Detection and Localization of Electrical Power Quality Disturbances

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***Abstract*—Power quality disturbance is an issue that is gaining the attention of researchers, electrical utilities and customers. For developing tools for power quality (PQ) analysis and diagnosis PQ data is required. Therefore the generation of the typical power quality disturbances by using the mathematical equations is presented in this paper. PQ signal analysis carried out using transformation techniques that have its own advantages and limitations. Wavelet transform is particularly useful in detecting discontinuities in signals, and this makes it appropriate for detection of disturbances in power quality. In this work, Mathematical models for various PQ signal disturbances are developed with the goal of detecting and localization them using wavelet transform. Various types of mother wavelets were used to process different power quality disturbance signals. The comparison results show clearly that PQ disturbances are detected and the exact location of the disturbance can also be found on the time scale.**

***Keywords*— PQ Disturbance Signal, Wavelet, Detection, MATLAB**

I. INTRODUCTION

The quality of electric power has become an important issue and wide spread use of sensitive electronic equipment, customers have become much more aware and sensitive to transient and other power abnormalities. In order to improve the power quality, the power disturbances should be monitored continuously [3].

Voltage levels, Harmonics, Flickering, and distortion of wave are the key parameters which decide the power quality. If these parameters are not healthy, then it is considered as poor quality of power supply. In order to improve electric power quality, the sources and causes of disturbances must be known before appropriate mitigating action can be taken and continuous recording of disturbance waveforms is necessary.

Wavelet Transform (WT) is a mathematical tool, which provides an automatic detection of Power Quality Disturbance (PQD) waveforms, especially using Daubechies family. Several types of Wavelets Network algorithms have been considered for detection of power quality problems [1].

The wavelet function is localized in time and frequency yielding wavelet coefficients at different scales. This gives the wavelet transform much greater compact support for analysis of signals with localized transient components arising in power quality disturbances manifested in voltage, current, or frequency deviations. Several types of wavelets have been considered [4] for detection, and localization of power quality problems as both time and frequency information are available by multiresolution analysis.

Wavelet Transform provides the time-scale analysis of the non-stationary signal[1][2]. It decomposes the signal to time scale representation rather than time-frequency representation. Wavelet transform (WT) expands a signal into several scales belonging to different frequency regions by using translation (shift in time) and dilation (compression in time) of a fixed wavelet function known as Mother Wavelet. Wavelet based signal processing technique is one of the new tools for power system transient analysis and power quality disturbance classification and also transmission line protection.

In this paper, the effectiveness of wavelet transform methods for analyzing different power quality events has been investigated. The starting time, end time and duration of power quality problem has been obtained. With the help of MATLAB the disturbances were introduced for analysis. With the aid of mother Wavelet such as Daubechies and haar, decomposition was done using MATLAB Wavelet Toolbox up to fourth level, according to the accuracy of information obtained. Finally the detection of all six types of disturbances was done.

II. POWER QUALITY DISTURBANCE CLASSES

There are various types of events that can degrade power quality, which makes the identification problems often elusive and difficult. In this paper detection algorithm was developed based on disturbance events from six major categories, which are as follow:

1. Sag / Undervoltage
2. Swell / Overvoltage
3. Waveform distortion
   (a) Harmonic
   (b) Harmonic with sag
   (c) Harmonic with swell
   (d) Notching
4. Transients
   (a) Oscillatory Transient
   (b) Impulsive Transient or Spike
5. Interruptions
6. Voltage fluctuations/Flicker

III. POWER QUALITY DISTURBANCE SIGNALS GENERATION

This section describes the mathematical model of generation of Power Quality Disturbance signals (PQD) in MATLAB environment. The primary objective of the system is to provide reference phase voltage waveforms, including special functions for generation of every possible PQD problem.

TABLE I
SIGNAL MODELS AND THEIR PARAMETERS [10]

PQ Distr-ubance	Model
Sine - wave	$x(t) = A\sin(\omega t)$ A=1.0
Sag	$x(t) = A\sin(\omega t)(1-\alpha(u(t-t_1)-u(t-t_2)))$ $t_1<t2$, $u(t)=1$, $t\geq 0$, $0.1\leq\alpha\leq 0.9$, $T\leq t2-t_1\leq 8T$
Swell	$x(t) = A\sin(\omega t)(1+\alpha(u(t-t_1)-u(t-t_2)))$ $t_1<t2$, $u(t)=1$, $t\geq 0$, $0.1\leq\alpha\leq 0.8$, $T\leq t_2-t_1\leq 8T$
Harm-onic	$x(t) = \alpha_1\sin(\omega t)+\alpha_3\sin(3\omega t)+\alpha_5\sin(5\omega t) + \alpha_7\sin(7\omega t)+\alpha_9\sin(9\omega t)$ $\alpha_1=1$, $0.06\leq\alpha_3\leq 0.6$, $0.02\leq\alpha_5\leq 0.2$, $0.008\leq\alpha_7\leq 0.08$, $0.005\leq\alpha_9\leq 0.05$,
Harm-onic with Sag	$x(t) = \left[\alpha_1\sin(\omega t)+\alpha_3\sin(3\omega t)+\alpha_5\sin(5\omega t)\right] \left[1-\alpha(u(t-t_1)-u(t-t_2))\right]$ $\alpha_1=1$, $0.06\leq\alpha_3\leq 0.6$, $0.02\leq\alpha_5\leq 0.2$, $0.1\leq\alpha\leq 0.9$, $T\leq t2-t_1\leq 9T$
Harm-onic with Swell	$x(t) = [\alpha_1\sin(\omega t)+\alpha_3\sin(3\omega t)+\alpha_5\sin(5\omega t)] [1+\alpha(u(t-t_1)-u(t-t_2))]$ $\alpha_1=1$, $0.06\leq\alpha_3\leq 0.6$, $0.02\leq\alpha_5\leq 0.2$, $0.1\leq\alpha\leq 0.9$, $T\leq t2-t_1\leq 9T$
Notch	$x(t) = \sin(\omega t) + sign(\sin(\omega t)) \left[\begin{array}{l}\sum_{n=1}^{i} k\times[u(t-(t_1+0.002n))- \\ u(t-(t_2+0.002n))]\end{array}\right]$ $0.1\leq k\leq 0.4$, $0.01T\leq t_2-t_1\leq 0.05T$, $t_2\geq 0$, $t_2\leq 0.5$
Oscill-atory Trans-ient	$x(t) = \sin(\omega t) + e^{((t_2-t)/\tau)\_(u(t-t_1)\_u(t-t_2))} \times\sin(2\pi f_n t)$ $0.1\leq\alpha\leq 0.9$, $0.5T\leq t2-t_1\leq 3T$, $300Hz\leq f_n\leq 900Hz$, $5ms\leq\tau\leq 40ms$
Impul-sive	$x(t) = \sin(\omega t) + sign(\sin(\omega t)) \left[\begin{array}{l}\sum_{n=1}^{i} k\times[u(t-(t_1+0.002n))- \\ u(t-(t_2+0.002n))]\end{array}\right]$ $0.1\leq k\leq 0.4$, $0.01T\leq t_2-t_1\leq 0.05T$, $t_2\geq 0$, $t_2\leq 0.5$
Interr-uption	$x(t) = \sin(\omega t)[1-\alpha(u(t-t_1)-u(t-t_2))]$ $0.9\leq\alpha\leq 1$, $T\leq t_2-t_1\leq 9T$
Fluct-uation	$x(t) = [1+\alpha\sin(b\omega t)]\sin(\omega t)$ $0.1\leq\alpha\leq 0.2$, $0.4\leq b\leq 0.6$
Flicker	$x(t) = A[1+\beta\sin(\gamma\omega t)]\sin(\omega t)$ $0.1\leq\beta\leq 0.2$, $0.1\leq\gamma\leq 0.2$

The system can be applied as a part of the procedures for verification testing and calibration of the instruments. This can also be applied as equipment developed for monitoring, measurement and software based processing of the basic PQ parameters, prescribed by the relevant quality standards. Power Quality disturbances (PQD) are studied in comparison to the normal sinusoidal signal. Each type of PQ disturbance is generated in MATLAB software using different parametric equations [7] [8] [9] [10]. Table 1 gives the signal generation models and their controlled parameters

Sag and swell events are modeled using step functions defined for periods between t_1 and t_2. Amplitude of step function is used to control the intensity of voltages for defining sag and swell. Harmonic signal consists of frequency components that are multiples of 1 KHz. In a PQ signal the disturbances in terms of harmonics will have more than three frequency components and are odd multiples of fundamental component. The odd harmonics also have voltage variations and thus affect the fundamental signal.

Parameters that define amplitudes of harmonic components given by α1, α2, α3 and α4 have variations from 0.02 to 0.6 and the square sum of all components should not exceed unit magnitude. These parameters are used to control the harmonic variation in a pure sine wave signal.

In signal disturbances that create exponential variations within a short duration of time interval are transients. Parameters such as α, w and K control the variations in transients in a given pure sine wave as shown in Table 1.

Transients occur for a short time interval, controlled by t_1 and t_2. During this time interval, the signal behaviours consists an exponential variation controlled by τ. Flicker is due to randomness in sag and swell affecting pure sine wave. Mathematical models for flicker are similar to sag and swell, but the duration of sag and swell is randomly added to the pure sine wave signal.

IV. DISCRETE WAVELET TRANSFORM

The Discrete Wavelet Transform (DWT), which is based on sub-band coding is found to yield a fast computation of Wavelet Transform. It is easy to implement and reduces the computation time and resources required. In the case of DWT, a time-scale representation of the digital signal is obtained using digital filtering techniques. The signal to be analyzed is passed through filters with different cutoff frequencies at different scales.

Filters are one of the most widely used signal processing functions. Wavelets can be realized by iteration of filters with rescaling. The resolution of the signal, which is a measure of the amount of detail information in the signal, is determined by the filtering operations, and the scale is determined by upsampling and downsampling (subsampling) operations[6].

The DWT is computed by successive lowpass and highpass filtering of the discrete time-domain signal as shown in Fig. 1. This is called the Mallat algorithm or Mallat-tree decomposition. Its significance is to connect the continuous-time mutiresolution to discrete-time filters. In the figure, the signal is denoted by the sequence x[n], where n is an integer.

The low pass filter is denoted by G_0 while the high pass filter is denoted by H_0. At each level, the high pass filter produces detail information, d[n], while the low pass filter associated with scaling function produces coarse approximations, a[n].

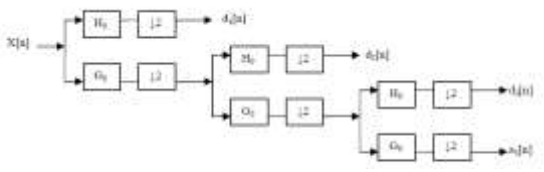


Fig. 1. Three-level Wavelet Decomposition Tree

At each decomposition level, the half band filters produce signals spanning only half the frequency band. This doubles the frequency resolution as the uncertainity in frequency is reduced by half.

In accordance with Nyquist's rule if the original signal has a highest frequency of ω, which requires a sampling frequency of 2ω radians, then it now has a highest frequency of ω/2 radians. It can now be sampled at a frequency of ω radians thus discarding half the samples with no loss of information. This decimation by 2 halves the time resolution as the entire signal is now represented by only half the number of samples. Thus, while the half band lowpass filtering removes half of the frequencies and halves the resolution, the decimation by 2 doubles the scale.

With this approach, the time resolution becomes arbitrarily good at high frequencies, while the frequency resolution becomes arbitrarily good at low frequencies. The time-frequency plane is thus resolved**.** The filtering and decimation process is continued until the desired level is reached. The maximum number of levels depends on the length of the signal. The DWT of the original signal is then obtained by concatenating all the coefficients, a[n] and d[n], starting from the last level of decomposition.

In this paper the wavelet-multi-resolution analysis is presented as a new tool for extracting the distortion features. The MRA is a tool that utilizes the DWT to represent the time domain signal f (t). It can be mapped into the wavelet domain and represented at different resolution levels in terms of the following expansion coefficients:

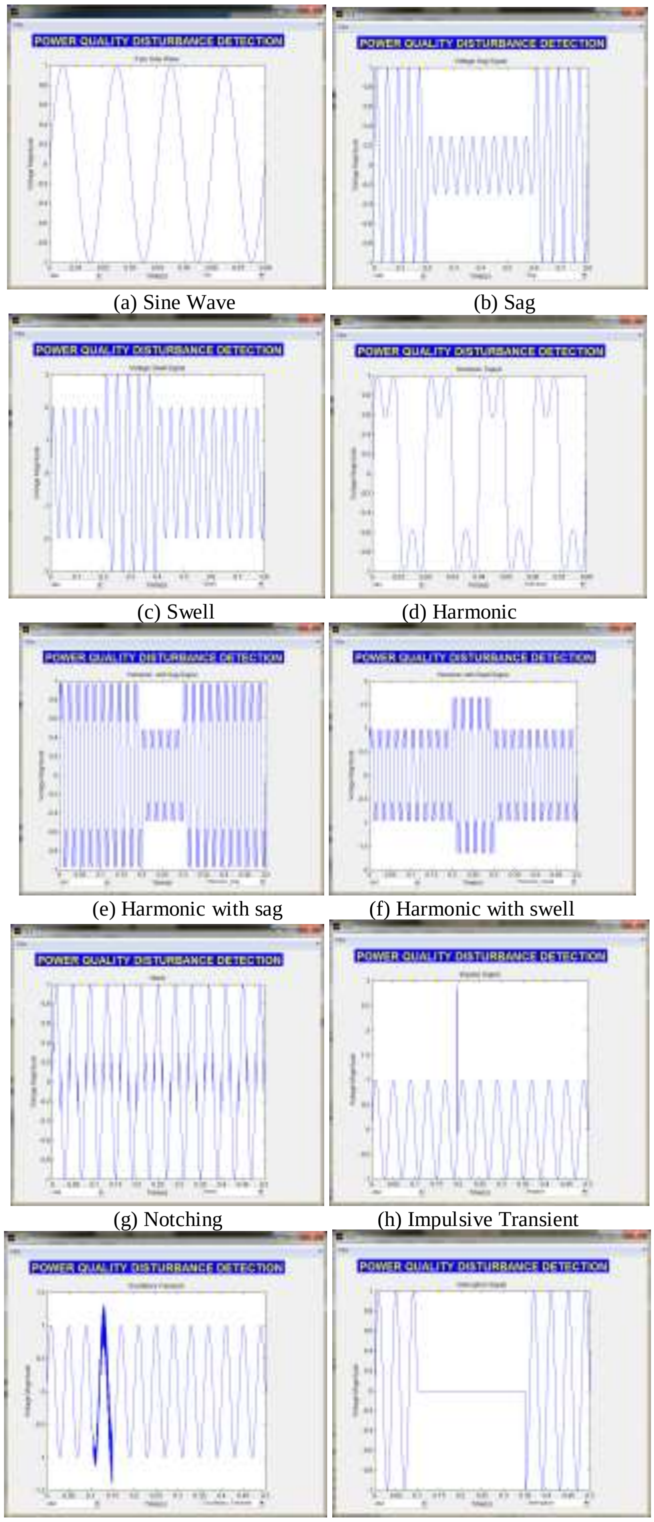
$$C_{signal} = [C_n|\ d_n||\ d_{n-1}||d_{n-2}|\text{---}\ |d_1|\ ] \qquad (1)$$

where, n is number of level, d represent the detail coefficients at different resolution levels, and C_n, represents the last approximate coefficients. Wavelet transform can be achieved by convolution and decimation.

V. Simulation Results

In this paper, there are two portions of simulation results. They are power quality disturbance signals generation and detection of disturbance. Firstly, PQ disturbance signals are generated in MATLAB based on the mathematical model described in Table 1.

One pure sine-wave signal (fundamental frequency = 50 Hz, amplitude 1, sampling frequency 12.8 kHz) and eleven PQ disturbance signals are generated. Fig. 2 shows the generated PQ disturbance signals.



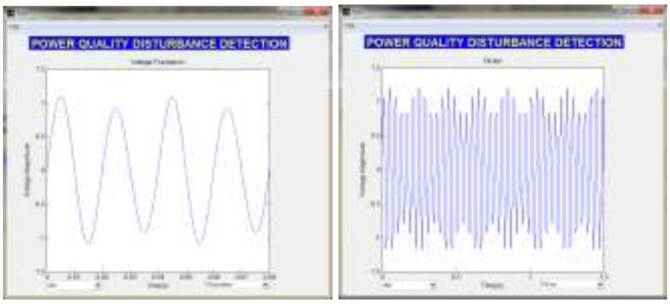
(a) Sine Wave (b) Sag

(c) Swell (d) Harmonic

(e) Harmonic with sag (f) Harmonic with swell

(g) Notching (h) Impulsive Transient

(i) Oscillatory Transient (j) Interruptions

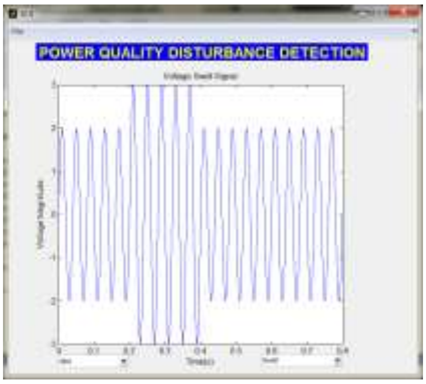


(k) Voltage fluctuations (l) Flicker

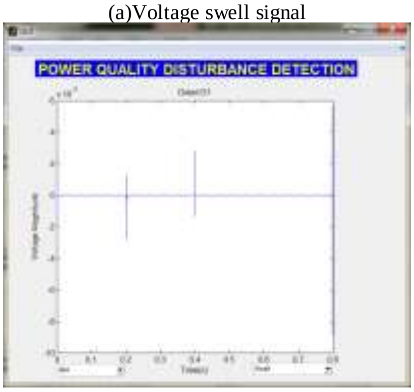
Fig. 2. Generated PQ disturbance signals

The generated PQ signals were simulated and processed with wavelet toolbox in MATLAB environment using wavelet db4 at level 4. A four-level decomposition of the distorted signal is carried out using mother wavelet db4. The following series of diagrams illustrate the first to fourth level details of application of wavelet transform in processing signals for different types of power quality disturbances.

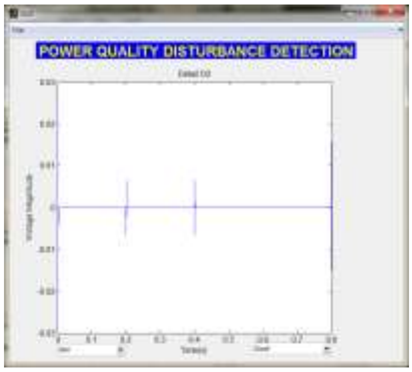
Fig. 3 shows the first four detailed versions of four-level decomposition of a voltage swell signal. Any changes in the pattern of signal can be detected and localized at the finer resolution levels. The detailed version of four-level is detected and localized at first finer resolution levels. The starting time of the swell is 0.2 s and the ending time is 0.4s. The duration of swell phenomenon can be detected and localized in the first detail level.



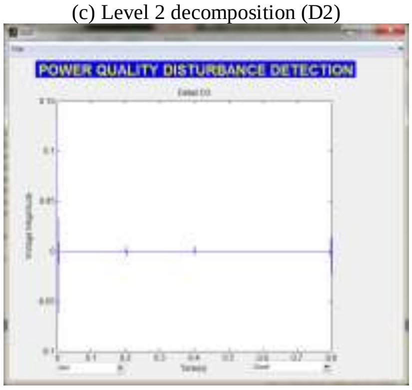
(a)Voltage swell signal



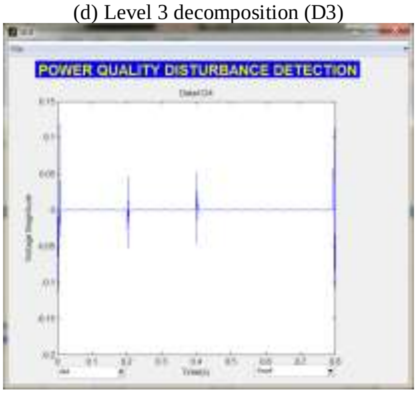
(b) Level 1 decomposition (D1)



(c) Level 2 decomposition (D2)



(d) Level 3 decomposition (D3)



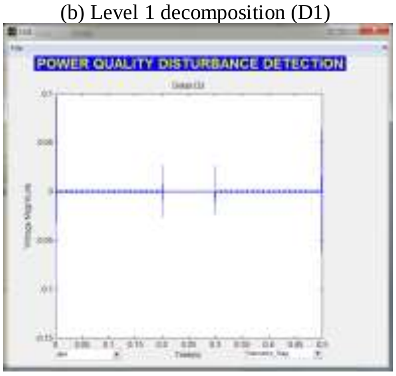
(e) Level 4 decomposition (D4)

Fig. 3. Detection of Voltage Swell Disturbance

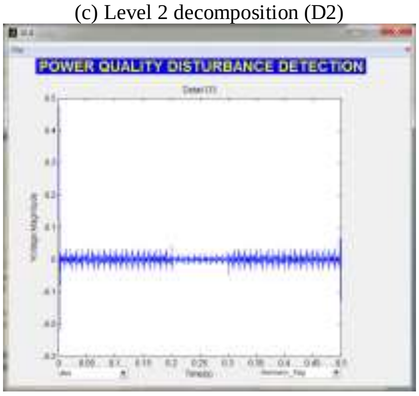
Fig. 4 describes the voltage signal having harmonics with sag and four detail levels of MRA decomposition respectively.

(a) Harmonic with Sag

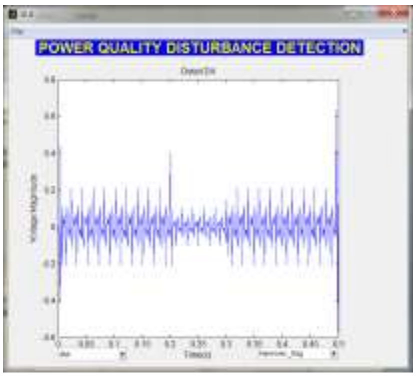
(b) Level 1 decomposition (D1)



(c) Level 2 decomposition (D2)



(d) Level 3 decomposition (D3)



(e) Level 4 decomposition (D4)

Fig. 4. Detection of voltage harmonics with sag disturbance

Fig. 5 illustrates the original signal, four-level decomposition of high frequency transient.

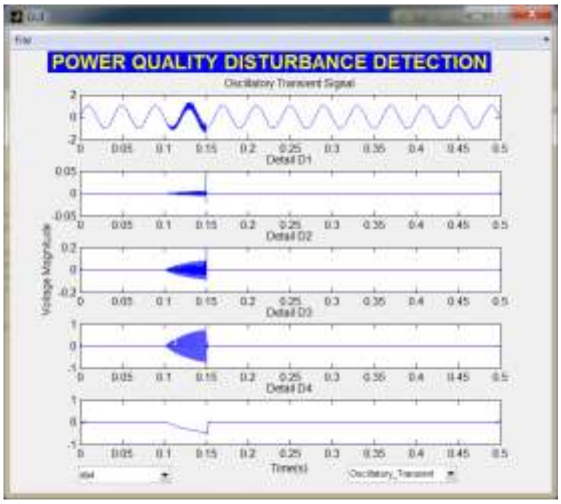


Fig. 5. Detection of oscillatory transient disturbance

An impulse case of signal with four-level decomposition is described in Fig. 6.

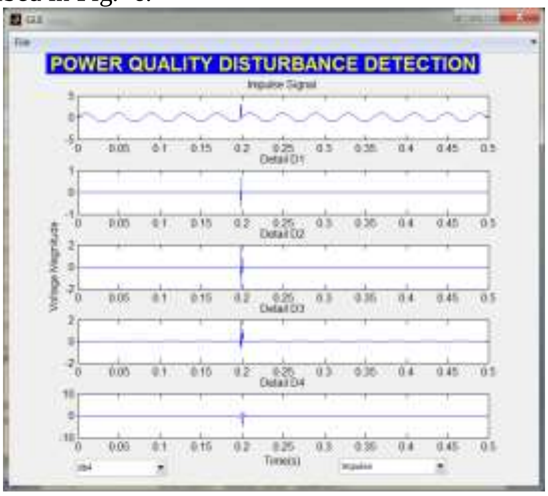


Fig. 6. Detection of impulse disturbance

Fig. 7 illustrates MRA decomposition and detailed levels of voltage Notching.

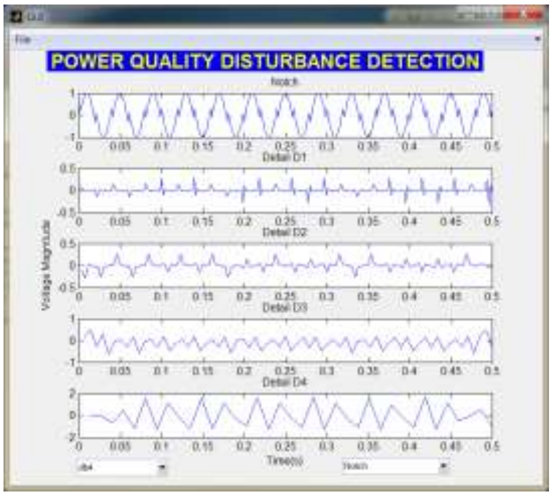


Fig. 7. Detection of notching disturbance

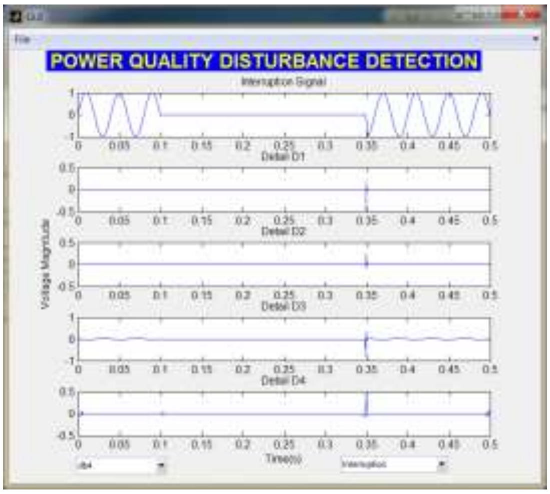


Fig. 8. Detection of interruption disturbance

In the above Fig. 8, the starting time of interruption can't be detected in the detail level 1 to 3. The duration of disturbance can be detected and localized in the fourth detail level clearly.

VI. CONCLUSION

Various forms of electrical power quality disturbances with the aim of detecting them using wavelet transform approach has been generated. Wavelet transform is useful in the identification of variation or discontinuities in signals. In this paper, wavelet transform is proposed to identify the power quality disturbance at its instance of occurrence. Power quality disturbances like sag, swell, harmonic, interruption, transience and harmonics are considered and are decomposed up to 4 levels using Db4 wavelet. For some disturbances it is sufficient to have only second or third level of decomposition. The exact location of the disturbance can also be found on the time scale. The wavelet MRA can effectively detect any type of PQD at a faster rate.

REFERENCES

[1] M. Sushama, Dr. G. Tulasi Ram Das, Dr A. Jaya Laxmi (2007), "Mitigation of Voltage Sags with Dynamic Voltage Restorer Using Wavelets" Presented at the international Conference "RACE2007" during MAR 22nd-24th.

[2] C. Sidney Bums, Ramesh A. Gopinath Haitao Guo, "Introduction to Wavelets and Wavelet Transforms", (1998).

[3] GAOUDA, A. M.—SALAMA, M. M. A.—SULTAN, M. R.—CHIKHANI, A. Y. : Application of Multiresolution Signal Decomposition For Monitoring Short-Duration Variations in Distribution Systems, IEEE Transactions on Power Delivery 15 No.2 (Oct 2000), 478-485.

[4] HUANG, S. J.—HSIEH, C. T.—HUANG, C. L. : Application of Wavelets to Classify Power System Disturbances, Electric Power System Research 47 No. 2 (Oct 1998), 87-93.

[5] GAOUDA, A. M.—SALAMA, M. M. A.—SULTAN, M. R.—CHIKHANI, A. Y. : Power Quality Detection and Classification UsingWavelet-Multiresolution Signal Decomposition, IEEE Transactions on PowerDelivery 14 No. 4 (Oct 1999), 1469-1476.

[6] Hannu Olkkonen, "Discrete Wavelet Transforms - Biomedical Applications", InTech Janeza Trdine 9, 51000 Rijeka, Croatia, 2011.

[7] Nermeen Talat, W.R.Ibrahim,George L.Kusic, "New Technique for Categorization of Power Quality Disturbances", Power Quality and Supply Reliability Conference, 2008, IEEE, pp: 11-16.

[8] Zhi-yong; L I.and; and Wei-lin,WU. "Classification of power quality combined disturbances based on phase space reconstruction and support vector machines". Journal of Zhejiang University SCIENCE A, 2008,Vol. 9, Issue:2, pp:173-181

[9] B.K.Panigrahi, V.R.Pandi,:„Optimal feature selection for classification of power quality disturbances using wavelet packet-based fuzzy k-nearest neighbour algorithm." IET Gener.Transm. Distrib., 2009,Vol. 3, Issue. 3, pp: 296-306

[10] Subhamita Roy and Sudipta Nath, "Classification of Power Quality Disturbances using Features of Signals". International Journal of Scientific and Research Publications, Volume 2, Issue 11, November 2012, pp:4