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Detection And Classification Of Power Quality Disturbances Using Discrete Wavelet Transform And Energy Entropy

[1]Suraj Kumar, [2]Dr. Tanuj Manglani
[1]Student, [2]Professor
[1]Yagyavalkya Institute of Technology, Jaipur,
[2]Yagyavalkya Institute of Technology, Jaipur

Abstract - **At present scenario, most of the devices in the electrical system show non linear characteristics which are responsible for generating disturbances which results in poor power quality. Poor power quality affects the performance of both the load side equipments as well as the power network equipments. Therefore, detection and classification of these disturbances are required distortions so as to provide a good power quality in the power system. For detection of PQ disturbances, discrete wavelet transforms plots up to the fourth level of decomposition of the voltage signal with PQ disturbance. The feature extraction of discrete wavelet transform coefficients are calculated and analyzed for classification of PQ disturbances. The proposed approach was implemented with the MATLAB codes.**

keywords - **DWT, energy entropy, PQ disturbances, power quality, detection of faults**

I. INTRODUCTION

Power quality is an important term in power system engineering which affects the power flow in the electrical system as it affects the performance of both the load side equipments as well as the power network equipments. Ideally, a good power supply must have pure sinusoidal wave shape without any disturbance or distortions and it must be within the voltage and frequency tolerances. At present scenario, various power electronic devices are used in the electrical system. These devices show non linear characteristics which are responsible for generating distortions and disturbances like Sag, Swell, Harmonic, Interruptions etc. These distortions in electrical power result in poor power quality. These distortions are responsible for the increment of power losses and also affect the performance of the system. Hence, it is required to detect and classify the distortions so as to provide a good power quality in the power system [1]. In the presented work, an algorithm is proposed which is based on discrete wavelet transform (DWT) which is used for the detection and classification of power quality disturbances. The proposed algorithm is implemented for the analysis of pure sine wave, voltage sag, voltage swell, interruption & harmonics.

II. DISCRETE WAVELET TRANSFORM

Wavelet transform has the ability to vary the window size in proportion to the different time-frequency resolution in the time-frequency plane. The wavelet's basic functions are called the mother wavelet, which can be stretched or compressed in the analysis windows [2]. This helps to isolate signal discontinuities and therefore to analyze the signal on various scales. A wavelet is a rapidly decaying wave like oscillation which has zero mean. A wavelet exits for a limited duration, unlike the sinusoidal wave that extends to infinity. Wavelets are available in different sizes and shapes. However, according to IEEE standards, Daubechies wavelet transformation delivers more accurate results than others in the event of transient power system faults. WT first breaks the signals down into frequency bands and analyzes them in time. Two major concepts are Scaling & Shifting in a wavelet. Discrete wavelets cannot be scaled and translated continuously, but can only be scaled and translated in discrete steps [3]. The transform output is the same number of coefficients as the input signal length. This therefore reduces memory and time. A DWT sample can be obtained by replacing $a = a^m$ and $b = n\ a^m b$, where m and n are the integers that represent the set of discrete scaling and shifting or translations. Discrete wavelet transform (DWT) is carried out using a multi resolution analysis (MRA) filter bank technique [4]. In MRA, a signal is filtered with a high-pass and low-pass filter to yield low-pass and high-pass sub banks, followed by the down sampling of two which produces half of the high and low-frequency input data point. High-pass filter yields high - frequency components called detailed coefficients (cD), while low-pass filter yields low - frequency components called approximation coefficients (cA) [5].

III. ENERGY EXTRACTION USING DWT

The detailed coefficients of disturbances have significant information of the signal and hence, this can be used to classify the PQ disturbances. Parseval's principal can be used in DWT to extract the total energy of approximated coefficient and detailed coefficients of the decomposed signal. and it is given by [6]:

$$ED_i = \sum_{J=1}^{N} \left|D_{i,j}\right|^2 \qquad (1)$$

$$EA_i = \sum_{J=1}^{N} \left|A_{i,j}\right|^2 \qquad (2)$$

where, *i* and *N* are the wavelet decomposition level and the number of coefficients of the detailed signal at each decomposition level respectively. EDi and EAi are the energies of the detailed coefficients & approximate coefficients at level i respectively.

IV. PROPOSED METHODOLOGY

Methodology adopted for the detection and classification of the single stage PQ disturbances is as follows:

- PQ disturbances like pure sine wave, sag, swell, harmonics and momentary interruption have been generated by mathematical models reported in [61-62].
- Using discrete wavelet transform, the single stage PQ disturbance signals were decomposed by means of a discrete wavelet transform (DWT) up to the level four.
- Several plots were obtained, like the approximation coefficient at the fourth decomposition level, the detail coefficient at the fourth decomposition level, the detail coefficient at the third decomposition level, the detail coefficient at the second decomposition level and the detail coefficient at the first decomposition level.
- The patterns of the above plots have been analyzed, which helps to detect the various Power Quality Disturbances.
- Energy Entropy of decomposed PQ disturbance signal is calculated for classification purpose.

V. SIMULATION RESULTS OF PQ DISTURBANCES

A) Detection of PQ disturbances

Voltage signal along with various disturbances is decomposed by DWT up to level four of decomposition with db4 as mother wavelet as approximation coefficient cA4, detail coefficient cD4, cD3, cD2, cD1 is shown in Fig. 5.1 to 5.5 as (b), (c), (d), (e) , (f) respectively.

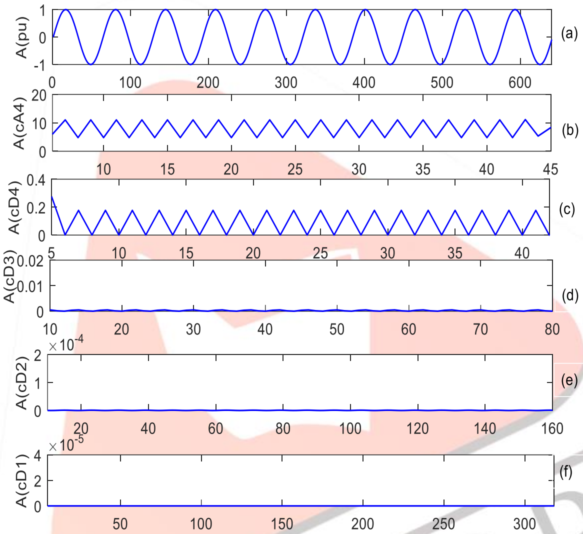

Fig. 1. Wavelet transform based decomposition of voltage signal of pure sine wave

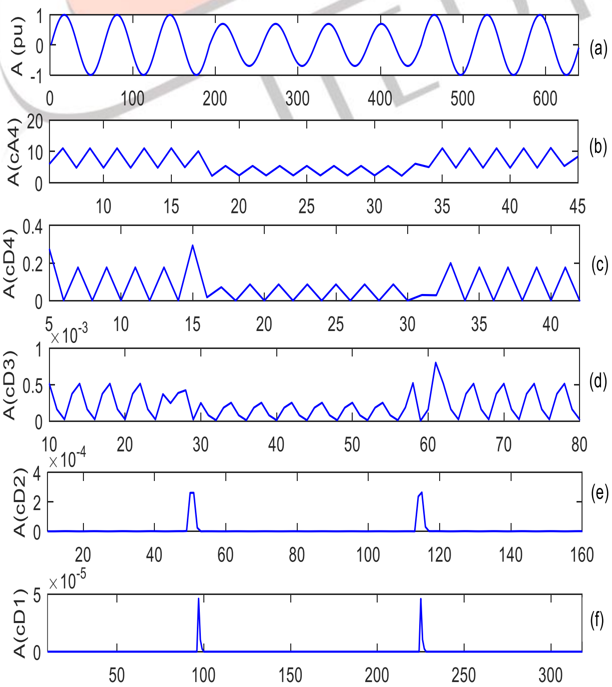

Fig.2. Wavelet transform based decomposition of voltage signal with voltage sag

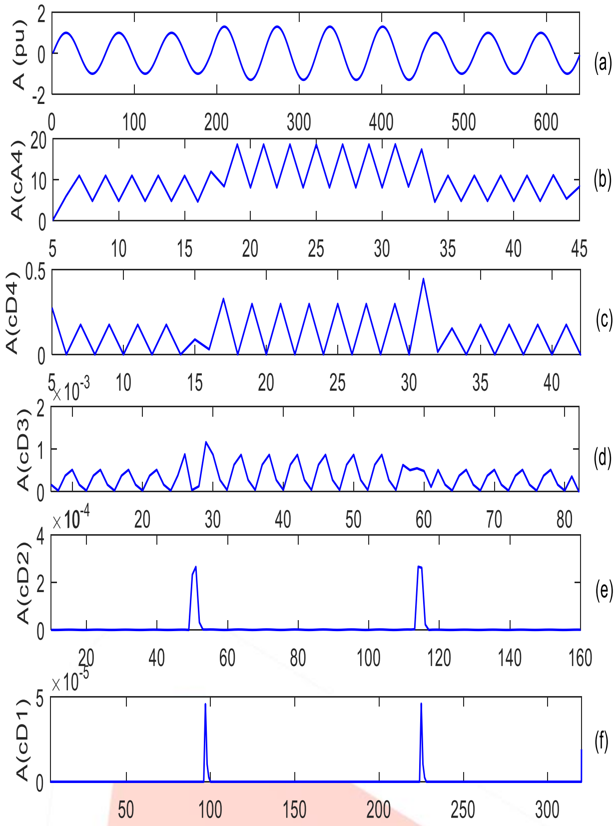

Fig. 3. Wavelet transform based decomposition of voltage signal with voltage swell

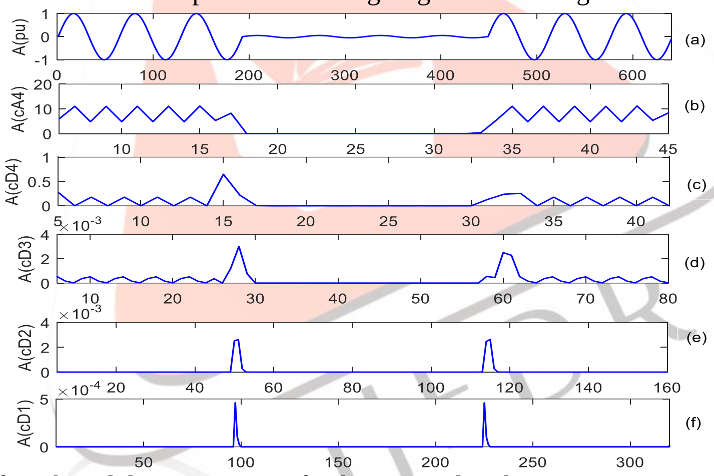

Fig. 4. Wavelet transform based decomposition of voltage signal with momentary interruption

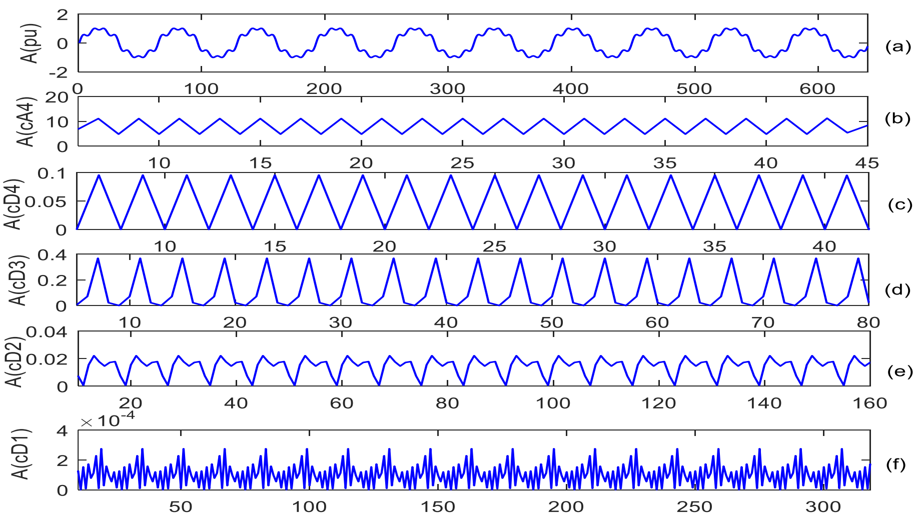

Fig. 5. Wavelet transform based decomposition of voltage signal with harmonics

No disturbance is examined in cD1, cD2 and cD3 in Fig. 1 (f),(e), (d) and hence, it is detected as pure sine wave. It is examined from cD1 of Fig. 2 (f) there were high magnitude peaks by the time of start and end of the sag in signal. These high magnitude peaks help to locate the voltage sag. It is examined from cD2 in Fig. 2 (e) there was also some high magnitude peaks in the voltage signal at the start and end of the sag. The magnitude of cD4 and cD3 reduces by the time of the voltage sag as seen in Fig. 2 (c) and (d). This reduced magnitude helps to identify the sag in voltage signal. It is examined from cD1 of Fig. 3 (f) there were high magnitude peaks by the time of start and end of the swell in signal. It is examined from cD2 in Fig. 3 (e) there was also some high magnitude peaks in the voltage signal at the start and end of the swell. It is examined from cD1 of Fig. 4 (f) there were high magnitude peaks by the time of start and end of the momentary interruption in signal. These high magnitude peaks help to locate the momentary interruption. The magnitude cD4 and cD3 reduces below 10% to the utmost magnitude and decreases nearly to zero by the time momentary interruption as in Fig. 4 (c) and (d). This reduced magnitude below 10% of utmost magnitude helps to identify the momentary interruption in signal. It is examined from the cD1 of Fig. 5 (f) there were regular patterns of the small magnitude peaks representing the occurrence of the harmonics. It is also examined from the cD2 in Fig. 5 (e) that there was also regular pattern of the peaks with compressed tops showing the occurrence of harmonics in the signal. The ripples of high magnitude monitored in cD4 and cD3 in Fig. 5 (c) and (d) also shows the occurrence of the harmonics in signal. The harmonics present in the voltage signal was not detected in cA4 as in Fig. 5 (b).

B) Classification of PQ Disturbances

Energies extracted from detailed coefficients of disturbances can be used for the classification purposes. Signal is decomposed up to ten levels in order to examine the feature vectors for each disturbance. Parseval's principal [6] can be used in DWT to extract the total energy of detailed coefficients of the decomposed signal. Table I shows energy of detailed coefficients up to ten levels for single stage power quality disturbances.

TABLE I
ENERGY CONTENT IN PQ DISTURBANCES

PQ EVENTS	Ed1	Ed2	Ed3	Ed4	Ed5	Ed6	Ed7	Ed8	Ed9	Ed10
Pure Sine Wave	0.0002	0.004	0.0416	0.923	6.272	62.529	0.078	0.112	0.516	0.405
Sag	0.0002	0.004	0.0441	0.922	6.026	60.603	0.087	0.171	0.532	0.45
Swell	0.0002	0.003	0.0389	0.949	6.554	64.679	0.089	0.078	0.499	0.365
Harmonics	0.0055	0.312	1.2047	0.342	3.976	39.69	0.107	0.209	0.985	0.766
Interruption	0.0004	0.005	0.0478	1.026	5.735	58.121	0.191	0.382	0.554	0.549

For classification of PQ disturbances, Average energy & percentage average energy entropy (PAEE) of detailed coefficients are calculated and shown in table II. Percentage average energy entropy is the entropy difference of average energy distribution during PQ disturbances and pure sine wave and is given by,

$$\%PAEE = \frac{W_{NS} - W_{DS}}{W_{DS}} * 100\% \qquad (3)$$

Where, W_{NS} is the average energy distribution of pure sine wave, W_{DS} is the average energy distribution of PQ disturbance at all decomposition levels.

TABLE II
AVERAGE ENERGY CONTENT IN DETAILED COEFFICEINTS OF DWT

PQ EVENTS	Average Energy of DWTC	% AEE of DWTC
Pure Sine Wave	7.088052118	0
Sag	6.883869031	-2.966
Swell	7.325449003	3.24
Harmonics	4.759799448	-48.914
Interruption	6.661100014	-6.409

Variation in average energy distribution of detailed coefficients of all disturbances is shown in Fig. 6 & with the help of this PQ disturbances can easily be classified. Also, a bar chart of PQ disturbances based on percentage average energy entropy of DWTC is shown in Fig. 7 & it can easily be observed that all PQ disturbances have different percentage average energy entropy which is quite fair for classification purpose. Hence, PQ disturbances can easily be distinguished and classified by average energy distribution of DWTC and percentage average energy entropy of DWTC.

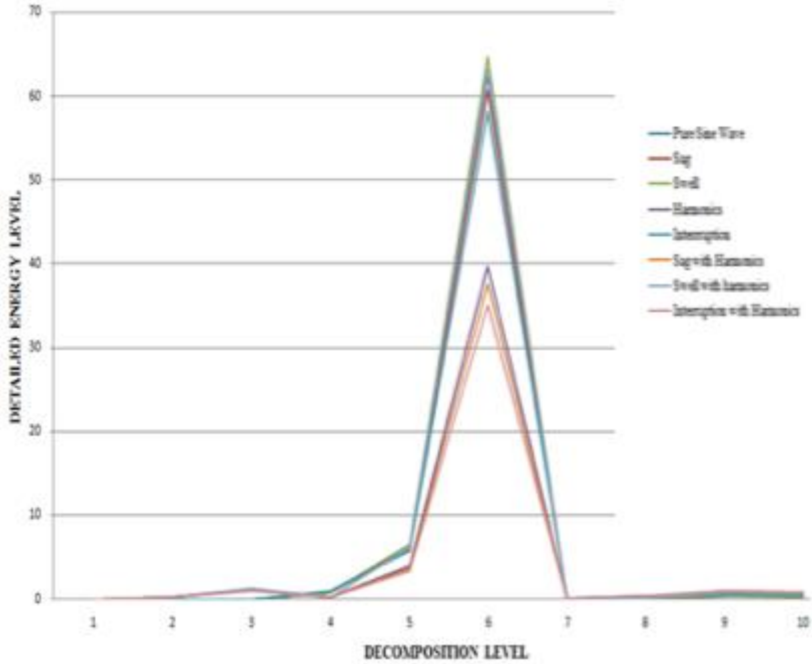

Fig. 6. Comparison Curve of Detailed Energy Level of various PQ Disturbances

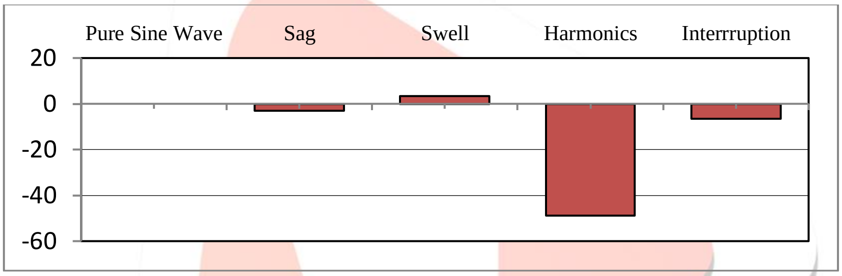

Fig. 7. Bar chart for classification of PQ events using PAEE

VI. CONCLUSIONS

In MATLAB, single stage power quality disturbances in one stage were generated. The single stage power quality disturbances examined in this study include pure sine wave, voltage sag, voltage swell, harmonics & momentary interruption. The voltage signals with these disturbances were decomposed using the DWT and analyzed up to level four of decomposition. The detail coefficients and approximation coefficients of the plots are used to detect single stage PQ disturbances. Classification of PQ disturbances is done on the basis of feature extraction. Energy of detailed coefficients of DWT is extracted as one of the features to classify PQ disturbances. Disturbance signal is decomposed up to ten levels in order to examine the energy distribution for each disturbance. Average Energy and Percentage average energy entropy of energy of detailed coefficients up to ten levels is calculated and analyzed for the classification of power quality disturbances. From average energy distribution curve, it can be observed that PQ disturbances have different average energy level which is used to classify the disturbances. Also, it can be observed from bar chart prepared using PAEE that each PQ disturbance has different bar size which clearly classifies PQ disturbances. Hence, the proposed algorithm based on the discrete wavelet transformation and energy feature extraction was concluded to be effective in recognizing and classifying the single stage as well as complex power quality disturbances.

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