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Adaptive current control strategy for harmonic compensation in single-phase solar inverters

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ABSTRACT

Nowadays, the power systems are submitted to current and voltage harmonics due to the increased presence of nonlinear loads and the wide use of power inverters to interface solar and wind power plants. Nevertheless, these inverters can also be used to compensate the current harmonics. Traditional harmonic detection methods extracts all harmonic current information and the control tuning tends to be complex and less flexible. Therefore, this work proposes an adaptive current harmonic control strategy applied in multifunctional single-phase solar inverters. The strategy is based on a novel detection method of the harmonic load current. The harmonic current detection method is frequency adaptive and designed to extract the load harmonic current with higher amplitude. The detected harmonic is compensated using an adaptive proportional resonant (PR) controller, reducing the grid current total harmonic distortion (THD). The detection method consists of two-cascaded phase-locked loop based on second order generalized integrator (SOGI-PLL) which uses the detected frequency to automatically tune the PR. The proposed method is explored in terms of nondetection zone, the impact of the SOGI-PLL parameters and the control stability analysis. Simulation and experimental results show the performance of the proposed control strategy, reducing significantly the grid current distortion.

1. Introduction

For the first time in four decades, the global carbon emissions related to energy consumption remained stable in 2014, while the global economy grew [1]. The high penetration level of renewable energy sources in the global electrical system is the reason associated with this stabilization [1]. However, some concerns are emerging due to the growth of renewable energy sources integration, especially wind and photovoltaic (PV) sources, into the electric power system such as: quality of the energy injected into the grid [2,3], security and support under grid faults [4–6], voltage regulation at the point of common coupling (PCC) during grid voltage sags [7], harmonic current compensation [8–10] and reactive power compensation [11].

The expansion of the electrical devices with nonlinear characteristic in the current and voltage relation have caused, for several years, concerns about the proliferation of harmonics in the power system [12–14]. Details about the nonlinear load behaviour is addressed in [15]. Devices such as power electronic converters, fluorescent lamps, electronic ballasts, thyristors, computers can lead to higher harmonic current levels which are responsible for efficiency reduction in the power grid, besides interacting with resonances present in the system [13,14,16]. Due to this fact, the IEEE and IEC harmonic standards contains recommendations for harmonic limitation at the point of common couple [16,17].

The use of power converters to interface renewable sources with the power system is regulated by grid codes in order to ensure the grid power quality. However, these devices can also improve the power quality of an installation. Several works show that PV inverters have been employed to compensate the harmonic current generated by nonlinear loads connected at the PCC. However, this ancillary service is limited by the converter rated current [8–10].

The main objective of the PV systems is to supply active power to the load/grid, but as generally the converter is operating below its rated current, the current margin can be used for the harmonic compensation. During the night, for example, all the converter current capability can be used for harmonic compensation.

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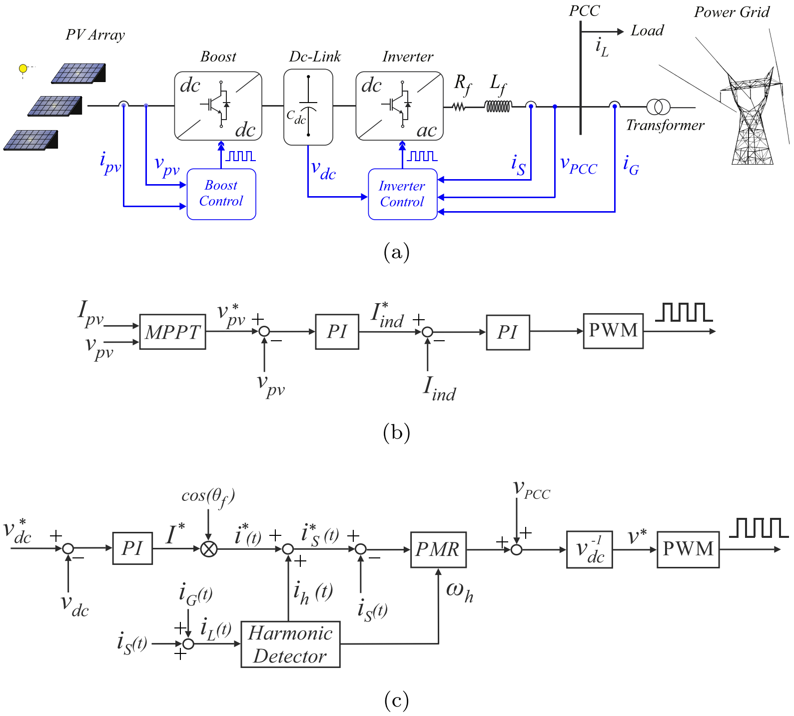

Fig. 1. (a) Single-phase grid-connected photovoltaic system, (b) boost control loop and (c) inverter control loop.

Many issues need to be defined in order to use photovoltaic inverter to compensate harmonic currents. The first one is the harmonic current detection method. Different strategies have been proposed in the literature. Refs. [8–10,18] apply the conservative power theory for current decomposition in three orthogonal components, the active, reactive and residual current component. In [19–21] it is used the instantaneous power theory to separate the current in average and oscillating components. Ref. [22] uses the instantaneous symmetrical components theory for extracting the reference currents. It should be emphasized that the detected harmonic current by the traditional methods contains all harmonic orders, and it increases the controller tuning complexity. Therefore, the additional computational processing is necessary to identify individual harmonic currents [23].

In single-phase applications with harmonic compensation, many works use proportional-resonant (PR) controllers, due to the presence of many frequencies in inverter current reference [24,25]. In these conditions, the conventional proportional-integral (PI) controller has steady state error due to its limited current tracking capability [24]. On the other hand, a PR controller must be tuned for each harmonic frequency in order to compensate the harmonic currents, increasing the control algorithm complexity [25].

This work proposes a harmonic detector algorithm which detects only the harmonic content with higher amplitude in the load current, and uses this information in the harmonic compensation process. If the harmonic current component with higher amplitude is eliminated, it is possible to reduce the grid current THD with low control algorithm complexity. This method consists of two-cascaded synchronous reference frame phase-locked loop (SRF-PLL) based on second order generalized integrator (SOGI-PLL) proposed in [26]. The harmonic controller consists of a proportional multi-resonant (PMR) controller whose resonance is frequency adaptive. The utilization of adaptive resonant controllers is addressed in [27,28] with focus to minimize the controller degradation associated with grid frequency deviation.

In view of the above discussions, the contributions of this paper are: a novel harmonic current detection method applied in single-phase PV inverters is proposed; analysis of a nondetection zone when harmonic components with similar amplitude are present in the load current; stability analysis of the adaptive resonant controller during variation in its resonant frequency.

This work is organized into the following sections. Section 2 introduces a discussion about the novel harmonic current detection method and its application in adaptive current control strategy. Section 3 presents the dynamic behaviour of the proposed harmonic detector as well as the stability of the adaptive control. Section 4 presents the simulation and experimental results to validate the proposed control strategy. Finally, conclusions are stated in Section 5.

2. Adaptive current harmonic control strategy

2.1. Control strategy

Generally, in single-phase PV system, the *dc*/*dc* stage with a boost converter is used to keep the desired dc-link voltage constant [2], as shown in Fig. 1a. The boost control strategy is shown in Fig. 1b, which consists of an outer loop, responsible for controlling the dc-bus voltage of the solar array v_{pv}, and an inner loop, responsible for controlling the current of the boost inductor I_{ind}. The voltage reference for the *dc*/*dc* stage loop is calculated by a maximum power point tracking (MPPT) algorithm, which maintains the solar array delivering the maximum power to the system at various levels of solar irradiance and temperature [29]. The electrical model of the solar panel is based on the mathematical model proposed in [30].

The inverter control strategy is shown in Fig. 1c. A PI compensator is used in the dc-link voltage control. This compensator calculates the active current amplitude I^* which will be injected into the power system. This signal is synchronized with PCC voltage and added to harmonic component detected by the proposed strategy. Finally, the controller calculates the converter modulation index v^*.

The control system is based on PMR controller composed of: a proportional controller, a resonant tuned to fundamental frequency