

Study of Degradation of Amorphous PV Module Performance Under Different Climatic Conditions

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ABSTRACT

Usually, manufacturers provide PV panels, accompanied with data measured under Standard Test Conditions (STC), i.e. determined at AM1.5 with an irradiance of 1000W/m² and a cell temperature equal to 25 C. In fact, these conditions do not reflect the reality of natural operation of PV panel conditions and these functional data associated with the real panel operating point may vary from one environment to another due to the change in weather conditions. The characterization of different types of PV panels under natural conditions of operation is, therefore, necessary in order to have a global view about the true electrical performance of different technologies at a given site. This work evaluates the influence of climatic conditions on the behavior of QS-60DGF module which has been installed at the Unit of Research in Renewable energy URERMS Adrar in the southern Algeria. The degradation evaluation of QS-60DGF module with different defects was performed, using (I-V/P-V) characteristics under daily weather conditions and the the visual inspection such as glass breakag. This study is to investigate the degradation rates of a-Si PV module after more than one year of outdoor exposure in desert conditions.

I. Introduction

The market of photovoltaic (PV) modules, although dominated by crystalline silicon with almost 90%, consists

of several technological branches sharing the 10% remaining stake [1] which are essentially the thin film technologies. Some studies presented in literature have shown that the different existing PV module technologies present different behaviors according to the climate and seasons [2,3] and some technologies may be suitable for a given region compared to others [4,5]. For this reason, comparative studies of the performance of PV modules are conducted in various regions all around the world like those reported in [2-7].

The performance and efficiency of photovoltaic modules is influenced by several factors such as solar radiation, ambient temperature, humidity, wind, shading and sand dust accumulation [8-13].

Several studies and research studies have evaluated the performance of photovoltaic modules in different climatic conditions, in particular the effect of sand dust accumulation and partial shading on energy loss in photovoltaic modules and arrays [14-21].

The main conclusion of these studies is that solar modules do not usually fail in a catastrophic way but experience steady power degradation over time [22, 23–34]. This degradation process has been observed to undergo two different stages: within the first year of exposure solar modules exhibit a rapid degradation [26, 27, 35], thereafter a slower linear degradation rate is observed. The Australian Cooperative Research Center [23] evaluated the performance of five different PV module technologies: c-Si, p-Si, triple junction a-Si, CIS and the laser grooved buried contact (LGBC) c-Si over 16 months of operation in a temperate climate (Perth, Australia). Crystalline and polycrystalline silicon PV modules showed a yearly power reduction of 2% while amorphous and CIS solar modules exhibited a significantly higher power reduction. The results for c-Si and p-Si PV modules cannot be used to extrapolate the module lifetime since it is known that the degradation rate is faster during the first year of field operation. In a study carried out by the Arizona State University East Photovoltaic Testing Laboratories [30], 44 modules from three different technologies were evaluated in Mesa, Arizona in hot-arid climatic conditions. Monocrystalline and polycrystalline silicon modules exhibited virtually the same low power degradation ($\approx 0.5\%$ yearly power degradation for both c-Si and p-Si) while a-Si multijunction modules degraded more intensively (1.16% yearly degradation).

The a-Si PV modules present a light-induced degradation (LID) due to the Staebler-Wronski effect (SWE) [36-39] and are attributed to recombination-induced breaking of weak Si-Si bonds by optically excited carriers after thermalization, thus producing defects that decrease carrier lifetime. The electrical performance degradation of these modules is very important during the initial exposure to outdoor light due to changes in photoconductivity and dark conductivity. This effect gradually tends to stabilize at power rates ranging from 10% to 30% of the nominal power of the PV module.

Several works have been conducted in attempt to explain the real performance characterization of the a-Si PV modules when deployed outdoors. The degradation rate can be based on the comparison of the monitoring outdoor performance with the initial indoor measurements taken as references [40-43], or by applying LR (Linear Regression) and CSD (Classical Seasonal Decomposition) methods with temperature correction [44,45].

The objective of this work is to conduct an empirical study on the effect of different temperatures and radiation on PV performance parameters. Performance degradation is evaluated after placing (QS-60DGF) module in a desert environment during more than one year. By using visual inspection of module defects or by the I-V characteristic measurement normalized at STC condition to compare with the initial IV characteristic produced by the manufacturer (STC Nominal Data), On the other hand, an experimental investigation of QS-60DGF module performance under two different days (clear and cloudy). And study the effect of partial shading and deposition of sand dust on power loss in photovoltaic modules (QS-60DGF), we perform also experimental investigation of the effect of varying temperature and irradiation on PV performance parameters for one day.

Adrar in the southern Algeria experiences hot and dry climate in the summer. Therefore, it is highly important to understand the effect of local climatic conditions on PV systems so as to enable installers and investors to estimate the reliability of PV systems for a longer lifetime. As a result, it was conducted an assesse and analyze of degradation rate of a-Si PV module. After that, comparison of PV modules degradation from the literature by taking into account different parameters (Climate, Test duration...) was presented.

II. Research Method

II.1. Experimental Setup

Evaluating the degradation of photovoltaic modules requires measurements of both the environmental parameters and the electrical parameters associated with the modules. As part of this work, a dedicated measurement platform has been set up. It is installed on the site of Research Unit in Renewable Energy URERMS Adrar which is a region situated in the south-west of Algeria.

It is also dedicated to determining the prevailing operating conditions of PV modules installed in our study area.

Before treating degradation of electrical performance, it is advisable to analyze climate data. Measurements were carried out at Adrar in the extreme south Algeria. This site is often exposed to high level of temperature. Figures 1-2 provides a summary of the climate data for two days. All data values were measured every 15 minutes from 00:00 a.m. to 11:45 p.m.

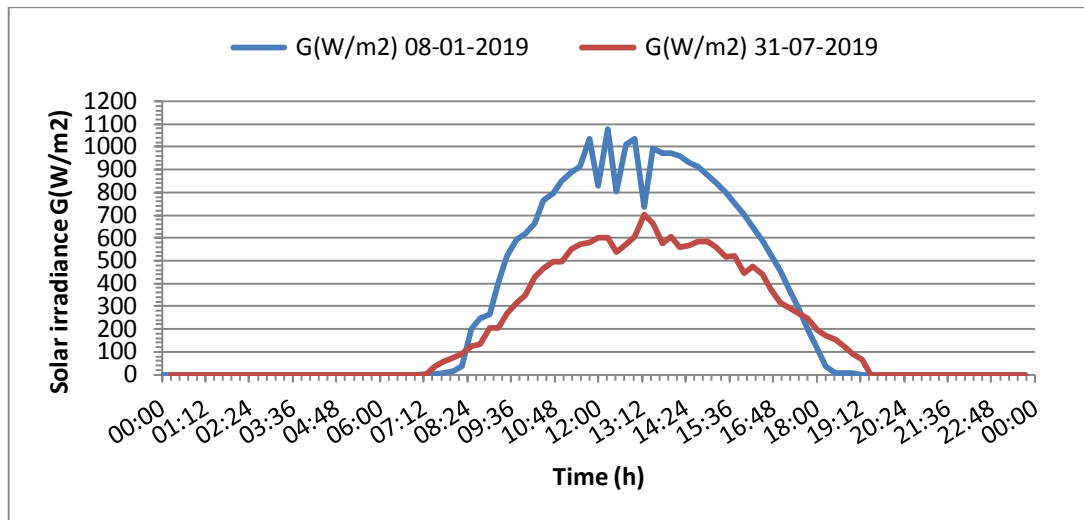


Figure 1. Solar irradiance of both winter and summer days

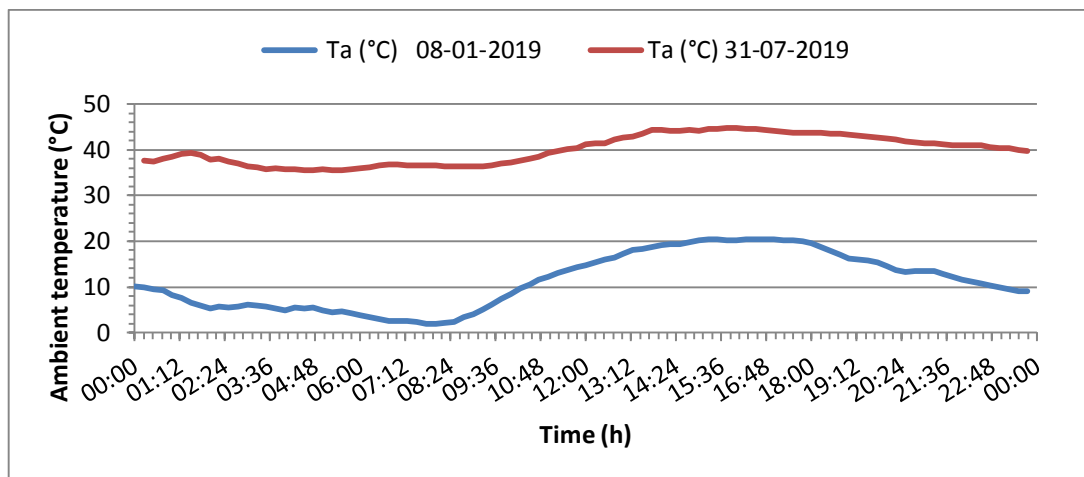


Figure 2. Ambient temperature of winter and summer days

Figures 1-2 shows the diurnal variation of solar radiation intensity and ambient temperature throughout the day from 00:00 am to 11:45 pm. The maximum values of ambient temperature and global radiation recorded were 20.4 $^{\circ}\text{C}$ and 1079 W/m^2 , on 08/01/2019 day and 44.8 $^{\circ}\text{C}$ 703.2 W/m^2 , on 31/07/2019 day. As seen from these figures, the maximum solar radiation intensity and maximum ambient temperature were observed at solar noon (12:00 to 16:00 hours).

It is clear that the site is characterized by high ambient temperature in summer day (31 July). However, the lower global daily irradiation measured in winter day (08 January).

II.2. Measurement platform

The measurement platform of PV module performance evaluation in this work is using the software and hardware of EKO instruments (MP-160 I-V tracer). This tracer equipment is used for the field measurement of the IV characteristic curves and main characteristic parameters of solar modules. The instrument measures simultaneously the Voltage and current, and also the incident solar irradiance and temperature using a pyranometer and a thermocouple. The acquired data are then processed and translated at standard test conditions (STC) in order to compare with the reference values of performances parameters at STC condition declared by the manufacturer of photovoltaic module (Table. 1).

Table.1 STC specifications for the modules.

Parameters	Symbol	Thin-Film a-Si (QS-60DGF)
Maximum power	Pm (W)	60
Open Circuit Voltage	Voc (V)	80.3
Short Circuit Current	Isc (A)	1.22
Voltage At Maximum Power	Vmp (V)	62.3
Current At Maximum Power	Imp (A)	0.96
Temperature Coefficient Of Open-Circuit Voltage	Kv (%/K)	-0.28
Temperature Coefficient Of Short-Circuit Current	Ki (%/K)	0.09

III. Experimental results and discussions

III.1. I-V And P-V Characteristics Curves Measurement Results

The results of the experimental investigation is carried out in both clear and cloudy days (clear day: 13-03-2019 at 11:25 AM, cloudy day: 04-04-2019 at 11:04 AM) The electrical parameters of these dusty and clean modules are provided in Table.2 (appendix) in order to assess the effect of cloudy day and the dust on output power reduction with the increasing solar irradiance both the open circuit voltage and the short circuit current increases and hence the maximum power point varies.

We note that the output power difference between the clean module in clear day and the clean module in cloudy day is equal to (42.7 W) and the output power difference between the clean module and the dusty module in cloudy day is equal to (2.77 W), the cause of this variation is the reduction in intensity of sunlight reaching the PV module, leading the decrease of short circuit current (Isc clean module (cloudy day): 0.25A, Isc clean module (clear day): 1.21 A).

III.2. Effect of variation of solar irradiation on photovoltaic performance parameters

For many commercial modules, the efficiency is not constant depending on the solar Irradiance, as we can see in figure.3 for QS-60DGF module. It was dropping regularly drastically at low solar Irradiance. This phenomenon is well neglected by manufacturers, who give no indication of the behavior of their low-light module.

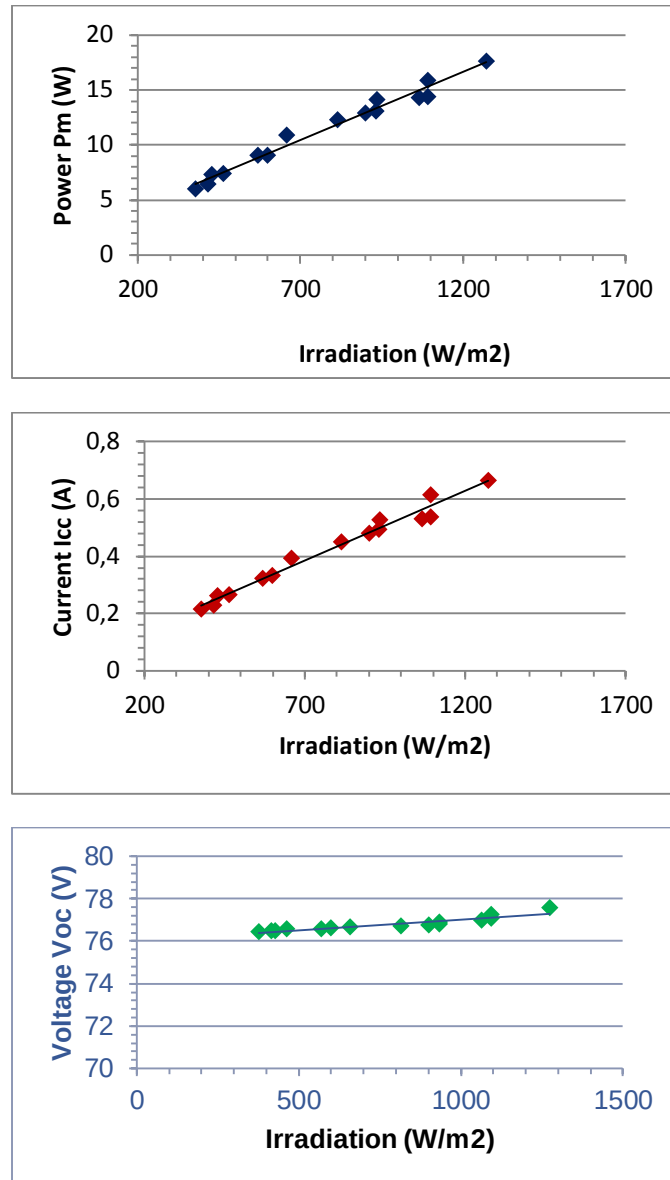


Figure 3. The variation of electrical parameters with different irradiances.

As the solar insolation keeps on changing throughout the day similarly I-V and P-V characteristics varies. With the increasing solar irradiance both the open circuit voltage and the short circuit current increases and hence the maximum power point varies. Temperature plays another major factor in determining the solar cell efficiency.

III.3. Effect of partial shading on the photovoltaic module performance

To better understand the impact of shading on the performance of PV modules, we characterize the behavior of a PV module by placing the module in different shading situations.

First, we characterized the behavior of the PV module without shading (reference) under external conditions for irradiation and temperature given. Then, under the same real conditions, we repeat the operation with a part of this module which is shaded according to the different situations given in Figure .4

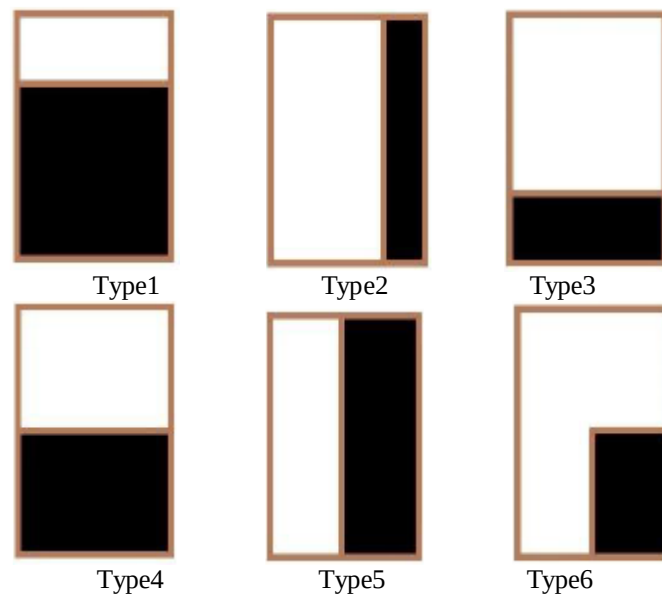


Figure. 4. Shadow pattern classification

Table 3. The experimental results of the effect of partial shading on performance parameters.

Type of shading	Pmax (W)	Vmax (V)	Imax (A)	FF	η (%)
No shading	12.358	44.454	0.278	0.370	2.629
Type1	0.601	35.8	0.017	0.504	0.089
Type2	1.164	44.420	0.026	0.148	0.167
Type3	6.5	37.404	0.174	0.274	0.731
Type4	2.215	36.894	0.06	0.299	0.309
Type5	1.055	34.315	0.031	0.340	0.140
Type6	8.437	43.585	0.194	0.369	1.068

From Table 3 we remark that the power decrease from 12.36 W (case no shading) to 0.601 W (cas type1 of shading), and also the efficiency from 2.63% to 0.089% due to the partial shading effect.

III.4. Analytical calculations of degradation rates

III.4.1. Visual Inspection Results

Glass breaking is an important degradation factor in photovoltaic modules. Where they occur most often during installation and maintenance, especially during the transfer of photovoltaic modules on their installation sites [46].

Module broken or with cracks may keep working properly. In Figure 5, illustrates this defect in glass surface of QS-60DGF PV module where it was characterized at the outdoor field of URERMS Adrar.

From table.4, a loss of more than 35% of output power is observed on this test. Glass breakage is an event that can be attributed to a thermal stress.

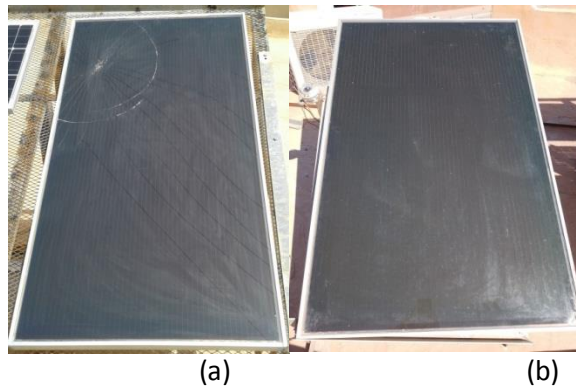


Figure 5. Glass breakage of (a) surface module and (b) without.

Table.4. PV parameters for modules with broken glass and without.

parameters	I _{sc} [A]	V _{oc} [V]	I _{pm} [A]	V _{pm} [V]	P _m [W]	FF	η [%]
Module unbroken	1.29	79.21	1.02	58.45	59.51	0.58	5.34
Module broken	0.90	77.19	0.69	56.29	38.58	0.55	3.46

In order to evaluate the photovoltaic performance modules under desert climatic condition, The global degradation (R_D) calculates the performance drop of each parameters such as maximum output current (I_{max}), maximum output voltage (V_{max}), maximum power output (P_{max}), opencircuit voltage (V_{oc}), short-circuit current (I_{sc}) and fill factor (FF) from the initial values, up to the experiment day by comparing the STC translated data with the ‘nominal’ rating, were calculated analytically by the following expressions [47,48]:

$$R_D(X)(\%) = \left(1 - \frac{X}{X_0}\right) \times 100$$

Where $X = [P_{max}, I_{max}, V_{max}, I_{sc}, V_{oc}, FF]$ after degradation and $X_0 = [P_{max0}, I_{max0}, V_{max0}, I_{sc0}, V_{oc0}, FF_0]$ represents the reference (Nominal) values of the parameters given by the manufacturer data under standard test conditions (STC).

The annual degradation rate (R_{Da}) is calculated from the global degradation factor. In this equation Δt represents the module’s exposure period (in years) from the first operation day until the test date.

$$R_{Da}(X)(\%) = \frac{G_D}{\Delta t}$$

Table 5 contains the values of degradation rates (R_D) and annual degradation rate (R_{Da}) for each performance parameter of Glass breakage modules after 14 months of outdoor exposure in real conditions.

Based on experimental results, a cracked PV module is practically diagnosed by an I–V characteristic which presents a significant drop of I_{sc} , there is also a drop of the resultant P_m and fill factor (FF). However, the open-circuit voltage (V_{oc}) has a lower degradation rate.

Table 5. degradation parameters of broken PV modules under STC conditions.

parameters	I _{sc} [A]	V _{oc} [V]	I _{pm} [A]	V _{pm} [V]	P _m [W]	FF
R_D(%)	26.23	3.87	28.12	9.65	35.7	14.06
R_{Da}(%)	21.85	3.22	23.43	8.04	29.75	11.71

In order to compare the R_{Da} values found under our climate with other climates, we summarized different values found in the literature in Table 6.

Table 6. Summary of some studies on thin-film PV module field degradation around the world

Location	Climate	Test duration	Modules technology	Degradation rate (%/years)	Reference
Perth (Australia)	Temperate	16–19 months	a-Si CIS	18.8 12.6	[49]
Mesa, Arizona (USA)	Desert	2.7 years 6.7 years	a-Si a-Si	3.52 1.16	[50]
Cologne (Germany)	Sub-oceanique	5 years	a-Si (A) a-Si (B)	1.76 2.21	[51]
Benguerir (Morocco)	Desert	2.5 years	TF	1.73	[52]
Malaysia	Humid climatic	16 months	a-Si	20.4	[53]
Gurgaon, India	Sub-tropical	28 months	a-Si	6.4	[54]
Singapore	Tropics	3 years	Single a-Si a-Si/a-Si	2.0 2.0	[55]
Jaén (Spain)	Dry and sunny	16 months	a-Si	18.8	[56]
Oman	Hot and Humid	4 years	a-si	1.78	[57]
Present study	Desert	14 months	a-Si	29.7	

By means of comparison, a present study has demonstrated that averagely, the a-Si PV module reported degradation rates of 23%/year whereas 0.5%/year was the reported median [58]. More precisely, studies conducted on outdoor exposed a-Si photovoltaic modules exhibited approximately 1.76-2.21%/year performance losses [51] however it has been reported that Rd values are of 20.4% in Malaysia. These values are lower than what we found in our measurement, this is mainly due to the harsh atmosphere in our region. Another important remark from the previous studies is that the degradation process follows two different stages: a rapid degradation for the first years of exposure followed by a slow linear degradation rate [27].

III. Conclusion

The study of the degradation of photovoltaic modules and the impact of environmental constraints such as dust on their performance provides interesting information for the photovoltaic sector.

Our work is part of a process of analysis of degradation of the photovoltaic systems installed in the south of Algeria. The exploitation of the electrical characteristics of the QS-60DGF module allowed us to make the comparison between different situations typical of a Saharan environment.

The results show that the cloud cover and the accumulation of dust on the surface of the solar module have a significant impact on photovoltaic solar performance. The effect of cloud cover is immediate with a decrease in global solar irradiance and therefore in the power produced for a short period, while the effect of dust accumulation has a long-term effect.

Analysis of the different PV module technologies indicates that shading results in a reduction in the electrical characteristics (current, voltage and power) for each type of shade.

The obtained experimental results show that the loss of the maximum power output (Pmax) of module without Glass breakage is (59.51 W) and module with Glass breakage is (38.58 W) which prove the effect of long time exposure of modules under Desert climatic conditions.

The average degradation rate, however, is around 29%/year. This value is relatively higher than what we found in literature. This is mainly due to the harsh atmosphere in Adrar southern Algeria. Nevertheless, this region has one of the best solar potential in the world with 3500 hours of solar radiation per year.

In future works, we will study the major causes and factors of degradations noted in this paper. It is necessary to increase the number of modules studied over longer exposure duration in our study area.

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Appendix:

Table.2. PV parameters for clean and dusty modules.

parameters	I _{sc} [A]	V _{oc} [V]	I _{pm} [A]	V _{pm} [V]	P _m [W]	FF	η [%]
Clear day + clean module	1.21	75.67	0.97	55.43	53.66	0.58	4.90
Cloudy day+ clean module	0.25	73.39	0.19	56.57	10.96	0.59	4.59
Cloudy day+ dusty module	0.19	72.1	0.15	56.09	8.19	0.59	4.35

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