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An accurate model for simulating energetic behavior of PV grid connected inverters

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ABSTRACT

This paper proposes a new model for characterizing the energetic behavior of grid connected PV inverters. The model has been obtained from a detailed study of main loss processes in small size PV inverters in the market. The main advantage of the used method is to obtain a model that comprises two antagonistic features, since both are simple, easy to compute and apply, and accurate. One of the main features of this model is how it handles the maximum power point tracking (MPPT) and the efficiency: in both parts the model uses the same approach and it is achieved by two resistive elements which simulate the losses inherent to each parameter. This makes this model easy to implement, compact and refined. The model presented here also includes other parameters, such as start threshold, standby consumption and islanding behavior. In order to validate the model, the values of all the parameters listed above have been obtained and adjusted using field measurements for several commercial inverters, and the behavior of the model applied to a particular inverter has been compared with real data under different working conditions, taken from a facility located in Madrid. The results show a good fit between the model values and the real data.

As an example, the model has been implemented in PSPICE electronic simulator, and this approach has been used to teach grid-connected PV systems. The use of this model for the maintenance of working PV facilities is also shown.

1. Introduction

Simulation of photovoltaic systems is becoming more and more important. There are a wide variety of software packages that allow you to make easier the processes of design and analysis of grid connected photovoltaic systems.

Referring to those focused on the design, we can find tools for the economic calculation of the systems, tools for dimensioning of the components, and those that integrate both economics and sizing issues.

The software programs for economic analysis allow you to calculate the total cost of photovoltaics systems, because they contain a database of commercial elements and their market prices. If the software includes the calculation of the energy generated, it will allow us to determine the payback time of the installation and thus calculate investment feasibility. These programs perform relatively simple calculations, and require little interaction with the user. In this group we can find RETScreen [1] and PVSYST [2].

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For the sizing of photovoltaic systems, some companies have developed their own programs, mostly in spreadsheets, which allow them to undertake their projects of PV systems, but there are other programs that perform this function [3].

Referring to those focused on the analysis, we found that some of them simulate the generation of the system, others estimate shading losses, others help to optimize the system, etc.

PV simulation programs take data from a system already sized and provide a detailed time analysis of its operation. This analysis allows us to verify the sizing done, to check the impact on production of a malfunction or a voluntary stop of the system, to test the performance under different conditions, etc. Among others, the most used are: HOMER [4], which allows the simulation of hybrid systems, PV-DesignPro [5], and PVSYST.

On the other hand, generic simulators are those designed for the study of different types of problems. Most of them also allow simulations of photovoltaic systems, both stand-alone and grid-connected. There are a wide variety of tools of this type, and there have been published papers where you can find examples of applications in photovoltaic systems; for example with the programming languages R [6] or JAVA [7], or in commercial programs for electrical simulation [8–10]. From those used for photovoltaic simulation we can highlight two:

- SIMULINK is suitable when you want to simulate the behavior of systems with photovoltaic and mechanical parts such as an electric vehicle, as in [11]. But it may also be applied to the simulation of control strategies in photovoltaic systems [12], to the performance evaluation of the MPPT of the inverter [13,14], to the improvement in the design of PV inverters [16] and to simulate the behavior of PV cells and modules [17,18]. SIMULINK is also useful for full modeling of stand-alone, grid-connected and hybrid photovoltaic systems [19], and allows identifying the system using parameters extraction methods from real measurements and diagnosing potential faults [20], which helps in the maintenance of the systems. We also found examples of application in the area of the photovoltaic systems teaching in [21].
- SPICE simulation environment is the mostly used in electronics. Also its use for the simulation of photovoltaic systems has a long history. There are a vast literature on power converters simulations [22,23], the study of their faults [24] and the MPPT [25] to validate its use in photovoltaic systems. In regard to the photovoltaic elements, we can find models of the solar cell [26] and the solar panel [27], these models can help to study the effect of shading and propose solutions [28], to determine the need for the use of bypass and blocking diodes [29,30]. In academia and for teaching purposes the simulator was used to study the performance of solar cells and panels [26] and there are tools to simulate photovoltaic systems in Undergraduate and Master Degree courses [31].

There are two different kinds of models to simulate a photovoltaic inverter:

1. Topological models, which includes the whole electric scheme of the inverter, or a simplified version of it, as in [8–10,12,15,16,23,24,31]. These models allow detailed short time simulations and they are very useful for the electronics design. However, usually the models are too complex and only can simulate the inverters for which they were created, and have a little use in PV simulation. They are more concerned with the long-term behavior of the system. These models are not related to the model proposed in this paper, thus it will not be studied.
2. Behavioral models, which are focused on the input–output relationships and on the working principles of the inverter. These models are more generics and can simulate any inverter with the same operating principle. There are application examples in [22] for islanding behavior, for the maximum power point tracking (MPPT) in [13,14,25,31], and for the inverter efficiency in [25,31,32].

The proposed model belongs to the group “behavioral models”; for this reason some of them are detailed next.

The MPPT model in [13] simulates the control strategy, which is different for every case of study. To simulate the efficiency, it uses only six values of the efficiency curve. A model is proposed in [14] with two main blocks: a DC/DC converter and a control circuit. In [25], a digital controller is developed for a MPPT based on “Perturbation & Observation” method. Finally, [31] shows a model based on an ideal DC/DC converter with constant MPPT efficiency.

The efficiency model proposed in [25] is a lookup table with values depending on the input power. For intermediate values, a linear interpolation is used. The model presented in [31] considers a constant efficiency for the inverter, so the output power is oversized for low values of the input power. The one proposed in [32] is a losses model, similar to the proposed in this paper. Both will be compared in Section 3.2.

This paper focuses on the inverter of photovoltaic systems and their characterization. The rest of the paper is structured as follows. Section 2 describes a model for photovoltaic inverter that can be simulated with any of the simulators described above. Section 3 presents the methodology for the calculation and validation of the model. Section 4 shows a selection of examples based on the last application mentioned in the previous paragraph.

Finally, the drawn conclusions from this contribution are provided.

2. Inverter model

The inverter model developed can simulate several characteristics related with its behavior. These can be divided into two groups: Energetic performance and islanding protections.