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Wavelet Packet Transform Based Parameter for the Analysis of Short Duration Power Quality Disturbances

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Abstract: The nature of today's power system has become highly dynamic due to the increased use of nonlinear loads, power electronics based equipment and changed power system regulations. Conventionally, the Fourier transform (FT) is used for the power quality (PQ) analysis with parameters such as; THD and TDD. These parameters are suitable for stationary disturbances only. The recent state of power system demands to analyze the PQ disturbances on the basis of magnitude, time and frequency. In this paper, a new parameter based on Wavelet Packet Transform (WPT) is defined and tested for the short duration PQ disturbances such as; voltage sag, voltage swell, momentary interruptions, oscillatory transients and harmonics, simulated as per their broad definitions provided by the IEEE 1159-2009 standards.

Keywords: Power quality index, time-frequency distribution, Wavelet packet transform, Distribution.

1. INTRODUCTION

The dynamic load conditions, evolution of power electronic switching based equipment, strengthened power system regulations has made power quality (PQ) an important concern for power engineers (Billinton *et al.,* 2002). Poor PQ is detrimental to utility as well as to its consumers; though the consumer load itself is one of the major contributors towards PQ deterioration. The regular operations of the utility such as; load switching, fault clearing also adds to the PQ deterioration (Rodríguez *et al.,* 2012). The computation of the amount of deviation of the real PQ signal from the required high quality signal (i.e. pure signal) leads to the analysis of the PQ events. Conventionally, Fourier Transform (FT) based indices such as; THD and TDD were utilized. These indices are strong indicators of PQ as long as the stationary PQ disturbances like harmonics are concerned. FT converts the Amplitude-time distribution of the power signal to magnitude-frequency distribution (Uyar *et al.,* 2009). Thus, time information is vanished.

The IEEE standards 1159-2009 define the PQ disturbances in terms of magnitude, duration and frequency content (IEEE standards, 2009). The PQ disturbances such as; voltage sag, voltage swell, momentary interruptions, harmonics, transients have become very common in the changed load conditions in past few years. The PQ is no more limited to stationary harmonic disturbances only. This creates the need of analysing PQ events with a suitable signal processing technique; which can account both stationary and non-stationary disturbances.

Digital signal processing techniques are utilized for the analysis of PQ events, both in time domain as well as in frequency domain. Form factor, Crest factor, RMS value defines the PQ in the time domain, whereas THD, TDD, DIN defines the PQ in the frequency domain. Time resolution in Frequency domain signal is zero and same way Frequency resolution in Time domain signal is zero. Thus, in both representations the important information are missing (Heydt *et al.,* 1998).

Researchers have applied different signal processing techniques for the analysis of PQ. Short time Fourier transform (STFT) based power quality quantification is suggested in (Jaramillo *et al.,* 2006). STFT based methods are always a compromise between time and frequency resolution caused by fixed window width. Wavelet transform (WT) can simultaneously give time and frequency information of the PQ signals and has been utilized in number of research (Erişti *et al.,* 2010; Kandil *et al.,* 2001; Abdullah *et al.,* 2007). PQ indices based on wavelet packet transform are defined in (Morsi *et al.*, 2011). PQ indices based on Cohen's class (Yong-June S. *et al.,* 2002) are also developed and reported. A modified version of wavelet transform with a movable and scalable window; S-transform is also used for the PQ analysis in recently (Chilukuri *et al.,* 2004; Dash *et al.,* 2003; Fengzhan *et al.,* 2007, Naik *et al.,* 2013).

In this paper, a parameter is defined for the identification and analysis of the commonly occurring PQ events such as; voltage sag, voltage swell, momentary interruptions, harmonics, oscillatory transients etc. The proposed parameter is based on the wavelet packet transform (WPT). The proposed parameter is plotted with respect to the WPT decomposition levels. Based on these plots; specific parameters are further extracted for the identification of the respective PQ disturbances. The proposed parameters show its possible utilization in automatic PQ disturbance identification and classification.

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After this introduction; section 2 describes the WPT technique and the way it is applied in this paper. Section 3 explains the mathematical expressions used for the computation of the proposed parameter. The results and discussions are summarized in section 4 and in the end the conclusions are made.

2. THE WAVELET PACKET TRANSFORM

The time domain signals give amplitude-time representation giving zero frequency resolution. The FT converts the amplitude-time representation to magnitude-frequency representation giving zero time resolution. The STFT suffers with the issue of being a compromise between time and frequency resolution because of the fixed window width. WT solves the issue of time and frequency resolution to a great extent, but suffers with the feasibility aspect. Complex computation of WT makes it unsuitable for the practical applications. The discrete wavelet transform (DWT) reduces the computational complexity of WT and is used in this was been utilized in many PQ analysis applications.

WPT used in this work is an extension of the idea of DWT. In DWT, the sampled signals are analysed by half frequency high pass and low pass filter at the first level called details cD1 and approximations cA1, then at every level, the details (cDj) are further analysed in the same way. In WPT both details and approximations are analysed at every level of decomposition. Fig. 1 shows the WPT algorithm. At level (0,0) the sampled signal is passed through first level of half band high pass and half band low pass filters to get detail cD(1,0) and approximation cA(1,1) and the process is continued further till the desired level is decomposed. In WPT, similar to DWT, at every level of decomposition the signal is down-sampled by the factor of 2. WPT decomposition tree, up to three level of decomposition is shown in Fig. 1. The original signal is at level (0,0), (1,0) and (1,1) are respectively the details and approximations of the first level of decomposition and so on.

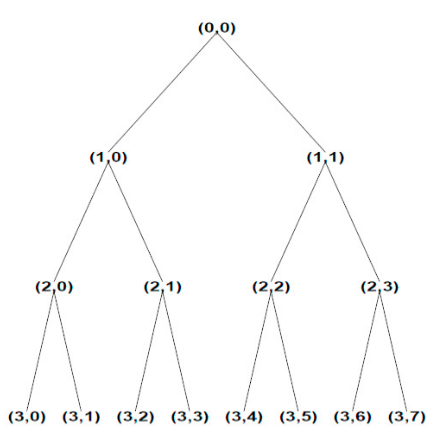

Fig. 1. WPT decomposition up to three levels

This makes WPT a strong contender for PQ analysis as it can simultaneously analyse both high and low frequency content of the time series. Voltage sag, swell and interruptions are related with low frequencies while oscillatory transients and harmonics contain medium and/or higher frequencies.

3. COMPUTATION OF PROPOSED PARAMETER

The short duration disturbances such as; voltage sag, voltage swell, interruptions, oscillatory transients are simulated using MATLAB environment with the respective variations in time, magnitude and frequencies as per IEEE 1159-2009 standards.

Figs. 2(a) to 2(c) shows respectively the voltage sag, voltage swell and momentary interruption signals acquired with 20 kHz sampling frequency for the analysis. The voltage sag and voltage swell are simulated with 20% to 50% variation in magnitude and 2 cycles to 5 cycle durations. The momentary interruption signals simulated for 2 cycle to 5 cycle durations.

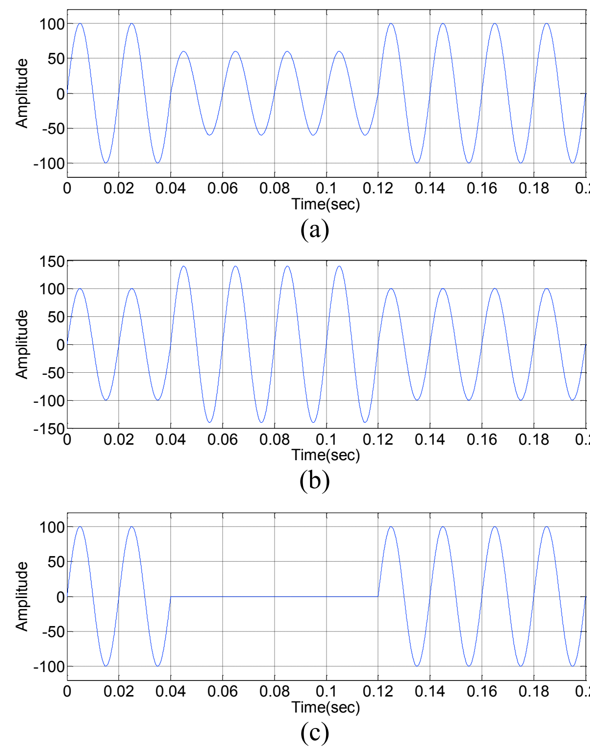

Fig. 2. (a) Voltage sag signal (b) voltage swell signal, (c) momentary interruption

The Oscillatory transient signals are simulated to have transient frequency variations of 3.5 kHz to 8 kHz in four steps. The most common PQ disturbances; harmonics having THDs variations of 4.50% to 23.97% in four steps are also simulated and analysed with the proposed WPT based parameter. The simulated oscillatory transient and harmonic signals are shown in Figs. 3(a) and 3(b) respectively.

The simulated signals are processed with WPT upto level three with db9 wavelet function. A parameter $RMS_{WPT}(i,j)$ based on the RMS value of the WPT co-efficient is defined and computed for all the signals as;

$$RMS_{WPT} = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left(x(i)^2\right)} \qquad (1.1)$$

Where,

n= length of the i^{th} WPT decomposition