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PV systems linked to the grid: Parameter identification with a heuristic procedure

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ABSTRACT

This paper focuses on a PV system linked to the electric grid by power electronic converters, identification of the five parameters modeling for photovoltaic systems and the assessment of the shading effect. Normally, the technical information for photovoltaic panels is too restricted to identify the five parameters. An undemanding heuristic method is used to find the five parameters for photovoltaic systems, requiring only the open circuit, maximum power, and short circuit data. The *I–V* and the *P–V* curves for a monocrystalline, polycrystalline and amorphous photovoltaic systems are computed from the parameters identification and validated by comparison with experimental ones. Also, the *I–V* and the *P–V* curves under the effect of partial shading are obtained from those parameters. The modeling for the converters emulates the association of a DC–DC boost with a two-level power inverter in order to follow the performance of a testing commercial inverter employed on an experimental system.

1. Introduction

The demand for sources of sustainable energy, the shortage of fossil fuels and the need for carbon footprint reduction have resulted in a global awareness of the importance of alternative energy sources and efficiency in the use of energy [1]. Renewable energy sources are likely to have a significant role in the world energy supply in the upcoming future. Among the renewable energy sources, solar energy has ubiquity and abundance [2,3]. Hence, if technology find is way through the development of cheaper converts of solar into electric energy and with better efficiency, solar energy will eventually be the most important source of sustainable energy for power supply, delivering energy in the neighborhood of where it is needed [4,5].

Apart from the solar thermal exploitation, the spreading of PV systems is being encouraged by delivering energy in the neighborhood of where it is needed tariffs and by the price drop in crystalline cells [6]. At present, significant photovoltaic (PV) deployment has occurred, particularly in Germany, Spain and Japan [7]. PV energy has exceptional conditions in Portugal to be exploited, because this European country has significant levels of solar radiation to go into exploitation. Sunshine hours in the mainland of Portugal vary between 1800 and 3100 h per year [8]. Hence, the country has a huge potential for solar energy exploitation, the biggest PV system is in Moura, with an installed capacity of 46 MWp.

A PV system directly converts solar energy into direct electric current energy. Solar cells are made of several types of semiconductors using different manufacturing processes [9]. The energy converted by a solar cell depends on the substrate properties, on the temperature of the junction and on the incoming solar radiation [10], known as irradiation. The solar radiation is composed of photons with different levels of energy. But not all photons are useful in order to originate the photo current, the remainder energy passes by or is adsorbed as thermal agitation, contributing to the definition of the temperature on the solar cell [11].

A PV array may be either a panel or a set of panels connected to form large PV systems with or without tracking systems. But, even with tracking systems a correct consideration of the space for the operational neighborhood have to be assessed to avoid mutual shading.

Power-electronic converters are usually used to process the direct electric current coming from PV system, for instance, are used as inverters to deliver an alternate current and may be used to: regulate the voltage and current at the load, control the power

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flow in grid-connected systems and implement maximum power point tracking (MPPT) [12,13]. Generally, the energy conversation by a PV system is assumed to be in a tight neighborhood of the maximum power point due to the MPPT. Hence, the normal useful working portion on *I–V* characteristic is in the neighborhood of maximum power, so the tuned curve should have higher precision at this portion [13]. Hence, this is an important point to be considered in the identification of the equivalent parameters of a model for the *I–V* characteristic.

The shading on the PV panel, for instances, due to a passing cloud or neighboring buildings causes not only energy loss in the conversion, but also further non-linearity on the *I–V* characteristics [14,15]. A non-protected shaded panel of a non-uniform illuminated PV system can be submitted to a negative voltage. If there is no protection, cells breakdowns can happen during non-uniform illumination. Hence, normally in order to protect the cells an extra *p–n* junction is implemented as a bypass diode. For instance, one bypass diode connected in parallel with each set of 18 cells [16] or with a panel is common practice as a compromise between protection and increase on the cost due to the extra *p–n* junction.

Also shading pattern with hasty change is not easy for the tracking of the maximum power point (MPP), because with non-uniform illumination usually there will be multiple local MPPs and they will change as fast as does the illumination. Under shadowing conditions a PV system can have large energy losses and even small shadows can noticeably affect the energy yield [17].

Modeling is an important part of engineering design. The use of computers and powerful software has allowed to predict the performance of complex systems and to assist the almost near optimal design for better systems. Not only simulation is possible, but also performance can be predicted and monitored in real time. In what regards PV modeling, researchers have used equivalent electrical circuits to model the characteristics of a solar cell when subjected to environmental variations, i.e., irradiance and temperature. The equivalent electrical circuit of a solar cell with its parameters has been a tool to emulate the *I–V* characteristics of PV systems [7,18–20]. The equivalent circuit parameters of solar cells are intimately related to the internal solid-state physics acting within the solar cell [21,22]. The equivalent circuit parameters accessing is an important aspect for PV system applications in what regards the design and the simulation of those modules in order to uncover their behavior.

A PV system linked or not to the utility grid consists not only on solar cells, but also on several other apparatus, for instance: storage elements; power converters; control blocks. Hence, to have a correct evaluation is necessary that all models have enough accuracy in what regards the real behavior influencing the overall system performance [23].

By far, the simplest equivalent electrical circuits approach for a PV system is a current source in parallel with a diode [24]. Some authors state as a fact that the solution with a single diode model, i.e., current source in parallel with only one diode, for modeling a PV system integrated into the electric grid is enough to obtain satisfactory results [25]. But it seems to be dependent on what one considers by satisfactory results and what one wants to uncover about the reality in order to take proper action and avoid malfunction problems with the PV systems integration into the electric grid. An improved version for equivalent circuits is the five parameter modeling of the photovoltaic system, with the additional inclusion of a shunt and a series resistance. The shunt resistance accounts for the cell linkage current losses. The series resistance accounts for the joule losses. This version is justified for better accuracy and is the object of analysis in this paper in order to find a simple as possible parameter identification.

Typically, the parameters provided by the PV manufacturers are the open circuit voltage, the short circuit current, the current and voltage at maximum power, the temperature coefficients at open circuit voltage, short circuit current and the NOCT [26–28], but these parameters provide limited operational data for the five parameters modeling.

Power electronic converters have been developed for integrating renewable energy sources with the electric grid. The use of power electronic converters, i.e., inverters are particularly indispensable in PV systems, the inverter is necessary for two accomplishments: the accomplishment of adjusting the low DC voltage of the PV module to the voltage level of the electric grid using a two power converter topology, a DC–DC topology and a DC–AC topology; the accomplishment of the maximum power point (MPP) tracking due to the fact of the power delivered by the modules being very sensitive to the point of operation in the *I–V* curve, the inverter is able to comply with functionality to circumvent this fact [29,30].

This paper focuses on the five parameters identification for the modeling of photovoltaic systems, using three solar cell technologies as a case study for the simulation of the *I–V*, shading characteristics and PV system implemented with a DC–DC boost and a two-level inverter topology. Experimental results are considered in this paper to allow a comparison with the ones given by the modeling. The paper is organized as follows. Section 'Modeling' presents the solar cell model, the iterative procedure for the identification of the five parameters, the PV system with a DC–DC boost and a two-level inverter topology and the main expressions used in the modeling. Section 'Control strategy' presents the control strategy, consisting in pulse width modulation (PWM) by space vector modulation (SVM) associated with sliding mode (SM) for controlling the converter. Section 'Case studies' presents the case studies respectively the simulation and the comparison with the experimental results of the PV system linked to the electric grid by a commercial inverter. Finally, the conclusions are drawn in Section 'Conclusions'.

2. Modeling

2.1 PV module

An improved parameter identification procedure of a photovoltaic module in order to acquire the *I–V* characteristics with the usual data given by the PV system industry is presented by the authors in [31]. The equivalent circuit model for a solar module simulation consisting on a current controlled generator, single-diode D_1, shunt and series resistances, bypass protection diode D_2 is shown in Fig. 1.

Also the equivalent circuit model can be used to simulate an individual cell. But if all cells of a module, a panel or array are subjected to the same irradiance, then the equivalent circuit with the bypass protection diode is also the one shown in Fig. 1, where *G* is

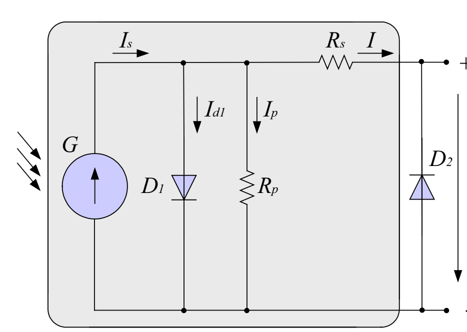

Fig. 1. Equivalent circuit model for a solar module.