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Analysis of active islanding detection methods for grid-connected microinverters for renewable energy processing

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ABSTRACT

This paper presents the analysis and comparison of the main active techniques for islanding detection used in grid-connected microinverters for power processing of renewable energy sources. These techniques can be classified into two classes: techniques introducing positive feedback in the control of the inverter and techniques based on harmonics injection. Accurate PSIM™ simulations have been carried out in order to perform a comparative analysis of the techniques under study and to establish their advantages and disadvantages according to IEEE standards.

1. Introduction

In recent years, a major global priority is the development of renewable energy. These energy sources produce lower pollution in terms of CO_2 emissions than conventional fossil fuels. From this point of view the distributed generation concept takes importance and it represents a paradigm shift from centralized power generation [1,2].

Distributed generation can be defined as small-scale generators installed near the loads with the ability of interacting with the grid importing or exporting energy [3].

Under this scheme, autonomous low power converters called microinverters [4] have been developed. The microinverters have the ability of operating both in grid connected mode by injecting energy from renewable sources (solar energy, wind energy, fuel cells, among others) to the grid, and in islanding mode feeding local loads without grid connection. Besides, they can be connected to other inverters with similar characteristics to supply a higher number of loads, being easy to expand [5,6].

When a distributed generator (DG) is injecting power to the grid, one feature that should be taken into account is the islanding condition. The condition of "islanding" in DGs is an electrical phenomenon that occurs when the energy supplied by the power grid is interrupted due to various factors and the DGs continue energizing some or the entire load. Thus, the power grid stops controlling this isolated part of the distribution system, which contains both loads and generation. Therefore, islanding operation of grid-connected inverters may compromise security, restoration of service and the reliability of the equipment [7].

In the case of several DGs connected to a low-voltage power grid, it is possible that the amount of energy generated by the distributed system agrees with the amount of energy consumed by the loads on the grid. Under this situation, there is no energy flow towards the grid and the distributed systems may fail to detect a possible power grid disconnection, so that the DGs may continue feeding the loads leading to an "islanding" condition. In addition, when the islanding condition happens, there is a primary security condition which forces the generator system to disconnect from the de-energized grid without taking into account the connected loads.

The "islanding" effect in inverters may result from a failure detected by the grid and the consequent switch opening, accidental opening of the electrical supply because of equipment failure, sudden changes in the electric distribution systems and loads, intentional disconnection for maintenance services either on the network or in the service, human error, vandalism or acts of nature.

There are many reasons why islanding should be anticipated in the distributed generation systems connected to the grid. The main reasons are safety, liability and maintenance of the quality of the supplied energy.

For the above reasons, islanding detection is a mandatory feature that should be taken into account in distributed generation

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systems. Several algorithms have been proposed in the last few years to solve it.

Islanding detection techniques can be divided into remote and local ones, and also into passive and active techniques [8]. Active techniques resident in the inverter, which are discussed in this article, introduce disturbances in the output of the inverter in order to affect a certain parameter that comes out of range in an islanding situation.

There are different active methods based on positive feedback in published literature [8–10]. Some of these methods are: variation of active and reactive power [11], Sandia voltage shift (SVS) and Sandia frequency shift [12,13], slip-mode frequency shift (SMS) [14], active frequency drift (AFD) [15], and general electric frequency schemes (GEFS) [16], among others.

The paper is organized as follows. First, the grid-connected microinverter used to perform the study will be described. Second, different active resident methods will be presented. Next, these methods will be evaluated with RLC loads according to the standards. Finally, some conclusions will be presented.

2. Description of the microinverter system

Fig. 1 shows the scheme of the microinverter that has been used to evaluate the islanding detection algorithms. It is fed by two parallel connected 220 W photovoltaic panels. The panels voltage is in the range 26–36.7 V in the maximum power point (MPP), so that a DC–DC stage is needed to raise the voltage supplied by the panels to suitable levels (400 V) for grid connection of the power processing system. The power stage chosen for this purpose is a push–pull DC–DC converter. This topology is a good choice for low input voltage and medium power. Its advantage when compared to full-bridge DC–DC converters is that only two power transistors are needed. When compared to a half-bridge DC–DC converter, the push–pull does not need a capacitive input voltage divider with high RMS currents. The main drawback of the push–pull topology is that the power transistors withstand twice the input voltage, but that is not a problem in low input voltage applications. For DC–AC conversion a current-controlled H-bridge bipolar PWM inverter [17] with an output LCL filter [18,19] has been chosen. Note that the use of a push–pull topology provides galvanic isolation without the need of bulky and heavy low frequency transformers.

As it can be observed from Fig. 1, the control of the push–pull converter starts from a maximum power point tracker (MPPT), implemented by a P and O (perturb and observe) algorithm [20–22]. The output of the MPPT, V_{g_ref}, is the reference of the PV string voltage, V_g. The error between both signals is amplified by a PI voltage controller whose output is the control voltage, V_c, of the peak current mode control loop (CIC) [23]. This control voltage limits the peak value of the current through the primary of the push–pull transformer, avoiding its saturation. In the peak current mode control PWM modulator an external stabilization ramp, S_e, is added to the sensed transformer current (S_n). F_M is the PWM modulator gain. This value should be adjusted properly in order to guarantee the stability of the current loop. Fig. 2 shows the aspect of a conventional CIC loop applied to a push–pull converter.

The PWM inverter has an inner current controller based on a harmonic compensator [24] in order to comply with the IEEE 929-2000 standard [25], in terms of the THD of the current injected to the grid. The reference of the current loop is made of the sum of two terms: a power-feedforward term used to achieve a fast response of the inverter control with regard to changes in the power generated by the panels [26], and the output of the PI controller of the inverter DC link voltage. The resulting sum is the amplitude of the inverter reference current, that is synchronized with the fundamental component of the grid voltage by means of a phase locked loop (dqPLL) implemented using the synchronous rotating reference frame technique [27,28]. Fig. 3 shows the dqPLL block diagram.

Table 1 summarizes the nominal values of the microinverter.

Table 2 shows the expression of the chosen regulators for both the inner current loops and the outer loop, crossover frequencies and phase margins, for the microinverter studied.

Apparently, the islanding detection algorithms could be also evaluated by simplifying the power inverter by eliminating the MPPT algorithms and the dc voltage regulation loop of the inverter (in that case, a constant DC link voltage should be assumed). However, those algorithms can be affected by the islanding detection, and vice versa. Therefore, they have been taken into account in this study.

3. Active islanding detection methods

These techniques intentionally introduce disturbances at the output of the inverter in order to determine whether they affect voltage, frequency or impedance parameters, in which case it is

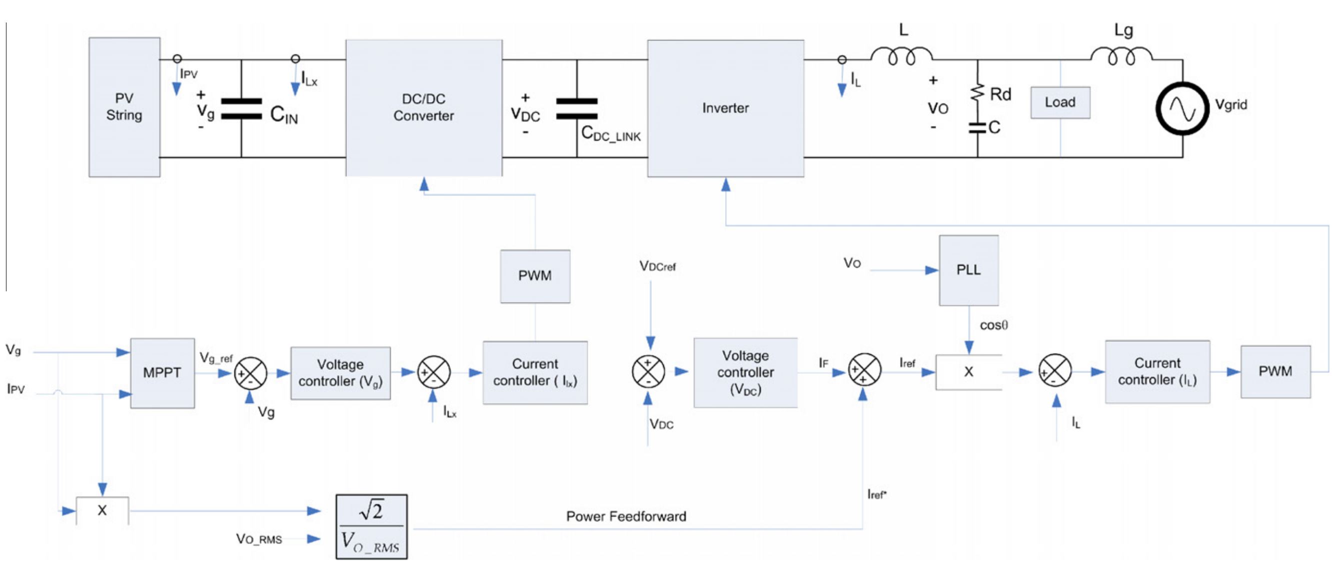

Fig. 1. Block diagram of the microinverter.