Electric Power Systems Research 161 (2018) 26–44

Contents lists available at ScienceDirect

Electric Power Systems Research

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

# Power quality assessment and event detection in hybrid power system

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ARTICLE INFO

*Article history:*
Received 29 January 2018
Received in revised form 3 March 2018
Accepted 29 March 2018

*Keywords:*
Hybrid power system
Power quality
Renewable energy
Solar energy
Stockwell's transform
Wind energy

ABSTRACT

Renewable energy (RE) sources when integrated to utility network to form hybrid power system pose challenges in terms of stability and power quality. A method based on Stockwell's transform (*S*-transform) is presented in this paper for power quality (PQ) assessment and detection of islanding, outage and grid synchronization of renewable energy sources. Voltage signals are decomposed using multi-resolution analysis (MRA) of *S*-transform and features extracted are realized to assess the power quality disturbances associated with various events. Operational events are detected with the help of features extracted from the *S*-transform based decomposition of negative sequence component of voltage. A power quality index is proposed to rank the various operational events based on power quality. Proposed algorithm has been tested successfully on IEEE-13 bus test system with necessary modifications to integrate wind and solar PV generators to form the hybrid power system. Simulation results are validated in real time environment with the help of real time digital simulation (RTDS) system.



## 1. Introduction

Renewable energy (RE) sources have emerged as an ultimate solution to the problems such as global warming, pollution and increasing demand of the electricity [1]. Hence, major RE sources integrated to existing utility network to form hybrid power system include solar photovoltaic (PV) system and wind energy conversion system (WECS). These sources influence the power quality, grid stability, reliability and issues related to safety [2]. Environmental characteristics such as variations in wind and change in solar insolation greatly affect voltage profile in the hybrid power system leading to sag, swell, etc. Further, the increased penetration level of RE sources also deteriorates power quality [3]. Poor power quality causes motor failures, inaccurate metering, overheating of lines, premature ageing of devices, maloperation of protection equipments and interference with communication circuits [4]. Further, the converters used for the grid integration of RE sources may also reject to operate due to PQ disturbances. Therefore, there is a need to perform detailed analysis of power quality disturbances associated with RE sources based hybrid power system.

Islanding is a scenario in which utility network is disconnected in the event of network disturbances where RE sources tries to meet out local demand of power [5]. This leads to PQ problems and may cause serious damage to RE sources if utility power is wrongly restored [6]. This requires early detection of event to provide anti-islanding protections. Islanding detection methods are classified into active and passive types. Passive methods are based on selection of appropriate threshold. The reported passive methods are based on total harmonic distortions (THD) and voltage unbalance which have their own demerits. A method using communication channel and circuit breaker control for remote islanding detection in a wind and solar energy based hybrid utility grid has been proposed by the authors in [7]. The proposed method has the advantages that it is independent of type of local load, successfully work during resonance condition, zero non-detection zone, independent of load and the type of inverter used for grid integration of RE sources. In [8], authors investigated the performance of a passive method used for islanding detection using wavelet packet transform (WPT) in the presence of solar PV system during various scenarios of PQ disturbances. A comparative study of WPT based method with the method based on wavelet transform (WT) for islanding detection in a 3-phase utility network interfaced with solar PV inverter is also presented. A detailed study of a technique based on computational intelligence was used for detection of islanding in utility networks interfaced with RE sources [9]. An active anti-islanding detection approach for 3-phase grid-

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https://doi.org/10.1016/j.epsr.2018.03.026
0378-7796/

connected converters in the RE sources based hybrid power system is reported in [10].

A detailed research work is carried out in the field of recognition of PQ events associated with RE sources in distribution network utilizing artificial intelligence (AI) and digital signal processing techniques [11]. The signal processing techniques employed for this purpose include Fourier transform (FT), short time Fourier transform (STFT), wavelet transform (WT), discrete wavelet transform (DWT) and Stockwell transform (*S*-transform). FT provides only the frequency resolution and STFT suffers from disadvantages of fixed window size. However, the WT provides multi-resolution analysis (MRA) with variable window size i.e. small window for high frequency and large window for low frequency. Both WT and DWT are successfully utilized for detection of PQ events in Ref. [12]. The *S*-transform is an advanced version of wavelet transform which also provides phase angle information. This transform has been effectively used in the area of PQ detection using a moving and scalable Gaussian window [13]. This transform due to its additional features provides efficient detection of PQ events [14]. Biswal et al. [15] proposed an algorithm for recognition of PQ events using a fast variant of *S*-transform and decision tree (DT) based classifier. Kaddah et al. [16] proposed a probabilistic PQ index for utility grids with high wind energy penetration level to assess the power quality. A method for detection of islanding event and PQ disturbances in the hybrid utility grid has been proposed in [17]. Hsu et al. [18] investigated the impacts of a high wind energy penetration on the performance of distribution network. Classification of various islanding events and power quality disturbances using support vector machine (SVM) and modular probabilistic neural network (PNN) in the hybrid power system has been presented in [19]. Heideri et al. [20] presented a method using transient state signal analysis for islanding detection in power system with RE penetration. Classification of PQ disturbances using Fuzzy C-means (FCM) clustering and chemotactic differential evolution based on decision tree has been reported in [21]. Mahela et al. [22] proposed an algorithm using *S*-transform and FCM clustering for recognition of PQ disturbances associated with solar PV system integrated to distribution utility system. Experimental investigations of the PQ disturbances associated with grid connected photovoltaic systems in urban distribution network are reported in [23]. Assessment of the PQ disturbances associated with the 3-phase utility network in the presence of solar PV system with different stages of power extraction circuits is reported in [24]. In [25], authors presented a rule-based method to estimate the voltage variations associated with supervisory control and data acquisition (SCADA) system of a renewable power generation system. This method has demerit that the sampling rate of analysed power signal is not an integral multiple of samples per fundamental cycle which may lead to estimation errors.

This paper presents event detection and recognition of power quality disturbances in hybrid power system with the help of features extracted from *S*-transform based decomposition of sequence and total voltages. A technique using *S*-transform based decomposition of negative sequence voltage has been presented for the detection of operational events like islanding, outage of wind/solar PV generators and grid synchronization of wind/solar PV generators in the hybrid power system. Features extracted from the *S*-matrix corresponding to *S*-transform based decomposition of negative sequence voltage effectively detects the various events. This paper also presents an algorithm for recognition of the PQ disturbances associated with the above mentioned events in the hybrid utility grid using feature plots extracted from *S*-matrix obtained from the *S*-transform based decomposition of voltage signal. Sum absolute values plot obtained by sum of absolute values of each column of *S*-matrix is introduced to improve the efficiency of proposed algorithm. Total harmonic distortions of voltage and current are obtained using fast Fourier transform (FFT). Variations in the power frequency are obtained by direct monitoring of system frequency. A power quality index is introduced to rank the various operational events in the terms of power quality. Simulation results are validated in the real time to effectively establish the proposed algorithm. Main contributions of the research work presented in the field of hybrid power system are as follows:

- Introduction of operational field of hybrid power system addressing detection of operational events and associated power quality disturbances.
- Proposition of an approach for detection of various operational events in hybrid power system.
- Proposition of an approach for the recognition of PQ disturbances associated with various operational events.
- Proposition of sum absolute values curve to improve the performance of *S*-transform for event detection and PQ analysis.
- Proposition of power quality index to rank the various operational events in terms of power quality.

This paper is structured into seven sections. Proposed methodologies for detection of PQ disturbances, islanding, outage and synchronization of generators are detailed in Section 2. The proposed hybrid power system for testing the algorithm has been described in Section 3. Simulation results related to detection of operational events under investigation are presented in Section 4. Section 5 covers simulation results related to detection of PQ events. Validation of results in real time is reported in Section 6. Section 7 concludes the proposed research work.

## 2. Proposed methodology

This section describes two proposed algorithms. First algorithm, based on negative sequence voltage is used for the detection of operational events like islanding, outage and grid synchronization of RE sources. Second algorithm is used for the recognition of PQ disturbances associated with the above mentioned events during various operating scenarios. These methods are effectively applicable in the presence of battery energy storage system used to store surplus energy at some time interval of the day. Stockwell transform used for the decomposition of negative sequence voltage for the detection of events and decomposition of voltage for the recognition of PQ disturbances is also presented in detail.

### 2.1. Stockwell transform

The information related to the events and PQ disturbances is contained in the amplitude and phase of the spectrum. Phase of the mother wavelet is modified in order to utilize the information contained in phase of the continuous wavelet transform (CWT). CWT of a function $h(t)$ is defined by the following relation.

$$W(\tau, a) = \int_{-\infty}^{\infty} h(t)\omega(t-\tau, a)dt \tag{1}$$

where $\omega(t, d)$ is a scaled replica of fundamental mother wavelet, $d$ is dilation which controls the resolution and determines width of the wavelet. Dilation factor is reciprocal of the frequency [6].

The *S*-transform of a function $h(t)$ can be obtained by multiplying CWT with a phase factor as detailed below [13].

$$S(\tau, f) = e^{i2\pi ft}W(\tau, d) \tag{2}$$

where mother wavelet is given by

$$w(t, f) = \frac{|f|}{\sqrt{2\pi}}e^{-\frac{t^2f^2}{2}}e^{-i2\pi ft} \tag{3}$$