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Software method for harmonic content evaluation of grid connected converters from distributed power generation systems

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ABSTRACT

This paper is deals with the implementation of a software control method for harmonic content evaluation in the *dq* synchronous rotating reference frame for grid side VSIs (Voltage Source Inverters) used in DPGS (distributed power generation systems) applications. In order to verify the performance of the proposed approach, in experiments a DC voltage source (playing the role of a generic renewable energy source) is connected to the grid using a two-level inverter. Additionally, the control structure of the grid side converter is presented the possibility of low order harmonics compensation is also discussed. A comparative study in terms of current harmonic distortion between two different proportional gain values of the PI controller running in steady state condition is made, through simulations and experiments. The comparative study is performed to demonstrate the stability and effectiveness of the PI control algorithm across a wide range of operating conditions with the software method. The analyzed structure was simulated using Simulink software and then implemented and tested at laboratory level using a dSPACE setup. The experimental and simulation results confirm that the proposed software control method achieves good current tracking, thus satisfying grid-connection harmonics standards.

I. Introduction

Nowadays fossil fuels are the main energy supplier for the worldwide economy. However, as they are depleting and cause significant environmental problems, the focus is moving towards on alternative resources for power generation. RES (renewable energy sources) like wind, sun and small and micro hydro are seen as a reliable alternative to the traditional energy sources. DPGS (distributed power generation systems) based on renewable energy resources experience a constant growth. The majorities of renewable energy systems are connected to the utility network by power electronics, and are spread along the power system.

Consequently, grid interconnection requirements are evolving towards distributed generators which are able to accommodate control algorithms that enable a better control of generated power and the ability to contribute to power system stability if necessary [1,2]. Different control strategies and configurations of hybrid distributed generation systems are presented in Ref. [3] and a literature review of grid-connected versus stand-alone energy systems can be found in Refs. [4,5].

The increased interest in renewable energy production coupled with higher and higher demand from the energy distribution companies, with respect to grid energy injection and grid support in case of a failure, raises new challenges in terms of control for RES systems [6]. A general block diagram of a DPGS is shown in Fig. 1. The generated power can be delivered to the local loads or can be injected into the utility network, depending where the generation system is connected. In our configuration the latter case is considered.

The main aspects investigated in this paper are the control part of a power converter connected to the grid by means of a passive filter and an adequate harmonic compensation technique. In the literature, different power converter topologies are used to interface DPGS with the utility network [7–11]. In this work, the investigation is limited to the control of a three phase PWM (pulse width modulated) two level VSI (voltage source inverter), the most used power electronic interface for RES [12]. In order to accommodate a wide range of DPGS, the input power sources are not considered, the inverter being powered by a DC power source.

A synchronous rotating *dq* frame PI current controller was chosen to control the VSI. A description of the advantages and disadvantages of the *dq*-PI current controller is presented in Refs. [13,14]. The quality of the injected current is influenced by the current control strategy.

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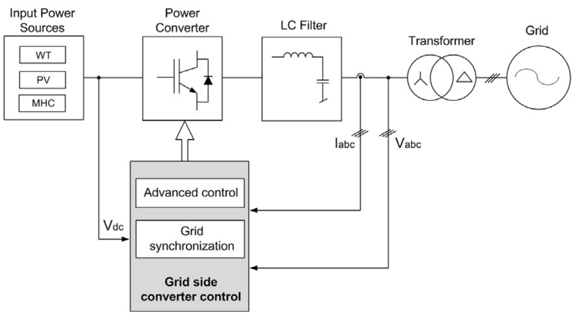

Fig. 1. Block diagram of the analyzed grid connected topology.

Traditionally, the inverter output current is improved by tuning the controllers while monitoring the low order harmonics. As a trade-off between a good noise rejection and good dynamics for the analyzed structure, the tuned parameters of the PI controller used in the simulation and experiments are set as follows: the integrator gain was set to $K_i = 1000$ while two different values ($K_p = 10$ and $K_p = 20$) were chosen for the proportional gain value, which determines the bandwidth and stability phase margin [15–17]. The controller gains were determined by trial and error method and the values are not changed when the controller is transformed in different reference frames [18]. A comparative study between these two values is presented in the simulation and experimental section. By adding a HC (Harmonic Compensator) to the current controller, a good harmonics rejection is obtained in both analyzed cases. A PLL (phase locked loop) is employed in order to detect the grid phase angle θ and the grid frequency.

The proposed software control method has the capability of providing active and reactive powers and as well harmonic currents with a fast dynamic response. In the different simulation and experimental results of the analyzed cases (without and with HC) have been completed in order to achieve controller effectiveness and a reduced THD (total harmonic distortion). The results prove the high performance of this control strategy in DPGS applications in comparison with other existing strategies. Another advantage is that the proposed control method can be used for different types of distributed generation resources as power quality improvement devices in a power distribution network.

The reminder of this paper is organized as follows: in Section 2 the configuration of the grid connected system with the control methods is presented. Section 3 describes the simulation and experimental results while conclusions are provided in Section 4.

2. Controller configuration for grid connected system

The configuration of the analyzed grid connected inverter is shown in Fig. 1. A DC power supply is considered as input power sources; a VSI with PI current controller and HC (Harmonic Compensator), a synchronization technique, a LCL (inductive–capacitive–inductive) filter, a delta transformer connection and the utility grid complete the topology.

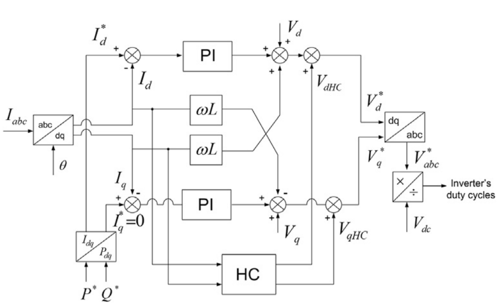

Fig. 2. The *dq* current control based on PI controller with HC.

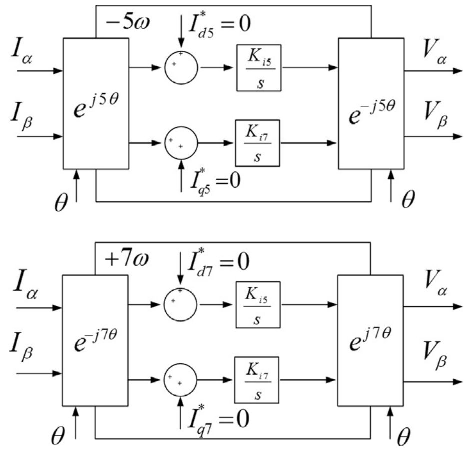

Fig. 3. The HC diagram for PI controllers.

Fig. 2 shows the structure of the grid side converter control circuit based on PI current controllers in *dq* frame control involving cross coupling and feed forward of the grid voltages. By using the Park's transformation, the three phase currents and voltages are transformed from the *abc* frame into the *dq* frame.

The i_q current component determines the reactive power value while the i_d decides the active power flow. Thus the active and reactive power can be controlled independently.

Beside the use of PI controllers for current regulation, as Fig. 2 illustrates, cross-coupling terms and the grid voltage feed-forward may be necessary in order to obtain best results [19].

The current controller input is the error between the measured and the reference grid currents. The current controller output is the reference grid voltage, which divided by the DC source voltage gives the inverter duty cycle. A HC is applied in synchronous reference frames, where the currents are DC quantities, thus eliminating the steady-state error, in order to obtain an improved power quality for the studied configuration.

In the case of DPGS, high dynamics and harmonics compensation, especially low order harmonics, are required. The compensation capability of the low order harmonics in the case of PI controllers is very poor without HC, standing as a major drawback when using it in grid connected systems. For this reason it is necessary to use a HC technique.

As the most important harmonics in the current spectrum are usual the 5th and 7th (see Fig. 14), in this paper the HC is designed to compensate these two selected harmonics. As shown in Fig. 3, the two controllers should be implemented in two frames rotating at -5ω and $+7\omega$. Two transformation modules are necessary to transfer the αβ stationary quadrature system into a *dq* synchronous rotating frame and vice versa. Noticeable is in this case the complexity of the control algorithm, compared with the structure implemented in stationary reference frame [15,20].

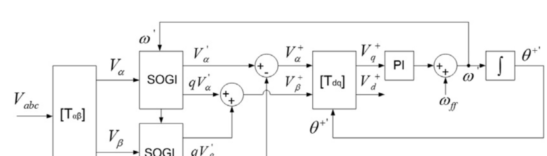

Fig. 4. Block diagram of the three-phase DSOGI-PLL.