Competing Risk of Degradation Processes of a Photovoltaic System under Several Conditions

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***Abstract*—The regions of Sahara provide a very important solar resource, trying countries to move towards the production of photovoltaic energy. But operating systems are installed in a hostile environment and equipment is more vulnerable than in the north. This paper deals with the failure mechanisms of photovoltaic system and highlights the effect of competing risk of breakdowns initiated by severe weather in the south. The effect of the sandstorm is not often discussed in the literature, for this a special interest has been given to this phenomenon in this paper. The work developed in this paper was initiated following our understanding of the interest granted by a group of countries from the Maghreb and from Europe to develop green energy in the DESERTEC project, considered of regional significance.**

***Index Terms*—photovoltaic system, saharan region, failure mechanisms, degradation**

I. Introduction

The Maghreb countries and particularly Algeria, profit from an exceptional sunning of 3000h of sunshine per year with a high level of radiation [1], [2] which places it at the head of the producers of energy of the future.

It is clearly directed towards a new configuration of the architecture of the electric system, based on a decentralized and ecologic production of electricity. Regarding its geographical position, the objective is not only supplying domestic demand, but also exporting electrical energy to Europe. This allows introducing the scope of the DESERTEC project for electricity production from solar resource. This ambitious project will encourage other oil producers from North Africa countries to follow the example of Algeria. This article aims to carry out the electrical characterizations of photovoltaic modules UDTS-50. The tests are carried out in natural environment and under solar illumination on the Saharan site of the URER-MS of Adrar (Algeria), characterized by an intense sunning and a raised ambient temperature. It is observed that the extremely rigorous saharian conditions lead to extreme requirements with respect to solar technologies. Photovoltaic systems are much more vulnerable than those operating in the northern regions and technology equipment standards does not necessarily assumed the competing risk of degradation sitting in these hostile environment. In the literature, many works were completed everywhere in the world treating the performances of photovoltaic systems under various environmental conditions, but rather dealing with the effect of sandstorm.

Harrouni and Maafi [3] have presented an experimental analysis at a fine scale of time (10 minutes) of the output of conversion of a generator containing single silicon crystal cells in desert environment. This analysis showed that the yield of generator is equal to 8.5% instead of 17% in a conventional one. This variation of the output is due to the influence of various climatic parameters which characterize the desert area where the studied photovoltaic generator operates especially at the ambient temperature. This latter has a direct influence on the accumulator battery which ensures the storage of the surplus of solar energy. Indeed, the high temperatures can generate the boiling of the battery.

Sadok and Mehdaoui [4], have presented the obtained results from the analysis of the (I-V) characteristics of the photovoltaic panels which were examined in a Saharan area (Adrar). The study includes the determination of most representative parameters of the panels by employing numerical methods for an exponential model. The study has also included the degradation of the modules' performances. The values of degradation factors have revealed that the modules have lost nearly the third of their initial performances. Unfortunately, the lack of suitable instruments did not contribute to go deeply into the degradation phenomenon; nevertheless, this can be attributed to different factors like ultra violet light absorption, encapsulant discoloration and hot spot formation.

Nabil Kahoul and al [5] have performed an experimental study of early degradation of photovoltaic modules (UDTS-50) functioning for a period of 11 years in a region of the Sahara (URER-MS ADRAR). The series resistance reduces the voltage produced by the cell, which ultimately reduces the PV module performance.

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Experimental results show that some PV modules degrade up to 12% compared to their initial state. The performance analysis of the others tested modules revealed some defects, such as cracked cells and physical material defects. The identification of the origin of degradation and failure modes and how they affect the photovoltaic modules is necessary to improve the reliability of photovoltaic installations.

Shaharin and al [6] have studied and simulated the effect of an artificial dust under a constant radiance in a laboratory on the performances of solar panel. Dust has an effect on the performance of the solar panel; the reduction of the maximum power is estimated at more than 18%. Under a greater irradiation, the effect of dust is slightly reduced but not negligible.

II. Visual Inspections and Observations Analysis

After meticulous visual inspections of the modules in the solar station of MELOUKA (Adrar), several classes of defects were detected. The most important ones are shown in the following Fig. 1, Fig. 2 and Fig. 3, described as: dirt on the glass, color changes and encapsulation defect respectively.

Accumulation of dust from the outdoor environment on the panels of solar photovoltaic system is natural; the accumulated dust can reduce the performance of solar panels by reducing the performance of its optical transmission and by limiting the amount of solar radiation that reaches the solar cell as shown in Fig. 1.

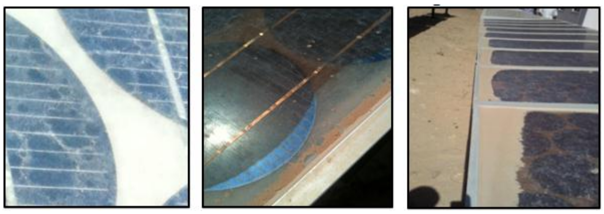

Figure 1. Degradation of the optical properties of glass (station of MELOUKA).

Visual inspection has revealed a significant browning of the encapsulant on the inside of a module. This effect often happens after long term exposure to ultra violet sunlight with module operating temperature near 50℃ [7]. The examined photovoltaic module revealed natural EVA discoloration on all of its cells covering about 90% of their area as shown in Fig. 2. The EVA discoloration appears not only on the surface of the cell but also on the street surface between the cells [8]. Browning of the ethylene-vinyl acetate (EVA) encapsulate used in crystalline silicon photovoltaic modules can reduce the efficiency because of decreased light transmittance [9].

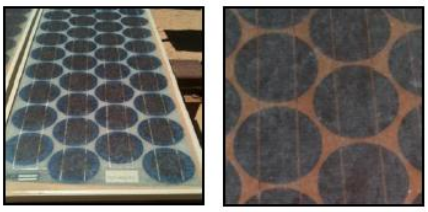

Figure 2. Discolored EVA (station of MELOUKA).

In desert regions, the combination of wind, sand and dust can cause abrasion of the front glass and frosting of the glass surface. It reduces the electrical performance of the photovoltaic module. Also, it can damage the AR coatings of the front cover [10]. Interconnect degradation in crystalline silicon modules occurs when the joined cell-to-ribbon or ribbon-to-ribbon area changes in structure or in geometry. The characteristics directly attributable to interconnect degradation include increased series resistance in the electrical circuit, increased heating in the module, and localized hot spots causing burns at the solder-joints, at the polymer backsheet, and in the encapsulate [11].

Module delamination is resulting from loss of adhesion between the encapsulate on other module layers. These phenomena are gathered in Fig. 3.

Figure 3. Broken glass, broken ribbon and delamination (station of MELOUKA).

The effect of long-term exposure at too significant rise, in the ambient temperature, is the bursting of the box as shown in Fig. 4, after that, dust can deteriorate the function of the anti-parallel diodes. Its effects are: Oxidation of screws, short circuit of the electric circuit, and corrosion of the connections inside of the box.

Figure 4. Effect of temperature and sand wind on junction box (station of MELOUKA).

Electrochemical corrosion can appear with the junction of two metals in the presence of dust. The speed of the corrosion depends on the nature of the electrolyte. In a salty atmosphere, the speed increases considerably as indicated in Fig. 5.

Figure 5. Battery degraded (station of MELOUKA).

III. Experimentation

The experimental setup used for the outdoor measurements contains module to test; they were facing toward the equator and mounted on a fixed structure which was tilted at an angle equaling the latitude of the site. These modules are of UDTS-50 type, as identified in Table I, which utilizes single crystal silicon cells. The values of the solar radiation and the ambient temperature are given by pyranometer and a thermocouple, respectively. All these information were saved to files given by the I-V curve tracer MP-160.

TABLE I. THE MAIN PARAMETERS OF THE USED MODULE UDTS-50

Parameter	Value
Pmax (watts)	53.21
Voc (V)	21.28
Isc (A)	3.49
FF (%)	71.64

In the photovoltaic technology, it is clear that the modules do not necessary maintain their initial performances given by the manufacturer as shown above, so in our case the performances are compared to those of operating module as the reference.

IV. SIMULATION AND RESULTS DISCUSSION

The interest of this simulation is to follow the behavior of the current (A) as a function of voltage (V) often studied under the cited mechanism of degradation. The simulation was done using Matlab software package. The obtained results are given in Fig. 6 and Fig. 7 and the power losses corresponding to each test are gathered in Table II and Table III.

TABLE II. ESTIMATION OF POWER LOSSES IN THE CASE OF DUSTY ENVIRONMENT AND IN THE CASE OF CONTINUOUS DEGRADATION

Test	Reference	Effect of dusty environment			Effect of continuous degradation	
		Fine dust	Wind dust	Dust storm	Less	More
Pmax (STC)	52.29	43.35	28.87	21.36	47.704	44.404
Loss (%)	0	17.09	44.79	59.15	8.77	15.09

TABLE III. ESTIMATION OF POWER LOSSES IN THE CASE OF PHYSICAL DEFECT

Test	Effect physical defect		
	Broken glass	Sand	cardboard
Pmax (STC)	30.464	44.264	46.164
Loss (%)	47.79	15.35	11.71

The power loss is significant regarding wind dust and dust storm as shown in Table II. It is equivalent to the losses in the case of broken glasses as indicated in Table III.

The effect of dirt and pollution are given for two cases:

In the uniform case, shown in Fig. 6(a), the fall in power can be explained by the reduction in the quantity of the radiations collected by the module. The total shape of the curve (I-V) corresponding to this test is similar to that of reference but the current is reduced. Moreover the contact of sand grains with glass of the module (the sand is at origin of glass manufacturing) led to an optical reduction in the properties of glass because microscopic stripes appear on it and traps the sand grains. This phenomenon was already introduced in Fig. 1.

In the non-uniform case, shown in Fig. 6(a), the fall in power is very significant especially if the module is covered with an important quantity of sand. The appearance of inflection point on the curve is synonymous with conduction of one or more by-pass diodes. The sand wind is into major part responsible of this phenomenon because a band of dirtiness, as shown in Fig. 1, is formed on the inferior edge of the module which is prolonged to the top (towards the interior) with time causing shadings on the cells.

Another phenomenon observed and treated corresponds to the continuous degradation. On the site of Adrar, the operating temperature of the modules can reach 70 ℃. The loss in power increases with the intensity of discoloration from 8.77% to 15.07% as presented in Table II and Fig. 6(b). The discoloration of the EVA causes the reduction of its optical transmission; therefore the current of the module is decreasing.

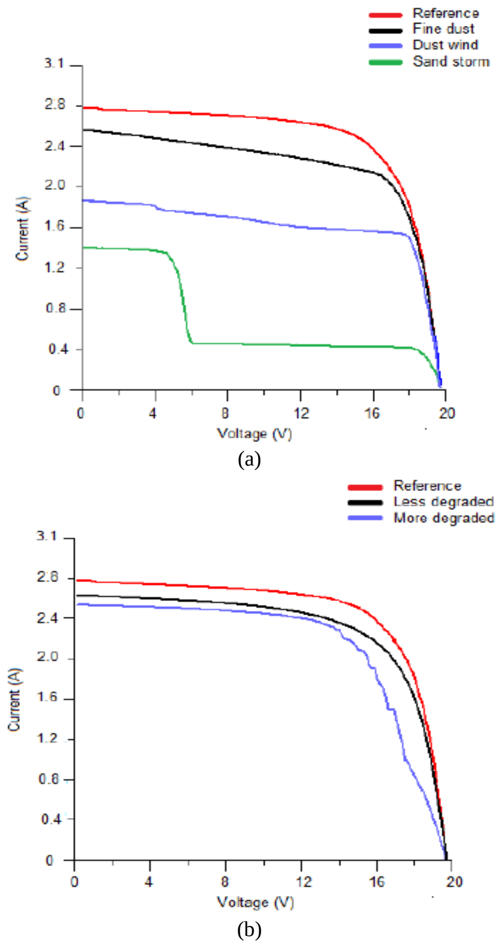

Figure 6. (a) Effect of the dust; (b) effect of continuous degradation.

Another phenomenon observed and treated corresponds to physical defects, namely: defects of encapsulation, glass breakage and shad effect. The breaking of glass is a phenomenon which can be allotted to a thermal stress. The inflection point is synonymous to conduction of the by-pass diodes as for the slope between Voc and Vmpp which is due to the increase in series resistance (terminal corrosion out of the connector's metal in the module, junction box or on the buses) as explained earlier and shown in Fig. 7(a).

A falling shadow on a group of cells will reduce the total output by two mechanisms; such as: reducing the energy input to the cell, and increasing the energy losses in the shaded cells as shown in Fig. 7(b). The curves obtained for the two tests of shade are almost similar, but power losses are more significant in the case of shade with sand as shown in Table III, because its granulose structure makes it very opaque and makes increasing the temperature of the module. This induced effect lead the cells to operate under reverse bias mode, developing higher temperatures within the cell due to Joule effect.

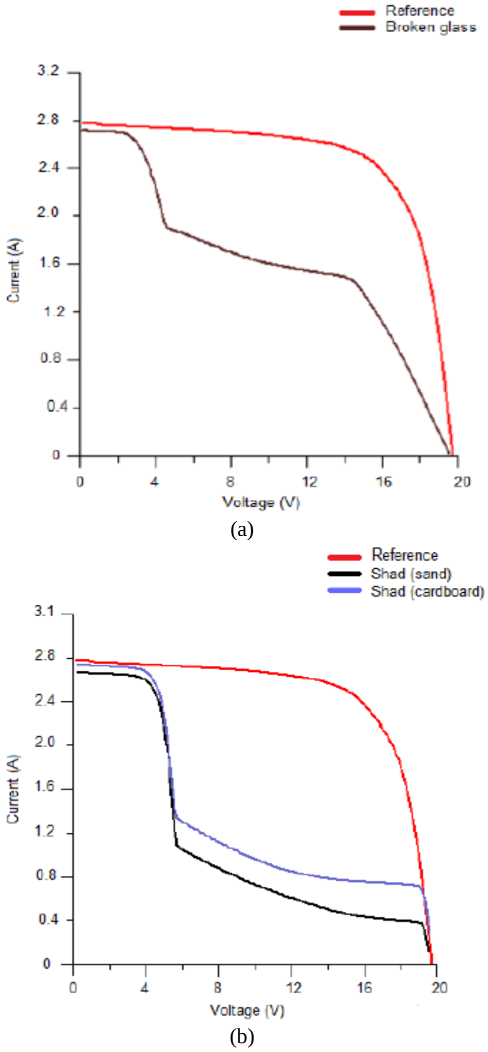

Figure 7. (a) Effect of the defect of encapsulation glass breakage; (b) effect of the shade.

V. Conclusion

The Algerian Sahara is the best suited to photovoltaic power generation due to abundant availability of sunlight throughout the year. The ambition of the completion of the DESERTEC project and the immensity of the system predicted makes that technologies of the solar panel and the auxiliary equipment's to install must fulfill the requirement of this arid and constraining environment. In this paper a number of failure modes of photovoltaic system were identified and observed in the field. In addition to the influence of temperature and of the irradiance, dust accumulation, which is significant over a relatively short period of time, has a significant impact on the performances of the system by reducing the amount of sunlight that the PV panels are exposed, polluting the components connections and degrading the system energy storage. In addition to some maintenance actions which can be judged obvious, such as: cleaning the panels after a sandstorm, it is useful to think to provide a rotating system functioning with the importance of the speed and the continence of sand during the sandstorm. The inclination of the panels will be monitored by a sand debit meter.

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