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Comparative experimental study of performance degradation of amorphous silicon and crystalline silicon in outdoor exposed in Cologne

I. Faye[1*], A. Ndiaye[1,2], D. Kobor[1], U. Blieske[3] and M. Ayituv[3]

[1]Laboratory of chemical physique of materiaux, UASZ – Ziguinchor, Senegal.
[2]Centre International de Formation et de Recherche en Energie Solaire (CIFRES), ESP-UCAD, BP 5085 Dakar-Fann, Sénégal.
[3]Cologne Institue for Renewable Energy TH-Köln Cologne, Germany.

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The photovoltaic (PV) lifetime and the return-on-investment for local PV system installation rely on long-term device performance. Understanding the efficient degradation behavior under a given set of environmental conditions is, therefore, a primary goal for experimental research and economic analysis. The modules were characterized with measurement of their I-V features under similar outdoor condition. Moreover, measurement of different meteorological parameters like humidity and temperature is done from the weather station. The present study aims to measure electrical characteristics (I_{sc}, V_{oc}, P_{max} and FF) in monocrystalline and amorphous silicon modules exposed for 5 years in a sub-oceanique climate in Cologne. The results show the P_{max} of monocrystalline silicone has more degradation (3.41%/year) than the amorphous silicon (1.76%/year).

Key words: PV module, amorphous, crystalline, degradation.

INTRODUCTION

Converting Sun light to electricity using photovoltaic (PV) technology is one of the most promising ways to achieve the rapidly increasing global electricity demand with pollution free environment. Photovoltaic industry has grown at an extraordinary pace in the past two decades. Energy produced by a PV module deployed outdoors depend greatly on the PV materials, solar insolation (Ogbomo et al., 2017). Over time, the electrical energy output will decrease, commonly due to humidity, thermal cycling, ultra-violet radiation and moistures ingress (Advances et al., 2010).

The crystalline silicon photovoltaic (c-Si PV) module, according to Ogbomo et al. (2017), reportedly reveals 84% highest market share, 25% best power conversion efficiency (PCE), along with energy payback time (EPBT) of around 48 months. Also, silicon solar cells have been

*Corresponding author. E-mail: issafaye1211@gmail.com.

identified as the most viable preference appropriate for large volume production (Advances et al., 2010, Zarmai et al., 2015).

This necessitates having a technology that will handle repositioning for the global uptake. The construction and advancement of successive generation of robust and dependable crystalline silicon photovoltaic modules is largely reliant on the extensive knowledge of the thermo-mechanical deformation mechanics. This awareness will inform on the critical parameters design considerations and prerequisite of the module's future generation. In any PV system, module degradation as a phenomenon is unavoidable. A research conducted by NREL shows that module rates of degradation can advance up to 4% per year whereas average rate of degradation is estimated at reduction of 0.8% per year in power output (Ndiaye et al., 2013a). Photovoltaic degradation is the slow and continuous breakdown of characteristics of module component which perhaps restricts its operating potential to within acceptable performance limits (Jordan and Kurtz 2013). A PV module that is degraded can perform its principal role of electricity generation from sunlight, however, with a reduced power output. Nevertheless, the module's degraded state can become more challenging when it goes beyond a critical degradation threshold (Charki et al., 2012).

A series of descriptive photovoltaic modules parameters after indoor calculation under standard test conditions (STC), are normally given by manufacturers. Regarding outdoor, change in parameters were observed depending on the location and climatic conditions (Bücher et al., 1997, Gottschalg et al., 2013). Phinikarides et al. (2015) carried out an investigation on 12 grid-connected photovoltaic systems in Cyprus centered upon multi-crystalline silicon (multi-c-Si), mono-crystalline silicon (mono-c-Si), Heterojunction with Intrinsic Thin layer (HIT), CdTe, CIGS and a-Si. They also observed that both the mono-c-Si and multi-c-Si technologies displayed higher seasonal variations, with greater average standard deviation when compared with thin film technologies (Phinikarides et al., 2015). The research findings prove that the amorphous single junction silicon (a-Si) module has outperformed the multi-crystalline silicon (mc-Si) module in the course of the summer period but performed below expectation throughout the winter period. Nevertheless, throughout the year, there was improved performance in the HIT module than mc-Si module (Marion et al., 2014) when several module technologies performance in various locations in the USA were investigated. They observed that compared to the other module technologies found in Cocoa and Eugene locations, a-Si_µc-Si and (CdTe) modules has enhanced performance. This study comparatively assessed and analyzed two different photovoltaic technologies on the same outdoor conditions to ascertain the better performing PV technology in such climatic conditions.

MATERIALS AND METHODS

To investigate the performance of the PV module, tree PV technologies (mono-crystalline and amorphous-crystalline silicon) were examined. A broad explanation of all modules investigated in the roof of solar laboratory of TH-cologne University was presented. Each module examined is mounted facing southwards and inclined at fixed tilt of 14° (latitude zone) on the aluminum support. The key electrical specifications of the tested PV modules like maximum voltage (V_{max}), maximum power rating (P_{max}), open circuit voltage (V_{oc}), short circuit current (I_{sc}) and maximum current (I_{max}) are presented in Table 1. For a few years now, the modules have been in operation. Therefore, under the standard test conditions (AM 1.5, 1000 W/m^2), performance parameters (I–V and P–V curves, V_{oc}, I_{sc}, FF and P_{max}) are examined.

Experimental study

The photovoltaic platform shown in Figure 1 is used in this study. It was installed at Cologne, a city in western Germany, in the state of North Rhin-Westphalia, and also in Leverkusen (a nearby city). Here, the climate is rainy, humid and sub-oceanic, influenced by the Atlantic Ocean, leading to cold but not freezing winters, and mild summer. In January, the average temperature is 2.5°C, whereas in July it is 19°C. Precipitation is relatively abundant, about 8000 mm per year, but above it is frequent and well spread throughout the seasons. Yet, summer remains the rainiest season; while from November to March, the wind blows quite often and can be very strong. The variation of humidity and temperature of the day which we have done the measurement is shown in Figures 2 and 3. Global degradation (GD) along with degradation rate (DR) for the various PV module performance parameters (P_{max}, V_{max}, I_{max}, V_{oc}, I_{sc}, η and FF) for every one of the two photovoltaic modules is next examined. A summary of PV modules parameters (P_{max}, V_{max}, I_{max}, V_{oc}, I_{sc} and FF) is presented in Table 1. Using standard test conditions (STC), all tests were conducted in conformity with AM 1.5, 25°C and 1000 W/m^2.

RESULTS AND DISCUSSION

I–V and P–V curves, open-circuit voltage V_{oc}, short-circuit current I_{sc}, the maximum power output P_{max} along with the fill factor FF remains the most significant electrical features of a PV module and are defined and demonstrated subsequently.

I–V and P–V curves

At the present conditions of irradiance (light level) and temperature, the current–voltage (I–V) curve of a photovoltaic module (or string) explains its energy conversion potential. The curve theoretically characterizes current and voltage combinations in which the string is either 'loaded' or 'operated', if the irradiance as well as cell temperature could be kept constant. A distinctive I–V curve, the P–V or power-voltage curve computed from it, alongside strategic points on these curves is shown in Figure 4. Also, the I–V curve span ranges from short circuit current (I_{sc}) at zero volts, to zero current at open circuit voltage (V_{oc}) as observed in

Table 1. Characteristics parameter of two technology.

PV module type	Parameter	Values
Crystalline silicone	Power (P_{max})	240W+/- 3%
	Open circuit Voltage (V_{oc})	36.72V
	Short circuit current (I_{sc})	8.74A
	MPP current (I_{pm})	8.31A
	MPP voltage(V_{mp})	28.89 V
	Application class	A
	Permissible system voltage	1000 VDC
	Maximum Reverse Current	12.5 A
Amorphe silicone	Nominal power (P_{nom})	125W+/- 4%
	Open circuit voltage (V_{oc})	59,3V
	Short circuit current (I_{sc})	3,22A
	Voltage at maximum Power (V_{mp})	44.0V
	Current at maximum Power (I_{mp})	2.84A
	Maximum series fuse rating	5.0A
	Maximum system voltage (V_{system})	1000V
	Fire class rating	C

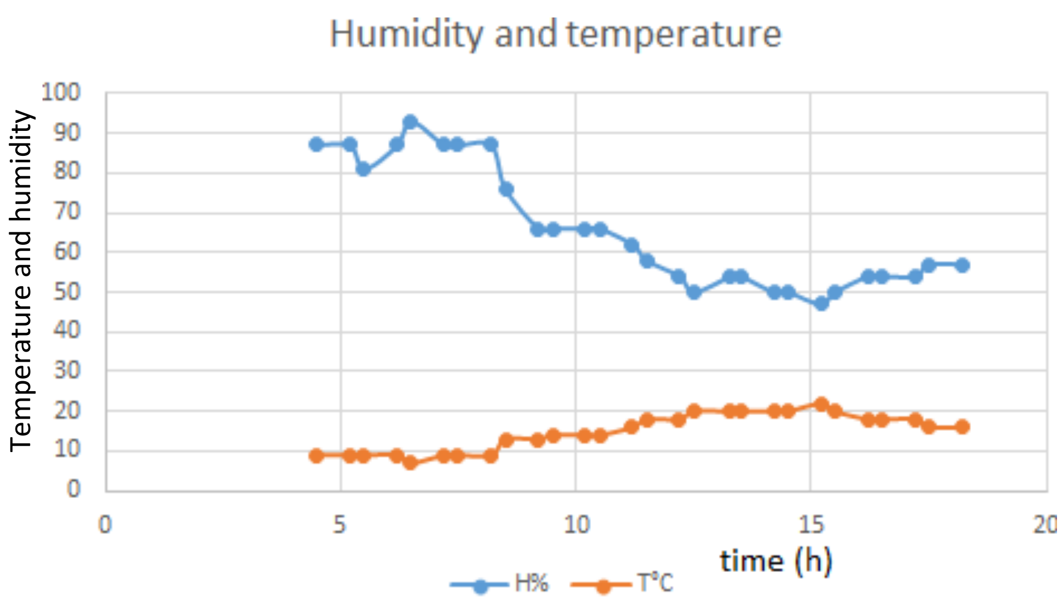

Figure 1. Measurement of humidity and temperature during the day by station meteorological.

Figures 5 and 6. The maximum power point (Imp, V_{mp}), found at the 'knee' of a normal I–V curve, is the point where maximum electrical power is generated by the array. One of the jobs of the inverter in an operating PV system is to continuously adjust the load, attempting to locate the particular point on the I–V curve where the whole array yields the highest DC power.

Degradation determination

A photovoltaic module parameter global degradation

Figure 2. The technology crystalline silicone (a) and amorphe silicone (b) in field exposed for 5 years.

Figure 3. ESL-Solar for measurement.

states the degradation of parameter determined from when the PV module was first put into service to the date it was experienced and can be stated as:

$$GD(\%) = \frac{Y(t0) - Y(tn)}{Y0(t0)} \times 100 \quad (1)$$

Where $Y(t_n)$ and $Y(t_0)$ denote the parameter value examined in the STC conditions at time t_n and t_0, respectively; t_0 denotes the initial time which corresponds to when the PV module was first put into service and tn refers to the instant of conducting the tests. Therefore, the photovoltaic module degradation rate (DR) is expressed by the following equation:

$$(DR)(\%) = \frac{\mathrm{GD}}{\Delta \mathrm{t}} \quad (2)$$

Each of the module is denoted by a separate symbol: red for Monocrystalline-Silicon (mc-Si) and blue for amorphe-

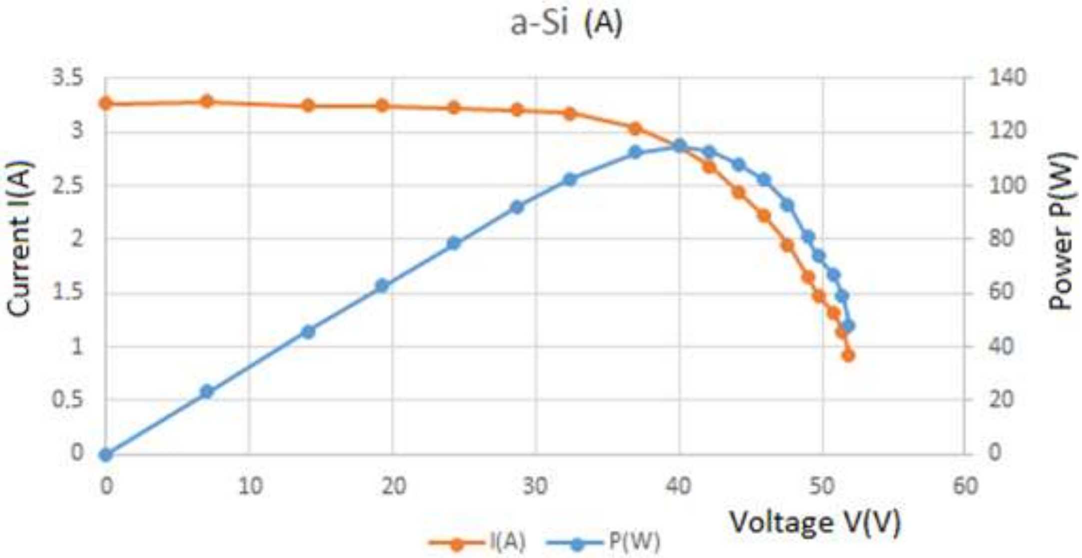

Figure 4. Characteristics I-V and P-V of a-Si (A) after five years exposed.

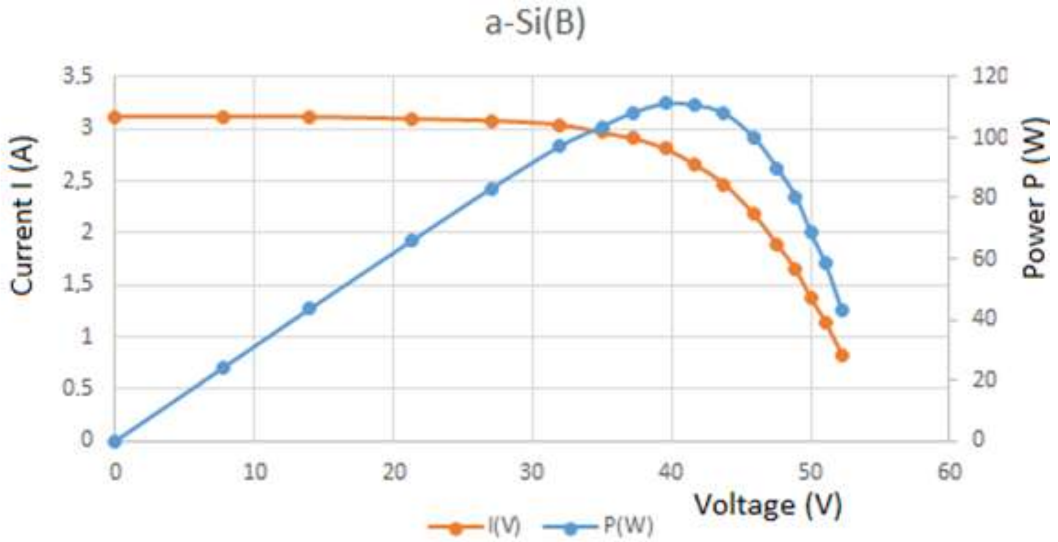

Figure 5. Characteristics I-V and P-V of a-Si (B) after five years field.

Silicon (a-Si) modules. Also, the open-circuit voltage (Voc) observably has a zero rate of degradation for all photovoltaic modules (Table 2). For the short circuit current, lowest degradation rates were observed in modules A (a-Si) and B (a-Si); in fact, they displayed the lowest operating time. Nonetheless, highest rates of degradation for all parameters were observed in the modules C (mc-Si). However, the photovoltaic modules with the greater P_{max} degradation are described by enormous contributions due to FF degradation. Module A (a-Si) and B (a-Si) have the minimum degradation rate in P_{max} of below 1.76%/year and 2.21%/year, respectively. However, degradation higher than 1.5%/year was observed in other PV modules compared to Module C (3.41%/year). After five years of operation, the two modules with different technologies A (a-Si) and C (c-Si) demonstrate the different rate of degradation. Nonetheless, the other performance parameters such as

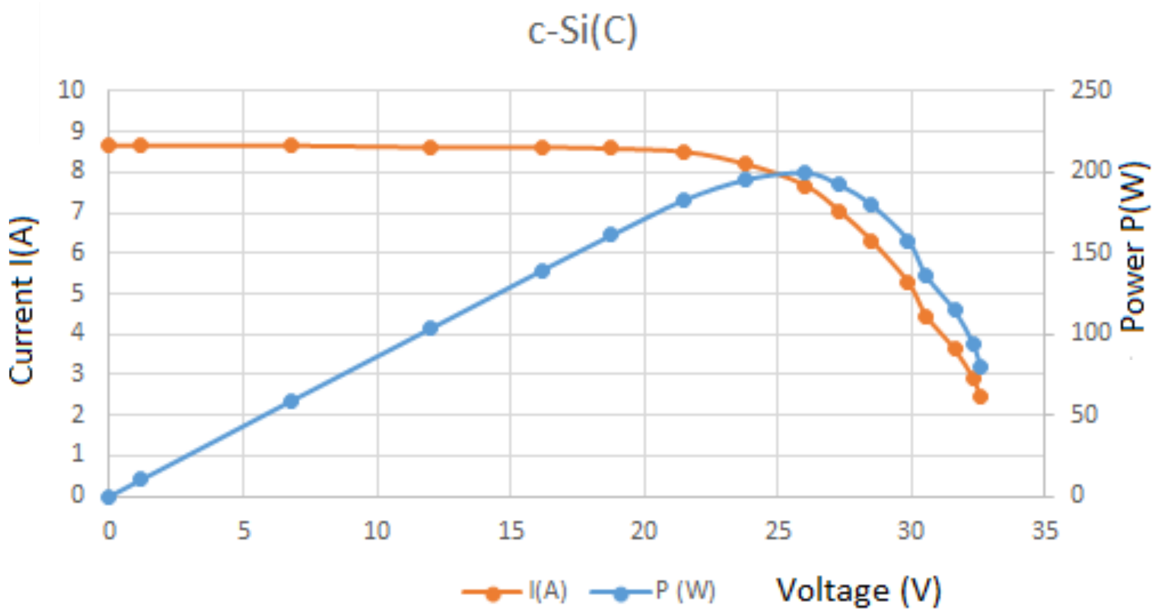

Figure 6. Characteristics I-V and P-V of c-Si (C) after five years in field.

Table 2. A summary of degradation parameters for amorphe silicone and crystalline silicone.

Module technology	Parameter	Initial value	Global degradation (%)	Degradation rate (%/year)
Monocrystalline	P_{max}	240+/- 3% W	17.08	3.41
	V_{max}	28.89V		
	I_{max}	8.31A		
	V_{oc}	36.72V	0.95%	2.26
	I_{sc}	8.74A	3.41%	0.18
Silicone amorphe (B)	P_{max}	125+/- 4%W	11.05%	2.21
	V_{max}	44V		
	I_{max}	2.84A		
	V_{oc}	59.36V	11.87%	2.33
	I_{sc}	3.22A	3.41%	0.68
	FF	1,52		
Silicone amorphe (A)	P_{max}	125+/-4%W	8.8%	1.76
	V_{oc}	59.36V	12,55%	2.5
	I_{sc}	3.22A	0.31%	0.062

V_{max}, I_{max}, I_{sc} and FF degradation rates vary and does not show any correlation between one technology and another. Certainly, there is higher degradation in V_{max} and I_{sc} for the module A (mc-Si) whereas I_{max} and FF are more degraded with module D (pc-Si). Still, there are only few published long-term studies on PV modules degradation.

Degradation of P_{max}, V_{max}, I_{max}, V_{oc}, I_{sc} and FF

Both from the global degradation and from the different performance results, degradation parameters were obtained. Parameters of PV modules (P_{max}, V_{max}, I_{max}, V_{oc}, I_{sc} and FF) are presented in Table 2. All tests are conducted in the standard test conditions (STC)

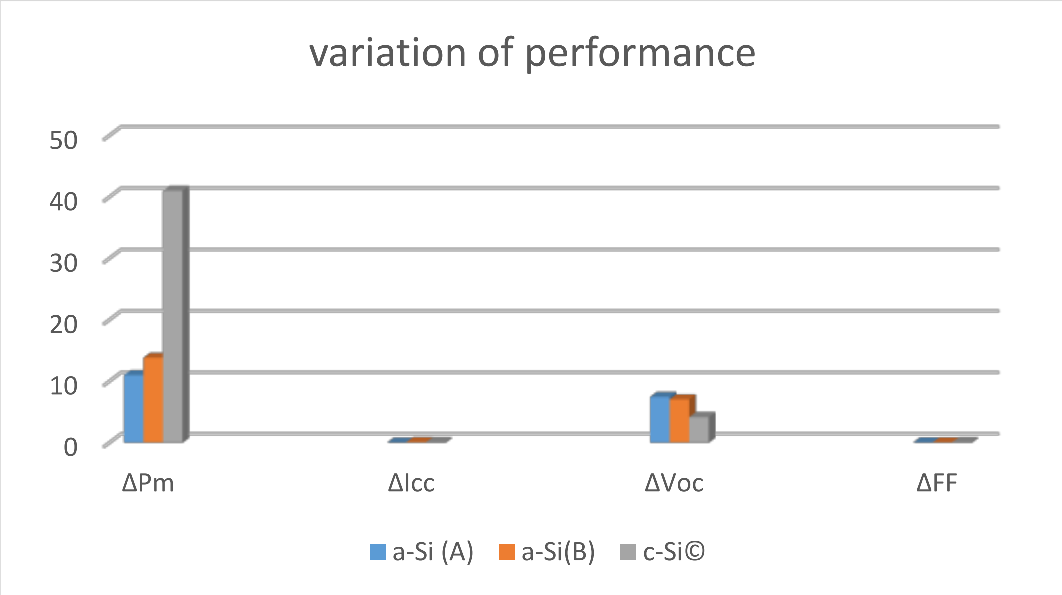

Figure 7. Degradation rates for individual performance parameters of each technology of PV module.

corresponding to AM 1.5, 25 _C and 1000 W/m^2. A comparison of the rate of degradation of the four photovoltaic modules for all studied parameters is shown in Figure 7. It is observed that the short-circuit current (Isc) has a less degradation rate for a-Si than the c-Si. It was in 1983 at the Joint Research Center in north Italy that we first had an exposition of this with a moderate subtropical climate (_10–35 _C, > 90% RH). They found a relation between high performance losses (>20%) and fill factor losses which is as a result of an increased series resistance. It is also possible to relate the moderate performance losses (<20%) to the Isc losses, which is triggered by optical properties degradation. We determine the long-term losses to be between 0.2 and 1.0% per annum. By means of comparison, a recent study has demonstrated that averagely, the different PV technologies historically reported degradation rates of between 0.3 to 3%/year whereas 0.5%/year was the reported median (Jordan et al., 2010). More precisely, studies conducted on outdoor exposed mono and multi-c-Si photovoltaic modules exhibited approximately 0.7%/year performance losses (Ndiaye et al., 2014). This large difference was due to the different environmental conditions like dust, humidity, temperature and UV radiation (Ndiaye et al., 2013b).

Conclusion

This paper examines the comparative performance outdoor of PV modules. Tree PV modules (monocrystalline silicon and amorphe-silicon) were laid bare during a few years on the Solar Laboratory site of University in Cologne where the environment condition was stressed. The study revealed that there were relative differences in PV module technology of performance parameters between the time of first putting service of PV modules and after a few exposition years under cologne climate. For all PV modules, P_{max}, I_{max}, I_{sc} and FF remains the most degraded performance features. Also, the value of parameters degradation varied for each technology. The maximum power output (P_{max}) shows the highest loss that can be from 1.71%/year for amorphous silicon to 3.41%/year for monocrystalline silicone. However, the short-circuit current (I_{sc}) is not degraded for amorph silicone and a considerable degradation with mono-crystalline silicone after these few exposition years for all PV modules studied.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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