Ancillary services provided by photovoltaic inverters: Single and three phase control strategies

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\textbf{A B S T R A C T}

Photovoltaic (PV) inverters are power electronic based converters with fast response in the range of milliseconds. Besides, due to solar irradiance variation, these converters have excess capacity that can be used to provide ancillary services to the main grid. Traditionally, ancillary services such as reactive power injection and frequency support are provided by hydro and thermal generation. This work is focused on the analysis of how PV inverters can perform ancillary services and support the grid. Control strategies for reactive power injection and harmonic current compensation are explored. Furthermore, the inverter current saturation plays an important role, once high currents can damage the inverter or reduce its lifetime. Case studies for single and three-phase PV inverters are presented. It is observed that the ancillary service priority must be defined in order to guarantee PV inverter operation under nominal conditions.

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1. Introduction

In grid-connected photovoltaic (PV) system, there is a based power electronic converter, that injects direct current (DC) from PV panels into the alternating current (AC) grid. This electronic converter, known as inverter, can be connected to single-phase or three-phase power systems [1]. The single-phase PV inverters are commonly used for applications up to 7 kW. Above this value, three-phase inverters are recommended for ensuring a better power balance among the phases.

In most applications, single-phase and three-phase photovoltaic inverters extract the PV panel energy and inject it into the grid, with unitary power factor. Due to solar irradiance variation during the day, the PV inverters have an operation margin, in terms of current, which is not used over the PV system daily operation. Fig. 1(a) is defined as the maximal injected power of an inverter, and Fig. 1(b) shows an operation curve of a real PV plant during a typical sunny day. The operation curve does not exceed 30\% of the total operation area. Thereby, it remains an area of 70\%, which can be used for ancillary services, as shown in Fig. 1(c).

The most common ancillary services required by the Operation Systems are reactive power injection and frequency support. Furthermore, a maximal current harmonic distortion is allowed, depending on the voltage level at the Point of Common

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Coupling (PCC). These ancillary services supported by PV systems have been discussed in recent years, given the importance of taking advantage of the PV system excess capacity.

Several control challenges are associated when the PV systems are used to perform ancillary services in order to improve the grid power quality. For example, in harmonic compensation, it is important to detect the current or voltage harmonic information. In reference [2] is used the method based on conservative power theory to detect the harmonic current of the load. On the other hand, in [3] is used the PCC voltage information for harmonic compensation through a voltage control loop.

Furthermore, the PV inverter has a current limitation which cannot be exceeded. For this reason, it is important to design the strategy to limit the inverter current during ancillary service operation, ensuring the rated current below the reference. The determination of a current limit is relatively simple for reactive power compensation. However, when harmonic current compensation is involved, it is very difficult to calculate the inverter current peak by an analytical expression.

In view of the above discussions, the contribution of this work is to present an overview of ancillary services provided by PV systems with focuses on reactive power and harmonic current compensation. Several control strategies in different reference frames are presented for single-phase and three-phase systems, including partial compensation. Additionally, computational simulation results are included to show the performance of the PV single-phase and three-phase system during reactive power and harmonic current compensation. This work brings a theoretical basis of control strategies applied to photovoltaic inverters performing reactive power and harmonic current compensation.

This paper has an overview of the PV system structures in Section 2 and an overview of the main ancillary services that the PV systems can provide in Section 3. In Section 4, several control schemes for PV inverter including the capability to perform reactive power injection and harmonic current compensation are described. In Section 5, the inverter current controller and strategies for partial compensation of the reactive power and harmonic current are explored. Section 6 describes the parameters used in the case study, and Section 7 shows the main results for both single and three-phase PV inverters during reactive power injection and harmonic current compensation. Finally, conclusions are stated in Section 8.

2. Conventional structure of PV systems

The aim of this section is to provide a brief overview of the conventional structure of PV systems. A generic topology of a grid-connected PV system is shown in Fig. 2. The dc/dc stage is commonly used in single-phase system due to power oscillation in the 2nd harmonic frequency, [4]. This power oscillation causes dc-link voltage fluctuation and reduces the MPPT algorithm efficiency when PV modules are connected directly to the inverter DC-link.

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Fig. 1. Operation curve of a real PV system during an operation day. (a) Operation total area during one day. (b) Operation curve of a real PV plant during a measurement day. (c) Available operation area for ancillary services.

Fig. 2. Generic scheme of the grid-connected photovoltaic system for single-phase and three-phase applications.
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