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Techniques and Experimental Results for Performance Analysis of Photovoltaic Modules Installed in Buildings

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Abstract

Photovotaic (PV) modules applied to buildings form a unique surface at the same roof inclination, replacing the tiles. Such PV systems are affected by thermal and mechanical stresses, and remarkable dirt. Another issue is the partial shading with possible failure of bypass diodes. In this paper a sample of PV modules, affected by the previous issues, was tested by electroluminescence and I-V curve scanning, to quantify power losses according to the causes. The experimental results are presented, demonstrating that the most important causes of losses are the cracks in module's solar cells and the failure of their bypass diodes.

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Keywords: PV module; experimental techniques; electroluminescence; *I-V* curve scanning; building applied PV.

1. Introduction

It is very advisable the installation of Photovoltaic (PV) generators in urban areas to create distributed generation, which permits to produce a substantial amount of the electricity close to the demand [1]. However, some technical issues arise when conventional PV modules are attached in building rooftop subjected to aesthetical and economic constraints. These constraints may be summarized in three items studied in this paper. Firstly, the installation of PV modules must be at the same height of the roof tiles, replacing them. Secondly, the PV modules must have the same tilt angle of the roof. Thirdly, the PV modules must be placed close each other to form a unique surface, even in the presence of obstacles on the roof, to minimize the usage of metallic structures and the time of installation. The linked

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technical issues, described in this paper, generate a worsening of the operational performance up to the complete failure of PV modules. To detect this underperformance, appropriate techniques are employed to quantify the amount of power losses and to recognize their causes.

As well known, the PV modules are subject to many experimental tests before their operational life. They are the qualification tests to simulate 25 years of exposition to the environmental agents. The degradation rate of PV modules is artificially accelerated within a few days of tests in laboratory. On the other hand, the techniques to determine the performance of PV modules, during their life, regard both the electrical efficiency and the structural adequacy of the solar cells inside every PV module. These techniques include the measurement of the current-voltage (*I-V*) characteristic curves and the evaluation of images from thermo-graphic cameras with different wavelength bands. Such bands are 7.5—13 μm for hot spot identification and 1.1—1.2 μm for electroluminescence. The abovementioned tests may be periodically performed to check if the PV system behavior is satisfying. The test for hot spot identification is normally performed in field with the PV modules in operation to detect hot cells when, in shading conditions, good cells supply power to defective cells. The electroluminescence test carried out in dark room, after disassembly of a PV module from metallic structure, provides qualitative information about the electrical efficiency of the solar cells inside the PV module under test. The color uniformity of the cells and their brightness are a qualitative warranty of good efficiency. On the other hand, to have available an adequate amount of information, it is needed to carry out the Laser Beam Induced Current (LBIC) test [2]; however, this is a very expensive test. Usually, the electroluminescence test, together with the information provided by the correction of the I-V curve measurement to STC, is sufficient to determine the behavior of a PV module and the possible causes of its underperformance. Further tests, to be performed in case of evident reduction in the open circuit voltage, regard the measurement of the *I-V* curves of bypass diodes. They are connected in anti-parallel to groups of solar cells inside the junction box of the PV module to protect the cells against the generation of reverse voltage as a consequence of I-V mismatch for shading effect.

This article provides a deep understanding of the amount and causes of performance worsening. The experimental tests are carried out in outdoor conditions if they regard the *I-V* curves and in laboratory if they concern the electroluminescence.

Nomenclature

α_T	temperature coefficient of short circuit current (A/°C)	
β_T	temperature coefficient of the open circuit voltage (V/°C)	
FF	fill factor of the *I-V* curve, corresponding to ratio $P_{max}/(V_{oc} \cdot I_{sc})$	
G	solar irradiance (W/m^2), at standard test conditions G_{STC}=1000 W/m^2	
η	PV conversion efficiency	
$I_{mpp,c}$	current in maximum power point, corrected to standard test conditions (A)	$\Delta I_{mpp,rel} = (I_{mpp,c} - I_{mpp,d})/I_{mpp,d}$
$I_{mpp,d}$	current in maximum power point at STC, declared by manufacturer (A)	
I_{Pmax}	current in maximum power point measures at experimental conditions (A)	
$I_{sc,d}$	short-circuit current at STC declared by manufacturer (A)	
I_{sc}	short-circuit current measured at experimental conditions (A)	
N_s	number of series connected cells	
$P_{mpp,c}$	maximum power corrected to STC (W)	$\Delta P_{rel} = (P_{mpp,c} - P_{mpp,d})/P_{mpp,d}$
$P_{mpp,d}$	maximum power at STC declared by manufacturer (W)	
P_{max}	maximum power measured at experimental conditions (W)	
T_a	ambient temperature (°C)	
T_C	cell temperature T_C (°C), at standard test conditions T_{STC}= 25°C	
$V_{mpp,c}$	voltage in maximum power corrected to STC (V)	$\Delta V_{mpp,rel} = (V_{mpp,c} - V_{mpp,d})/V_{mpp,d}$
$V_{mpp,d}$	voltage in maximum power point at STC declared by manufacturer (V)	
V_{Pmax}	voltage in maximum power point measured at experimental conditions (V)	
$V_{oc,d}$	open circuit voltage at STC declared by manufacturer (V)	