International Conference on Green Energy & Environmental Engineering (GEEE-2018)
Proceedings of Engineering and Technology – PET
Vol.37 pp.76-81

Contribution to the degradation modelling of a polycrystalline photovoltaic cell under the effect of stochastic thermal cycles of a desert environment

M. Boussaid[1], A. Belghachi[2], K. Agroui[3]

[1]*Department of Material Sciences, Laboratory of energy environment and information systems (LEEIS), University of Ahmed Draia, Adrar, Algeria*
[3]*Development Unit of Silicon Technology; PB 399, 2 BD Dr. Frantz Fanon, Algeria*
[1]*Street 11 December 1960, Adrar (01000), Algeria*
[3]*PB 399, 2 BD Dr. Frantz Fanon, Algiers, Algeria*
[1] `mohammedboussaid1@gmail.com`
[3]`kagroui@hotmail.com`
[2] *Department of Physics, Laboratory of Physics of Devices Semiconductor (LPDS); University of BECHAR*
[2]*PO Box 417, BECHAR, Algeria*
[2]`abelghachi@yahoo.fr`

***Abstract*— a photovoltaic module is characterized by the electric power it delivers when conventionally subjected to standard conditions (1000W/m2, 25°C). Unfortunately, this power suffers degradation over time. The climatic factors degrading these electric generators vary from one natural environment to another. In this study, and independently of any other environmental factor, we have arrived to simulate by the accelerated tests (which was the only possible methodology) the effect of stochastic thermal cycles (exhibiting the narrow variation in daily temperature in the Sahara of Algeria) on the continuous degradation of electrical characteristics, in particular the nominal power, of a polycrystalline PV cell. Modeling by Weibull model allowed us to estimate an average life of 27 years for degradation 52% about. This result comparable by what is already published in this area confirm the responsibility of the varied temperature in the form of stochastic thermal cycles in desert environments on the degradation phenomenon of PV cell (modules).**

***Keywords*—– degradation, cell photovoltaic, thermal cycles, desert environments, lifetimes.**

I. INTRODUCTION

Several studies of the literature have presented the degradation of polycrystalline silicon PV modules, (unfortunately none on cells), when exposed in natural environments. Among these studies, a study confirmed that after 20 years of continuous exposure, a matrix of 70 polycrystalline silicon photovoltaic modules has undergone an average performance decay of 0.24% per year, in a moderate subtropical climate environment. (Ispra, Italy) [1,2]. Another study stated that after only one year of exposure in a tropical climate environment, the electrical powers of two modules of type (a-Si) and (poly-Si) were degraded to 60% and 56% respectively their initial values [3]. In addition to these results, another study has shown that some PV modules (m-Si and Poly-Si) have been degraded by ranging from 0.22% / year to 2.96% / year [4]. The polycrystalline modules were the best in terms of reliability, long term, with a degradation of 0.41% per year, in a natural environment, lower than the value presented by Jordan and Kurtz (0.61% / year) [5]. In a tropical environment (Ghana), the exposure of 14 polycrystalline silicon modules during a 19-year period recorded a degradation rate of the nominal power of 21% to 35% [6]. Examination of failure showed degradation at a rate of 1.2% per year for polycrystalline modules, 0.8% per year for mono-crystalline modules [7]. An important study has found that the power of 204 modules (123 m-Si and 81 poly-Si) have recorded degradations that vary between 0 and 6% per year, after exposure periods of 18 to 24 years, in a moderate subtropical environment. The average degradation is of the order of 2.4% ± 1.7% per year for both types of modules [8]. In a Saharan environment (southern Algeria), the degradation rate of the polycrystalline modules was very high, ranging from 3.33% / year to 4.64% / year, unlike the mono-crystalline modules which recorded a rate of the order of 1.22% / year after 28 years of exposure [9, 10]. These measurement uncertainties, which gave different results, for the estimation of the degradation of the polycrystalline modules, were the objective of a study which had presented some methods of evaluation of degradation after duration of exposure of 12 years in a Saharan environment. It has managed to estimate an average rate by all methods of 2% per year [11]. We believe that accelerated tests are the only possible methodology to independently see the effect of daily temperature variation in a desert environment on the degradation of a module (or PV cell), as we can never move away from other factors in the air of a natural. Wolgemut (2011) presented a table showing failure modes according to the type of accelerated test. The breakage or disconnection of the cells is appropriate for a thermal cycling test of IEC61215 type [12, 13]. Remi Laronde, using the accelerated tests, estimated an average lifetime of 438.54 years ± 8.01years, and 25-year duration for degradation close to 0.0132% for mono crystalline PV modules in a hot, humid climate environment [14].

II. RESEARCH METHOD

The strategy of accelerated tests theory is based on the effect of exposing the studied system to amplified conditions compared with normal conditions ones in order to deduce the degradation of the constitutional characteristics of the system (reliability law, lifetime ...). Then, by means of a law of acceleration (law of accelerated life), we will be able to determine the characteristics under normal conditions. The theory is to follow the steps below:

ISSN 2356-5608

1. Know the mechanisms of failure under the normal conditions of use.
2. Choose the amplified constraints while respecting the technological limits.
3. Establish the reliability laws under the applied constraints.
4. Identify the law of acceleration of passage between the amplified conditions and the normal conditions.

We have exposed two cells homologous of polycrystalline silicon; have the same characteristics, named (C1 and C2) at 200 regular thermal cycles, such as:

- The first cell (C1) is exposed to cycles varying from (+ 5˚C to + 75˚C).
- The second cell (C2) is exposed to cycles ranging from (+ 5˚C to + 85˚C).

Each cycle lasted an hour and a quarter. Figure1 presents these cells:

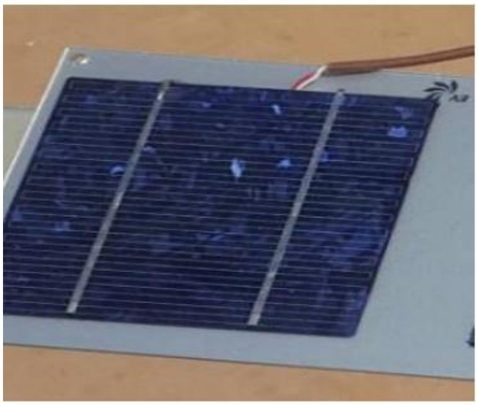

Fig 1 The PV cell before exposure to the test

The average stochastic variation in daily temperature over a year in the Saharan environment (the region of south-west Algeria) is usually between (+ 5˚C and 45˚C) [15]. Figure 2:

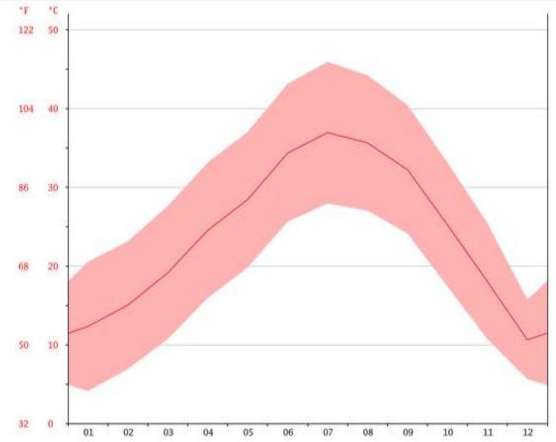

Fig 2 Annual limits of temperature in the region of Adrar

Hence the accelerated test is defined by the following stress cases:

- The 1st stress constitutes 200 regular thermal cycles of (5˚C to + 75˚C), named S1.
- The 2nd stress constitutes 200 regular thermal cycles, from (5˚C to + 85˚C), named S2.
- The normal stress (under normal conditions), from (5˚C to + 45˚C), named S0.

The graphs of the electrical characteristics (I-V, P-V) of the PV cells are plotted by means of a solar analyser linked to a PC. The data we have received is redrawn and presented in the figures below. The characteristics before exposure to thermal stresses are presented in the following figure 3:

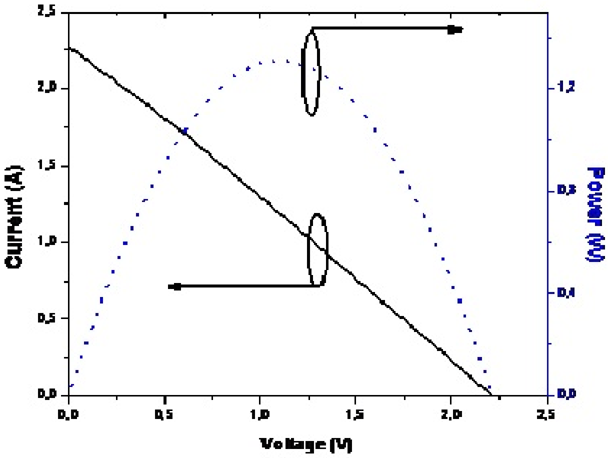

Fig 3 Characteristics of cell before exposure to the thermal cycling test

Since, we do not have a climatic chamber to carry out the thermal cycles in a continuous way, according to the norms IEC61215; we used a laboratory thermal oven where the cycles are realized, manually and discontinuously.

The following figure 4 presents the diagram of the simulated cycles:

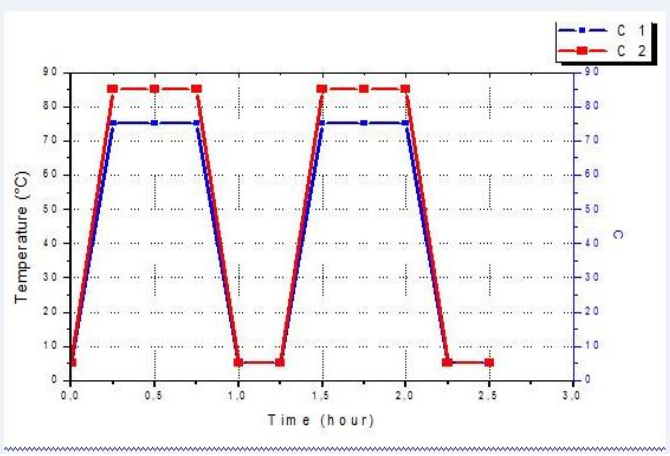

Fig 4 Simulated thermal cycles

III. RESULTS AND DISCUSSION

After each 40 thermal cycles (50 hours), the results obtained are shown in Figure 5, 6, 7, 8, 9 and 10, respectively (they are given in the standard conditions- 1000W/m2 and 25°C- using the solar analyser).

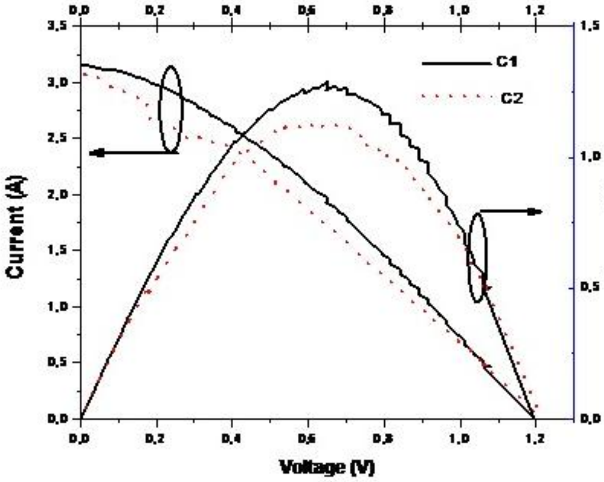

Fig 5 Characteristics of the two cells after exposure to 40 thermal cycles

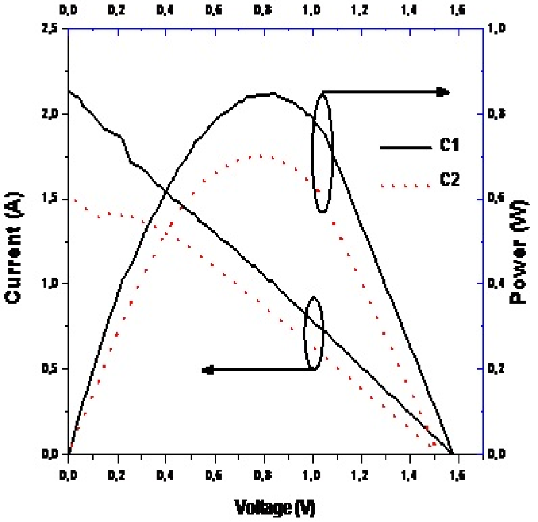

Fig 6 Characteristics of two cells after exposure to 80 thermal cycles

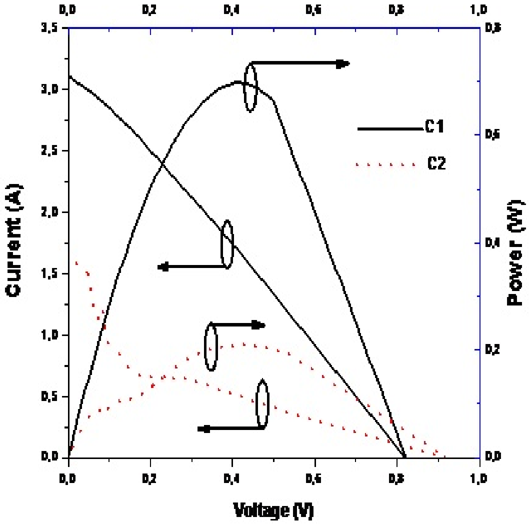

Fig 7 Characteristics of two cells after exposure to 120 thermal cycles

Fig 8 Cell (C2) after exposure to 160 thermal cycles

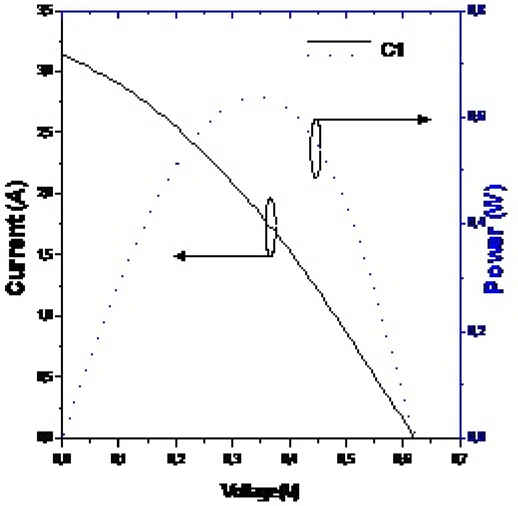

Fig 9 Characteristics of the cell (C1) after exposure to 160 thermal cycles

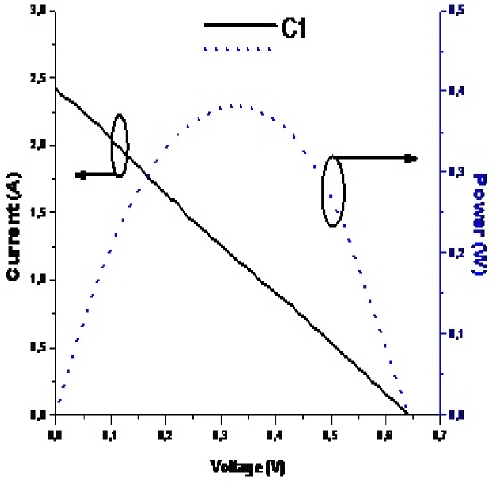

Fig 10 Characteristics of the cell (C1) after exposure to 200 thermal cycles

Quantities extracted from curves of the preceding figures indicate the degradation of the electrical performance of the two cells. They are shown in table 1 below.

TABLE 1
The electrical quantities of the cells (C1 and C2) after each measurement

		I_{SC} (A)	V_{OC} (V)	P_m (W)	FF (%)
Before exposure		2.262	2.218	1.310	0.261
After exposure to 40 thermal cycles	Cell 1	3.161	1.194	1.289	0.342
	Cell 2	3.107	1.218	1.127	0.298
After exposure to 80 thermal cycles	Cell 1	2.128	1.581	0.846	0.251
	Cell 2	1.563	1.523	0.699	0.294
After exposure to 120 thermal cycles	Cell 1	3.108	0.822	0.697	0.273
	Cell 2	1.623	0.919	0.209	0.140
After exposure to 160 thermal cycles	Cell 1	3.124	0.622	0.638	0.328
	Cell 2	----	----	-----	----
After exposure to 200 thermal cycles	Cell 1	2.415	0.643	0.380	0.245
	Cell 2	----	-----	-----	----

ISSN 2356-5608

It noted that a 20% higher degradation of the maximum power delivered by a cell makes the system in a pseudo-fault state [12]. We notice that:

- The starting power of the two cells is degraded successively. The degradation in cell C2 is higher than that in cell C1.
- The same remark for the voltages of the open circuit (after simple increases).
- A slight increase in short circuit current is recorded in both cells. This result is in agreement with those already published by the references [16, 17].
- The FF (form factor) is slightly increased at the beginning, so that it eventually becomes degraded.

IV. MODELING OF THE RELIABILITY

The Weibull distribution is already tested, by previous studies [12, 14, and 18], that she was adequate to estimate the reliability of the photovoltaic modules. It is normal to choose it to model the reliabilities of the cells under the constraints defined previously. The Weibull model is characterized by [19, 20, and 21]:

- Reliability function is :

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad (2)$$

With:

- β: parameter of the form of model ($\beta > 0$)
- η : scale parameter ($\eta > 0$), which indicates the magnitude of the average lifetime, denoted by MTBF (Mean Time Between Failure)

- The instantaneous failure rate is given by:

$$h(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \qquad (3)$$

- The average life (MTBF) is given by:

$$MTBF = \eta\Gamma\left(1+\frac{1}{\beta}\right) \qquad (4)$$

- Where Γ is the function defined by:

$$\Gamma\left(1+\frac{1}{\beta}\right) = \int_0^{\infty} x^{1/\beta} e^{-x}\, dx \qquad (5)$$

The Weibull model can model the reliability of an electronic system according to the β value in the three life phases [14]:

1) If $\beta < 1$ the failure rate decreases, this is the run-in period. This decrease is explained by the gradual elimination of defects. When this period is shorter, the system is reliable.
2) If $\beta = 1$ (Practically about 1) the failure rate is constant. The system is in useful period (should be the longest). The Weibull model in this case is an exponential model.
3) If $\beta > 1$ the failure rate is increasing, it is the period of the aging system.

The parameters of the model, under both stresses are determined by the average of a genetic algorithm built in Matlab. The following figure 12 shows the steps followed:

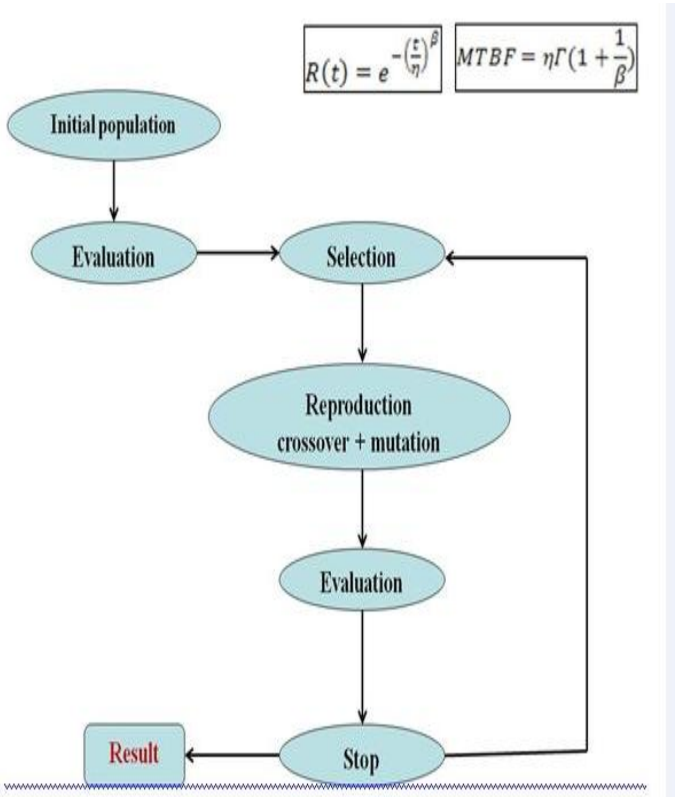

Fig 11 Flowchart of the genetic algorithm

Through the application of these 7 steps, a program was built by Matlab. We obtained the following results table 2:

TABLE 2
Weibull parameters estimated under amplified stress conditions

	Shape parameter(β)	Scale parameter(η)	Average lifetimes (τ in thermal cycle)
Stress S1	2.3333	203	179.8735
Stress S2	2.3333	94	83.2912

The graphs of the following Figure 12, 13 show the reliability of cells (C1, C2) under stress S1, S2:

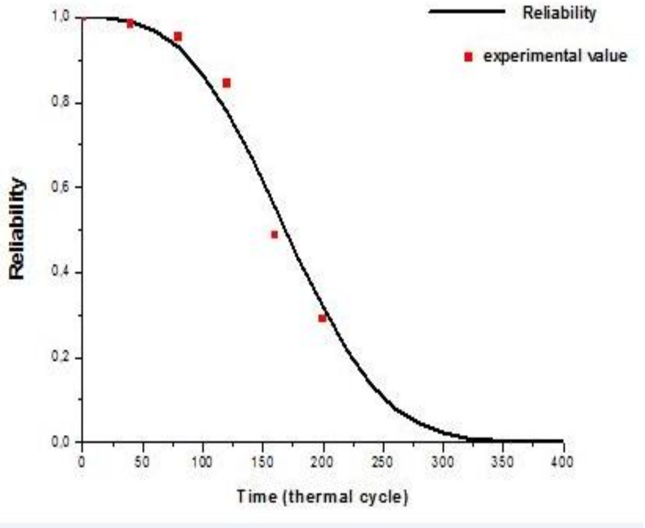

Fig 12 Reliability under stress S1 (reliability of C1)

ISSN 2356-5608

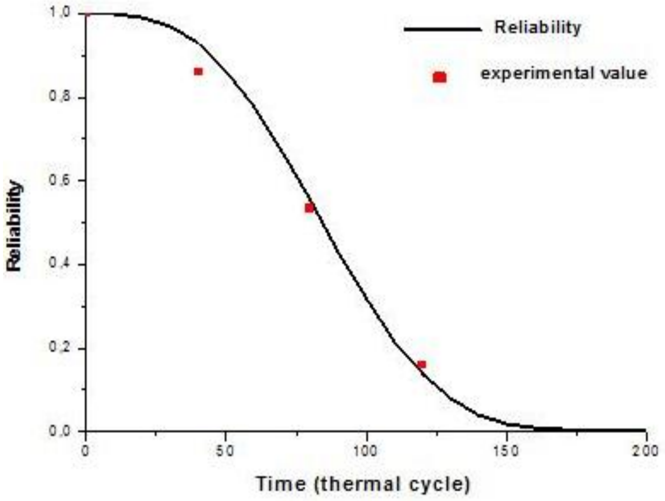

Fig 13 Reliability under stress S2 (reliability of C2)

By choosing the model of Coffin-Manson, the most suitable for thermal cycles [22], defined by:

$$\tau = N(T) = \frac{A}{\Delta T^{B}}$$

- τ : The average lifetime of the components subjected to fatigue due to the variation in temperature
- $N(T)$: Number of cycles up to break
- A and B: characteristic constants estimated from the results of the test.
- ΔT : Width of temperature variation (thermal cycle)

By the calculation, the constants of the model and the lifetime of the cells under the stress S0 are presented by:

TABLE 3
Constants of models (Coffin Manson and Weibull) under stress S0

A	**B**	**β_0**	**η_0**	**τ_0 (cycle)**
7823×10^{9}	5.7658	2.3333	210010	186090

The graph of Reliability in this case is simulated by:

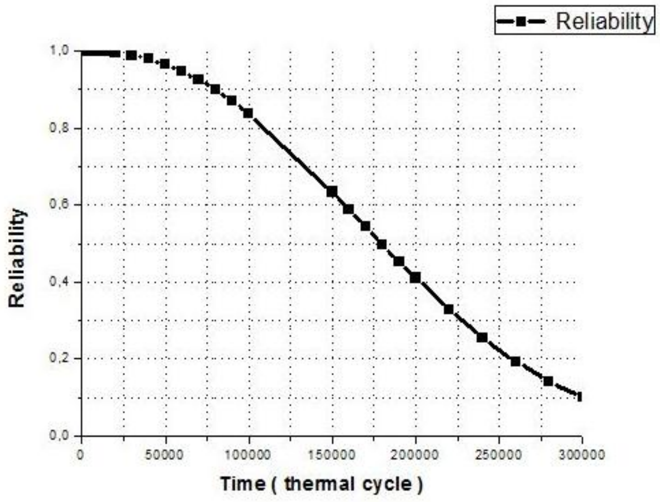

Fig 14 Reliability of polycrystalline cell under normal conditions

The mean lifetime under the stress S0, transformed into unit of time, has presented in:

TABLE 4
Mean lifetime of cell under the stress S0 into time unit

	T (thermal cycle)	**τ (hour)**	**τ (year)**
Stress S1	179.8735		
Stress S2	83.2912		
Stress S0	186090	232612.5	26.5357 ≈ 27

The estimated duration for a degradation of 20% of the starting power of cell is about 17 years, giving a degradation rate of 1.17% per year. This result is acceptable by comparing at the rate of degradation of 1% per year for the of a polycrystalline module in a similar natural medium [8]. (This is acceptable because the cell must be degrading more than the module).

V. CONCLUSION

Our main objective of this study was the approximate estimation of the effect of stochastic cycles of temperature in a desert environment (independently of other climatic factors) on the degradation phenomenon of polycrystalline PV cells. Accelerated testing was the only average that can be used to achieve this objective. Modeling by Weibull model allowed us to estimate an average life of 27 around years, for a degradation of 52% about, of the power initial value. The duration to see a degradation of 20% (pseudo-failure state) is order of 17 years. The average annual rate of degradation is order of 1.17% per year. By comparing this result with others presenting the degradations of the polycrystalline PV modules, we conclude the important role of the stochastic thermal cycles of a desert environment on the degradation phenomenon of PV cells (modules). For increase the service life of solar panels operated in Saharan natural environments, it's necessary to look for the reliable techniques to block the effect of narrow variation of temperature.

VI. ACKNOWLEDGMENT

I thank M. OTMANI permanent researcher from the Research Unit in Renewable Energy in Saharan Environments (URERMS-Adrar) for their help in experimentation.

VII. REFERENCES

[1]. Davide Polverini, Michael Field, Ewan Dunlop and Willem Zaaiman " Polycrystalline silicon PV modules performance and degradation over 20 years" Progress. Photovoltaic: Res. App. 21:1004–1015 Appl. 2013

[2]. Tony Sample and Alberto Pozza, “20-Year field exposed polycrystalline silicon PV modules: detailed visual inspection and analysis”, European Commission, DG JRC, Institute for Energy and Transport, Ispra (VA), Italy, 2013

[3]. Kholid Akhmad, Akio Kitamura, Fumio Yamamoto, Hiroaki Okamoto, Hideyuki Takakura, Yoshihiro

ISSN 2356-5608

Hamakawa, "Outdoor performance of amorphous silicon and polycrystalline silicon PV modules", Solar Energy Materials and Solar Cells, V 46, 3, 209-218, June 1997

[4]. Ababacar Ndiaye, Cheikh M.F. Kébé, Abdessamad Kobi, Papa A. Ndiaye, Vincent Sambou, Abdérafi Charki, "Degradation evaluation of crystalline-silicon photovoltaic modules after a few operation years in a tropical environment" Solar Energy, V103, 70-77, May 2014

[5]. Kieren Smith, “Degradation effects in photovoltaic modules”, Engineering thesis, Murdoch university, 2016

[6]. David A. Quansah et al, “Reliability and Degradation of Solar PV Modules—Case Study of 19-Year-Old Polycrystalline Modules in Ghana”, technologies, 22 May 2017

[7]. Marc Köntges and al, “Review of Failures of Photovoltaic Modules”, IEA PVPS Task 13 External final report IEA-PVPS March 2014

[8]. Tony Sample, "Failure modes and degradation rates from field-aged crystalline silicon modules", institute for energy, ISPRA, Italy, Golden USA, NREL, 17 February 2011

[9]. Nabil Kahoul et al, “Evaluating the reliability of crystalline silicon photovoltaic modules in harsh environment”, Renewable Energy 109,pp 66-72, 2017

[10]. F. Bandou et al, “Evaluation performance of photovoltaic modules after a long time operation in Saharan environment”, International Journal of Hydrogen Energy, 40, pp. 13839 – 13848, 2015.

[11]. Amor Fezzani1 et al, “Degradation and Performance Evaluation of PV Module in Desert Climate Conditions with Estimate Uncertainty in Measuring”, Serbian journal of electrical engineering Vol. 14, No. 2, 277-299, June 2017

[12]. G. T. Mani, J. Kuitche, "Accelerated Lifetime Testing Of Photovoltaic Modules ", July 2013.

[13]. Laronde, R., Charki, A., Bigaud, D, “Lifetime Estimation of a Photovoltaic Module Subjected to Corrosion Due to Damp Heat Testing”, Journal of Solar Energy Engineering 135 (2), 021010 (8 pages), Nov 21, 2012.

[14]. R. Laronde, " Fiabilité et durabilité d'un système complexe dédié aux énergies renouvelables application a un système photovoltaïque ", thèse, université d’Angers, septembre, 2011

[15]. CLIMATE-DATA .org

[16]. F. Khelfaoui, M. Remram. « Fonctionnement A Haute Température D’une Cellule Solaire A Base Du Silicium Poly Cristallin » Revu. Energy. Reno. 83-89, Chams 2000

[17]. Indra Bahadur Karki “Effect Of Temperature On The I-V Characteristics Of A Polycrystalline Solar Cell” Journal Of Nepal Physical Society, Vol. 3, No. 1, August-2015

[18]. M. Boussaid. A. Belghachi, K. Agroui. “Modelling Of The Aging Of PV Modules In A 388 Natural Environment” 2nd Istanbul International Conference On Engineering & 389 Technology, Computer, Basic & Applied Sciences – Ecba –2016 – Istanbul, 390 Turkey, January 5–6, 2016.

[19]. Philippe Saint Pierre, « Introduction à l'analyse des durées de survie », Université Pierre et Marie Curie, Février 2015

[20]. Morice E. « Quelques modèles mathématiques de durée de vie ». Revue de statistique appliquée, tome 14, 45–126, 1966.

[21]. M. Rausand, “system reliability theory Models, Statistical Methods, and Applications”, 2end edition, Arnljot Hay land (1924-2002)

[22]. O. Tebbi, « estimation des lois de fiabilité en mécanique par les essais accélérés », Thèse de Doctorat, université d’Angers, mars 2005

ISSN 2356-5608