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An adaptive control algorithm for grid-interfacing inverters in renewable energy based distributed generation systems

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ABSTRACT

This paper proposes an adaptive control algorithm for grid-interfacing inverters in renewable energy-based distributed generation systems. The proposed control algorithm functions in two different modes: basic power generation mode, harmonics compensation mode. In basic power generation mode, the inverter pumps desired amounts of active and reactive powers into the grid at the point of common coupling. In harmonics compensation mode, the control algorithm ensures sinusoidal grid current through load current harmonics mitigation in addition to desired power generation. Moreover, the proposed control algorithm does not use any detection methods for compensation of harmonic currents. Hence, it results in low computational burden. Based on the requirements, the proposed control algorithm can be operated in either of the modes. A proportional–integral controller-based closed loop control is employed for accurate control of the power injected into the grid. A frequency adaptive notch filter is used to synchronize the grid-interfacing inverter with the fundamental component of grid voltage without using any phase locked loop. The effectiveness of the proposed control algorithm in reference active and reactive powers generation, current harmonics compensation is demonstrated successfully by simulation and experimental results.

1. Introduction

On the pathway to address the concerns posed by conventional energy sources such as depletion of fossil fuels and climate changes, many countries are aiming to increase their share of energy generation from clean energy sources. The energy sources such as solar, wind, hydro and bio-fuel are the prime candidates of clean energy. Generally, the energy harnessed from renewables is first used to cater the needs of local community and the remaining energy will be pumped into the grid by means of power electronic interfaces [1]. Voltage source inverter (VSI)-based power electronic interfaces are being widely used for the grid integration of renewable energy sources (RESs) [2]. In [3], a three-level inverter has been used for grid interconnection of a photovoltaic system. Ref. [4] provides a comprehensive review on application multilevel inverters and their control in grid connected photovoltaic systems. Multilevel inverter topologies are increasingly used in distribution generation applications due to their advantages such as low switch losses, less harmonic distortion and reduced filter size. In [5], a multistage stage dc/ac converter has been proposed to improve the overall conversion efficiency.

Integration of RESs with the utility network has attracted a great deal of interest due to potential environmental and economic factors. Various control algorithms for grid interconnection RESs via VSIs are discussed [6]. The grid-interfacing VSIs are operated as controlled current source to inject the power generated by the RESs into the grid. In [7], the power injected into the grid is controlled by changing the phase difference between the grid voltage and the inverter voltage. In [8], particle swarm optimization method has been used to control the grid injected power. In [9], an adaptive neuro-fuzzy controller has been used to control a single-phase grid-coupled inverter. In addition to active power injection, the grid-tied inverters can also be used for simultaneous reactive power compensation [10]. A doubly fed induction generator (DFIG) system with reactive power compensation capabilities has been discussed in [11].

Owing to the proliferation of electronically switched nonlinear loads, the amount of harmonic current being released into the power distribution network is growing rapidly and causing degradation of grid voltages. An active power filter [12] can be used to mitigate the harmonics injected by nonlinear loads. Alternatively, the grid connected VSI itself can be controlled to compensate the harmonic and reactive currents drawn by the local loads to improve

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grid power quality. Therefore, inclusion of harmonic currents suppression capabilities in the grid-tied inverters is gaining interest. Mostly, the capacity of the VSIs employed in grid-interfacing of RESs is underutilized due to the intermittent nature of RES. The remaining capacity of the VSIs can be diverted to power quality improvement. Therefore, the control algorithm that is adopted for grid-interfacing VSIs must offer great flexibility to use the remaining capacity of VSIs for power quality improvement through ancillary services. A control scheme for grid-interfacing VSIs with power quality improving ancillary services such as active power filtering and reactive power injection is presented in [13]. In [14], a grid interfaced multi-level inverter with shunt compensation capabilities is discussed. A flexible control algorithm based on recursive least squares has been presented in [15] for power quality improvement in grid interfaced distributed generation systems.

In order to accommodate power quality improvement features such as active harmonic filtering and reactive power compensation, detection of harmonic and reactive currents is mandatory. Rapid and accurate detection of the harmonic signal, fast processing of the reference signal, and high dynamic response of the controller are the prime requirements for achieving desired level of compensation. Numerous control methodologies for detection of harmonic and reactive currents have been reported so far. The synchronously rotating d-q frame (SRF) theory [16] and instantaneous p-q theory [17] are the widely used conventional control algorithms to generate reference signals for harmonic currents compensation. In Ref. [18] also, the instantaneous p-q theory has been used for incorporating active harmonic filtering in grid-tied DFIG system. Ref. [19] has proposed a control algorithm for simultaneous active power generation and power quality improvement in wind energy driven DFIG system. In addition to aforementioned conventional methods, the detection methods employing artificial neural networks (ANN) [20] and fast Fourier transforms (FFT) [21] can be found in the literature. In [22], various ANN techniques have been compared for harmonic currents extraction and active power filtering.

Nonetheless, the performance of the aforementioned detection techniques is highly affected by grid voltage distortion and frequency variations. To address this issue, a detection method that is independent of grid voltage distortion is developed in [23]. This method employs second order frequency adaptive pre-filters such as second order generalized integrators (SOGIs) [24] and adaptive notch filters. Precise and accurate estimation of harmonic and reactive components of load current would significantly increase the computation burden and therefore demands high speed digital controllers. For a low cost solution and minimizing the computational burden, researchers have proposed harmonics detection free methods [25]. These methods are designed for healthy grid conditions. In case of abnormal grid condition, the performance of VSI varies highly depending on the control algorithm used.

In view of the above-stated drawbacks with the existing control algorithms, this article proposes a robust and harmonics detection free control algorithm. The proposed control also offers a flexibility to operate the grid-tied VSI in two different modes such as basic power generation mode and harmonics compensation mode for optimal utilization of VSI rating. Unlike the harmonic detection-free control algorithms reported, the proposed control algorithm is immune to grid voltage distortions and frequency fluctuations. The proposed control algorithm synchronizes the grid-interfacing VSI with the fundamental frequency component of grid voltage to make its performance independent of grid disturbances such as frequency fluctuations and voltage distortions. The fundamental frequency component of grid voltage is obtained by using a frequency adaptive notch filter (ANF) [23]. Adaptive nature of the ANF allows precise tracking of variations in the frequency and magnitude of the fundamental components and thereby eliminates the use of single-phase phase locked loop (PLL) [26]. This will further reduce the computational load on the digital processor. Closed-loop control of active and reactive powers with simple proportional-plus-integral (PI) controller based regulation is employed to achieve accurate tracking of reference powers with zero steady state errors. The key benefits of proposed control algorithm are summarized as follows:

1. Detection free harmonic and reactive currents compensation.
2. Accurate control of active and reactive powers.
3. Immune to grid voltage distortions and adaptive to frequency fluctuations.
4. PLL less grid synchronization.
5. Offers flexibility to operate in different modes.

The feasibility and the effectiveness of the proposed control algorithm are simultaneously verified through computer simulation studies and hardware-in-the-loop (HIL)-based experimental tests.

The rest of the paper is organized as follows: Section 2 discusses the configuration of the grid-interfacing VSI system under study. Section 3 presents the formulation of proposed PLL less frequency adaptive control algorithm and its various modes of operation. Section 4 validates the proposed control algorithm based on simulation and experimental results. Section 5 concludes the paper.

2. System configuration

Fig. 1 depicts the basic configuration of grid-interfacing single-phase H-bridge VSI in renewable energy systems consisting of renewable power generation units and different types of loads. Renewable energy sources, such as wind and solar, are typically used to generate electricity for residential users. The power generation units use dc/dc and dc/ac static power electronic converters for voltage conversion and battery banks for energy storage. The battery banks form a constant voltage dc bus. The power electronic converters perform maximum power point tracking and extract the maximum energy possible from wind and solar sources. Thus the energy extracted is fed to the grid via a single-phase VSI after serving the local loads. The grid-interfacing VSI is connected to single-phase distribution network with a coupling inductor (L_f) at the point of common coupling (PCC). The symbols i_g, i_{vsi} and i_l represent the grid current, VSI current, and load current, respectively. The grid voltage and the voltage at PCC are denoted as v_g and v_{pcc}, respectively.

3. Proposed control algorithm

This section describes the proposed adaptive control algorithm for single-phase grid interfaced VSI. The schematic of proposed control algorithm is shown in Fig. 2. As previously mentioned,

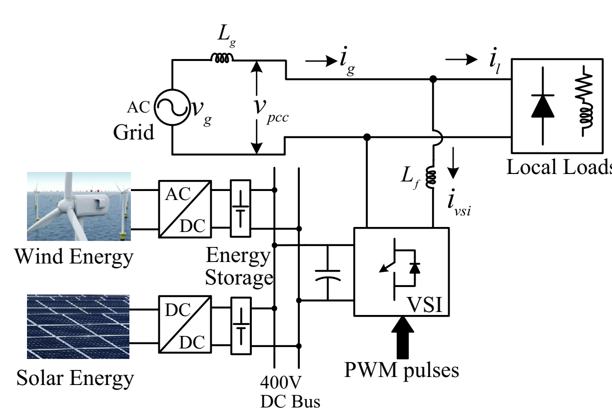

Fig. 1. Schematic of grid-interfacing single-phase inverter.