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An improved control scheme based in droop characteristic for microgrid converters

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ABSTRACT

In the present work, an improved version of the conventional-droop control for microgrid converter is presented. The modifications added to the control are based on a feed-forward current control that allows the converter to work in several modes, both when it is grid connected or in island. The use of this control represents the main contribution of this paper, permitting the inverter to work as a grid supporting source or ancillary services provider when it works grid connected. In this mode the converter varies the injected active and reactive power with the variation of voltage module and frequency using the same main control loop as when it is working in island mode.

1. Introduction

Distributed generation (DG) technologies have achieved a drastic increase during the last years derived from recent technological developments [1]. The influence of this type of generation on the distribution network stability can be positive or negative depending on the distribution system and the DG system operating characteristics [3]. The massive installation of DG systems can produce an important reduction of the electrical losses both in transmission and distribution networks, as well as CO_2 emissions. Another consequence would be a significant reduction in the investment on electrical facilities. Additionally, production of energy from waste heat through co-generation or combined cooling heat and power (CCHP) can give rise to an integrated high efficiency energy system. However, an increased use of DG systems in electrical networks without correct addressing coordination issues can result in a harmful influence in the electrical network, including problems in voltage regulation, voltage flicker generation due to sudden changes in generation levels of DG, increase of harmonics, and variations in short circuits levels, affecting the reliability and safety of the distribution system [4]. Fortunately, those problems can be avoided with an organized introduction of these resources in the electrical networks [5]. Additionally, the DG system can be used as ancillary services provider for voltage control, load regulation and spinning reserve [6].

The most suitable way to insert DG systems into the electrical network is through the use of microgrids. A microgrid, can be defined as a cluster of loads and microsources operating as a single controllable system providing both power and heat to its local area [7]. There exist different microgrid management philosophies that can be roughly categorized into three different groups [9]. The first group consists on a set of microgrids with a *physical prime mover* management in which a large unit absorbs all transient active and reactive power imbalances to maintain the voltage magnitude and frequency. The concept is very similar to the one used in conventional centralized generation systems. The cost of the central unit and the loss of stability when a fault occurs in that unit are the main problems of this approach. In the second group, the control system is based on a *virtual prime mover*. In this case a central control unit measures the microgrid state variables, and dispatches orders to microsources using a fast telecommunication system. This control scheme avoids the high cost of the central *physical prime mover* but the communication system bandwidth limits the expansion of the microgrid and additionally, a back-up system is needed in case of communication failure. The third approach is based on a *distributed control*. In this case, each unit responds automatically to variations in the local state variables. A number of researchers consider this type of control the most appropriate because neither a communication system nor a large central unit is needed [7,10,11]. Nowadays, there are some important projects on microgrids launched around the world [8,9] using the different microgrid management philosophies abovementioned.

Control of local state variables is commonly implemented in microgrid converters using a so called *droop characteristic* control. This type of control was first introduced for parallel connected inverters in a *standalone system* [12]. Recently, droop control has

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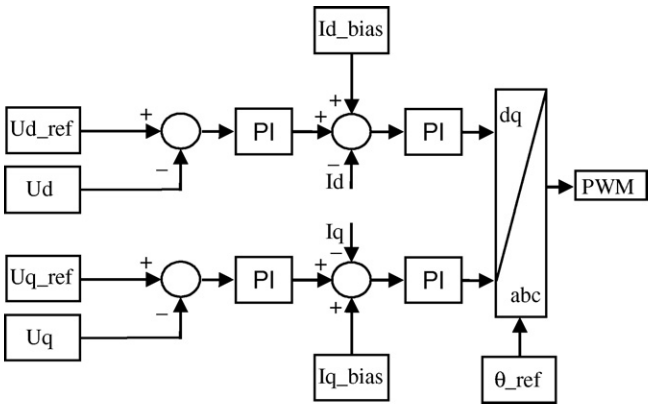

Fig. 1. Main control scheme.

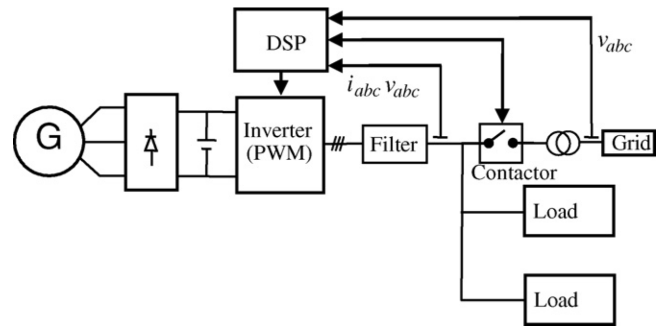

Fig. 2. Injection unit scheme.

been extended to microgrid distributed control [7,2]. A detailed analysis of the behavior of droop control based generators was presented in [13]. However, some researchers combine a distributed control with some kind of communication between the microsources [14,15]. In those cases, the microgrid primary control is distributed but secondary control loops are based on telecommunications. These control loops improve the power-quality and economic efficiency. When a telecommunication fault occurs, the primary controller acts as a back-up system.

This paper proposes an improved control scheme based on droop characteristic control. The proposed control system uses an inner current control loop in grid connected mode that modifies the injected active and reactive power as a function of the grid voltage, magnitude and frequency, therefore providing a grid support capability. In the island mode the power converter can operate in three different working submodes: (1)*conventional-droop mode*, which uses a conventional-droop characteristic control, (2) *power-quality mode*, which adapts the droops to provide the voltage magnitude and frequency nominal values and (3)*sync mode*, in which the droop characteristics are changed while the phase and voltage magnitude of the microgrid voltage are synchronized with the grid in order to get a smooth connection transient. The proposed control topology allows the inverter to work on several modes and make soft changes between a droop characteristic control and an inverse droop control.

2. Control strategies

Different control schemes compose the overall proposed control system. In this section, the different working modes of the proposed control are analyzed. The block diagram of the main control loop used for both working conditions is presented in Fig. 1, where U_{dref} and U_{qref} are the voltage references, U_d and U_q are the measured voltages after the filter (see Fig. 2), and I_d and I_q are the measured currents before the filter (see Fig. 2). It can be observed that this control loop is based on a traditional droop characteristic control loop improved with the introduction of feed-forward bias currents I_{dbias} and I_{qbias}. The use of these currents is the main contribution of this work and allows the converter to make a grid supporting labor when it is working in grid connected mode. In this situation, the proposed feed-forward control will make the converter to work as an inverse droop characteristic control, varying the injected active and reactive power as a function of measured voltage magnitude and frequency. For all island modes I_{d_bias} and I_{q_bias} are disabled and set to zero. It should be noted that the voltage reference of the q-axis, U_{qref}, is set to zero for both situations while the calculation of U_{dref} and frequency reference f_{ref} will depend on the working mode as it will be described as follows.

2.1. Island mode

Three possible working conditions are considered in island mode: conventional-droop mode, power-quality mode and sync mode. In either situation it is necessary to calculate the voltage Eq. (1) and frequency Eq. (2) references of the microgrid as it can be observed in Fig. 1, where P and Q are the measured active and reactive power respectively, P_0 and Q_0 are the rated active and reactive power U_0^* and f_0^* are voltage and frequency commands that depends on the selected island mode.

$$U_{dref} = U_0^* - K_p(Q - Q_0) \tag{1}$$

$$f_{ref} = f_0^* - K_q(P - P_0) \tag{2}$$

The droop characteristic constants, K_p and K_q, are calculated using Eqs. (3) and (4), where $f_{\max}$ and $U_{\max}$ are the maximum permitted frequency and voltage in island mode and $P_{\max}$ and $Q_{\max}$ are the maximum active power and reactive power that can be injected by the converter.

The choice of the droop constants K_p and K_q affects to the network stability. In general terms, we can assert that the higher the values of the droop constants, the lower the stability margin of the system. Some methods based on trial and error procedure [8,20], have been proposed to obtain the adequate values for these constants. However, to date, there is not too much work related with the analytical selection of this values considering microgrid dynamic. In [19] a methodology based on bifurcation theory is presented and discussed. The iterative methodology to obtain the best values depends not only on the studied generator parameters but also on the network parameters and other generator parameters.

$$K_p = \frac{f_{\max} - f_0}{P_{\max} - P_0} \tag{3}$$

$$K_d = \frac{U_{\max} - U_0}{Q_{\max} - Q_0} \tag{4}$$

2.1.1. Conventional-droop mode

This control strategy allows the inverter to work as a classical droop mode where the values of voltage and frequency are fixed according to Eqs. (6) and (5).

$$f_0^* = f_0 \equiv \text{rated frequency} \tag{5}$$

$$U_0^* = U_0 \equiv \text{rated voltage} \tag{6}$$

2.1.2. Power-quality mode

The Power-quality mode changes the position of the droop characteristic in order to recover the rated frequency and voltage when a change in the load occurs. As can be observed in Fig. 3, when the conventional-droop mode is activated and the microgrid reactive load is reduced from Q_0 to Q_2, the operating point is moved from A to B, increasing the voltage of the microgrid to U_2. If the power-quality mode is activated at that point, the droop characteristic