Multiresolution Analysis based Decomposition and Reconstruction of Power Quality Disturbances using Wavelet Transform

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ABSTRACT

Proper operation of a power system depends upon the quality of power supplied to consumers by transmission and distribution networks of utilities. Supply voltage across various industrial and domestic loads must be free of any disturbances, deviations, distortions, changes in frequency, and interruptions. The deviations in supplied power are termed as electrical power quality disturbances. Wavelet transform, a signal processing technique, is used for analyzing power quality disturbances. The disturbances considered for analysis are voltage sag, swell, interruption, transient, harmonics, and voltage fluctuations. The aim of this paper is to present multiresolution analysis based decomposition and reconstruction of power quality disturbances using wavelet transform. In multiresolution analysis based decomposition, the original power quality disturbance signals are decomposed into approximation and detail components at various levels by using discrete wavelet transform. After decomposition of the signals into different scales of resolution, information about the disturbance signals can be obtained. In multiresolution analysis based reconstruction, all the approximation and detail components, obtained at various levels, can be assembled back into the original power quality disturbance signals using inverse discrete wavelet transform with no loss of information. Multiresolution analysis based three level decomposition and reconstruction of power quality disturbances is processed by using Daubechies 4 (db4) as mother wavelet. One-dimensional analysis is carried out in MATLAB using the command line functions.

Key Words:approximations; details; discrete wavelet transform; power quality disturbances.

1. INTRODUCTION

Electrical power is supplied by utilities through transmission and distribution networks and must be free of any disturbances. The term power quality is used to refer the study related to all the disturbances that occur in supply voltage and load current due to faults and also monitoring considerations. Power quality is defined as a set of boundaries that allows electrical systems to function in their intended manner without significant loss of performance [1]. Power quality disturbance, also termed as power quality problem is defined as, "Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment" [2].Power quality disturbances are followed by faults occurring on a power system. Any deviation of voltage or current from the ideal is a power quality disturbance [3]. A power quality disturbance represents a voltage signal that varies with time carrying information about the quality of supply voltage. The characteristics of a signal include the amplitude, shape, phase and frequency content of the signal. In general, poor power quality may result into increased power losses, abnormal and undesirable behaviour of equipment, and interference with nearby communication lines. [4]. Proper recognition of the disturbances decides the improvement of electric power quality. The sources and causes of disturbances must be known before appropriate mitigating action can be taken.

Wavelet transform based on signal processing isused for an analysis of power quality disturbances.S.A.Probert et al. [5] presented wavelet analysis as a method of processing the data within a continuous signal so that the signal after a series of decomposition is represented at different frequency ranges.S.Santoso et al. [6] used multiresolution signal decomposition technique for decomposing a signal into its detailed and smoothed versions where detailed version consists of sharp edges, transitions and jumps.E.S.T Eldin [7] presented thatdetail coefficients are used for detection and approximations for characterization.The focus of this paper is to present wavelet analysis based decomposition and reconstruction of power quality disturbances generated in MATLAB and to illustrate that approximation signal contains general trend of the original signal and detail signal contains high frequency contents of the original signal. The original signal refers to voltage sag, swell, interruption, transient, harmonics, and voltage fluctuations.

2. POWER QUALITY DISTURBANCES

Power quality eventshave become an outstanding and troublesome issue because of the increased utilization of nonlinear power electronic loads and sensitive computer controlled and microprocessor-based equipment [8]. The seven categories of disturbances are transients, short duration voltage variations, long duration voltage variations, voltage imbalance, waveform distortion, voltage fluctuations and power frequency variations [9]. Short duration voltage variations are categorized as sags, swells, and interruptions. Long duration voltage variations are categorized as overvoltage, undervoltage and sustained interruptions. Different types of waveform distortion are DC offset, harmonics, interharmonics, notching and noise. The disturbances considered for wavelet analysis are voltage sag, swell, interruption, transient, harmonics, and voltage fluctuations.By using mathematicaldescribing equations for each power quality disturbance,waveformsare generated in MATLAB. Decomposition of the signals give an information about low and high frequency resolutions. This information gives the localisation of disturbances.

2.1. Voltage Sag

Voltage sag is a decrease in rms voltage to between 0.1 pu and 0.9 pu for durations from 0.5 cycles to 1 minute [9]. Voltage sag, shown in figure 1, is simulated in MATLAB and indicates a sudden decrease in voltage.

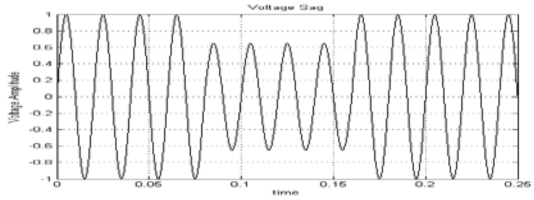

Figure 1: Voltage signal with sag disturbance

2.2. Voltage Swell

Voltage swell is an increase in rms voltage above 1.1 pu for durations from 0.5 cycle to 1 min [9]. Typical magnitudes are between 1.1 pu to 1.8 pu. Voltage swell, shown in figure 2, is simulated in MATLAB and indicates a sudden increase in voltage.

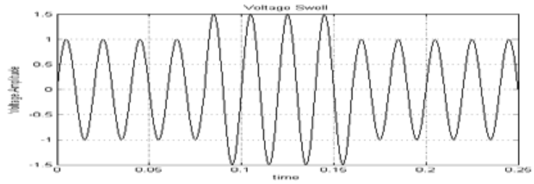

Figure 2: Voltage signal with swell

2.3. Interruption

An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min [9]. Voltage interruption, shown in figure 3, is simulated in MATLAB and indicates a complete loss of voltage for a short duration.

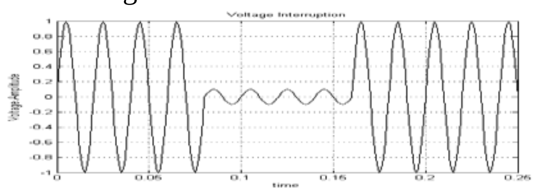

Fig.3 Voltage signal with an interruption

2.4. Transient

A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity [9]. Transient, shown in figure 4, is simulated in MATLAB and indicates a very short duration voltage spike in voltage waveform.

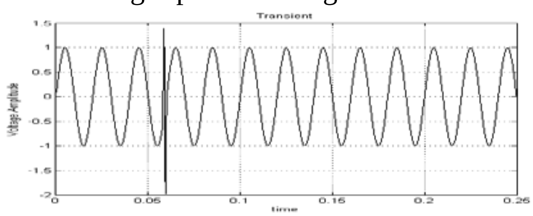

Figure 4: Voltage signal with a transient

2.5. Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the fundamental frequency [9]. The frequency at which the supply system is designed to operate is termed as fundamental frequency and will be either 50 Hz or 60 Hz.Voltage signal with harmonics, shown in figure 5, is simulated in MATLAB.

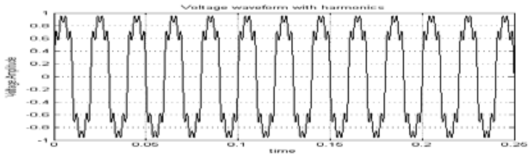

Figure 5:Voltage waveform with harmonics

2.6. Voltage Fluctuations

Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges of 0.95 pu to 1.05 pu [9]. Voltage waveform with fluctuations, shown in figure 6 is simulated in MATLAB.

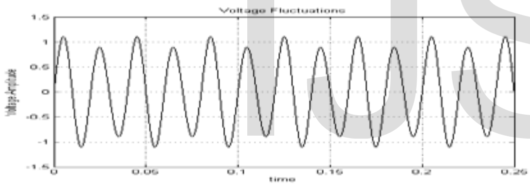

Figure 6: Voltage waveform with fluctuations

By determining the quality of power supply, suitable strategies can be chosen and followed by utilities to provide service without any interruption. So there is a requirement for an accurate analysis of power quality disturbances.

3. MULTIRESOLUTION ANALYSIS AND DISCRETE WAVELET TRANSFORM

The various power quality disturbances can be detected and classified using signal processing techniques. The electrical power service is subjected to variations due to power quality disturbances and results in either misoperation or failure of end-use equipment. Discrete wavelet transform is a time-scale analysis method that is particularly suitable for detecting transition or singular points in the signal waveforms and decomposes a signal into multi-resolution components [10]. The approach of filter banks, utilizing low pass filters and high pass filters, is considered for description of a signal in different frequency bands. Multiresolution analysis and filter-bank approach both of which in turn lead to the discrete wavelet transform. Wavelet transform analyses a stationary signal that decomposes a signal into different scales with different levels of resolution by dilating a single prototype function termed as mother wavelet [6].The approximations and details are at different frequency resolutions. Wavelet function is the mother wavelet which generates details. Scaling function is an aggregation of the mother wavelet at scales greater than one and generates approximations.

Wavelet family consists of Haar, Daubechies, biorthogonal, Coiflets, Symlets, Morlet, Mexican Hat, and Meyer wavelets. Power quality disturbance signals are decomposed into approximations and details using discrete wavelet transform by using Daubechies 4 (db4) as mother wavelet. Discrete wavelet transform is applied to the data of power quality disturbance waveforms. Db4 wavelet is stretched and shifted to obtain a set of template functions against which the power quality disturbances are compared. The width of the template function is termed as scale. Wavelet decomposition of a power quality disturbance signal involves filtering and downsampling as shown in figure 7 and wavelet reconstruction of a power quality disturbance signal involves upsampling and filtering as shown in figure8. Extraction of approximations and details from original signal is termed as multiresolution decomposition of a function which represents the original signal. Attainment of original signal from approximation and detail coefficients is termed as multiresolution reconstruction of the originalsignal. The wavelet transform of a signal is generated by finding linear combinations of wavelet functions to represent a signal and the weights of these linear combinations are termed as wavelet coefficients [11]. Approximation and detail coefficients are obtained by convolution of power quality disturbances with low pass and igh pass filters respectively and decimating by two. Reconstruction of original signal include upsampling of the approximation coefficients by two and by convolution of the result with low pass filter and upsampling of the detail coefficients by two and by convolution of the result with high pass filter. All the original power quality

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disturbances are reconstructed by inverse discrete wavelet transform.Wavelet analysis allows the use of long windows for precise low frequency content information and short windows for high frequency content information [12].

Scaling function is represented as $\varphi(t)$ and wavelet function as $\psi(t)$. A function $f(t)$ can be represented by discrete wavelet transform as [14],

$$f(t) = \sum_k c_j(k) 2^{j/2}\ \varphi(2^j t - k) + \sum_k d_j(k) 2^{j/2}\ \psi(2^j t - k) \qquad (1)$$

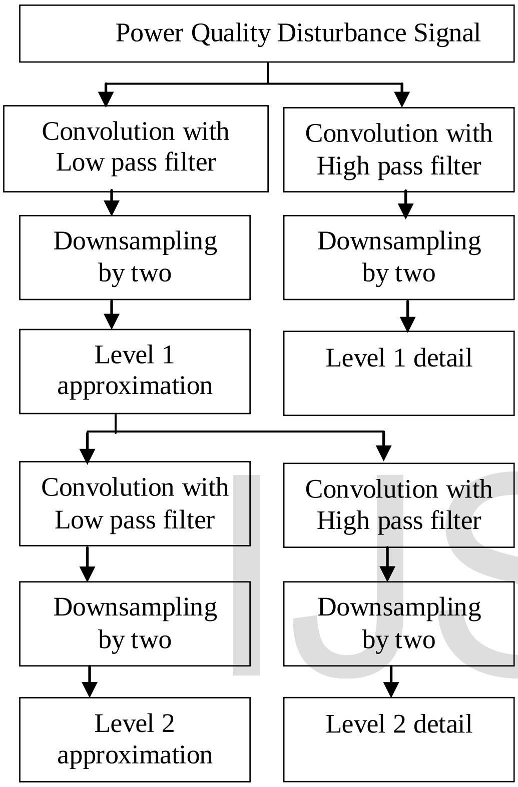

Figure 7: Multiresolution analysis based Decomposition

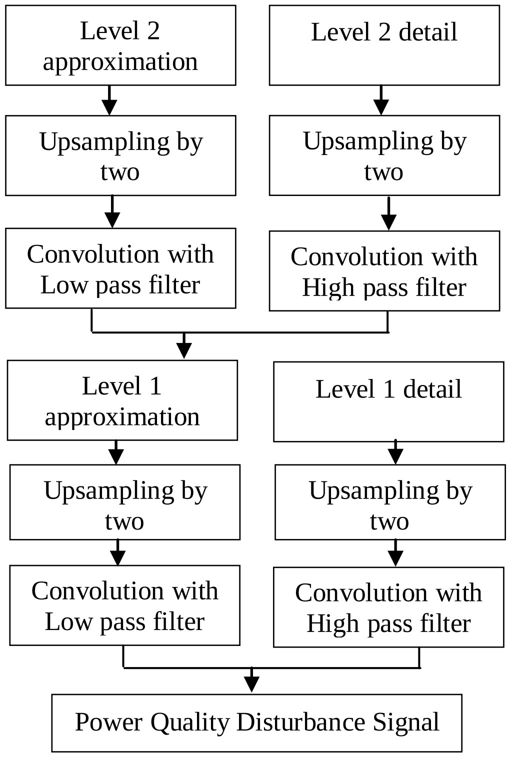

Figure 8: Multiresolution analysis based Reconstruction

The function $f(t)$ represents the power quality disturbance signals varying in time domain. In equation (1), the first summation gives a function that is of low resolution termed as approximation of the signal. The second summation gives a higher or finer resolution termed as detail of the signal. The term j refers to scaling parameter and k refers to shift parameter. The coefficients associated with scaling function and coefficients associated with wavelet function are given by equations (2) and (3) respectively.

$$c_j(k) = \int f(t)\varphi_{j,k}(t)dt \qquad (2)$$

$$d_j(k) = \int f(t)\psi_{j,k}(t)dt \qquad (3)$$

Wavelet functions will generate detail version of the original signal that is decomposed. Scaling function will generate the approximated version of the original signal that is decomposed. Approximations and details are obtained through a succession of convolution process [14].

4. DECOMPOSITION AND RECONSTRUCTION OF POWER QUALITY DISTURBANCES

Power quality disturbances like sag, swell, interruption, transient, harmonics and voltage fluctuations are considered and are decomposed and reconstructed using multiresolution analysis based discrete wavelet transform. The signals are decomposed to one level approximation and three level details. From the obtained approximations

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and details, the original power quality disturbance signals can be reconstructed. The approximations are the high-scale, low-frequency components of the signal and the details are low-scale, high-frequency components [15].Figures 9 to 14 show the power quality disturbances like sag, swell, interruption, transient, harmonics and voltage fluctuations are decomposed into level one approximation and three level details and also reconstructed power quality disturbances extracted from approximations and details.

The power quality disturbance signals are passed from various high pass and low pass filters which perform the operation of decomposition and reconstruction. The property of multiresolution signal decomposition has the ability of the technique to extract important information from the analysed distorted signal and has the ability to separate power quality problems that overlap in both tine and frequency [12].This process is based on one-dimensional analysis using MATLAB command line functions. The detail coefficients at the regular parts of a signal would be small as wavelet transform suppresses the regular parts of a signal while focusing on the irregular parts and this helps to detect and reveal the position of any irregularity in the signal [16]. By having a precise look at the detail coefficients in figures 9 to 14, information about the localization of power quality disturbance can be obtained.

For analysis purpose, three level decomposition is considered. One dimensional command line functions in MATLAB for one-step decomposition, extraction of approximation, detail coefficients, and one-step reconstruction are used for obtaining the waveforms shown in figures 9 to 14. One-step decomposition function by using discrete wavelet transform is used for generating approximation and detail coefficients from level 1 to level 3. The signal can be regenerated from approximation and detail coefficients from level 1 to level 3 by using inverse discrete wavelet transform in one-step reconstruction function.

Decomposition and reconstruction of power quality disturbances at different frequency resolution levels are based on wavelet functions and scaling functions in multiresolution analysis.An approximation gives the regular pattern of the original signal. Detail represents high-frequency contents of the original signal.As the approximation part of the signal is at a coarser level, good frequency resolution and poor time resolution

In figures 9, 10, and 11,Time is taken with an initial value of 0 to final value of 1000 samples with an increment of 0.1 and the disturbances of sag, swell, and interruption with magnitudes of 150V, 290V and 0V respectivelyare initiated from 380th sample to 700th samplewith a frequency of 640Hz. In figure 12, transient is initiated at 0.059th sample in 0.4 samples at a frequency of 50Hz with an initial value of 0 and an increment of 0.0001. In figure 13, harmonics are generated at a fundamental frequency of 314Hz, third order frequency of 942Hz, and fifth order frequency of 1.57kHz.In figure 14, voltage fluctuations are generated at a frequency of 640Hz.

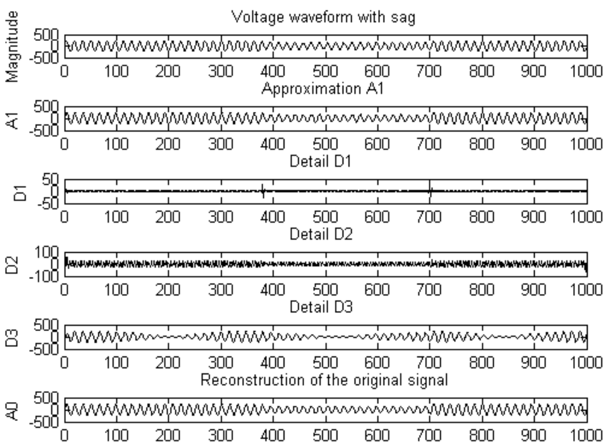

Figure 9: (a) Voltage signal with sag (b) Level 1 Approximation (c)-(e) Level 1, 2 and 3 details (f) Reconstruction of voltage signal with sag.

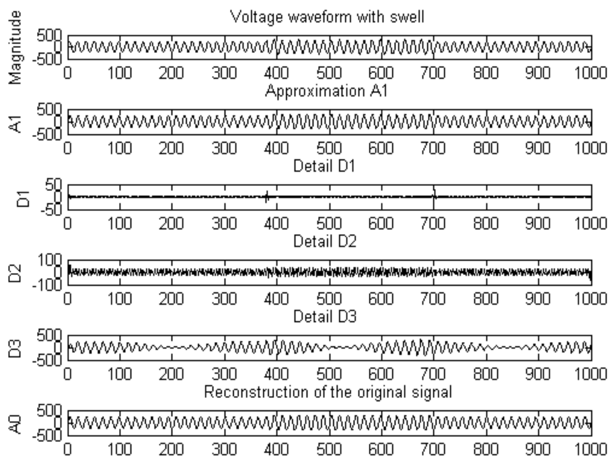

Figure 10: (a) Voltage signal with swell (b) Level 1 Approximation (c)-(e) Level 1, 2 and 3 details (f) Reconstruction of voltage signal with swell.

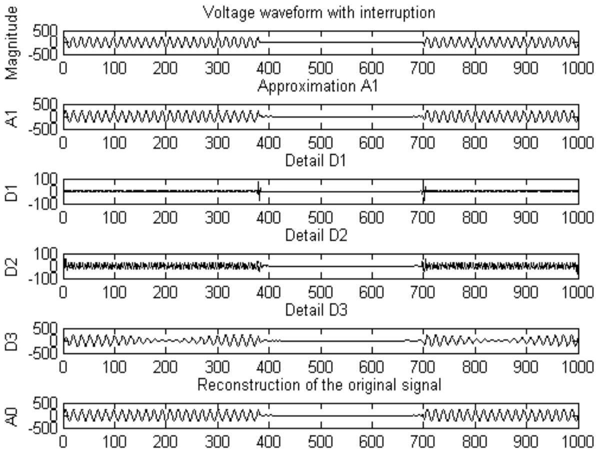

Figure 11: (a) Voltage signal with interruption (b) Level 1 Approximation (c)-(e) Level 1, 2 and 3 details (f) Reconstruction of voltage signal with interruption

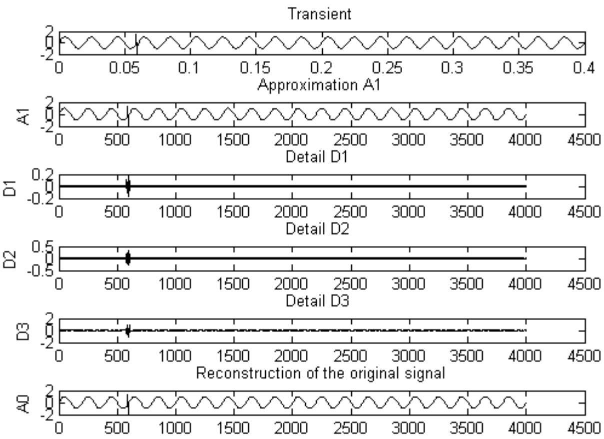

Figure 12: (a) Voltage signal with transient (b) Level 1 Approximation (c)-(e) Level 1, 2 and 3 details (f) Reconstruction of voltage signal with transient

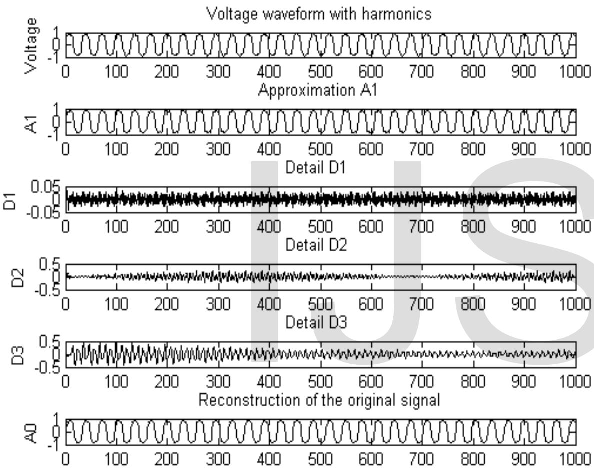

Figure 13: (a) Voltage signal with harmonics (b) Level 1 Approximation (c)-(e) Level 1, 2 and 3details (f) Reconstruction of voltage signal

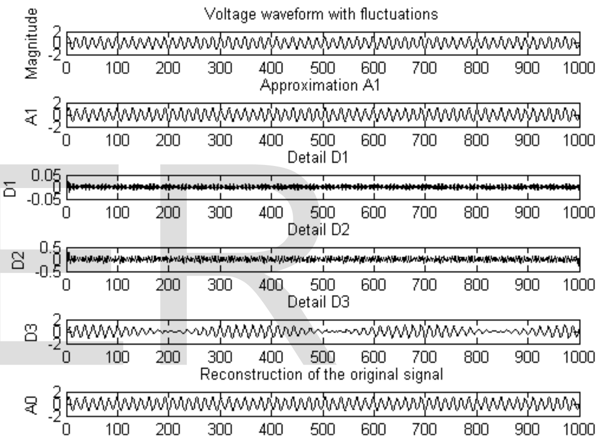

Figure 14: (a) Voltage signal with fluctuations (b) Level 1 Approximation (c)-(e) Level 1, 2 and 3 details (f) Reconstruction of voltage signal with fluctuations

5. CONCLUSION

The basic step in power quality evaluation is identification of the type of power quality problem. Approximations are high-scale, low-frequency components. Due to the features of low-scale and high-frequency, details give precise information about the detection and localization of power quality disturbances. Multiresolution analysis analyses the signal at different frequencies with different resolutions. The examination of the approximation and detail levels obtained from decomposition of power quality disturbance signals into different scales of resolution provides information about the location, duration, identification, discontinuities, beginning and ending of various power quality disturbances. Multiresolution analysis based discrete wavelet transform is applied, using suitable command line functions in MATLAB, for power quality disturbances for three level decomposition and reconstruction of the original signal.

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