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Assessment of PV modules shunt resistance dependence on solar irradiance

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Abstract

Modeling and simulation of photovoltaic systems, further than aiding on the project design phase, can be used to emulate the system performance in real time, therefore helping to identify any malfunction that may occur. Among the available performance models for photovoltaic systems, the single diode model is preferred by many authors, since it combines relative simplicity and accuracy. Previous works reported that this model has some limitations on describing the photovoltaic system *I–V* curves under low irradiances, indicating that the variation of the shunt resistance parameter with the irradiance level can be adopted to minimize this drawback. This paper aims to study the shunt resistance dependence on the irradiance level in order to evaluate some of the usual expressions proposed on the literature. A large area pulsed solar simulator model PASAN SunSim 3C was used to acquire the *I–V* characteristics of several photovoltaic modules of different brands and technologies under 20 distinct irradiance levels ranging from 75 W/m^2 to 1000 W/m^2. The shunt resistance parameter was calculated as the inverse slope of the *I–V* curve in the short circuit region, and fitting equations were derived for each photovoltaic technology. The results in general agreed with previous published works, showing the tendency of an increase of the shunt resistance on lower irradiance levels. Some empirical models tested did not present satisfactory accuracy to reproduce the experimental data. Although simpler, an inverse dependence of the shunt resistance on the irradiance using the measured value at STC as a reference was seen to describe adequately the experimental data. A preliminary study showed that the inclusion of this dependence on the single-diode model indeed increases the model accuracy, reducing the average error on the performed tests by more than half comparing to the original model.

Keywords: Photovoltaic module; Single-diode model; Shunt resistance

1. Introduction

The development of accurate simulation tools for photovoltaic (PV) systems is a crucial issue not only for project and performance prediction but also for plant operation supervision. An unreliable prediction model may cause financial losses if the energy to be produced by the system is overestimated, discouraging future investments on PV projects. Using an overly cautious estimation to

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avoid this problem is not a reasonable alternative either, since it may lead to a false conclusion that the system is not economically viable. The use of simulation as a tool to supervise photovoltaic systems can be of major assistance, since it may indicate when a device is not working correctly by comparing the actual operating conditions with the simulated ones. Evidently, an adequate accuracy is required on these cases; otherwise it would not be possible to properly identify a system malfunction.

The characteristic I–V curve, and therefore the power produced by a photovoltaic system, is highly dependent on the environmental conditions, namely the temperature and the solar irradiance. Several models are available to forecast the operation of photovoltaic systems. However, on the definition of the parameters for many models a problem arises: the data provided by the manufacturer datasheet usually contains only information at standard test conditions (STC), or at best also for the NOCT (nominal operating cell temperature). So, the knowledge of the dependence of the I–V curve parameters on the environmental conditions is necessary in order to establish a model valid for every condition.

Among the alternatives for representing the electrical characteristics of photovoltaic modules, the single diode five-parameter model is one of the most commonly used. Despite combining relative simplicity and accuracy, previous works have shown that as a drawback this model tends to fail on the description of I–V curves on lower irradiance conditions (Ishaque et al., 2011). The variation of the shunt resistance parameter with the irradiance can be adopted to minimize this limitation. The aim of this paper is to study the behavior of the shunt resistance with the irradiance level for several photovoltaic modules, in order to check the validity of some usual expressions and propose viable alternatives based on experimental data.

2. Photovoltaic devices modeling

An ideal solar cell can be described, from the basic theory of semiconductors, as a current source in parallel with a diode. Representing the diode current with the expression proposed by Shockley (1950), the characteristic I–V curve of the ideal solar cell is given by Eq. (1).

$$I = I_{ph,cell} - I_{0,cell}\left[\exp\left(\frac{qV_{cell}}{mkT}\right) - 1\right] \tag{1}$$

where I_{ph} is the photogenerated current by the cell, I_0 the reverse saturation or leakage current, q is the electron charge, V the applied voltage on the cell terminals, m the diode ideality factor, k the Boltzmann constant and T the absolute cell temperature.

Photovoltaic modules are assembled by connecting several cells in series. When representing a module, Eq. (1) is modified by adding one term representing the number of cells in series, N_s, and by replacing the cell parameters by the module ones, leading to Eq. (2).

$$I = I_{ph} - I_0\left[\exp\left(\frac{qV}{N_s mkT}\right) - 1\right] \tag{2}$$

However, this ideal photovoltaic module equation has little practical use, since photovoltaic modules with such characteristics are impossible to build. For a better description of the I–V characteristic of PV modules, a series resistance (R_s) is included. This component represents the resistance of the materials which compose the module and causes a reduction on the power converted by this device, and the resulting current I is then described by Eq. (3).

$$I = I_{ph} - I_0\left[\exp\left(\frac{q(V + IR_s)}{N_s mkT}\right) - 1\right] \tag{3}$$

In addition to the parameters of the ideal cell, the series resistance R_s must also be determined, increasing the number of unknown parameters to four. This model is known as the four-parameter model, and has been used for several authors such as Xiao et al. (2004) and Chenni et al. (2007), describing the behavior of PV devices adequately for irradiance level of 1000 W/m^2 under different temperatures. On other studies though, this method was shown to present a poor performance under certain conditions. Celik and Acikgoz (2007) exhibit a comparison between measured data for a sequence of five days, with two numerical simulations, one using the four-parameter model and another with a five-parameter model. The four-parameter model was shown inadequate to describe the PV system under some of the reported environmental conditions, with the five-parameter model presenting a better agreement.

The main difference between the two aforementioned models is the inclusion of the so-called shunt resistance (R_{sh}), which is connected in parallel with the diode. The complete circuit for the five-parameter model is presented on Fig. 1.

The current I is therefore given by Eq. (4).

$$I = I_{ph} - I_0\left[\exp\left(\frac{q(V + IR_s)}{N_s mkT}\right) - 1\right] - \frac{V + IR_s}{R_{sh}} \tag{4}$$

The shunt resistance accounts for alternative paths for the free carriers produced by the solar radiation. A high shunt resistance means that the vast majority of these carriers generate power, whereas a low resistance indicates large losses, affecting mainly the slope of the I–V curve on the proximity of the short circuit region. Breitenstein et al. (2004) attempts to reach a better understanding of the

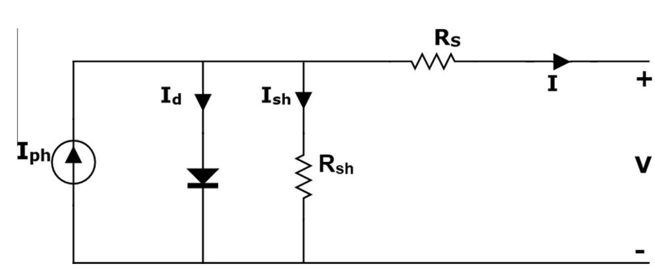

Fig. 1. Five-parameter model circuit.