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Integrated DWT–FFT approach for detection and classification of power quality disturbances

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ABSTRACT

The signals in the electrical power system always have some power quality disturbances and noise contents which is the biggest obstacle in detection and time localization. In this paper, an integrated rule based approach of discrete wavelet transform – fast Fourier transform is proposed. For the detection of power quality disturbance present in the input signal, the input waveform is processed by discrete wavelet transform. The discrete wavelet coefficients are used to calculate average energy entropy of squared detailed coefficients feature. The various power quality disturbances are initially detected and then classified into four main categories as disturbances related to sag, swell, interruption and harmonics using this feature. Further classification of each main category is done using fast Fourier transform features. The total twelve types of power quality disturbances including seven basic and five combinations which are very close to real situations, are considered for the classification which are generated by parametric equations. Also four another cases are considered by adding noise to four basic disturbances sag, swell, harmonics and flicker. All sixteen cases are simulated using Mathworks Matlab R2008b. The performance of classifier is tested for 150 test signals for various durations with different disturbances with and without noise. The developed classifier is able to achieve 99.043% accuracy. From the simulation results, it can be seen that the proposed approach is effective for the detection and classification of various power quality disturbances.

Introduction

The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environments is called power quality (PQ) [1]. The interest in PQ has been increased enormously since 1995 due to many reasons. All power equipments have become less tolerant to bad power quality. With the power system deregulation, there has been an increased need for study of various PQ issues since electricity consumers are demanding better power quality. The analysis of sources of PQ disturbances is an important task in order to understand the behaviors of the power system, to identify and implement an effective mitigation measures.

In recent years, the researchers have studied and proposed various methods for analysis, detection and classification of various PQ issues. The Fourier transform (FT) is used to process and analyze the stationary signals only. The FT is time independent and tells about frequency contents in the signal. The Discrete Fourier transform (DFT) is used for analysis of frequency content in steady state periodic signal and is suitable for harmonic analysis. However it is not capable to detect sudden or fast changes in waveform i.e. voltage dip, transients and voltage flickers, etc. The DFT has major drawbacks such as resolution, spectrum leakage as well as picket-fence effects [1]. The basics of wavelets and wavelet transform can be referred in [2]. The short time Fourier transforms (STFT) has the limitation of the fixed window width, hence it is inadequate for the analysis of the non-stationary PQ disturbances. The problem of all above signal processing methods are the principle of Heisenberg's uncertainty in which one cannot know what spectral components exist at what instance of time. The unique features that characterize power quality disturbances and techniques to extract from recorded disturbances are also presented [1,3]. The STFT fixed resolution problems have been solved using wavelet transform (WT) approach which does not need to assume the signal conditions. This makes it highly suitable for tracing changes in signal including fast changes in high-frequency components. The WT approach automatically adjusts the window width to give good time resolution and poor frequency resolution at high

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frequencies and good frequency resolution and poor time resolution at low frequencies [3,4]. The unique features that characterize power quality events and methodologies to extract them from recorded voltage or current waveforms using Fourier and wavelet transforms. Converter operation, transformer energization, and capacitor energization (which includes normal, back-to-back, and restrike on opening energization), representing three common power quality events at the distribution level, are presented [5]. The discrete short-time Fourier transform (STFT) is used for the time–frequency domain; dyadic and binary-tree wavelet filters for the time-scale domain. Dyadic wavelet filters are not suitable for the harmonic analysis of disturbance data. With a properly chosen window size, discrete STFT is also able to detect and analyze transients in a voltage disturbance [6]. The wavelet transform was introduced as a method for analyzing electromagnetic transients associated with power system faults and switching [7]. In their method, authors provide information related to the frequency composition of a waveform, it is more appropriate than the familiar Fourier methods for the non-periodic, wide-band signals associated with electromagnetic transients. It appears that the frequency domain data produced by the wavelet transform may be useful for analyzing the sources of transients through manual or automated feature detection schemes. The basic principles of wavelet analysis are set forth, and examples showing the application of the wavelet transform to actual power system transients were presented. The WT based on line disturbances detection and characterization of transients in transformers using DWT was also presented [8,9]. The basic ideas of discrete wavelet analysis for power quality detection is used, in which a variety of actual and simulated transient signals are then analyzed using the discrete wavelet transform that help demonstrate the power of wavelet analysis [10].

The continuous wavelet transform to detect and analyze voltage sags and transients is used. A recursive algorithm is used and improved to compute the time–frequency plane of these electrical disturbances. The characteristics of investigated signals were measured on a time–frequency plane. Detection and measurement results are compared using classical methods [11]. The DWT is used to extract the features of transients caused by the load/capacitor switching. The wavelet coefficients are then served as inputs to the hybrid self-organizing mapping neural network for detecting/identifying switching types and phase angles [12]. An effective MRA method has been presented for analyzing the power quality transients based on standard deviation and RMS value. The WT based de-noising techniques to remove noise effects on PQ disturbances is also proposed but it is also mentioned that its effectiveness degrades with decrease in signal to noise ratio [13,14]. The squared wavelet transform coefficients (SWTC) based approach and its effectiveness for detection and localization of transients due to load and capacitor switching is also presented [15].

A new time–frequency analysis Gabor–Winger transform (GWT) method is investigated for analysis of different PQ problems. Using this GWT only the beginning of PQ disturbances is detected [16]. An energy difference of multi-resolution analysis method is proposed for PQ disturbances detection and classification [17]. Hybrid signal processing combined with machine intelligence, WT based feature extraction approach, multi-resolution signal decomposition (MSD) technique, WT based de-noising, S-transform integrated with neural network, optimal feature selection methods and PQ events using WT and least squares support vector machines have been proposed for PQ events identification, detection and classification [18–22]. A prototype wavelet-based neural network classifier for recognizing PQ disturbances is implemented and tested under various transient conditions [23]. A noise-suppression scheme of noise-riding signals and an energy spectrum of the WTC in different scales calculated as well as the neuro-fuzzy classification system is then used for fuzzy rule construction and signal recognition [24]. The concept of DWT for feature extraction of power disturbance signal combined with artificial neural network and fuzzy logic incorporated as a powerful tool for detecting and classifying PQ problems. In this a different type of univariate randomly optimized neural network combined with DWT and fuzzy logic to have a better PQ disturbance classification accuracy is implemented [25].

Even though there has been lot of development in this area but still it is challenging and needs to be studied. The conventional analyzing methods does not provide clear and sufficient information on the time domain. In this paper, DWT based MSD technique with percentage energy entropy of squared detailed coefficient (EESDC) feature extraction method to detect, localize and for an automatic classification of PQ disturbances an integrated DWT–FFT approach with and without noisy environment is proposed. The paper is organized as follow. In Section "DWT and multi-resolution signal decomposition (MSD) analysis", DWT and multi-resolution analysis concepts are presented. The DWT algorithm implementation and PQ disturbance detection is presented in Sections "Application of DWT algorithm for PQ disturbance detection" and "Power quality signal disturbance detection" respectively. Various feature selected are discussed in Section "Feature extraction using DWT for classification of PQ disturbances". In Section "Performance of DWT based MRA under noisy environment", the proposed method performance is analyzed under noisy environments. Integrated approach of DWT–FFT is implemented in Section "Rule based system for an automatic classification of PQ disturbances". The proposed method comparison is discussed in Section "Performance comparison of proposed method" followed by conclusion in Section "Conclusions".

DWT and multi-resolution signal decomposition (MSD) analysis

The DWT uses the wavelet function (ψ) and scaling function (ϕ) to perform simultaneously the multi-resolution analysis (MRA) and reconstruction of the distorted signal. The DWT automatically makes narrow window size for high frequency and wide window size for low frequency. This feature of DWT make it possible to maintain an optimum time–frequency resolution at all frequency intervals.

MSD analysis

The recursive mathematical representation of MSD is given below:

$$A_j = D_{j+1} \oplus A_{j+1} = D_{j+1} \oplus D_{j+2} \oplus \cdots \oplus A_n \tag{1}$$

where, A_{j+1} is the approximated (smooth) signal at scale $j+1$, D_{j+1} is the detailed version for displaying all types of transient phenomena of the signal at scale $j+1$, $\oplus$ denotes an orthogonal summation, n represents the signal decomposition levels.

Modeling of DWT and MSD

A DWT gives a number of wavelet coefficients as per the number of discrete steps according to the dilation m and translation n integers. The wavelet coefficient can be described by two integers m and n. It can be done by selecting $a = a_0^m$ and $q = nq_0a_0^m$, where a_0 and q_0 are fixed segmentation step sizes for the scale and translation with $a_0 > 1$, $q_0 > 0$, $m, n \in z$ and z is the set of positive integers. The mother wavelet in DWT is given by [1],

$$\psi_{m,n}(t) = \frac{1}{\sqrt{a_0^m}}\psi\left(\frac{t - nq_0a_0^m}{a_0^m}\right) \tag{2}$$