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Application of lifting based wavelet transforms to characterize power quality events

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Abstract

This paper discusses the analysis of voltage disturbances in the time scale domain using Lifting Based Wavelet Transforms (LBWT) to quantify Power Quality (PQ) events. Characteristics of the investigated signals are generated on a time–frequency plane. Converter operation, load interruption/reenergizing, nonlinear loading and two types of capacitor switching, representing five common power quality events at the distribution level, are presented. These examples provide the basis for further characterization of other power quality events. Magnitudes of transient PQ events are located in the width of the signal. Furthermore, meaningful time and frequency components of transients are analyzed. The whole method is implemented and tested over a sample representing disturbances. Simulation results for five types of PQ events show that the proposed method is more efficient and faster in tracking signal dynamics than classical Wavelet Transforms (WT).

Keywords: Power quality; Power system disturbances; Power system transients; Discrete wavelet transforms; Lifting based wavelet transform

1. Introduction

In recent years, both utilities and consumers are becoming increasingly concerned with power quality (PQ) problems due to renewed interest in improving the quality of the electricity supply. The growing concern about PQ has been increased depending on the usage of modern sensitive equipments such as personal computers, workstations, uninterruptible power supplies and other nonlinear loads like adjustable speed drives, programmable logic controllers etc.

Fourier transforms (FT) and wavelet transforms (WT) have been used for power quality analysis. The classical Fourier transform is a purely frequency domain method. Sine and cosine waves are used in Fourier analyses as base functions and precisely located in frequency. So FT cannot be adequate in the analysis of high frequency and non-periodic signals like power system transient phenomena. FT can be used for characterization of steady state phenomena like harmonics [1,2]. A FT is a suitable method to analyze stationary signals. For non-stationary signals such as transient signals, the FT is not suitable. This approach, consisting of relating the temporal characteristics of a signal to its frequency spectrum by writing the signal as an infinite summation of weighted sine and cosine waves of multiples of the fundamental frequency, is insensitive to the transient components of power events. A short time Fourier transform (STFT) is used for time–frequency analysis of non-stationary signals where the use of the FT alone becomes inadequate. The STFT overcomes the time location problem, but it cannot provide multiple resolutions in time and in frequency. Because it is an important characteristic to analyze transient signals containing both high and low

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frequency components, the STFT cannot be successfully applied to non-periodic and high frequency transients like capacitor switching, although it overcomes the time location problem to a large extent compared with the classical FT [1,3].

To overcome the mentioned limitations of FT and STFT, wavelet transforms have been proposed by several authors. For several years, wavelet transforms have been used for detection and classification of power quality disturbances such as transients, voltage sags/swells, harmonics, notching caused by short circuits, load/capacitor switching, transformer energizing etc., [1–8]. The wavelet transform is particularly effective for representing various aspects of non-stationary signals such as trends, discontinuities and repeated patterns, where other signal processing approaches fail or are not as effective. Through wavelet decomposition, transient features are accurately captured and localized in both the time and frequency contexts.

A wavelet is an effective time–frequency analysis tool for analyzing transient signals. Its features of extraction and representation properties can be used to analyze various transient events in power signals. The discrete wavelet transform (DWT) analyzes the signal at different frequency bands with different resolutions by decomposing the signal into a coarse approximation and detail information. The DWT employs two sets of functions called scaling functions and wavelet functions, which are associated with low pass and high pass filters, respectively. The decomposition of the signal into the different frequency bands is simply obtained by successive high pass and low pass filtering of the time domain signal. Santoso [2] and Gu [3] gave an overview of the DWT developed for characterizing PQ events. They also compared the DWT and STFT. They used the wavelet transform to analyze and characterize the PQ events. Through wavelet decomposition of the PQ events, the transient features are accurately captured and localized in both the time and frequency contexts. The capability of this mathematical microscope to analyze different scales of electrical signals is shown to be a powerful tool for investigating small scale oscillations of PQ events.

In this work, a novel approach is proposed for PQ event characterization. The proposed method is based on discrete wavelets that are constructed by a lifting scheme. A lifting scheme is a new method to construct wavelets. The basic idea behind the lifting scheme is very simple. It starts with a trivial wavelet, which does nothing but it possesses the formal properties of a wavelet. The lifting scheme, then, gradually constructs a new wavelet with improved properties. Classical wavelets are known as a translation and a dilation of one fixed function. The Fourier transform is, then, a very important tool for first generation wavelets. On the other hand, a construction with the lifting scheme is entirely spatial and is, therefore, ideally suited for building second generation wavelets when no Fourier transform is available. In addition, construction of the lifting based discrete wavelet not only needs less computational time compared to that of the classical wavelet transform (CWT) but also it is an easier process.

A lifting based wavelet function has been designed to achieve exact band separation in the frequency domain. As such, it is suitable for analysis and characterization of PQ events because it can be used to locate the frequency bands of interest precisely. The result of the lifting based discrete wavelet transform (LBDWT) can be represented by a series of complex valued wavelet coefficients. The module of these complex wavelet coefficients represent the energy of the original signal at different frequency bands or decomposition levels appearing at different times. By investigating this complex wavelet coefficient module, the time–frequency characteristics of the original signal can be obtained.

2. Lifting based wavelet transform

The wavelet transform specifically permits discriminating between non-stationary signals with different frequency features [9]. A signal is stationary if it does not change much over time. A Fourier transform can be applied to the stationary signals. However, like transients, plenty of signals contain non-stationary or transitory characteristics. Hence, it is not a good idea to apply a Fourier transform directly to such signals. The wavelet transform decomposes a signal into a set of basic functions called wavelets. These basic functions are obtained by dilations, contractions and shifts of a unique function called the wavelet prototype. Continuous wavelets are functions generated from one single function ψ by dilations and translations [9–11].

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right) \tag{1}$$

where b is real valued and is called the shift parameter. The function set $(\psi_{a,b}(t))$ is called a wavelet family. Since the parameters (a,b) are continuous valued, the transform is called a continuous wavelet transform. The definition of classical wavelets as dilations of one function means that high frequency wavelets correspond to $a<1$, or narrow width, while low frequency wavelets have $a>1$, or wider width. In the wavelet transform, $f(t)$ is expressed as a linear combination of the scaling and wavelet functions. Both the scaling functions and the wavelet functions are complete sets [11]. However, it is common to employ both wavelet and scaling functions in the transform representation. In general, the scale and shift parameters of the wavelet family are discretized as

$$\begin{aligned} a &= a_0^j \\ b &= kb_0a_0^j \end{aligned} \tag{2}$$

where j and k are integers. The function family with discretized parameters becomes

$$\psi_{j,k}(t) = a_0^{-j/2}\psi(a^{-j}t - kb_0) \tag{3}$$

$\psi_{j,k}(t)$ is called the discrete wavelet transform (DWT) basis. The DWT analyses the signal at different frequency bands