INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 13839–13848

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Evaluation performance of photovoltaic modules after a long time operation in Saharan environment

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ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form
14 April 2015
Accepted 16 April 2015
Available online 14 May 2015

Keywords:
Photovoltaic module
Degradation
Performance
Aging
Desert environment

ABSTRACT

Reliability and lifetime of photovoltaic (PV) systems depend mainly on the energy performance of modules and on their different degradation modes. Accordingly, research must be focused on degradations of PV modules. This paper presents the results of investigations carried out on the degradation mechanisms of PV modules of the Melouka central in the area of Adrar in Algeria after 28 years of exposure in the Saharan environment. Main degradation modes are observed through visual inspection of PV modules: discoloration of encapsulant, broken and abrasion of glass, delamination, discoloration and hot spot of cells, oxidation of front grid fingers and thermal shocks. The current-voltage (I-V) characteristics are acquired with outdoor measurements in the site. The experimental results permit to detect both hot spots and thermal shocks which are the most detrimental total defects visually observable in the site, and to quantify the reduction of electrical performance data correlated with visual degradation data. A maximum power (P_{max}) degradation rate of 1.22%/year is found which is closely related to short-circuit current (I_{sc}) of 0.78%/year, followed by fill factor (*FF*) of 0.57%/year and finally short-circuit voltage (V_{oc}) of 0.1%/year. Akin results are reported in literature for PV modules exploited under desert climate for long duration.

Introduction

Many photovoltaic (PV) modules have been installed all over the world. However, the reliability and lifetime of PV systems depend mainly on the energy performance of the modules and on their degradations [1,2]. The identification of the degradation modes and the evaluation of their importance constitute a challenge because a high degradation rate leads directly to a loss of power output and therefore to a reduction on the investment return [3]. In addition, the aging of photovoltaic modules also results in different alterations during their

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http://dx.doi.org/10.1016/j.ijhydene.2015.04.091

operations which depend on the site of implantation [4,5] and which affect the various parts of a PV array: glass, encapsulating materials commonly ethylene-vinyl-acetate (EVA), silicon cell, reflective material on the rear of the cell (for example aluminum or Tedlar), collector fillers and resistant glass back sheet. Environmental stresses (heat, wind, humidity, UV radiations, shading of sand etc.) influence the performance of PV modules and lead to degradation effects [6]. Discoloration of the encapsulant (EVA) which appears on 98% of the plant modules strongly covers their entire tedlar background [6–10]. The literature survey indicates that the browning of EVA is reversed by oxygen in the presence of UV radiations, in a process called photo-oxidative bleaching [8]. The main cause of this effect in EVA and ethylene copolymer films is UV radiation exposure combined with temperatures above 50 °C that cause a change in the chemical structure of the polymer as described by Oreski and Wallner [10]. In the research work of Yang and Whitfield [11], it has been reported that the yellowing of EVA (upon exposure to high temperatures for long durations) reduces the transmission spectra of the degraded EVA. The short-circuit current would reduce linearly with the increase of the Yellowing Index (degree of browning) of the encapsulant. Deterioration of the anti-reflection layer and browning of cells are similar to a shading effect like when the front glass is covered by a layer of sand [12]. This induced shading effect makes cells operate under bias mode, developing higher temperatures within the cells by Joule effect [13]. Formation of hot spots [14–16], humidity infiltration, delamination and corrosion [13,17], cracks and bubbles in the back sheet [18,19], as well as interconnect degradations modify the structure or geometry of the cell-to-ribbon or ribbon-to-ribbon contact areas [14].

The lifetime of PV modules is estimated at about 20–25 years. Lifetime is based on the warranty of less than 90% of initial maximum power after 10 years of use and less than 80% after 25 years of utilization. All cost calculations are based on a lifetime of 20 years but this duration could be extended for some module series [20]. Lifetime and alterations vary from one environment to another [21,22]. Long-term in situ measurements are instructive as they allow a better insight of aging and operating of PV modules beyond lifetime which enable one to apprehend the degradation mechanisms, to improve performances and to eventually extend the exploitation duration.

The performance of photovoltaic modules in desert environment is extremely influenced by aging effects caused by exposure to solar radiations, humidity ingress and higher temperature. Several investigations have been performed in desert environment. Power degradation rates have been namely reported. Berman and Faiman obtained 1.3%/year after 3.4 years of operating of polycrystalline PV modules in the Negev desert [23]. Raghuraman et al. conducted outdoor tests on 44 modules from eight different manufacturers for three different PV technologies [24]. They found a power degradation rate of 0.4%/year after 4 years of use for monocrystalline silicon PV modules. For polycrystalline silicon PV modules the rate is 0.53%/year after 2.7 years and for amorphous silicon ones, it is of 1.16%/year after 6.7 years and 3.52%/year after 2.7 years. Dechthummarong et al. [25] studied an array of 32 modules that operated for over 27 years under harsh conditions of hot-desert in Arizona and found that one third of the modules were non-functional with less than 30% of the original power, while the rest of the set exhibited an average power degradation of 1.08%/year. Recently for Tilonia in India, in this hot and dry climatic zone, the measurements carried out provided a mean power degradation rate of 1.17%/year for mono-crystalline silicon photovoltaic modules tested outdoors [26]. For comparison, Jordan et al. calculated a rate of 1.24%/year considering various technologies and climates [27].

In the present work, we have for objective to inquire and evaluate the degradation mechanisms which we observe on a plant of PV modules in the southern Saharan region of Algeria in Adrar after 28 years of exposure. First, the most important types of defects taking place in the installation are inquired. A second part is devoted to develop the PV module model which serves to plot curves of the experimental results of current-voltage (I-V) characteristics, for a sample of defected modules. Thirdly, we present the method to calculate the uncertainty of measured values and the degradation rates at standard test conditions (STC) for electrical performances: maximum power output (P_{max}), short-circuit current (I_{sc}), open-circuit voltage (V_{oc}) and fill factor (*FF*). In the final section, we discuss the results for the detected flaws of the studied PV modules and their impact on the electrical characteristics. We show that the obtained yearly degradation rates are in agreement with the other research results in desert environment.

Experimental setup

Photovoltaic central

The 30.24 kW Melouka central in Adrar was the first PV platform installed in Algeria (Fig. 1). It is located at North Latitude of 27.52°N, West Longitude of 17°W and elevation from sea level is of 279 m, in a region bathed in a large solar field. The realization of this plant was made in the context of cooperation between Algeria and Belgium in 1985 to supply autonomous applications. It consists of a photovoltaic field, which is composed of 864 PV modules of type Belgosolar, divided in forty eight strings each of 630 Wp nominal power oriented and interconnected in appropriate ways to produce the desired solar energy. Solar energy is converted directly into electricity using monocrystalline silicon PV cells. The encapsulation is used for the mechanical connection of the whole module and involves a front side in glass. The cells are embedded in a transparent resin that ensures the sealing and protection

Fig. 1 – Overview of the Melouka photovoltaic central in Sahara (area of Adrar, Algeria).