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Assessing the early degradation of photovoltaic modules performance in the Saharan region

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ABSTRACT

In this study, the electrical performance degradation of photovoltaic modules (UDTS-50) functioning for a period of 11 years in a region of the Sahara (URER-MS ADRAR) is analyzed. This paper is devoted to an experimental study of current–voltage characteristics of several PV modules exposed to the extreme weather conditions in desert area. The electrical performance degradation and failure modes are estimated from series of current–voltage characteristics performed in the field. 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.

1. Introduction

The reliability of photovoltaic modules has always been one of the most important subjects as reliability and lifetime is the key for overall system performance and warranty. Manufacturers of PV modules usually give a guarantee for at least 20 years [1,2]. In the process of operation, many factors have adverse effect on PV panel and result in output value lower than normal, such as the early degradation and fault of PV panel [3,4]. There are other factors that affect the output of a photovoltaic power panel [5]. These factors need to be understood so that the customer has realistic expectations of overall system output under variable environmental conditions over time.

An experimental bench is used to characterize PV modules operate for a period exceeding 11 years under desert weather conditions. The PV module performance degradation is estimated from series of current–voltage characteristics (*I–V*) carried out at Adrar in southern part of Algeria (high operating temperatures). The use of the characteristic *I–V* to detect and locate the defects was carried out in very few works. On the other hand, analysis in the reverse has been performed by many studies. Such analysis consists in studying impact of the various defects (in the cell, module) on PV module performance, hence the *I–V* characteristic thereof. The extraction of representative parameters (series resistance, maximum power point at STC, etc.) allows detecting the fault in PV module (increase of series resistance between cells, cell degradation, etc.) [6]. In the presented paper different types of photovoltaic defects are reviewed.

This paper is organized as follows. In Section 2, we introduce the PV module model used in this study. Section 3 presents an effective method to estimate the degradation rate at STC. Section 4 includes the experimental results and discusses the main detected defects in PV panels. Finally, in Section 5, the conclusion is drawn.

2. Model of the studied PV module

2.1. Photovoltaic module UDTS-50

The photovoltaic module UDTS-50 consists of 36 monocrystalline silicon cells "0.385 m^2 the panel area" connected in series and two bypass diodes connected in parallel (overlapped bypass diodes) Fig. 1, with a maximum power of 50 W. This module is protected by a tempered glass plate, EVA resin, impermeable PV back sheet and aluminum frame.

2.2. Equivalent circuit of the PV module

The photovoltaic module UDTS-50 is modeled by the equivalent circuit diagram (Fig. 2) with a single diode. This model comprises a current source (I_{ph}), a diode and two resistors (R_s and R_p) [7].

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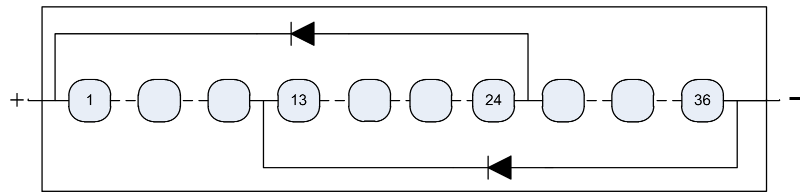

Fig. 1. Internal connection of cells and bypass diodes inside the PV module UDTS-50.

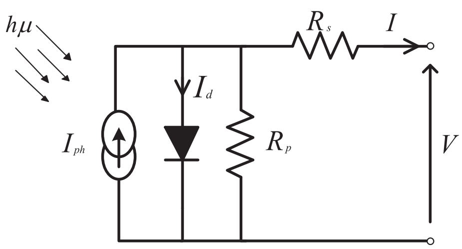

Fig. 2. Single-diode model of PV cell.

The characteristic equation *I–V* is given by:

$$I = I_{ph} - I_0\left[exp\left(\frac{V + IR_s}{AV_t}\right) - 1\right] - \frac{V + IR_s}{R_p} \quad (1)$$

where I_{ph}: Photo generated current (proportional to incident radiation). I_0: Saturation current of diode. R_s: Cell series resistance. R_p: Cell parallel resistance. A: Diode quality factor. V_t: Thermal voltage.

In this section, the PV model parameters; I_{ph}, I_0, R_s and R_p are determined based on electrical parameters; V_{oc}, I_{sc}, V_{mp}, I_{mp} and A. The aim is to find the model parameters such that the resulted *I–V* curve accurately matches the experimental curve [8]. These parameters are obtained by solving the fundamental Eq. (1) for the key points. the values for R_s and R_p are computed by an efficient iteration method.

Fig. 3 shows the experimental and simulated curves of PV module UDTS-50 based on experimental input data (T = 38.5 °C and G = 0.837 kw/m^2). In this figure, the simulated result has been compared to the experimental data. It is observed that simulated and experimental results match accurately at three key points: open circuit, maximum power, and short circuit. The two curves are also reasonably close at other points.

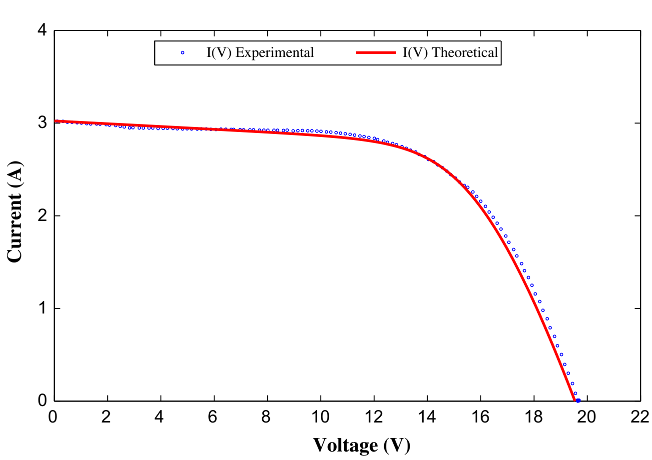

Fig. 3. *I–V* experimental and theoretical characteristic of module UDTS-50.

3. Experimental setup

For outdoor module performance measurements under natural sunlight and environmental conditions, the MP-160 *I–V* tracer is used to test several modules and it offers a high level of flexibility. The calculation accuracy for current and voltage values of *I–V* curve is 0.5% against full scale. During exposure tests, automatic measurement can be scheduled for continuous data retrieval and make an automatic STC conversion of the measurable modules parameters (Fig. 4). The solar irradiations are measured by the pyranometer. Simultaneously, individual temperature measurements are performed with the thermocouple attached to the back side of PV module. The *I–V* tracer save the measurements in Microsoft Excel format (.XL) and then the curves are plotted by MATLAB.

Before treating degradation of electrical performance, it is advisable to analyze climate data. The site climate data reported from research unit of renewable energy in Saharan middle, Adrar "www.urerms.dz". Measurements were carried out at Adrar in the extreme south Algeria. This site is often exposed to high level of temperature. Fig. 5 gives a summary of ambient temperature. All data values were measured every 2 s from 7:00 a.m. to 7:00 p.m.

It is clear that the site is always characterized by high temperature values, typically average ambient temperature above 40 °C (in estival months), with peaks around 63 °C in July (in outdoor). The annual average of global daily irradiation measured on inclined plane exceeds the value of 7 kW h/m^2.

3.1. PV module degradation

The photovoltaic modules will suffer degradations caused by exposure to sunlight, humidity and high temperature which is manifested by a change in the values of its parameters and performance [9]. To study the evolution in time of PV modules performance, one should know their *I–V* characteristic curves obtained in outdoor test as well as those provided by the manufacturer and corresponding to standard conditions (STC). These data can be used as standards for the same type of modules under test. However, the data provided by the manufacturer are insufficient because they are carried out in laboratory and indoor STC arent identical to outdoor STC. Furthermore, the performances of PV modules or PV systems on actual site are extremely influenced by environmental parameters; the total irradiance incident, solar spectral irradiance distribution, wind speed, air temperature and other factors of losses. Therefore, an outdoor characteristic of a module of the same type turns out to have a major utility. To do this, we chose a module of the same type (UDTS-50), the characteristic *I–V* is observed experimentally on the same site (Adrar). This module has been installed in its new condition, has practically not been affected by the degradation phenomenon.

3.2. Reference module

The reference module was characterized in 1995 using an experimental setup constituted by resistive load (rheostat) and