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Degradation evaluation of crystalline-silicon photovoltaic modules after a few operation years in a tropical environment

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Abstract

This paper presents an evaluation of the performance degradation of Photovoltaic modules after few operation years in a tropical environment. To this end, the International Center for Research and Training in solar energy at Dakar University and the Lasquo-ISTIA laboratory of Angers University have put in place a research project in order to investigate the impact of the tropical climatic conditions on the PV modules characteristics. Accordingly, two monocrystalline-silicon (mc-Si) PV modules and two polycrystalline- silicon (pc-Si) PV modules are installed at Dakar in Senegal and monitored during a few operation years: Module A (16 months), Module B (41 months), Module C (48 months) and Module D (48 months). After few operation years under tropical environment, the global degradation and the degradation rate of electrical characteristics such as I-V and P-V curves, open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), maximum ouput current (I_{max}), maximum output voltage (V_{max}), maximum power output (P_{max}) and fill factor (FF) are evaluate at standard test conditions (STC). This study reports on data collected from 4 distinct mono- and poly-crystalline modules deployed at Dakar University in Senegal. The study has shown that P_{max}, I_{max}, I_{sc} and FF are the most degraded performance characteristics for all PV modules. The maximum power output (P_{max}) presents the highest loss that can be from 0.22%/year to 2.96%/year. However, the open-circuit voltage (V_{oc}) is not degraded after these few exposition years for all studied PV modules.

Keywords: Photovoltaic module; Degradation; Tropical environment

1. Introduction

The performance of PV modules varies according to the climatic conditions and gradually deteriorates through the years (Adelstein and Sekulic, 2005; Cereghetti et al., 2003; Dunlop and Halton, 2005; Osterwald et al., 2006; Sanchez-Friera et al., 2011; Som and Al-Alawi, 1992). An important factor in the performance of PV technologies has always been their long-term reliability especially for the new emerging technologies. The most important issue in long-term performance assessments is degradation. Degradation is the outcome of a power or performance loss progression dependent on a number of factors such as degradation at the cell, module or even system level. In almost all cases, the main environmental factors related to known degradation mechanisms include temperature, humidity, water ingress and ultraviolet (UV) intensity. All these factors impose significant stress, over the lifetime

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of a PV device and as a result detailed understanding of the relation between external factors, stability issues and module degradation is necessary. In general, degradation mechanisms describe the effects from both physical mechanisms and chemical reactions and can occur at both PV cell, module and system level. More specifically, the degradation mechanisms at the cell level include gradual performance loss due to ageing of the material and loss of adhesion of the contacts or corrosion, which is usually the result of water vapor ingress. Other degradation mechanisms include metal mitigation through the p–n junction and antireflection coating deterioration. All the above mentioned degradation mechanisms have been obtained from previous experience on c-Si technologies (Dunlop and Halton, 2005; Quintana et al., 2002; Som and Al-Alawi, 1992). In the case of a-Si cells an important degradation mechanism occurs when this technology is first exposed to sunlight as the power stabilizes at a level that is approximately 70–80% of the initial power. This degradation mechanism is known as the Staebler–Wronski effect (Staebler and Wronski, 1977) and is attributed to recombination-induced breaking of weak Si–Si bonds by optically excited carriers after thermalization, thus producing-defects that decrease carrier lifetime (Stutzmann et al., 1985). At the module level, degradation occurs due to failure mechanisms of the cell and as a result of degradation of the packaging materials, interconnects, cell cracking, manufacturing defects, bypass diode failures, encapsulant failures and delamination (Munoz et al., 2011; Wenham et al., 2007). Degradation investigations using indoor methodologies are based on the acquisition of *I–V* curves and power at STC (Ndiaye et al., 2013a). The electrical characteristics of PV modules are initially measured at STC and then the modules are either exposed outdoors or indoors through accelerated procedures (Carr and Pryor, 2004; Meyer and Van Dyk, 2004; Osterwald et al., 2002). For each investigated PV cell or module the electrical characteristics are regularly acquired using the solar simulator and the current, voltage or power differences from the initial value that provides indications of the degradation rates at successive time periods.

A wide variety of degradation rates has been reported in the literature with respect to technologies, age, manufacturers, and geographic locations, and has been recently summarized (Jordan and Kurtz, 2011). Significant variation in the data can be caused by different module types, age, construction (encapsulation, front- and back-sheet), electrical set-up (open-circuit, short-circuit, load resistor, grid-tied), and measurement uncertainty (Skoczek et al., 2009). The literature contains an excellent review of long-term field testing based on discreet *IV* measurements (Sanchez-Friera et al., 2011), but fewer reports include more comprehensive *I–V* parameters investigation, including voltage and current at maximum power point (Chamberlin et al., 2011; Granata et al., 2009; Reis et al., 2002).

In this paper we present the degradation evaluation of electrical characteristics of crystalline-silicon PV modules such as *I–V* and *P–V* curves, open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), maximum ouput current (I_{max}), maximum output voltage (V_{max}), maximum power output (P_{max}) and fill factor (FF) in a tropical environment after a few operation years on four crystalline silicon (mc-Si and pc-Si) PV modules located at Dakar University in Senegal.

2. Experimental platform presentation

2.1. Photovoltaic test field

The photovoltaic platform shown in Fig. 1 is used in this study. It is installed at Dakar in Senegal. Senegal is located on the extreme western Africa between 12.5° and 16.5° North latitude and 12° and 17° West longitude. It presents a dry tropical climate characterized by two seasons: a dry season from November to June and a rainy season from July to October (ANAMS, 2012). Senegal has a significant solar potential with annual average radiation duration of about 3000 h and an exposure rate of 5.7 kWh/m^2/d. This radiation varies between the northern part which is more sunlit (5.8 kWh/m^2/d in Dakar) and the southern part, the richest in terms of precipitation (4.3 kWh/m^2/d in Ziguinchor) (PSA, 2011). The temperature varies from 16 °C around Dakar (January) to 38 °C in the South (October). The rainfall increases from North to South with an annual average of 300 mm in the extreme North and 1500 mm in the extreme South (ANAMS, 2012). The average relative humidity varies between 75% and 95% (Wofrance, 2012). The platform is installed in Dakar between 17.28° West longitude and 14.43° North latitude to 31 m altitude.

Platform consists of two monocrystalline (A and C) and two polycrystalline (B and D) photovoltaic modules. The technical characteristics of PV modules provided by the manufacturers are given in Table 1. The modules have operated during a few years: Module A (16 months), Module B (41 months), Module C (48 months) and Module D (48 months). Thus, performance parameters (*I–V* and *P–V* curves, V_{oc}, I_{sc}, FF and P_{max}) are measured under the standard test conditions (AM1.5, 1000 W/m^2,

Fig. 1. Photovoltaic test field at Dakar in Senegal.