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Rapid islanding detection using multi-level inverter for grid-interactive PV system

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ABSTRACT

A novel reference signal generator is combined with a multi-level inverter to form a rapid islanding detection scheme for grid-interactive PV system. The reference signal generator can easily be synchronized with the utility grid signal and produced a fixed magnitude and very low total harmonic distortion (THD) sinusoidal signal which is in phase with the utility grid signal. Unlike conventional phase-locked loop (PLL) circuitry, the reference signal generator can also provide a fixed magnitude sinusoidal signal even if the utility grid is disconnected and automatically re-synchronous with the grid rapidly. Consequently, seamless transfer between grid-connected and stand-alone modes could easily be achieved if anti-islanding protection is not required. If a saturation element is applied to the raw reference signal followed by the synthesis of the truncated signal using a multi-level inverter, the distinct flat-top feature of the synthesized signal can quickly and easily be identified if the network is in islanding mode at the point of common coupling. Experimental results are included to demonstrate the effectiveness of the proposed detection scheme.

1. Introduction

Photovoltaic (PV) system is gaining popularity across the world [1]. Integrating PV systems with the utility network poses challenges for anti-islanding schemes. Islanding is the continued operation of the grid-interactive inverter when the utility grid has been disconnected. The inverter must be able to detect an islanding situation, and take suitable measure such as disconnect from the grid in order to protect utility line workers and equipment. Failure to trip islanded generators can lead to problems such as threats to personnel safety, out-of-phase reclosing, and degradation of power quality.

Various islanding detection methods [2] have been developed in the past. The methods can briefly be classified into local islanding detection techniques and remote islanding detection techniques. The local islanding detection method relies on the measurement of system parameters at the PV system while the remote islanding detection method is based on the communication between the utility grid and the PV system. The local islanding detection can be subdivided into passive and active methods. The passive methods do not have any influence on the power quality since they just monitor certain grid parameters at the point of common coupling (PCC). Passive methods include under/over voltage detection, under/over frequency detection, voltage phase jump detection and voltage and current harmonics detection. In terms of islanding prevention, the primary weakness of passive methods is their relatively large non-detection zone (NDZ). In addition, the response times for these protective methodologies may be variable or unpredictable. To solve problems of passive methods, active methods usually involve procedures to inject small disturbances at the point of common coupling and detect the changes in the system parameters. However, all these detection schemes are not perfect and the shortcomings include:

(a) Presence of NDZ causing possible anti-islanding detection failure.
(b) Degradation of power quality and system stability.
(c) False operation in multiple PV systems.
(d) Requirement of additional circuitry or equipment.
(e) High implementation cost.

Therefore, further research and development is necessary. Recently, an accurate and less-disturbing active anti-islanding method suitable for grid-connected inverters using phase-locked loop (PLL) based grid synchronization was proposed in [3]. An improved method was reported in [4]. Although the common practice to synchronize an inverter output to the grid is using a PLL [5], major problems of this scheme are the poor dynamic response, and a small phase error among the inverters may cause circulating current among them. Consequently, more sophisticated algorithms

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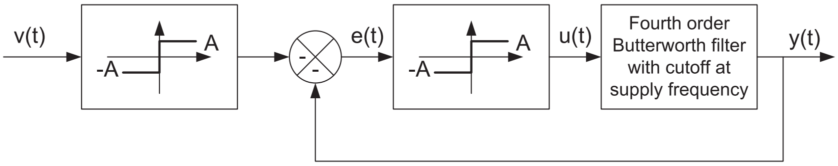

Fig. 1. Block diagram for the proposed reference signal generator.

are needed to improve the performance of PLL schemes. Latest development is to avoid perturbing the PLL signal. In [6], an improved active frequency drift (AFD) anti-islanding method was presented based on a different current distortion injection waveform. The proposed method generates 30% less THD compared to classic AFD in addition to faster island detection and improved NDZ. Another islanding detection method for a grid-connected inverter incorporating intermittent bilateral (IB) reactive power variation (RPV) was presented in [7]. The inverter output with IB reactive power enables the detection of an islanding and the RPV range could be derived in order to eliminate the NDZ. In this paper, a totally different approach is presented. A PLL-less rapid islanding detection scheme which uses a novel reference signal generator and a multi-level inverter grid interface is proposed. By combing the reference signal generator with the multi-level inverter grid interface, it is possible to generate features that can easily and rapidly be detected when the network is in islanding mode. The detection scheme can be extended to network with multiple PV systems if individual PV system has the same proposed reference signal generator and multi-level inverter. The reference signal generator can also provide a fixed magnitude sinusoidal signal even if the utility grid is disconnected and rapidly re-synchronous with the grid automatically. Consequently, seamless transfer between grid-connected and stand-alone modes could easily be achieved. Experimental results are included to demonstrate the effectiveness of the proposed detection scheme.

2. Novel reference signal generation for local interface

A signal which is in phase and of the same shape of the utility grid voltage is often required for PV grid-interactive inverter to synchronize the inverter current or voltage with the utility grid. Consider a relay of the form

$$u(t) = \begin{cases} A, & e(t) \geqslant 0 \\ -A, & e(t) < 0 \end{cases} \tag{1}$$

where $u(t)$ is the output of the relay, A is the output magnitude and $e(t)$ is the input signal. If the relay is connected to a fourth order lowpass Butterworth filter with a cutoff frequency at the supply frequency of the grid to form a closed-loop feedback system as shown in Fig. 1, the open-loop phase of the Butterworth filter at the cutoff frequency is -180° and the open-loop gain of the Butterworth filter at the cutoff frequency is $\frac{1}{\sqrt{2}}$ as shown in Fig. 2. According to relay feedback test [8,9], the closed-loop system will self-oscillate at the cutoff frequency and all higher harmonics generated by the relay output will be substantially attenuated by the fourth order Butterworth filter. The THD of the output signal is less than 1% and the amplitude of the output is fixed at $\frac{2\sqrt{2}A}{\pi}$, i.e. the output amplitude is fixed and can be adjusted by the relay output

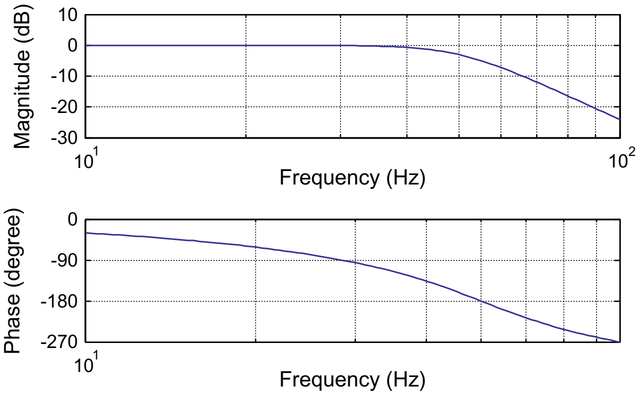

Fig. 2. Frequency response of the fourth order lowpass Butterworth filter with cutoff at 50 Hz.

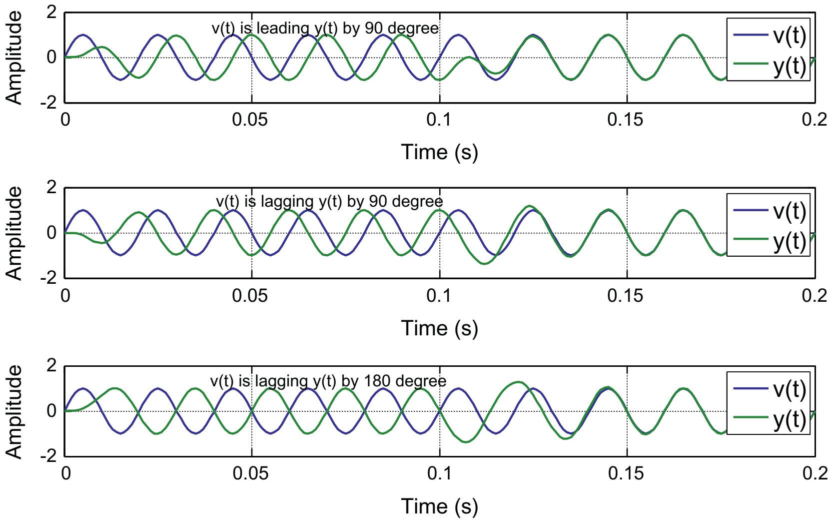

Fig. 3. Performances of the proposed reference signal generator.