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A new passive islanding detection method and its performance evaluation for multi-DG systems

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ABSTRACT

This paper presents a passive islanding detection method for inverter-based distributed generation based on empirical mode decomposition (EMD) technique. The voltage of point of common coupling (PCC) is measured and its intrinsic mode functions (IMFs) are obtained using EMD. The first IMF component of PCC per unit voltage is the parameter used for islanding detection. Performance of the proposed method is evaluated for single-DG and multi-DG cases. Simulation results performed in MATLAB/SIMULINK environment show that the islanding can be detected in less than two cycles, even for zero power mismatch. Moreover, the proposed method functions properly for various configurations of multi-DG systems, DGs switching events, various loadings of DGs and different DG interface controls.

1. Introduction

Environmental pollution of fossil fuels caused an increased application and penetration of distributed generation (DG) systems using renewable energy sources. Integration of these DGs to distribution network has remarkable advantages, including increased reliability and reduced line losses. On the other hand, some problems and concerns may be generated. One of the most critical concerns is islanding detection. Islanding is a condition in which a portion of the distribution network comprising local loads and one or more DGs remains energized while isolated from the rest of the system. Islanding detection is one of the mandatory requirements for DGs, specified in the IEEE Std. 929-2000 and IEEE Std. 1547-2003 [1,2]. Based on these standards, an unintentional island shall be detected within 2 s and the related DGs shall be isolated from the distribution system. Therefore, a fast and accurate islanding detection method is essential.

Islanding detection techniques are classified in two categories: remote and local techniques. Remote methods are based on the communication between utilities and DGs. In contrast, local methods use measured data at the DG site. Remote techniques are more reliable than local ones, but their implementation is more expensive. So, local methods are widely used for islanding detection. They can be categorized into passive, active and hybrid methods.

In passive techniques, system parameters like voltage, frequency, etc. are continuously monitored and compared with a predetermined threshold. Active methods intentionally inject disturbances into the system. Hybrid methods are a combination of passive and active methods. A comprehensive survey on islanding detection methods is presented in [3–6].

Active methods have relatively smaller non-detection zone (NDZ) than passive methods. But they degrade the power quality due to the perturbations introduced to the system. Since the passive methods are usually simple and easy to implement and do not introduce any disturbance, applying a passive method with small NDZ is preferred to an active method.

Time-frequency transform-based passive anti-islanding techniques have been recently proposed. Wavelet transform and S-transform have been presented for islanding detection in [7–12]. These transforms are applied on PCC voltage and current signals to get useful information and calculate suitable parameters, e.g. high frequency components and spectral energy of the signal.

Wavelet transform is basically a time-scale analysis, not a real time-frequency analysis. One of the problems of the wavelet analysis is its non-adaptive nature. Once the mother wavelet is selected, it cannot be changed during the analysis and have to be used to analyze all the data. Moreover, spectral wavelet analysis underlies an uncertainty principle, indicating that a time or frequency dependent information cannot be classified by the same accuracy, simultaneously.

The S-transform is a combination of the short time Fourier transform (STFT) and the wavelet transform by changing the shape of the S-transform wavelet. Although the S-transform can perform

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multi-resolution analysis and retain the frequency information, one cannot expect the predetermined Gaussian window to fit all signals. Moreover, it is more time consuming compared with other time-frequency based methods.

In this paper, an islanding detection technique based on the empirical mode decomposition (EMD) method is presented. EMD is a key part of the Hilbert–Huang Transform (HHT), which is a powerful tool for analyzing linear, non-linear, stationary and non-stationary signals. Unlike the above mentioned transforms, the HHT is an adaptive way to produce physically meaningful representation of data. The superiority of this method to wavelet transform, STFT and S-transform has been presented in the literature [13–16].

The majority of passive islanding detection methods are unable to detect islanding when the power mismatch in islanded system is close to zero [17–20]. Consequently they have large NDZ and are not suitable for islanding detection in multi-DG systems, accordingly. Recently, some passive methods which perform at small power mismatch have been presented [9–12,21–23]. But some of them have not been evaluated in multi-DG systems [9,21,22]. The proposed passive EMD-based method in this paper can detect islanding even when the generation and load exactly match (zero power mismatch) and thus its NDZ is zero. It functions properly in multi-DG systems, as well. Compared with other time-frequency based techniques, the proposed method is very simple, straightforward and easy to implement and has a small computation time. Extensive simulations are performed in single-DG and multi-DG systems with several case studies and the performance of the proposed technique is investigated. The detection time of the method and the required data window is also specified.

The paper is organized as follows: Section 2 describes the EMD method and the approach to obtain the IMF components of a signal. The studied system and its parameters are presented in Section 3. The details of the proposed method are described in Section 4. Sections 5 and 6 present the simulation results and performance evaluation of the proposed technique in single-DG and multi-DG systems, respectively. Finally, conclusions are given in Section 7.

2. Empirical mode decomposition

The concept of the empirical mode decomposition method is to identify the intrinsic oscillatory modes by their characteristic time scales in the data and then decompose the data accordingly. This method is also called the sifting process. EMD is used to decompose the signal into a finite and often small number of intrinsic mode functions. An IMF is a function that satisfies two conditions: (a) in the whole data set, the number of extrema and the number of zero crossings must either equal or differ at most by one; and (b) at any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero. The name “intrinsic mode function” is adopted because it represents the oscillation mode embedded in the data. Since the decomposition is based on the local characteristic time scale of the signal, it is applicable to nonlinear and non-stationary data [13].

Given a signal $X(t)$, the algorithm of EMD can be summarized as follows:

1) Identify local maxima and minima of signal $X(t)$.
2) Perform cubic spline interpolation between the maxima and the minima to obtain the envelopes $e_{\max}(t)$ and $e_{\min}(t)$, respectively.
3) Compute mean of the envelopes, $m(t) = (e_{\max}(t) + e_{\min}(t))/2$.
4) Extract $h_1(t) = X(t) - m(t)$.
5) If $h_1(t)$ is not an IMF (based on above definition), then repeat steps 1–4 on $h_1(t)$ instead of $X(t)$ until the new $h_1(t)$ satisfies the conditions of an IMF. The resultant IMF is called $c_1(t)$.
6) Compute the residue, $r_1(t) = X(t) - c_1(t)$.

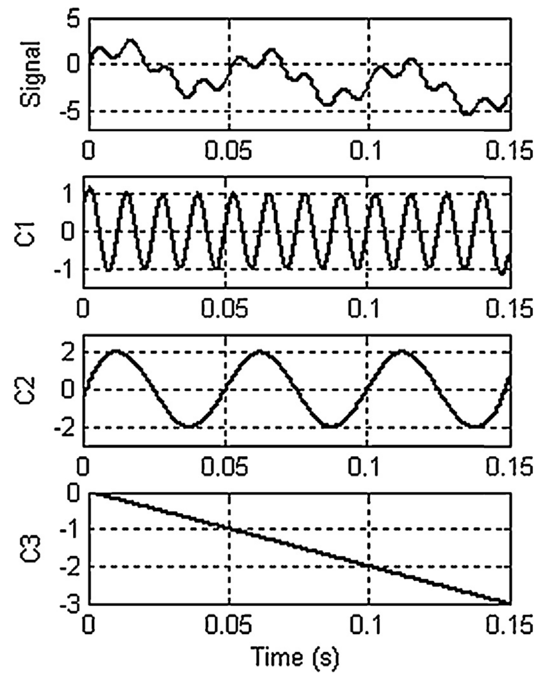

Fig. 1. The signal given in (3) and its IMF components.

7) The sifting process can be stopped either when the component $c_1(t)$ or the residue $r_1(t)$ becomes so small that it is less than the predetermined value of substantial consequence, or when the residue $r_1(t)$ becomes a monotonic function from which no more IMF can be extracted. Otherwise, repeat steps 1–6 on $r_1(t)$ to obtain the next IMF and a new residue.

Huang et al. determined a criterion for the sifting process to stop. This can be accomplished by limiting the size of the standard deviation, SD, computed from the two consecutive sifting results as:

$$SD = \sum_{t=0}^{T} \left[\frac{\left| h_{1(k-1)}(t) - h_{1k}(t) \right|^2}{h_{1(k-1)}^2(t)} \right] \tag{1}$$

where, T is the time interval in which EMD method is applied. A typical value for SD can be set between 0.2 and 0.3 [13].

If $c_1(t)$, $c_2(t)$,. . .,$c_n(t)$ are the IMF components and $r_n(t)$ is the residue extracted by EMD method, the original signal can be reconstructed as:

$$X(t) = \sum_{i=1}^{n} c_i(t) + r_n(t) \tag{2}$$

To see how the EMD works, signal $X(t)$ is considered as follows:

$$X(t) = -20t + 2\sin(40\pi t) + \sin(160\pi t) \tag{3}$$

The original signal and its IMFs obtained from EMD method are shown in Fig. 1. Based on this figure, EMD decomposes the signal with different time scales into its components effectively. This example simply shows the performance of the EMD method to extract different modes of the signal and the validity of results.

3. The studied system

The sample system shown in Fig. 2 has been considered to describe the proposed method and evaluate its performance. The system consists of an inverter-based DG, a three phase RLC load and the grid, which all connect to the PCC. The DG unit comprises a DC