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Analysis of Power Quality Disturbances in IEEE 14 Bus Test System

Swarnabala Upadhyaya

Department of Electrical and Electronics Engineering, SUIIT, Sambalpur-768019, India

Abstract

In recent times, the wavelet-based methodologies have been developed as suitable alternatives for the analysis of power quality (PQ) disturbance signals. Power quality monitoring is an essential service that many utilities maintain it for their industrial and larger commercial customers. The improvement in quality of power requires proper identification of source and cause the disturbances. So the detection of the different electrical disturbances which can cause PQ problems is a difficult task that requires a high level of engineering knowledge. The majority of the disturbances are non-stationary and transient in nature subsequently it requires advanced instruments and procedures for the examination analysis of PQ disturbances. In this work wavelet transform has been implemented for analysis of PQ disturbances. PQ disturbances have been generated by changing load in IEEE-14 bus system and decomposed utilizing wavelet decomposition algorithm for localization of disturbances. Two types of PQ events such as voltage sag and swell are analysed using Discrete Wavelet Transform (DWT) along with the normal sinusoidal signal. Each signal is decomposed up to four finer levels using DWT.

Keywords: Power quality disturbance, wavelet transform, discrete wavelet transform,

I. INTRODUCT ION

The power quality measurement is a critical parameter in the cutting edge power frameworks. The electrical engineer must comprehend a specific statistical information and framework when they break down the electric power quality issues. POWER QUALITY (PQ) can be characterized as the investigation of the nature of electric power signals. In modern electrical system end users have distinguished an expanding number of downsides created by electric PQ variation. Today's implemented equipment's in electrical utility are much more venerable to power quality (PQ) variation than before. The gear utilized are for the most part advanced or chip based containing power electronic segments which are sensitive to power quality disturbances. Subsequently, nowadays, clients request more elevated amounts of PQ to guarantee the best possible operation of such sensitive gear. The PQ of electrical power is normally ascribed to electrical cable aggravations, for example, wave shape issues, overvoltage, capacitor switching transients, harmonic distortion, and impulse transients [1]. In this way, electromagnetic transients, which are fleeting voltage surges sufficiently capable to smash a generator shaft, can bring about sudden disastrous harm. For reduction of these disturbances, characterization of the signal patterns like sag, swell, interruption etc. must be done first.

Majority of disturbances are non-stationary in nature hence it requires advanced techniques and systems for the detection of PQ disturbances. A typical Fourier transform is not a reasonable instrument for investigation of PQ aggravations as it gives just spectrum data of the signal without the time limitation data which is required to discover the begin time and end time and additionally the interim of the disturbance. The Short Time Fourier Transform (STFT) is another signal handling system but it is appropriate for stationary signs where the frequency does not change with time. However for non-stationary signs STFT does not perceive the signal dynamics because of the limitation of fixed window width [2], [3] and [4]. The time-frequency investigation procedure is more fitting for breaking down non-stationary signal since it gives both time and spectral data of the signal. The Discrete Wavelet Transform (DWT) is favoured on the grounds that it utilizes an adaptable window to recognize the time-frequency variations which results in a superior time-frequency resolution [5],[6].

The paper is organised as follows. Section-II describes the brief theory of DWT for carrying out the process of detection. The IEEE 14 bus system is given in Section-III. In Section-IV, the effectiveness of DWT is presented to detect different PQ disturbances in IEEE-14 bus system. Finally the Section-V, concludes the paper.

II. DISCRE T E WAVE L E T TRANSFORM (DWT)

Nowadays with the invention of the digital techniques, the PQ disturbances are monitored onsite and online. The detection of PQ disturbances has undergone significant advancements after the use of wavelet transform (WT) recently. Whereas FT and STFT use exponential basis functions, the WT uses a wavelet basis function which gives much better results. The wavelet basis function scales itself in accordance with the frequency under examination. The signal is decomposed into several different frequency levels using wavelet transform and these are called as wavelet coefficients. There are two types of WT based on the type of signal: continuous wavelet transform (CWT) and discrete wavelet transform (DWT). DWT based decomposition is used for discrete time signal and CWT based decomposition is utilized for continuous time signal [7],[8],[9].

The WT represents the signal as a combination of wavelets at different location (position or amplitude) and scales (duration or time). Mathematically, for a signal x(t) the continuous wavelet transform [10] is defined as

$$CWT(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) g\left(\frac{t-b}{a}\right) dt \qquad (1)$$

where g(.) is the mother wavelet, a is the dilation or scale factor and b is the translation factor. Both a and b are continuous variables. The discrete wavelet transform is used to decompose a discretized signal into different resolution levels by reducing the substantial redundancy of CWT.

Similarly, the DWT assessment has two stages. Determination of wavelet coefficients $h_d(n)$ and $g_d(n)$ is the principal stage. *X(n)* in the wavelet domain is represented by these coefficients. The expression for DWT is given [11] as

$$DWT(a,b) = \frac{1}{\sqrt{a_0^m}} \sum_n x(n) g\left(\frac{k - nb_0 a_0^m}{a_0^m}\right) \quad (2)$$

where g(.) is the mother wavelet, k is an integer which is used to refer the sample, scaling parameter and translation parameter. Here, both a and b vary in the discrete manner. The parameter *a* corresponds to scale and frequency domain property. The parameter *b* corresponds to time domain property. In addition, $1/\sqrt{a}$ is the normalization value.

From these coefficients, calculation of both the approximated and detailed version of the original signal is achieved, these wavelet coefficients are called cA1(n) and cD1(n) as defined below

$$cD_1(n) = \sum_{k=-\infty}^{\infty} X(k).g_d(2n-k) \quad (3)$$

$$cA_1(n) = \sum_{k=-\infty}^{\infty} X(k).h_d(2n-k) \quad (4)$$

The high pass and low pass filters are called as the "Quadrature mirror filters" and are related by the equation [12]

$$h[L-1-n] = (-1)^n L(n) \quad (5)$$

where, L is the filter length.

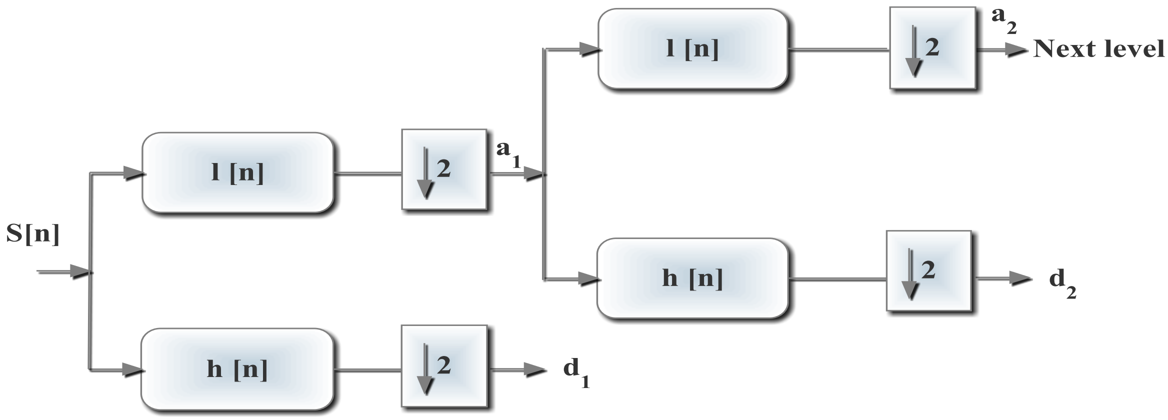

Fig.2. Block diagram of DWT decomposition

Where,

l(n)= Impulse response of LPF

h(n)= Impulse response of HPF

S(n)= Discretized original signal

a_1= Approximate coefficient of level 1 decomposition/output of first LPF

d_1= Detail coefficient of level 1 decomposition/output of first HPF

a_2= Approximate coefficient of level 2 decomposition/output of second LPF

d_2= Detail coefficient of level 2 decomposition/output of second HPF

The Wavelet pattern of a signal depends on the selection of mother wavelet [13]. This selection process is also based on the similarity of the wave shape of the mother wavelet and wave shape of the target signal [14]. For the slow and the long transient disturbances, db8 (Daubechies wavelet of order 8) and db10 are suitable, whereas for the fast and the short transient disturbances db4 and db6 are suitable. However, for the detection of both the fast and slow disturbances, db4 is selected as a suitable mother wavelet as it is most localized, i.e., compactly supported [3].

III. POW E R QUAL IT Y DIST URBANCE MODEL

The IEEE 14 Bus Test Case represents a portion of the American Electric Power System (in the Midwestern US) as of February, 1962. The IEEE 14-bus test case represents a simple approximation of the American Electric Power system as of February 1962.

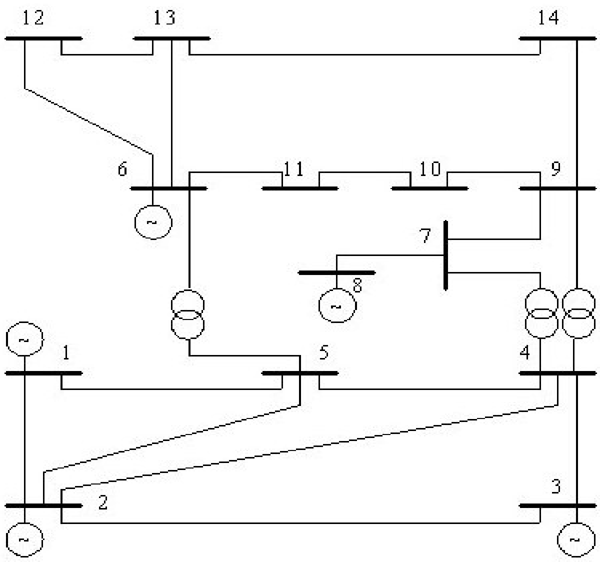

Fig. 1: Single line diagram of IEEE 14 Bus Test System

It has 14 buses, 5 generators, 11 loads and 20 transmission lines. Bus 2 is the slack bus and the buses1, 3, 6, 8 are the PV bus.

The data given is on 100MVA base. The minimum and maximum limits of voltage magnitude and phase angle are considered to be 0.95p.u. to 1.05p.u. and -45^0 to $+45^0$ respectively [16]. It consists of five synchronous machines. There are 11 loads in the system totalling 259 MW and 81.3 Mvar. IEEE 14 Bus Test System is studied using Newton-Raphson Power Flow Method.

IV. RESULTS AND DISCUSSIONS

The PQ disturbances captured from the point of common coupling are fed as inputs to DWT. The output of DWT along with the original signal are presented below in ordered to observe the suitability of DWT for detection of PQ disturbance.

A. Pure Sinusoidal Wave

A pure sinusoidal wave of voltage signal has been considered in Fig.2. By implementing DWT, the signal has been decomposed up to four decomposition levels are shown in Fig.2 along with the original sine wave.

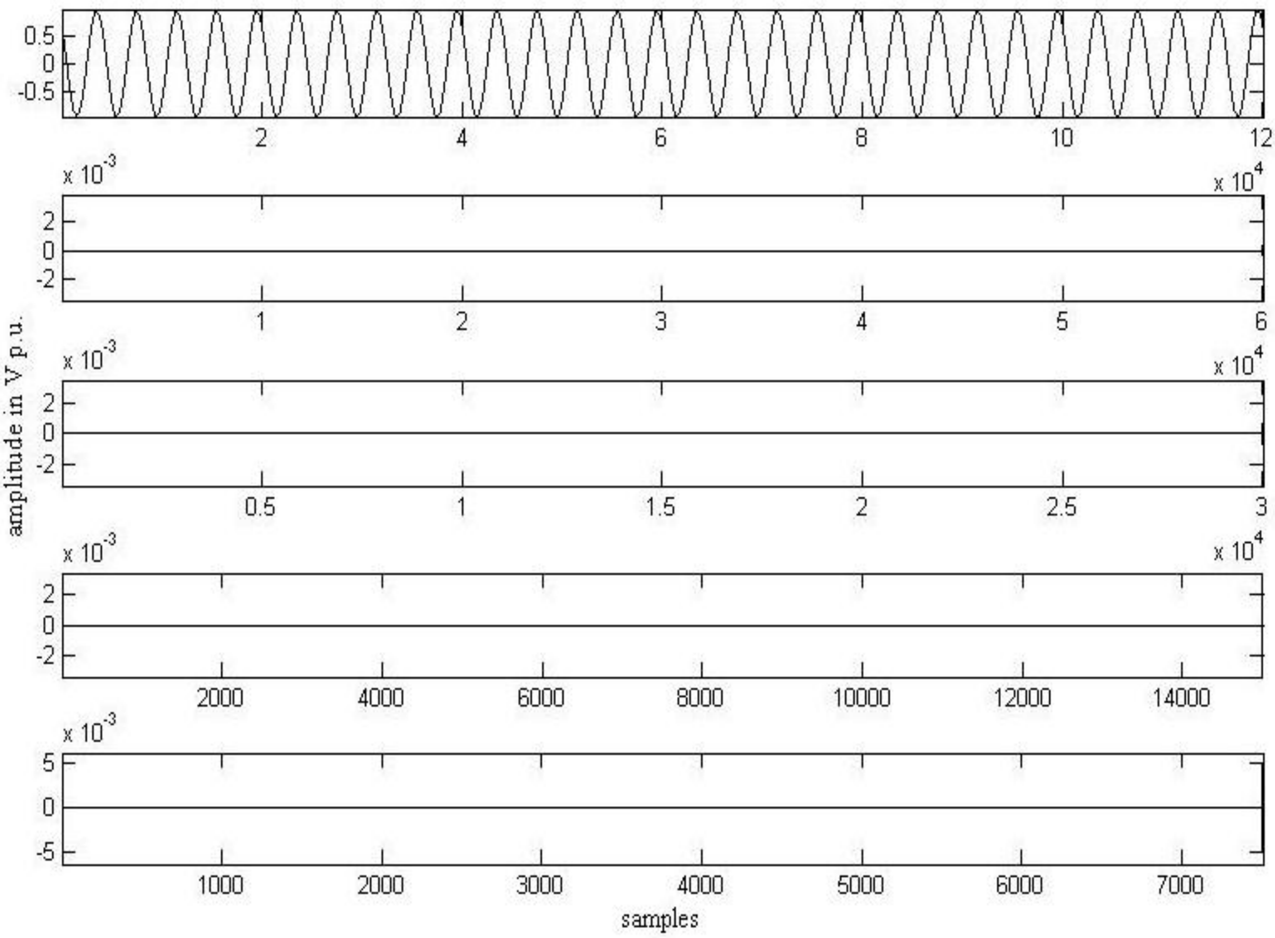

Fig. 2: Decomposition of pure sine wave using DWT

The vertical axis represents the amplitude of voltage signal in volt V p.u. (per unit) and similarly the horizontal axis presents the time (in second) in terms of samples. As it is distortion free signal so there is deviation in waveforms of the decomposition levels of DWT.

B. Pure Sinusoidal Wave with Sag

A pure sine wave signal with sag captured at PCC by changing the load is considered for analysed. The four finer decomposition levels of the DWT along with the original signal are presented in shown in Fig. 3. The decomposition levels show exact instant of occurrence of the disturbance. The disturbance is detected and localized using DWT decomposition. The start and end points of the disturbance are clearly identified even at the finer decomposition levels.

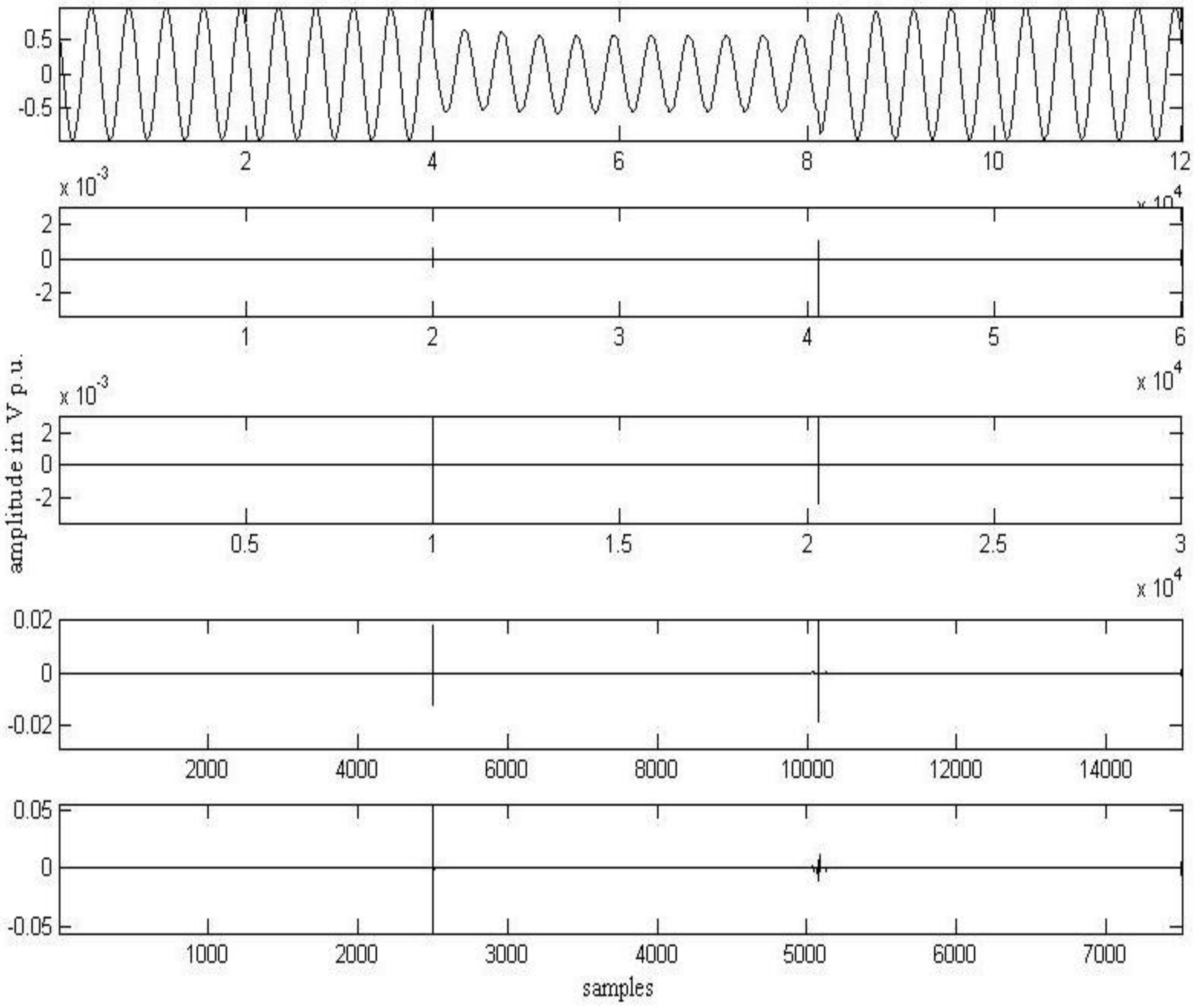

Fig. 3: Decomposition of pure sine wave with sag using DWT

C. Pure Sinusoidal Wave with Swell

Similarly, the swell in pure sine wave is detected and localized in the decomposed levels using DWT. The point of occurrence of the swell and also the duration can be easily identified in each decomposition levels. The swell in pure sine wave is detected and localized in the decomposed levels using DWT

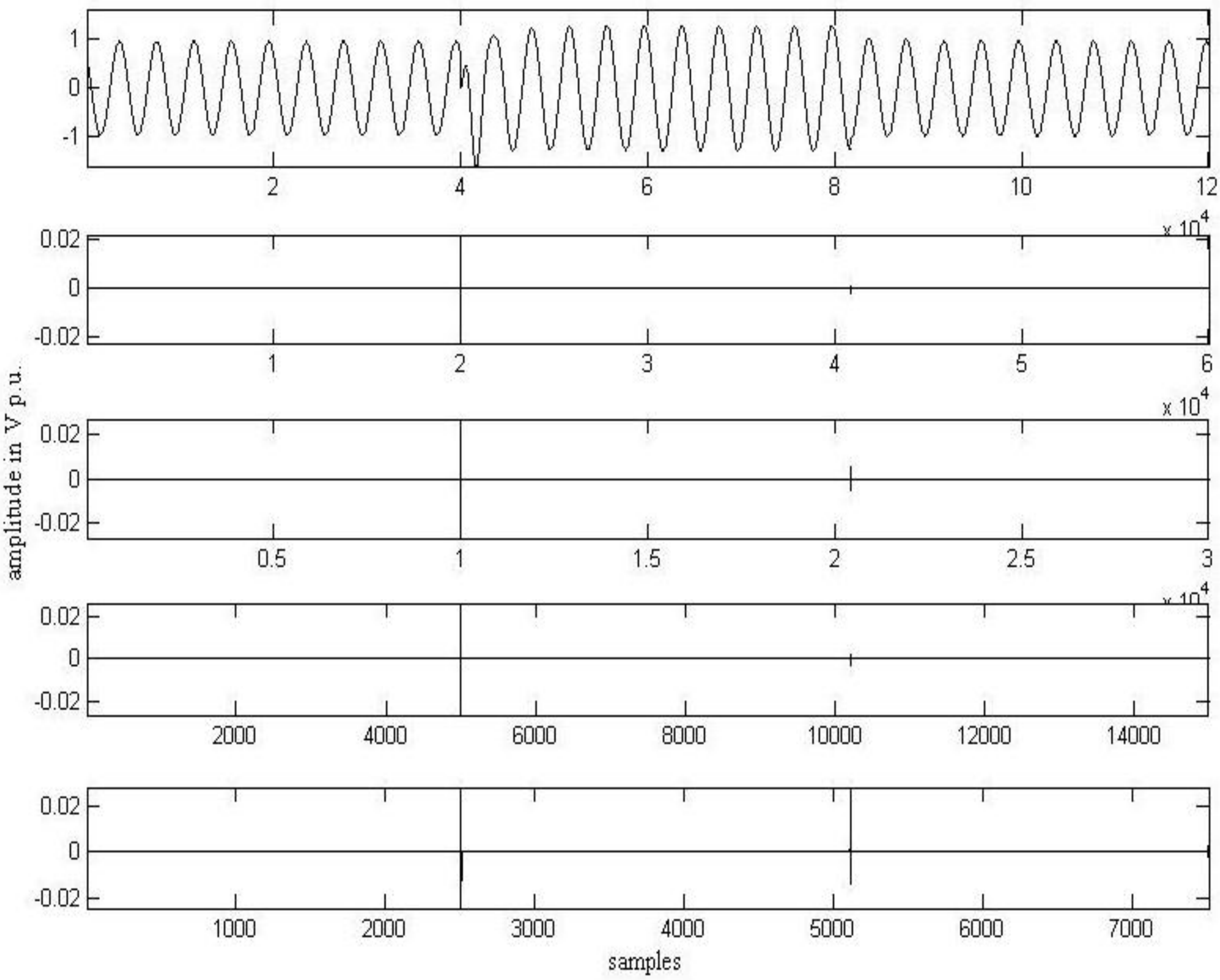

Fig. 4: Decomposition of pure sine wave with swell using DWT

From the Fig.2, Fig.3 and Fig.4, it can be observed, that as the pure sine wave is distortion free, so the decomposition level have no deviation or cut mark whereas the distorted signals have deviations in waveforms . Inception and end point of distortions are properly localized even at the finer decomposition levels.

V. CONCLUSION

The Wavelet Transform is a significant tool for the analysis in PQ environment disturbances. In this paper two distinctive PQ disturbances have been analysed. As a matter of first importance these disturbances are decomposed into different levels utilizing wavelet decomposition algorithm and the type of disturbance have been identified. This demonstrates that the wavelet transform as a signal handling device is very effective in analyzing the PQ disturbances. The WT is a frequency space approach where the signals are analyzed at various frequency determination levels.

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