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

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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 module. 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 confirms the responsibility of the varied temperature in the form of stochastic thermal cycles in desert environments on the degradation phenomenon of PV 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, 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, 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:

1. Know the mechanisms of failure under the normal conditions of use.

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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).

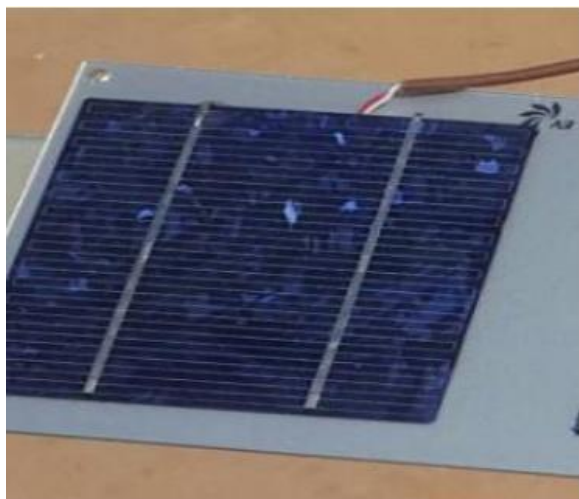Each cycle lasted an hour and a quarter. Figure1 presents these cells:

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). Figure 2:
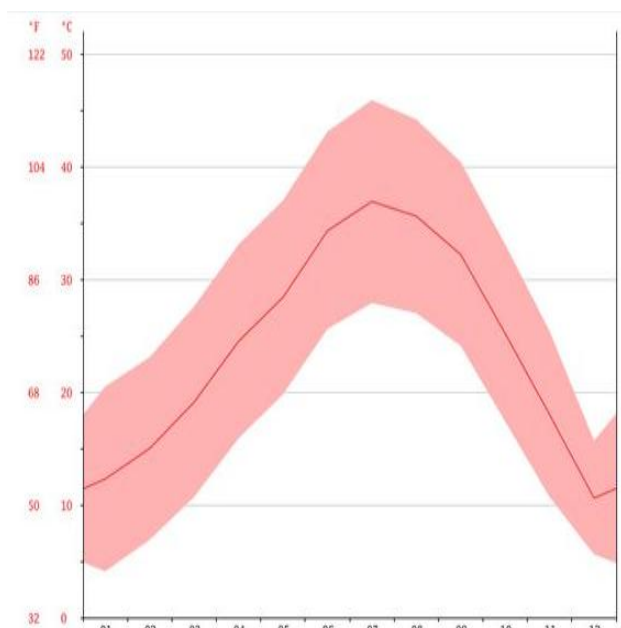

Fig 2 Annual limits of temperature in the region of Adrar [15]

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, Figure 3:
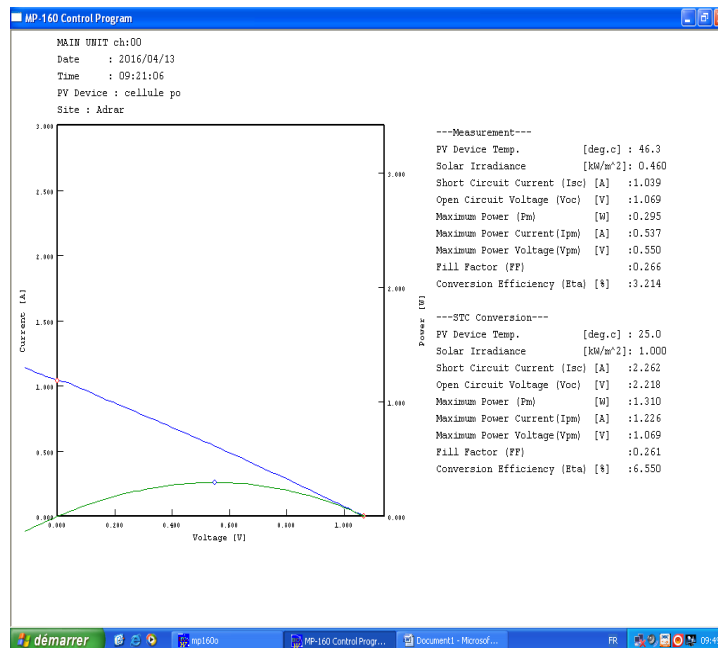

Fig 3 the originals characteristics of cell before exposure to the thermal cycling test

The data we received is redrawn under the standard conditions and presented in the figures below. The characteristics before exposure to thermal stresses are presented in the following figure 4:
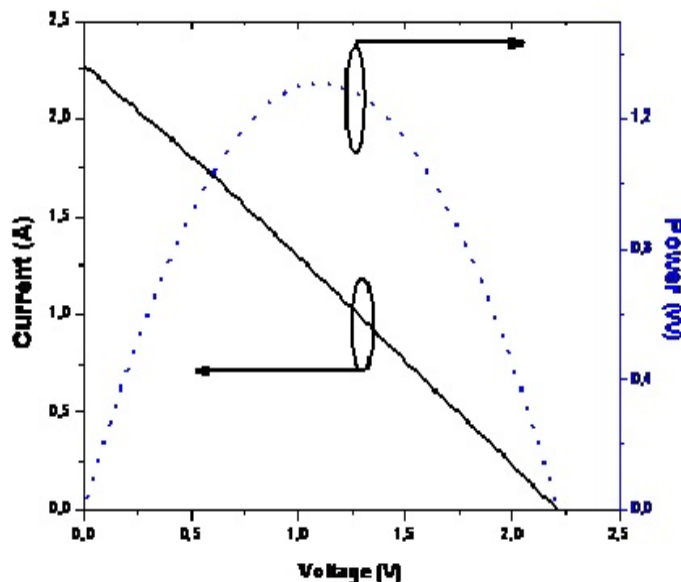

Fig 4 Characteristics of cell before exposure to the thermal cycling test in STC conversion

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.

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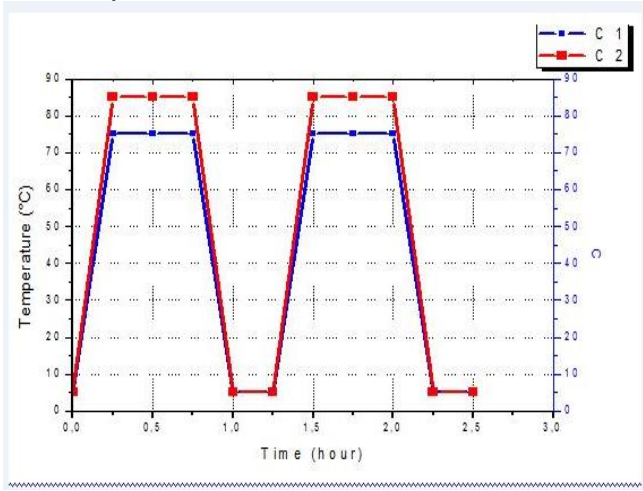The following figure 5 presents the diagram of the simulated cycles:

Fig 5 Simulated thermal cycles

III. RESULTS AND DISCUSSION

After each 40 thermal cycles (50 hours), the results obtained are shown in Figure 6, 7, 8, 9, 10 and 11, respectively (they are given in the standard conditions-1000W/m2 and 25°C- using the solar analyser).
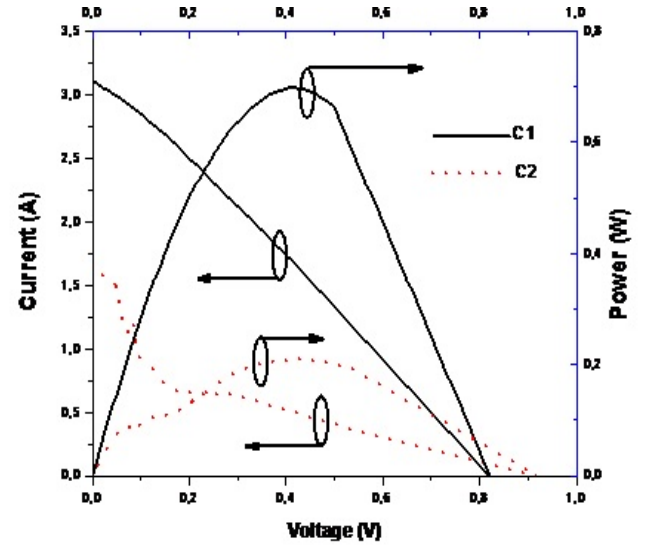

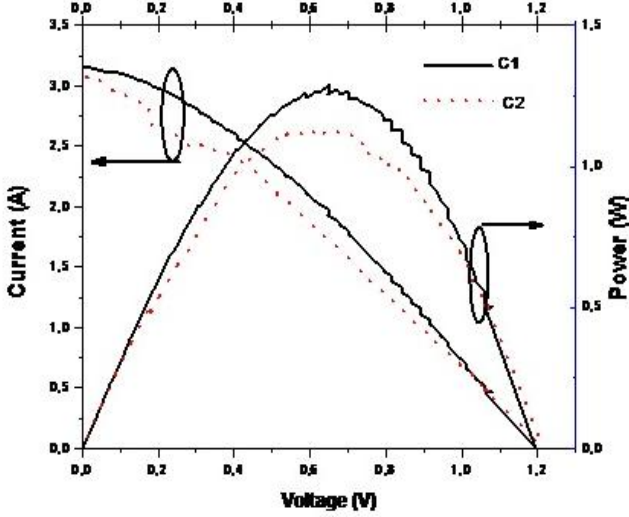Fig 6 Characteristics of the two cells after exposure to 40 thermal cycles

Fig 7 Characteristics of two cells after exposure to 80 thermal cycles
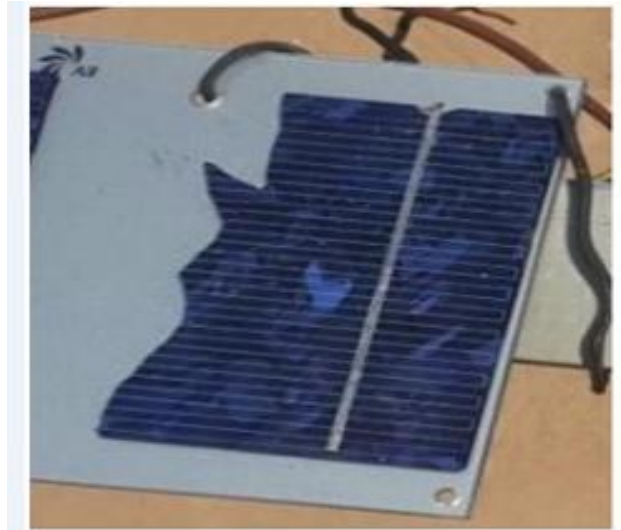

Fig 8 Characteristics of two cells after exposure to 120 thermal cycles
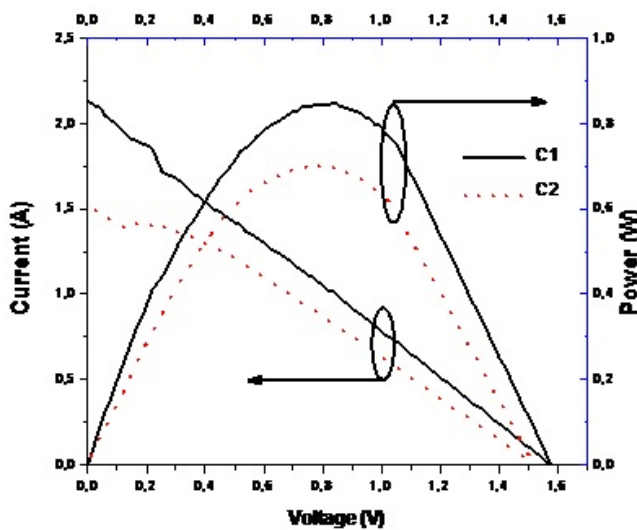

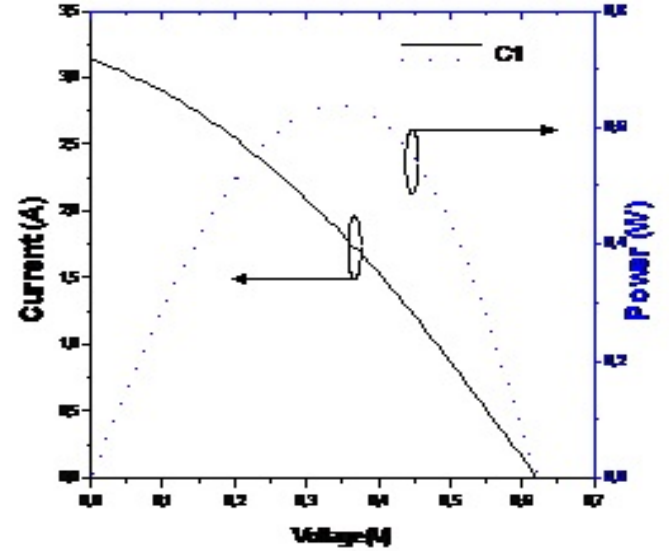Fig 9 Cell (C2) after exposure to 160 thermal cycles

Fig 10 Characteristics of the cell (C1) after exposure to 160 thermal cycles
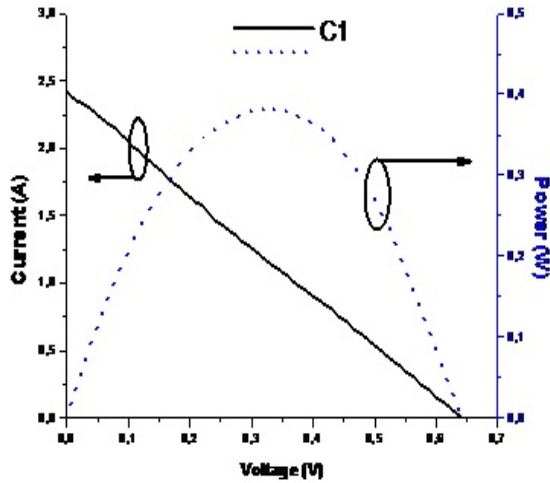
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Fig 11 Characteristics of the cell (C1) after exposure to 200 thermal cycles

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	----	-----	-----	----

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. It's an iterative stochastic algorithm that uses an initial population to reach an optimal solution of any problem. The chosen population initially has evolved from generation to generation, or the individuals, the most adapted, have the great chance to reproduce. The following figure 12 shows the steps followed:
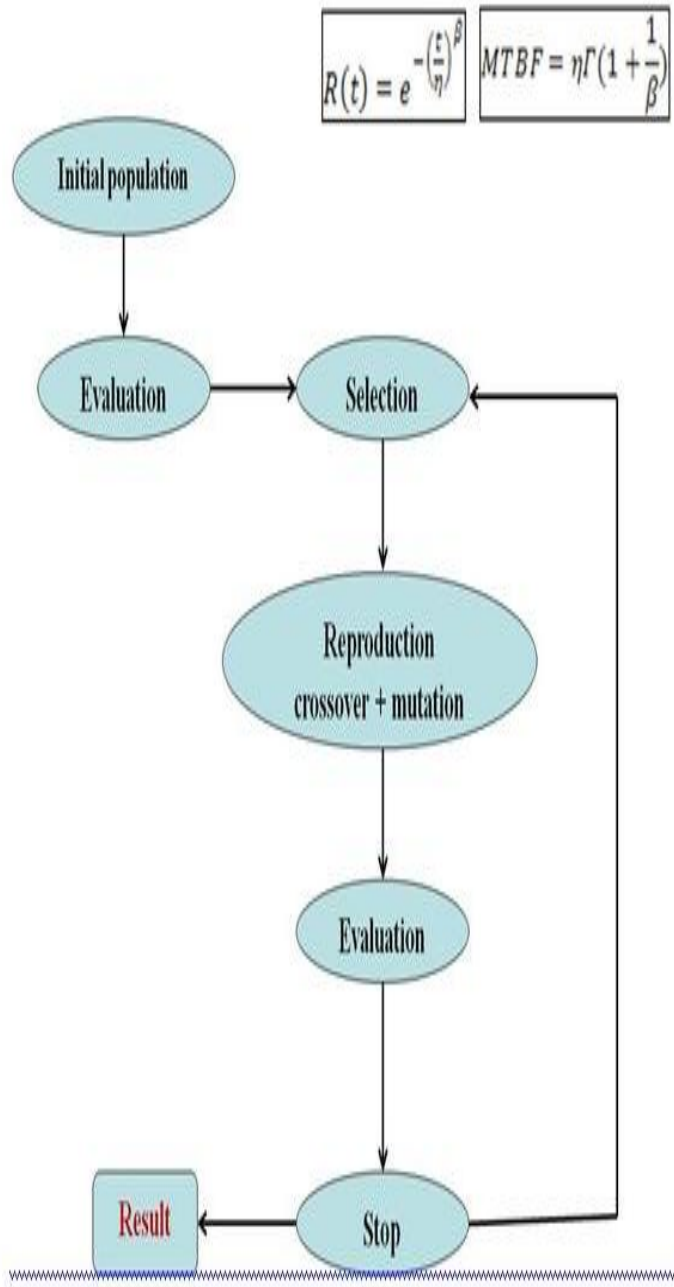
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$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad MTBF = \eta\Gamma\left(1+\frac{1}{\beta}\right)$$

Fig 12 Flowchart of the genetic algorithm

Fig 13 Reliability under stress S1 (reliability of C1)
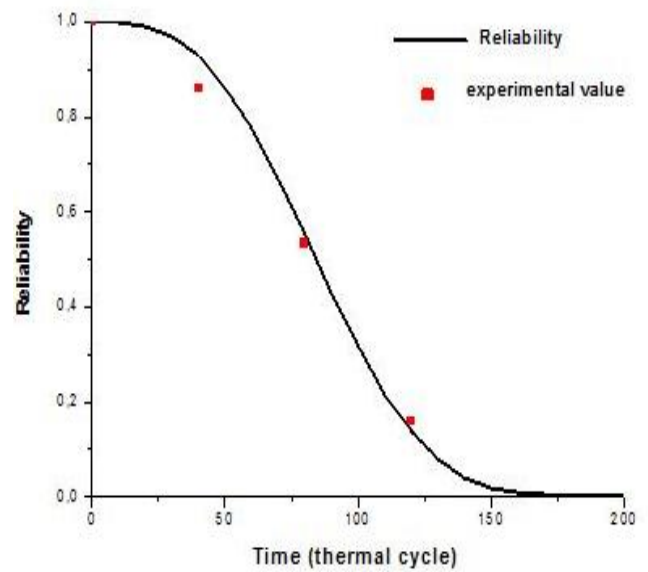
Fig 14 Reliability under stress S2 (reliability of C2)

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 13, 14 show the reliability of cells (C1, C2) under stress S1, S2:
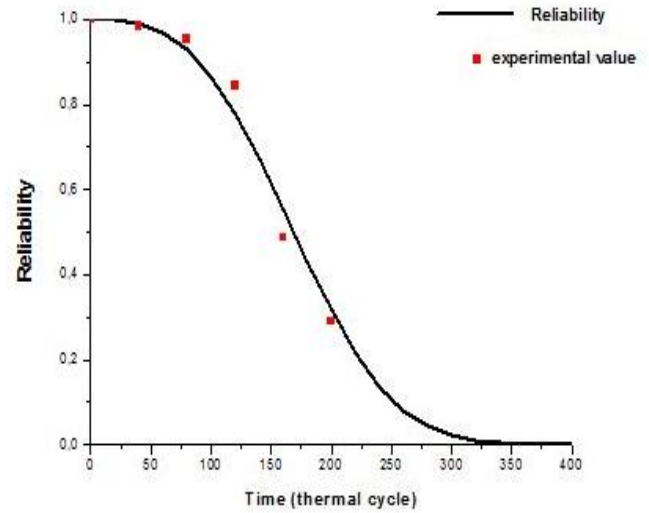
By choosing the model of Coffin-Manson, the most suitable for thermal cycles [22], defined by:

$$\tau = N(T) = \frac{A}{\Delta T^B} \qquad (6)$$

- 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

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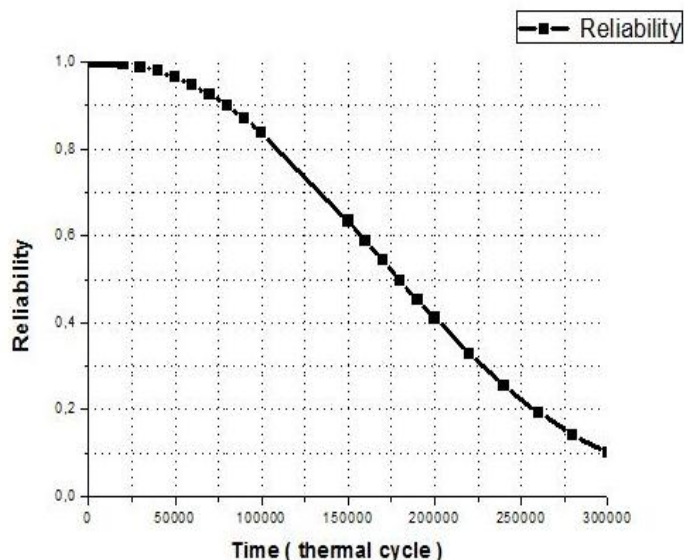The graph of Reliability in this case is simulated by:

Fig 15 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	$26.5357 \approx 27$

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

VII. REFERENCES

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