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Performance evaluation of two solar photovoltaic technologies under atmospheric exposure using artificial neural network models

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Abstract

Experimental results are presented from monitoring the electrical power after exposure to external weather conditions of two different solar modules technologies, one of them a mono-crystalline 55 W silicon and the other a flexible organic solar module of 12.4 W. During the observation period the temperature, relative humidity, and irradiance were monitored. With these records an artificial neural network model was trained, validated and tested, delivering the electric power based on the three monitored parameters. These models were subjected to a sensitivity analysis with respect to the input variables and from the electrical point of view, a better performance for the organic flexible module was achieved specially under conditions of higher relative humidity, higher temperatures and lower irradiances. Finally this tool helps for prediction of the performance of these photovoltaic technologies at broad different environmental conditions.

Keywords: Silicon solar modules; Organic solar modules; Photovoltaic performance; Artificial neural networks

1. Introduction

Photovoltaic panels are devices that capture energy from a light source such as the sun and convert it into electricity. The power generation is subject to the radiation and the spectral response of photosensitive materials used in the cell to generate an electromotive force proportional due to the incidence energy.

The electrical performance of a solar cell is measured conventionally by an *I–V* curve, which relates the voltage and the current generated by the cell to different electrical load conditions at specific temperature and solar irradiation (typically 25 °C and 1000 W/m^2 respectively in standard test conditions). This curve is generally specified through 5 points: the open voltage (V_{oc}, 0), short circuit current (0, I_{sc}), the maximum power (V_{mp}, I_{mp}) and another 2 operative points around the maximum power point. From the *I–V* curve, solar cell devices in the laboratory have been modeled as a constant current source whose value depends on the load connected to its terminals, and the expression that describes the behavior of these two variables is a non-linear-implicit equation (Jain and Kapoor, 2005). This equation can be represented as an equivalent electrical circuit with 2 or more diodes, and the parameters from the equivalent electrical circuit or from the implicit equation that represent the solar cell *I–V* characteristics at specific conditions can be extracted using an optimization method. The most common reported are genetic algorithms (Zagrouba et al., 2010), particle swarm (Macabebe et al.,

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Nomenclature

b	offset of the model
E_{mse}	mean square error
E_x	irradiance in $\mathrm{W/m^2}$
g	temperature coefficient in 1/°C
I	identity matrix
I_{mp}	maximum current point
I_{sc}	short circuit current
J	Jacobian-dependent of ANN size
N	number of data evaluated
P_{MPP}	power in the maximum point to 25 °C
P_{MPPt}	power according to the irradiance at a non-standard condition,
Si	silicon
T_{cell}	temperature of the cell.
t_i	target
μ_k	learning rate
V_{mp}	maximum voltage point
V_{oc}	open circuit voltage
$\upsilon(x_k)$	linear combiner output of the ANN
W_k	weights and bias of the ANN
w_i	weights of the connections
x_i	inputs of the model
y	output of the model

Terminology

ANN	artificial neural network
PLC	Programmable Logic Controller
TF	transfer function

2011), artificial neural networks (ANN) (Mellit et al., 2013; Celik, 2011; Karatepe et al., 2006; Chekired et al., 2014), among others (Valerio et al., 2010; Almonacid et al., 2010).

The electrical power generated by the cell changes as temperature and solar irradiation changes as occurring in outdoor. For that reason the I–V curve and some parameters of the model used to represent the performance of the cell are also variable. One simple way to consider these variations is though the Eq. (1), which express the relationship between the electrical power generated by the cell as function of the irradiance and temperature taking into account the standard test conditions (Mellit et al., 2013).

$$P_{\mathrm{MPPt}} = P_{\mathrm{MPP}} \cdot \frac{E_x}{1000} \cdot (1 - g \cdot (T_{\mathrm{cell}} - 25)) \tag{1}$$

where P_{MPPt} is the power according to the irradiance at a non-standard condition, P_{MPP} is the power in the maximum point to 25 °C, E_x is the irradiance in $\mathrm{W/m^2}$, g is the temperature coefficient in 1/°C (this term is negative) and T_{cell} is the temperature of the cell.

There has been a tremendous scientific and industrial effort in terms of developing emerging technologies in order to reduce costs and increase the performance of the devices. Other aspects as architectural integration through flexibility, transparency and low weight have also been subject of study. Novel organic and hybrid cells (Wright and Uddin, 2012; Heeger, 2014) have proven to be one of the most promising technologies recently developed to fulfill the above mentioned requirements. For example efficiencies of 9.2% for hybrid devices under inverted configuration have been reported (Zhicai et al., 2012), and more recently the company Heliatek reported efficiencies up to 12% (http://www.heliatek.com) for organic solar cells. Other recent technologies involves dye sensitized solar cells (Gong et al., 2012), quantum cells (Tang and Sargent, 2011), perovskites solar cells (Liu et al., 2013) with remarkable 15% efficiency, among others.

Some protocols have been established to measure organic solar cell devices for accurate lifetime determination (Reese et al., 2011) including different categories of test

Fig. 1. Equipment used for monitoring the solar modules. Left. weather station. Right. PLC.