Sustainable Energy, Grids and Networks 9 (2017) 13–26

Contents lists available at ScienceDirect

Sustainable Energy, Grids and Networks

journal homepage: www.elsevier.com/locate/segan

An islanding detection algorithm for distributed generation based on Hilbert–Huang transform and extreme learning machine

M. Mishra [a,*], M. Sahani [b], P.K. Rout [b]

[a] Department of Electrical Engineering, Siksha O Anusandhan University, Bhubaneswar, Odisha, 751030, India
[b] Department of Electrical and Electronics Engineering, Siksha O Anusandhan University, Bhubaneswar, Odisha, 751030, India

ARTICLE INFO

Article history:
Received 16 May 2016
Received in revised form
19 October 2016
Accepted 11 November 2016
Available online 18 November 2016

Keywords:
Distributed generation
Hilbert transform
Empirical mode decomposition
Extreme learning machine
Intrinsic mode function

ABSTRACT

This study presents a novel method to detect an islanding condition in a distribution system with distributed generations (DGs). The proposed approach is based on Hilbert–Huang transform (HHT) and Extreme learning machine (ELM). The system taken for testing of the proposed method consists of different types of DGs like hydro turbine generator with synchronous machine and wind turbine generator with asynchronous machine. The analysis starts with extracting the non-stationary three phase voltage signals at the target DG end and decomposed into mono component signals, called intrinsic mode function (IMF), by the empirical mode decomposition (EMD) method. In the next step, the amplitude, phase angle and frequency of the components are computed by applying the HHT to each IMF. Then, the different distinguish features are calculated such as, energy, standard deviation of phase and amplitude to track the islanding condition from different non-islanding conditions like single line to ground fault, line to line fault, three phase fault, voltage sag, voltage swell, sudden load change, capacitor switching and other DG tripping etc. To test the accuracy of proposed method, a modified ELM classifier is developed based on the feature index. It has been found that the proposed HHT–ELM technique is highly successful to discriminate islanding events under a wide range of operating conditions from the other type of disturbances in the power distribution network. The proposed scheme is simulated by the MATLAB/SIMULINK environment.

1. Introduction

Nowadays, the microgrid can be considered as another substitute of power generation to meet the exponential growth of load demand for a sustainable, reliable and green energy supply. Microgrid is a low/medium voltage energy network combined with distributed generators (DGs), storage devices and different types of small loads [1,2]. Several types of DGs are integrated into the grid at the distribution level like photovoltaic (PV), fuel cells, micro hydro turbines, small wind turbines, biomass and geothermal energies. Despite of the many advantages of DG connection to the utility grid, there are many issues to be focused on and among those one of the major issues is islanding detection. Islanding is a situation in which part of the distribution network is disconnected from the utility and the load still supplied by the local distributed resources (DRs). This type of situation is undesirable because various operational problems arise related to power quality, safety hazard, voltage and frequency instability, and damage to the system equipment, etc. [3,4]. Thus, the current standard practice is to detect accurately the formation of an unintentional island and disconnect all DGs immediately from the electrical power system. According to IEEE 1547-2003 standard, the isolation time should be less than 2 s for small variation in voltage and frequency and to be within 0.16 s for large variations of voltage and frequency. The related DGs shall be isolated within that period from the distribution system [5].

In the recent past, several islanding detection methods have been proposed by the researchers and are enumerated in the literature [6–8]. In general, the islanding detection methods are broadly classified as passive, active and communication based detection schemes. The local information of signal variation (voltage, current, frequency, etc.) at target DGs is used for islanding detection in passive technique. The implementation does not have any adverse effect on the normal operation of the DG system. Also, the passive method has the merits of not suffering from power quality issue, proficient to faster detection of islanding and can be easily implemented for all types of DG configuration. However, a higher non-detection zone and appropriate threshold setting are the major limitations of passive method. Based on this algorithm, under/over frequency [9], under/over voltage [10],

* Corresponding author.
E-mail address: manohar2006mishra@gmail.com (M. Mishra).

http://dx.doi.org/10.1016/j.segan.2016.11.002
2352-4677/

rate of change of power [11], rate of change of frequency [12], voltage surge [13], and harmonic distortion measurement [14] are some of the most commonly used passive islanding methods. On the other hand, an external perturbation is injected into the control system locally and the consequent responses to these disturbances are taken as a measurement for detection in case of active methods [15,14,16–18]. A smaller non-detection zone (NDZ) is the main advantage of active technique compared to passive schemes. However, the active technique has demerits of voltage fluctuation, complex structure, degradation of power quality (PQ) and voltage instability. The hybrid techniques are the combination of active and passive schemes. For achieving higher effectiveness by compensating the individual limitations, here a two stage process is followed [19,20]. Finally, in communication based techniques the telecommunication devices are used to trip distributed resources (DRs) through various communication schemes. Both the above methods have very complex design and less reliable in operation than the other techniques.

Recently the time–frequency based digital relaying for power system fault detection is becoming more attractive. This time–frequency analysis based techniques are usually used to improve the passive methods. Many researchers have proposed different techniques based on wavelet transform (WT), wavelet packet transform (WPT) and s-transform (ST) in their time–frequency analysis based schemes for islanding detection [21–24]. Wavelet transform is basically a time-scale analysis and is non-adaptive in nature. Batch processing steps in wavelet transform introduces delay and is considered as one of the major limitation of applying in power system fault detection. Oversensitive to noisy signals and computational complexity are also the demerits of WT. On the other hand, although the S-transform can perform multi-resolution analysis of retaining the frequency information, one cannot expect the predetermined Gaussian window to fit for all types of signals. Moreover, it is more time consuming compared with other time–frequency based methods. An appropriate absolute threshold setting is also a disadvantage of passive islanding detection methods. A large threshold value varies often fails to detect islanding, while a small value always prone to false tripping of DG. To overcome this problem, pattern recognition techniques (PRTs) like DT, ANN, SVM, PNN, ANFIS and Fuzzy logic are integrated with time–frequency based methods to detect islanding [8].

This paper proposes a novel approach to detect islanding condition based on Hilbert–Huang transform (HHT). HHT is a time–frequency based technique combined with EMD and Hilbert transform. Therefore, HHT is a very robust, highly adaptive and rigorous method for feature extraction. The non-stationary power signals can be analyzed by the HHT [25–27]. The three phase voltage signals are extracted at the target DG end, which are then decomposed into mono component signals by EMD method and are called as intrinsic mode function (IMF). The instantaneous amplitude, phase angle and frequency information of the components are computed next by using Hilbert–Huang transform to all IMF components. Then, the different features characterizing the signals are computed such as, energy, standard deviation of phase and amplitude to track the islanding condition from different non-islanding condition like single line to ground fault, line to line fault, three phase fault, voltage sag, voltage swell, sudden load change, capacitor switching and other DG tripping etc. In this work, a modified extreme learning machine (ELM) classifier has been adopted to classify islanding and non-islanding events, due to its better accuracy and much faster execution than SVM and other recently used classifiers [28–31]. The results are also further analyzed with different noisy conditions. It has been found that, compared with other time–frequency based techniques, the proposed method is very simple, straight forward and easy to implement with small computational time.

The remaining contents of this paper are divided into four sections. Section 2 presents the system model taken for the study. Section 3 introduces the basic theory of HHT algorithm in detail. The intelligent ELM classifier used for the islanding detection is discussed in Section 4. Evaluation and comparison results of the proposed approach for islanding detection are given in Section 5. Lastly; conclusion drawn from the study is given in Section 6.

2. Sample system studied

In this paper, to investigate the proposed method, a multi DG radial distribution system is considered as shown in Fig. 1. The components of the studied system are modeled using MATLAB/SIMULINK tool. Two numbers of DGs, one as hydro turbine and governor system with a synchronous generator (DG1) and another is a wind turbine with a synchronous generator (DG2) are integrated into the main grid at the point of common coupling (PCC). The generic model of hydro turbine and governor system is given in [32], which implements a nonlinear hydraulic turbine model, a PID governor system and a servomotor. The wind turbine model uses the Wind Turbine block of the Distributed Resources/Wind Generation MATLAB/SIMULINK library. The generic model of wind turbine generator model is given in [33]. Here, a Proportional–Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The main grid is modeled having parameter like short-circuit power rating of 1000 MVA, rated voltage of 79 kV and X/R ratio of 10. A 10 MW synchronous generator considered as DG1 is connected to a grid of rating 79 kV through a feeder length of 30 kM and rating 13 kV. Similarly a 1.5 MW asynchronous generator driven by wind turbine considered as DG2 is integrated into a grid of rating 79 kV through a feeder of length 30 kM and rating 13 kV. L1 and L2 are representing the two major loads attached to the PCC bus. To access the voltage/current signals for detecting islanding and non-islanding conditions, relays are placed at the DGs (DG-1, DG-2) end. In this study a sampling frequency of 3.8 kHz having 64 numbers of samples in one cycle on the 60 Hz base frequency is considered. The rating and other system data are mentioned in the Appendix.

3. Basic theory of proposed methodology

3.1. The empirical mode decomposition method

The EMD method is the initial step of HHT. Here the signal $X(t)$ is decomposed into mono component signals, called as IMFs. The following conditions must be satisfied by every single IMF at the stage of decomposition [25].

(1) For the entire dataset the number of extrema and the number of zero crossings are either equal or it may differ at most by one.
(2) The total mean value calculation of the envelope based on the local maxima and the envelope based on the local minima is zero at every point.

A comprehensive explanation of the technique is stated stepwise as follow:

step (1) The decomposition technique needs to utilize the envelopes based on the local maxima and minima separately.
step (2) Local extrema and minima are calculated first. Next cubic spline functions are applied for joining local maxima as the upper envelope and local minima as the lower envelope.