), Santiago.silvestre@upc.edu (S. Silvestre).

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TFPV modules (Elbaset et al., 2016) and analysis of the performance ratio (PR) of CdTe, a_Si:H micromorph and CIS TFPV modules (Moreno-Sáez et al., 2016; Balaska et al., 2017). Moreover, the performance evaluation and degradation analysis of micromorph, a-Si:H, CIS and CdTe was also recently reported in several climate conditions (Aste et al., 2014; Kichou et al., 2016a; Silvestre et al., 2016; Kichou et al., 2016b; Rawat et al., 2017). The selection of the best TFPV technology for each specific climate condition is crucial in order to improve the energy generated by PV systems.

This work presents an analysis of two TFPV module technologies under outdoor long term exposure in semi-arid climate conditions. Three years was the period of the study, from January 2014 to December 2016.

The paper is organised as follows: Section 2 gives a description of the methodology by detailing the TFPV modules, the monitoring system and the techniques used to analyse the behaviour of the TFPV modules. Section 3 presents the results and discussion of the degradation and stabilisation period of each technology. Finally, in Section 4, the most important conclusions are summarised.

2. Methodology

2.1. Description of the PV modules and monitoring system

The two PV modules considered in this work correspond to the following TF technologies: a-Si:H/μc-Si:H (micromorph) and copper indium selenide (CIS). The main parameters of the TFPV modules at standard test conditions (STC): G = 1000 W/m^2 AM1.5 G, Tc = 25 °C, used in this study are given in Table 1.

The two TFPV module technologies were installed at the University of Saida in Algeria. Saida city is located between the north and the south of Algeria near the border of high plateaux with an altitude of 868 m, latitude: 34° 49′ 60″ north and longitude 0° 9′ east. The TFPV modules were mounted at the University of Saida faced to south with a tilt angle of 30°. Saida is renowned by its semi-arid climate with influences of Saharan climate especially in the summer.

The monitoring system was set to scan the electrical and meteorological parameters every 10 min. The electrical parameters of the PV modules were obtained by measuring their I-V curves by a system based on capacitor load. The I-V curve measurement system is synchronised to a weather station which allows recording the meteorological parameters to CR1000 data logger from Campbell Scientific. The irradiance was measured using HukseFlux SR20 Pyranometer wit tilt response < ± 0.2% (0–90° at 1000 W/m^2), the ambient temperature and relative humidity were sensed by Vaisala HMP155 probe with temperature and relative humidity accuracy of ± 0.20 °C and ± 1.7% respectively. The wind speed and direction were measured by Young 05106 sensor with an accuracy of ± 0.3 m/s and ± 3° of wind direction. The T type thermocouple cables attached to the back surface of the modules were used to sense the modules temperature and are also recorded with the environmental parameters by the CR1000 data logger.

Table 1
Main parameters of PV modules obtained from the manufacturers' data sheet.

	PV module	
	Sharp NA-121	Solar Frontier SF150-S
Technology	a-Si:H/μc-Si:H	CIS
Peak power (W)	110	150
Voltage at nominal power (V)	53.5	81.5
Current at nominal power (A)	2.04	1.85
Isc (A)	2.5	2.2
Voc (V)	71	108
Temperature coefficient - power δ (%/°C)	−0.35	−0.31
Temperature coefficient - Voltage β (%/°C)	−0.39	−0.3
Temperature coefficient - current α (%/°C)	0.056	0.01
Efficiency η (%)	9	12.2

The annual daily average and the standard deviation values of meteorological parameters recorded in sun hours during the monitoring campaign are summarised in Table 2 and Fig. 1.

Fig. 1 shows the PV modules temperatures: Average, minimum and maximum in monthly average values along the monitoring campaign. As it can be seen in the figure, the CIS PV module presents always higher temperatures than the micromorph PV module.

2.2. Effective peak power of the PV modules

The analysis of the behaviour of the output power of the PV modules is based in the application of two techniques described in this section: The evaluation of the effective peak power and the power-irradiance technique.

The effective peak power of a PV module, $P*_M$, is given by the following equation (Martínez-Moreno et al., 2012; Nofuentes et al., 2006):

$$P_M^* = \frac{G^* P_{DC}}{G} Tf \tag{1}$$

where P_{DC}, G and $G*$ are the DC output power of the PV module, the irradiance, and irradiance at STC respectively. Tf is the thermal factor defined as follows:

$$Tf = \frac{1}{[1 + \delta(T_m - T_m^*)]} \tag{2}$$

where T_m is the PV module temperature, T_m* is the module temperature at STC and δ is the power temperature coefficient of the PV modules given in Table 1.

The evaluation of $P*_M$ was carried out as the product of the normalized values of the MPP current, Imn, and voltage, Vmn, obtained from the following equations Limmanee et al., 2016:

$$Imn = \frac{Im\left(\frac{G^*}{G}\right)}{[1 + \alpha(T_m - T_m^*)]} \tag{3}$$

$$Vmn = \frac{Vm}{[1 + \beta(T_m - T_m^*)]} \tag{4}$$

where Im and Vm are the measured current and voltage at the MPP, α and β are the current and voltage temperature coefficients of the PV modules respectively.

The evaluation of $P*_M$ from the monitoring data set was performed after disregarding data recorded at low irradiance values. Only measurements taken at $G > 700$ W/m^2 were used. Above this irradiance threshold the shape of varying solar spectra closely resembles that of the spectral AM1.5G reference spectrum Silvestre et al., 2016. Consequently, no spectral effects are taken into account in Eq. (1).

The degradation rate, DR (%/year), of the TFPV modules is evaluated by means of a linear least square fitting method of the $P*_M$ by using Eq. (5).

$$DR = 100\frac{12b}{a} \tag{5}$$

where b (W/month) is the slope of line and a (W) is the y intercept of the trend line obtained for $P*_M$ (Sharma et al., 2014; Malvoni et al., 2017):

$$y = a + bx \tag{6}$$

2.3. Power-Irradiance technique

The power-irradiance technique is the method used in this work to analyse the stabilization period of the TFPV modules. This method was