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Performance evaluation of WPT based islanding detection for grid-connected PV systems

Smitha Joyce Pinto *, Gayadhar Panda

Dept. of Electrical Engineering, NIT Meghalaya, Shillong, India

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ABSTRACT

Recent developments in power electronics technology have emerged towards the generation of electrical power from the renewable energy sources. Among renewable energy sources, solar energy has garnered more importance because of less maintenance and environmental friendly. In grid connected mode, distributed power generation system (DPGS) requires reliable islanding detection technique to find the electrical grid status and operate the grid connected inverter effectively. This paper investigates a comparative performance analysis of wavelet transform (WT) and wavelet packet transform (WPT) based detection in a three-phase grid connected PV inverter system under various power quality disturbances and islanding situation. The WT and WPT coefficients are determined by applying db4 wavelet basis functions, which are obtained optimally for analyzing perturbations that occur in grid connected PV system. The wavelet transform produces large errors due to spectral leakages in frequency bands. On the other hand, WPT provides uniform frequency subband with better time frequency resolution over WT. Finally, the feasibility of proposed WPT based islanding detection method is verified by simulating the system in MATLAB/SIMULINK environment. The simulated results demonstrate the better performance of WPT over WT technique and proved as an accurate, fast and reliable detection technique.

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Introduction

In modern power systems, generation of electricity from renewable energy sources has gained more attention due to the advancement in power electronics technology. PV sources are widely used in many applications because of less maintenance and environmental friendly. The efficiency, power quality, stability and reliability will directly affect the performance and investment efficiency of the entire DPGS [1]. The inverter output voltage and the grid voltage are to be maintained at the same phase angle, frequency and amplitude with the help of a suitable current control strategy to achieve proper synchronization [2]. The efficiency of grid connected PV system is affected by the inverter operation [3,4], structure of the PV panel and maximum power point tracking (MPPT) algorithm [5,6]. However, according to international standards, the detection of unintentional islanding condition for grid connected PV inverter system must also be considered to avoid potential hazards [7,8].

Islanding situation of grid-connected PV inverters arises when the local network containing such inverter is disconnected from the main utility grid, but the local loads connected at the point of common coupling (PCC) gets power only from PV system. This situation may lead to many potential hazards because of power supply without control and/or supervision of utility. For reliable operation of grid connected DG system, this situation needs to be detected and protected effectively [9]. Many recent studies have been devoted with various islanding detection strategies and these techniques are mainly classified into two groups such as passive and active methods [10].

There are various passive detection methods such as over current, over/under voltage, over/under frequency and harmonic distortion schemes [11,12]. The main advantage of passive detection schemes is of maintaining good power quality in the system. In existing literature, islanding situation is detected by observing and analyzing many other parameters such as rate of change of frequency, power and phase jump. The purpose of these schemes is to detect the grid status and execute the tripping signal at the time of disturbance. When the power mismatch is very low, the passive schemes fail to detect the islanding scenario. This range of power mismatch is known as Non Detection Zone (NDZ) of the schemes [13]. It has been found that effectiveness of passive schemes

* Corresponding author.
E-mail addresses: smitha_joyce@yahoo.co.in (S.J. Pinto), p_gayadhar@yahoo.com (G. Panda).

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depend on the selection of threshold parameters and range of their NDZ. If the threshold range is set small, there is a chance of occurring nuisance tripping and if threshold is high, islanding situation and power quality disturbances may not be detected accurately. Hence passive detection schemes are not sufficient for monitoring the utility grid accurately. To overcome these problems associated with passive methods, active detection schemes are introduced in protection [14]. These schemes inject perturbation into the output signal and analyze the changes on the magnitude, frequency, impedance or phase of the voltage at PCC, when islanding situation arises. When DG is grid connected, these disturbance signals do not affect the performance of the system. When DG is islanded, disturbance signals drift the parameter to detectable limits. Various active islanding detection techniques used in grid connected PV systems have been reported in literature [15]. There are various active islanding techniques such as output power variation (OPV), impedance measurement (IM) [16], sliding mode frequency shift (SMS) [17], active frequency drift (AFD) [18], active frequency drift with positive feedback (AFDPF) [19], Sandia frequency shift (SFS) [20] and adaptive logic phase shift [21]. The drawbacks of these methods are of power quality degradation, high cost, and poor detection time as compared to passive methods. Moreover, the perturbations are injected into the system at predefined intervals even though it is not required during the normal operation. Furthermore, if an islanding situation occurs just after the injection of pre-defined perturbation, then it has to wait for the next perturbation in determining the electrical grid status. Hybrid method is introduced with the combined features of both active and passive detection methods [22]. During islanding detection procedure, passive method is used as primary detection scheme and the active method is implemented when the islanding is suspected by the passive detection scheme. The demerits of hybrid methods are high cost, degradation of power quality and more detection time. Average rate of voltage change and real power shift [23], and power spectral density [24] are some popular hybrid methods.

In this regard, signal processing techniques are mostly used to achieve fast and accurate islanding detection. The basic signal processing methods such as Discrete Fourier Transform (DFT), Short time Fourier Transform (STFT) and wavelet transforms (WT) are used for islanding detection. WT has an excellent time–frequency localization capability for which it is applied as an effective tool to analyze any power quality disturbance waveform [25–31]. However, WT based signal analysis has limitations such as batch processing step, non-uniform frequency subband, less flexible and detection failure under noisy conditions. On the other hand, analysis of any distorted waveform based on WPT provides more flexibility and uniform/non-uniform frequency spectrum [32]. To achieve accurate grid monitoring, WPT based anti-islanding scheme is described in this proposed work. The main advantage of proposed scheme is to reduce NDZ of passive method to zero without degradation of power quality. The effectiveness of proposed WPT based islanding detection technique employed for grid connected PV systems under distorted and unbalanced grid voltage is analyzed with the help of MATLAB/SIMULINK. Grid connected PV inverter uses d–q based wavelet packet transform technique to determine the status of the electrical grid. The complete structure of WPT provides flexibility for the signal representation to achieve better classification accuracy.

In this paper, Section ''Problem statement'' describes the overall system and Section ''Wavelet packet analysis applied in detecting islanding condition'' describes about WT and WPT based detection under islanding situation and power quality disturbances. The simulation results and discussion are presented in Section ''Simulation results and discussion'' and conclusion of the proposed work is presented in Section ''Conclusion''.

Problem statement

Fig. 1 illustrates overall system configuration of a grid connected PV system. The system comprises of (i) PV panel that generates direct current from sunlight, (ii) DC–DC converter for boosting the dc voltage, (iii) DC–AC full-bridge inverter, which is used to convert dc to ac voltage using plug-in repetitive current control based pulse width modulation (PWM) scheme and (iv) passive filter connected at inverter output for elimination of unwanted signal. With the application of MPPT algorithm, duty cycle of dc–dc converter is regulated for achieving MPP under the change in environmental condition. Hence, the MPP tracker computes the power that will be fed into the grid, whereas the DC voltage controller maintains constant DC voltage at the input of the inverter [33]. Both MPPT and DC voltage controller contribute to obtain the reference current as depicted in Fig. 1. The performance of plug-in repetitive current controller is applied for generation of switching pulses for inverter to achieve almost pure sinusoidal voltage and reduce harmonics [34,35]. Wavelet analysis is applied for obtaining time–frequency localization and capturing a certain frequency band. The performance of WPT based islanding detection technique is compared with WT method under various power quality disturbances to maintain safety, reliable and good quality of power supply.

Wavelet packet analysis applied in detecting islanding condition

Islanding detection

Islanding situation of a grid connected PV system arises when a local section is isolated from the main utility grid by the help of circuit breaker (CB). Considering the system as shown in Fig. 2, PV power generation system consisting of PV array and an inverter is connected to the local utility grid at node PCC through transformer. The utility grid at right of PCC can be disconnected from PV system by executing the tripping signal to CB. However, the local load connected at node PCC is fed power by PV inverter. In case of $P_{load} = P_{PV}$ and $Q_{load} = Q_{PV} = 0$, there is no current flow through the switch; and power fed from utility grid to local load is zero. If the switch were opened under this condition, no change will occur at node PCC. This means there is no change in signal that identifies islanding of a grid.

The equivalent circuit of grid connected system with RLC load is depicted in Fig. 3. When the system is under normal operation; the real and reactor power $P_{PV} + jQ_{PV}$ flows from the PV inverter to node PCC, $P_{load} + jQ_{load}$ flows from node PCC to the local load and the power flows from utility grid to node PCC is $\Delta P + j\Delta Q$. These power equations are expressed in (1) and (2).

$$\Delta P = P_{load} - P_{PV} \tag{1}$$

$$\Delta Q = Q_{load} - Q_{PV} \tag{2}$$

The impedance, phase angle, resonant frequency f_0, and quality factor Q_f are expressed in following Eqs. (3)–(6).

$$|Z| = \frac{1}{\sqrt{\frac{1}{R^2} + \left(\frac{1}{\omega L} - \omega C\right)^2}} = \frac{R}{\sqrt{1 + Q_f^2\left(\frac{f_0}{f} - \frac{f}{f_0}\right)^2}} \tag{3}$$

$$Q_{load} = \tan^{-1}\left[R\left(\frac{1}{\omega L} - \omega C\right)\right] = \tan^{-1}\left[Q_f\left(\frac{f_0}{f} - \frac{f}{f_0}\right)\right] \tag{4}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{5}$$

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