International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 06 | June 2020 www.irjet.net p-ISSN: 2395-0072

Investigation of Complex Power Quality Disturbances using Discrete Wavelet Transform

Vishna Ram[1], M. K. Bhaskar[2], Surendra Singh[3] and Dharmendra Jain[4]

[1]ME Scholar, [2]Professor, [3&4]PhD Scholar
Department of Electrical Engineering, MBM Engineering College, Jai Narayan Vyas University, Jodhpur, Rajasthan, India.

Abstract – *This research work aims to investigate power quality disturbances using discrete wavelet transform technique. MATLAB is used for generation of power quality disturbances using mathematical relations as per IEEE Standard-1159. The investigated power quality disturbances are single stage as well as complex power quality disturbances. These power quality signals are decomposed using discrete wavelet transform with db4 as mother wavelet up to level 4 of decomposition. The plots related to detail coefficients and approximation coefficients are analyzed for detection of PQ disturbances. Power quality disturbance present in the signals are detected and classified using the features of these plots.*

Key Words: **IEEE, Single Stage Power Quality disturbances, Complex power quality disturbance, discrete wavelet transform, power quality**.

1. INTRODUCTION

The considerable changes in a business environment have increased the use of sensitive electronic components, computers, programmable logic controllers, protection and relaying equipments, which have increased the power consumption [1]. The simultaneous occurrence of two or more than two of these disturbances is known as complex power quality disturbance. These disturbances causes the problems such as failure of equipments, short life time of the equipments, malfunction of equipments, instability of the system, reduced efficiency of equipments etc. [2]. Increasing consumer expectation with the requirement of green supply around the globe, where integration of renewable energy sources to the distribution grid is the focus area of smart grid, Electrical Power Systems are expected to deliver power supply continuously at high quality to the consumers. Economy of ant country suffers with huge losses when there are voltage or current abnormalities present in the power delivery. Any deviation / disturbance manifested in the voltage, current and frequency from the standard rating is treated as power quality (PQ) problem that results in failure or malfunctioning of electrical/electronic equipments [3]. Power quality disturbances and resulting problems are due to increasing use of the solid state switching devices, power electronically switched loads, non-linear loads, lighting controls, unbalanced power systems, industrial plant rectifiers and inverters as well as data processing equipments [4]. Therefore, power quality needs to be monitored and improved. The advanced signal processing and Artificial Intelligence techniques are proposed for recognition of Power Quality Disturbances [5]. The mathematical and signal processing techniques have been utilized for the detection and classification of single stage as well as complex PQ disturbances. An approach for the recognition of PQ disturbances in the power system using wavelet transform and radial basis function neural network (RBFNN) has been reported in [6]. Mahela *et al.* [7], presented a comprehensive review of various signal processing and artificial intelligent techniques utilized for the automatic recognition of PQ disturbances as well as effect of noise on the detection and classification of these events. Commonly used PQ detection techniques include Fourier transform, Kalman filter, wavelet transform, S-transform, Hilbert Huang transform, Gabor transforms etc. The artificial intelligent tools used for the classification of PQ disturbances are support vector machine, artificial neural network, expert systems, Fuzzy logic, k-nearest neighbor etc. [8]. One variant of Fourier Transform, the Short Time Fourier Transform (STFT) divides the signal into small segments, where these signal segments can be assumed to be stationary and utilized for detection of PQ disturbance [9].

2. SIGNALS GENERATION OF PQ DISTURBANCES

The single stage power quality disturbances are generated using the mathematical relations reported in [10]. The generated single stage power quality disturbances include pure sine wave, voltage sag, voltage swell, momentary interruption, oscillatory transient, impulsive transient and notch. The discrete wavelet transform based plots of pure sine wave are used as the reference curves for the detection of PQ disturbance present in the signal. Single stage Power Quality Disturbances has been investigated in [11] & [12]. The complex power quality disturbances are generated using the various combinations of the above mentioned single stage PQ disturbances. The generated complex power quality disturbances include (voltage sag + harmonics), (voltage swell + harmonics), (momentary interruption + harmonics), (oscillatory transient + voltage sag), (impulsive transient + voltage sag), (oscillatory transient + voltage sag + harmonics), (impulsive transient + voltage sag + harmonics), and (Oscillatory Transient + Impulsive Transient + Voltage sag + Harmonics). The discrete wavelet transform based plots of pure sine wave are used as the reference curves for the detection of PQ disturbance present in signal.

3. ALGORITHM STEPS TO BE IMPLEMENTED

Discrete wavelet transform with db4 as mother wavelet is used for decomposing power quality disturbances up to third level of decomposition. The plots of detail coefficients at all the three levels and approximation coefficient at the third level of decomposition are obtained for all the investigated PQ disturbances. Performance of proposed algorithm has been compared with the techniques reported in literature to validate the effectiveness of the proposed algorithm.

4. SIMULATION RESULTS

The results related to detection and classification of complex power quality disturbances using discrete wavelet transform are presented in this section. The voltage signal with complex power quality disturbances is decomposed using discrete wavelet transform with db4 as mother wavelet up to third level of decomposition. The detail coefficients at all the levels and approximation coefficient at third level are used for recognition of complex power quality disturbances. The numbers of power quality disturbances available simultaneously in the voltage signal indicate the degree of complexity. The discrete wavelet transform based plots related to pure sine wave are used as reference curves for the detection of complex power quality disturbances.

4.1 PURE SINUSOIDAL VOLTAGE SIGNAL

The pure sinusoidal voltage signal is decomposed up to level 3 using DWT with db4 as mother wavelet. The plots of pure sine wave, approximation coefficient (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 1 (a), (b), (c), (d) and (e) respectively. It can be observed that significant changes are not detected in the plots related to the detail coefficients whereas the fundamental frequency component appears in the approximation coefficient at level 3. These plots can be used as the reference plots for the detection of PQ disturbances associated with the voltage signal.

4.2 VOLTAGE SAG WITH HARMONICS

The voltage signal with voltage sag and harmonics has the degree two complexities. This signal is decomposed up to level 3 using DWT with db4 as mother wavelet. The plots of voltage signal, approximation coefficient (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 2 (a), (b), (c), (d) and (e) respectively. The high magnitude peaks at sample numbers 100 and 230 indicate the initiation and end of voltage sag. The decrease in magnitude of all the plots related to the detail and approximation coefficients indicate the presence of voltage sag. Presence of continuous ripples in the detail coefficients cD2 and cD3 detects the harmonic components present in the voltage signal.

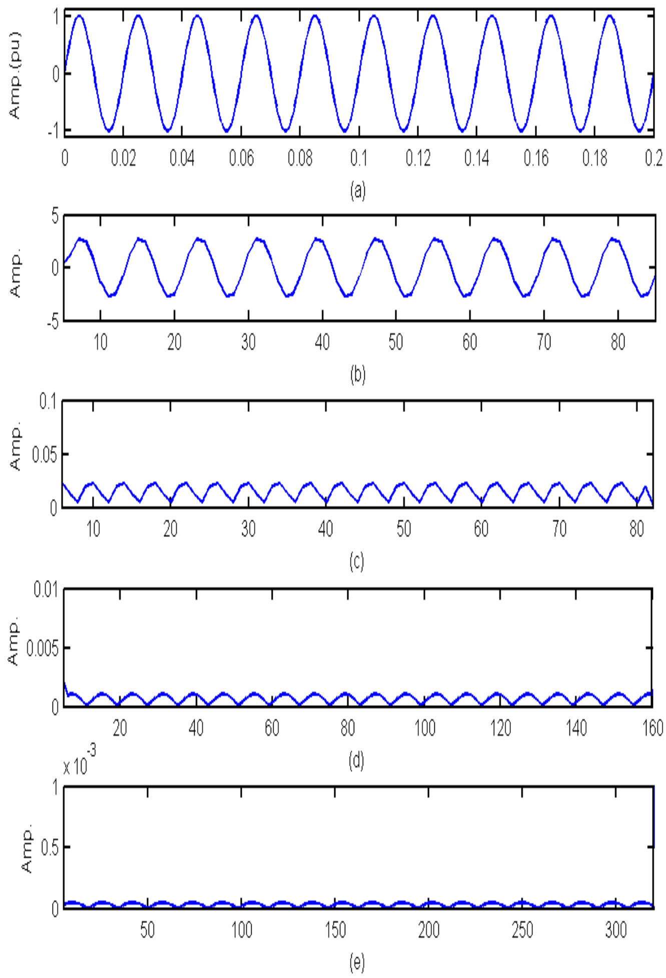

Fig-1 : Discrete wavelet transform based decomposition of pure sine wave (a) pure sine wave signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

4.3 VOLTAGE SWELL WITH HARMONICS

The voltage signal with voltage swell and harmonics is a degree two complex PQ disturbance. This signal is decomposed using DWT with db4 as mother wavelet up to third level of decomposition. The plots of voltage signal, approximation coefficient at third level (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 3 (a), (b), (c), (d) and (e) respectively. The high magnitude peaks at sample numbers 100 and 230 indicate the initiation and end of voltage swell. Increase in the magnitude of all plots related to the detail and approximation coefficients indicate the presence of voltage swell. Presence of continuous ripples in the detail coefficients cD2 and cD3 detects the harmonic components present in the voltage signal.

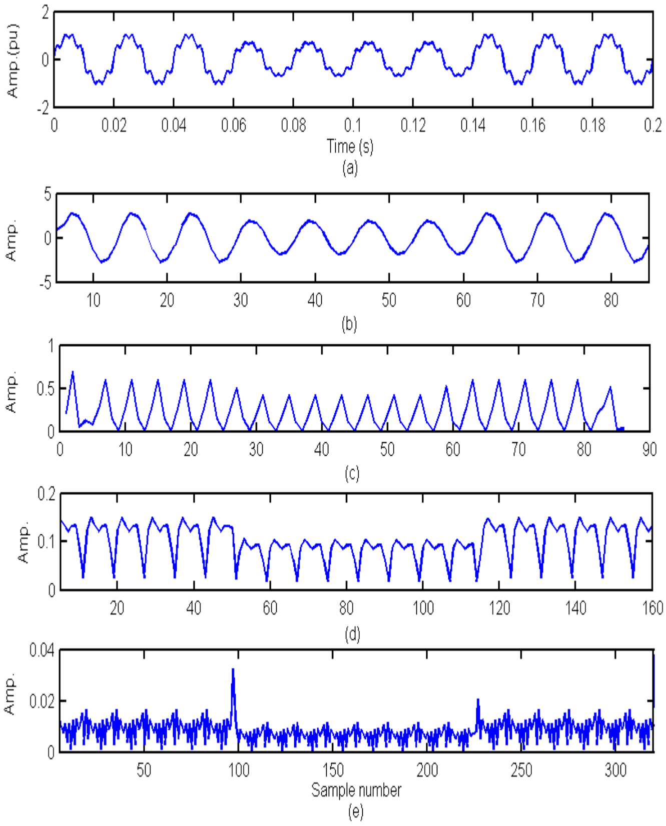

Fig-2: Discrete wavelet transform based decomposition of voltage signal with voltage sag and harmonics (a) voltage signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

4.4 MONENTARY INTERRUPTION WITH HARMONICS

The voltage signal with momentary interruption and harmonics is known as degree two complex PQ disturbances. The voltage with this PQ disturbance is decomposed up to level 3 using DWT with db4 as mother wavelet. The plots of voltage signal, approximation coefficient (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 4.4 (a), (b), (c), (d) and (e) respectively. The high magnitude peaks at sample numbers 100 and 230 indicate the initiation and end of momentary interruption. Reduction in magnitude of all the plots related to the detail and approximation coefficients nearly zero indicate the presence of momentary interruption in the voltage signal. Presence of continuous ripples in the detail coefficients cD2 and cD3 detects the harmonic components present in the voltage signal.

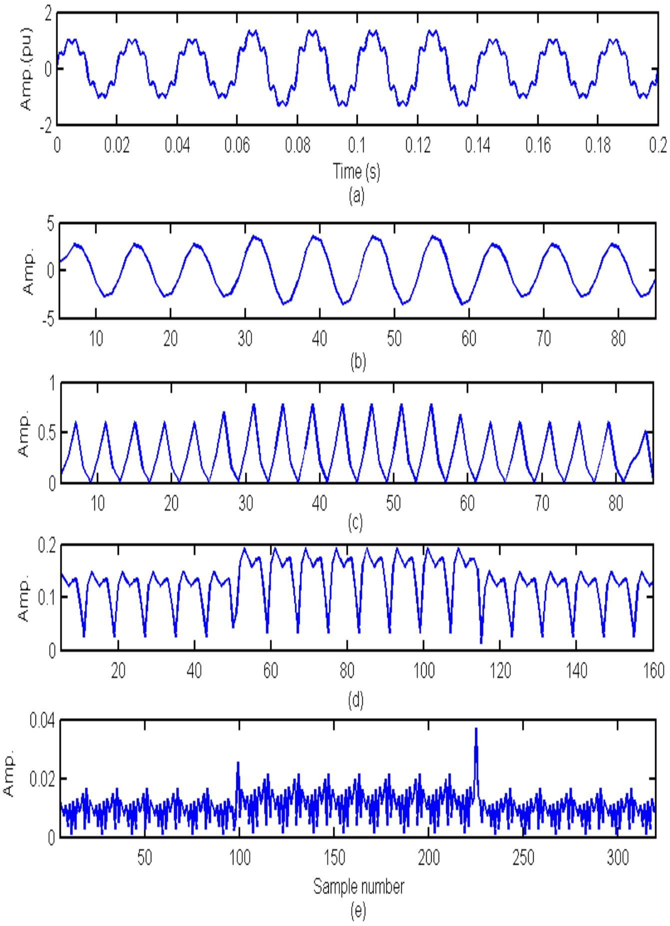

Fig-3: Discrete wavelet transform based decomposition of voltage signal with voltage swell and harmonics (a) voltage signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

4.5 IMPULSIVE TRANSIENT WITH VOLTAGE SAG

The voltages signal with impulsive transient (IT) and voltage sag is a PQ disturbance of degree two complexities. This signal is decomposed up to level 3 using DWT with db4 as mother wavelet. The plots of voltage signal, approximation coefficient (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 4.5 (a), (b), (c), (d) and (e) respectively. The high magnitude peaks available in all the plots related to detail and approximation coefficients indicate detects the impulsive transient available in the voltage signal. Decrease in magnitude of plot related to the approximation coefficient between the sample numbers 45 to 70 indicate the presence of voltage sag in the voltage signal.

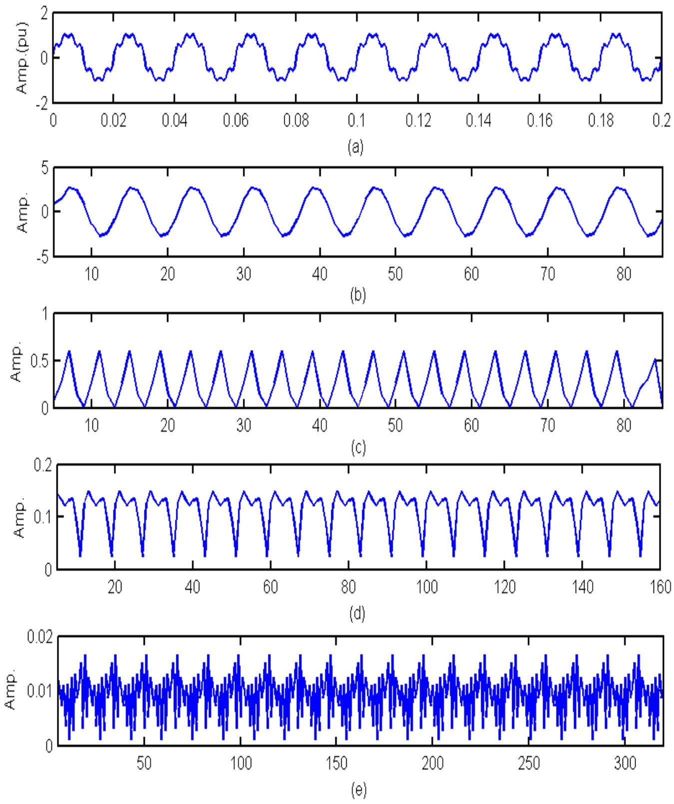

Fig-4: Discrete wavelet transform based decomposition of voltage signal with momentary interruption and harmonics (a) voltage signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

4.6 SIMULTANEOUS OCCURRENCE OF VOLTAGE SWELL, OSCILLATORY TRANSIENT AND HARMONICS

The voltage signals with simultaneous occurrence of voltage swell, oscillatory transient (OT) and harmonics is PQ disturbance of degree three complexities. This signal is decomposed up to level 3 using DWT with db4 as mother wavelet. The plots of voltage signal, approximation coefficient at third level (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 4.6 (a), (b), (c), (d) and (e) respectively. High magnitudes available in the plots related to the detail coefficients cD1 and cD3 indicate the presence of oscillatory transient. The two high magnitude peaks in the plot of detail coefficient cD2 are due to the initiation and end of the OT. Hence, this also helps in the detection of OT. Presence of continuous ripples in the detail coefficients cD2 and cD3 detects the harmonics in voltage signal. Increase in magnitude of plot related to the approximation coefficient between the sample numbers 45 to 70 indicates the presence of voltage swell in the voltage signal.

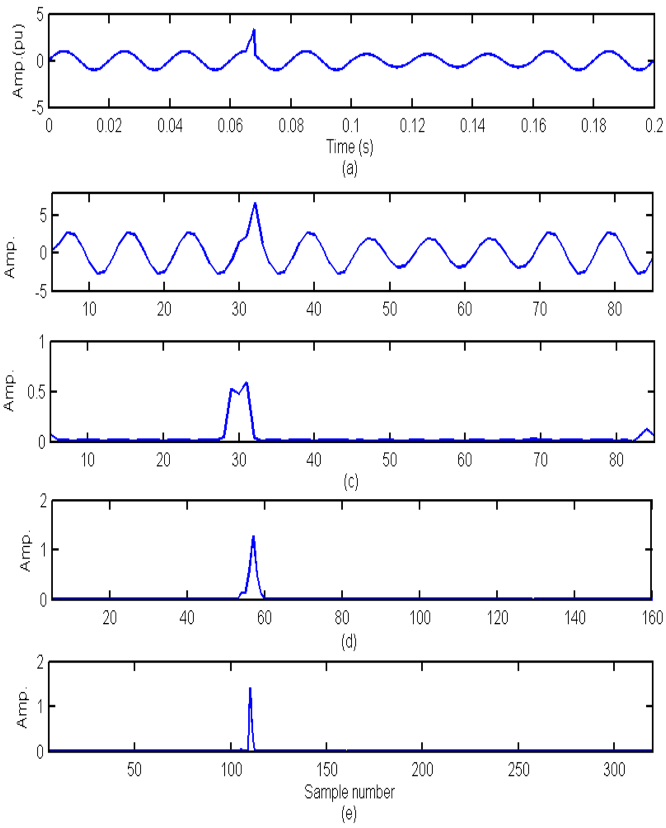

Fig-5 Discrete wavelet transform based decomposition of voltage signal with impulsive transient and voltage sag (a) voltage signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

4.7 SIMULTANEOUS OCCURRENCE OF VOLTAGE SAG, OSCILLATORY TRANSIENT AND HARMONICS

The voltage signals with simultaneous occurrence of voltage sag, oscillatory transient (OT) and harmonics is PQ disturbance of degree three complexities. This signal is decomposed up to level 3 using DWT with db4 as mother wavelet. The plots of voltage signal, approximation coefficient at third level (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 4.7 (a), (b), (c), (d) and (e) respectively. High magnitudes available in the plots related to detail coefficients cD1 and cD3 indicate the presence of oscillatory transient. The two high magnitude peaks in the plot of detail coefficient cD2 are due to the initiation and end of the OT. Hence, this also helps in the detection of OT. The presence of continuous ripples in the detail coefficients cD2 and cD3 detects the harmonics in the voltage signal. Decrease in magnitude of plot related to the approximation coefficient between the sample numbers 45 to 70 indicate the presence of voltage sag in the voltage signal.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 06 | June 2020 www.irjet.net p-ISSN: 2395-0072

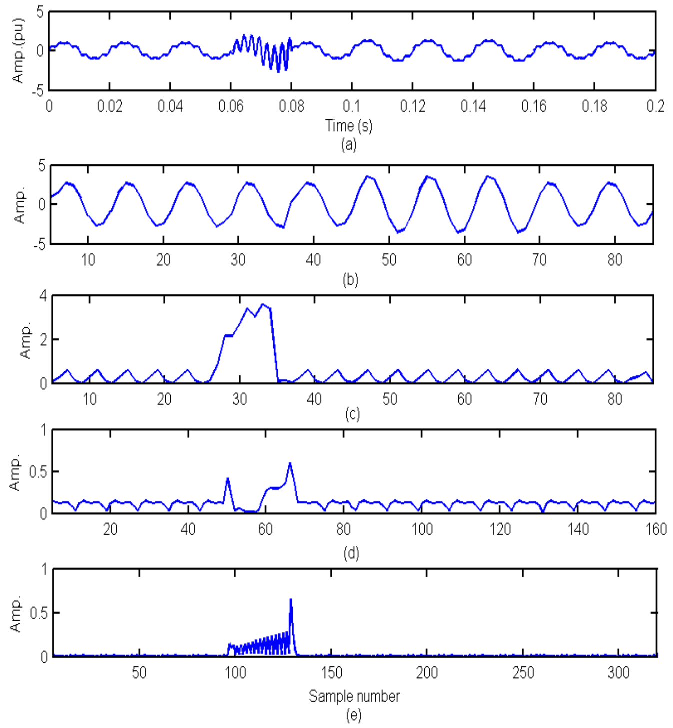

Fig-6: Discrete wavelet transform based decomposition of voltage signal with oscillatory transient, voltage swell and harmonics (a) voltage signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

4.8 SIMULTANEOUS OCCURRENCE OF OSCILLATORY TRANSIENT , IMPULSIVE TRANSIENT VOLTAGE SAG, AND HARMONICS

The voltage signals with simultaneous occurrence of voltage sag, oscillatory transient (OT), impulsive transient and harmonics are PQ disturbance of degree four complexities. This signal is decomposed up to level 3 using DWT with db4 as mother wavelet. The plots of voltage signal, approximation coefficient at third level (cA3), detail coefficient at third level (cD3), detail coefficient at second level (cD2) and detail coefficient at first level (cD1) of decomposition are shown in Figs. 4.8 (a), (b), (c), (d) and (e) respectively. High magnitudes available in the plots related to the detail coefficients cD1 and cD3 indicate presence of the oscillatory transient. The two high magnitude peaks at sample number 50 and 70 in the plot of detail coefficient cD2 are due to the initiation and end of the OT. Hence, this also helps in the detection of OT. The first high magnitude sharp peak in the plots related to all the detail coefficients detects the presence of IT in the voltage signal. The presence of continuous ripples in the plots of detail coefficients cD2 and cD3 detects the harmonics in the voltage signal. Decrease in magnitude of plot related to the approximation coefficient between the sample numbers 45 to 70 indicate the presence of voltage sag in the voltage signal.

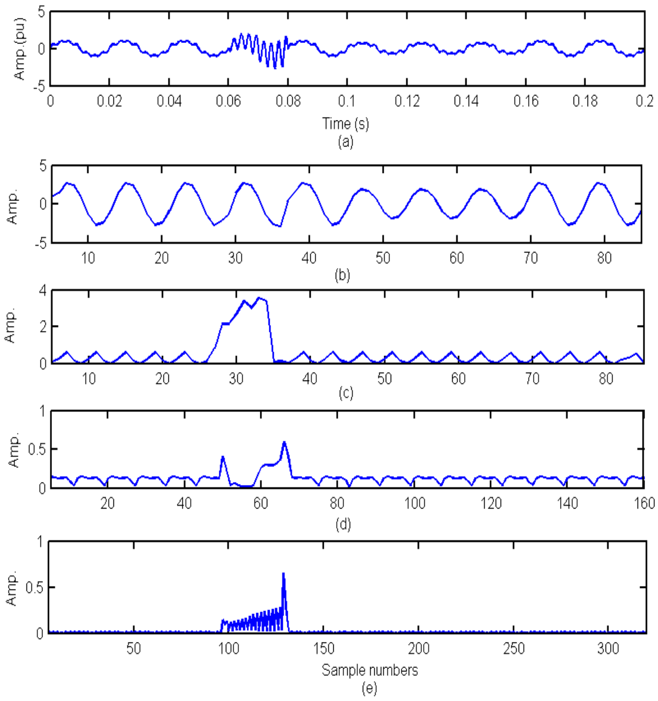

Fig-7: Discrete wavelet transform based decomposition of voltage signal with oscillatory transient, voltage sag and harmonics (a) voltage signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

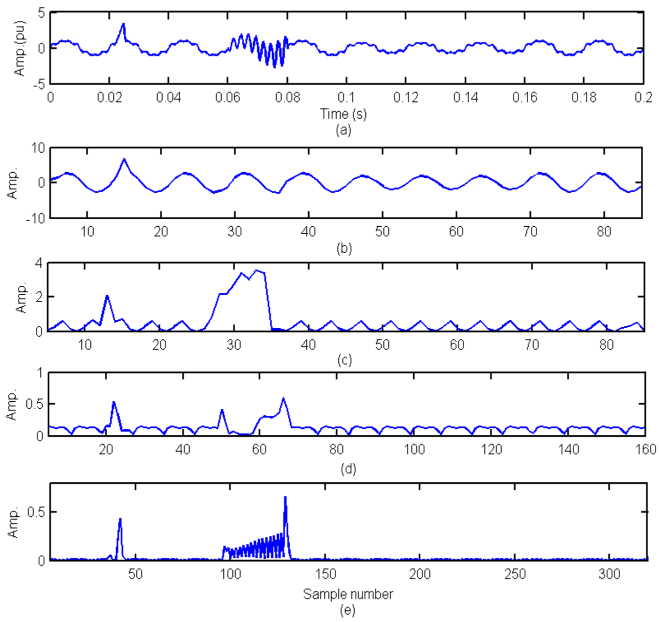

Fig-8: Discrete wavelet transform based decomposition of voltage signal with oscillatory transient, impulsive transient, sag and harmonics (a) voltage signal (b) approximation coefficient at third level (cA3) (c) detail coefficient at third level (cD3) (d) detail coefficient at second level (cD2) (e) detail coefficient at first level (cD1).

5. POWER QUALITY DISTURBANCES CLASSIFICATION

The features extracted from DWT based plots are used for ruled decision tree to classify various complex PQ disturbances. Flowchart of classification with decision rules is shown in the Fig. 5.1. The performance of proposed algorithm has been tested on 30 data sets of each PQ disturbance. The performance in terms of correctly classified and misclassified PQ disturbances is provided in the Table 5.1. The efficiency of classification of each complex PQ disturbance and overall efficiency of classification is also provided in this Table.

Table -1: PERFORMANCE OF CLASSIFICATION OF SINGLE STAGE PQ DISTURBANCES

PQ Event	Class symbol	Correctly classified	Misclassified	Efficiency (%)
Voltage Sag + Harmonics	C1	28	2	93.33
Voltage Swell + Harmonics	C2	28	2	93.33
Interruption + harmonics	C3	29	1	96.67
OT + Voltage Sag	C4	29	1	96.67
IT + Voltage Sag	C5	29	1	96.67
Voltage Swell + OT + Harmonics	C6	27	3	90.00
Voltage Sag + OT + Harmonics	C7	27	3	90.00
OT + IT + Voltage sag + Harmonics	C8	26	4	86.67
Overall efficiency				92.9175

6. COMPERATIVE PERFORMANCE RESULTS

The performance of proposed algorithm has been compared with the techniques reported in the reference [12], and [13] and comparison of performance is provided in Table 5.2. From the Table 5.2, it can be observed that the efficiency of proposed algorithm is higher than the algorithms reported in the references [13], and [14].

Table -2:

References	Type of Technique	Efficiency
[13]	DWT+ANN	89
[14]	WT+SOMN	91
Proposed	DWT+RBDT	92.9175

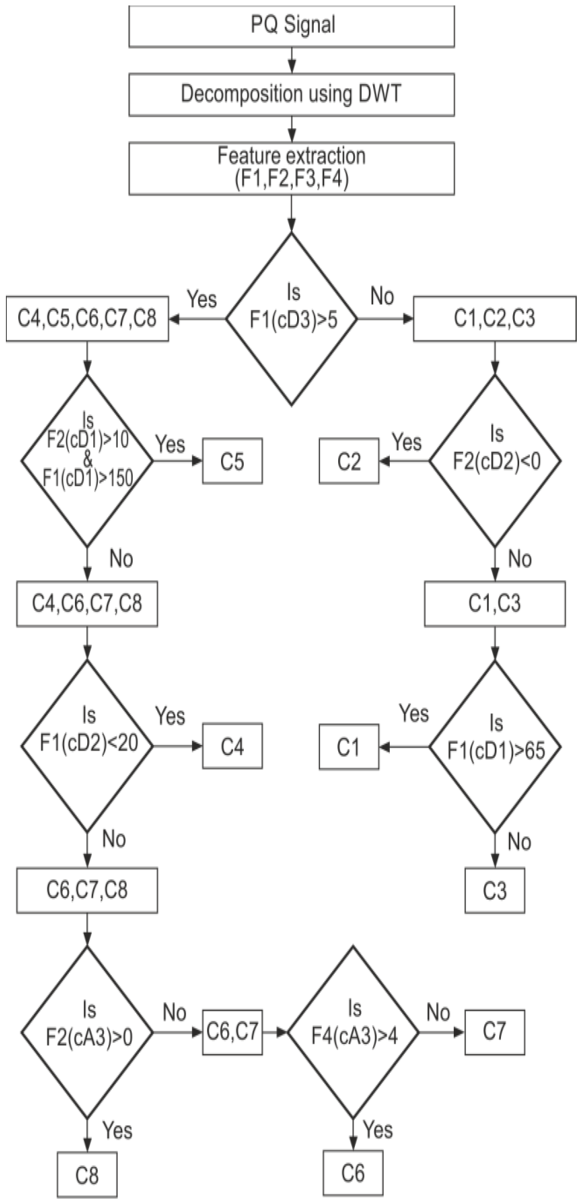

Fig-9: Ruled decision tree based flow chart for the classification of Complex PQ disturbances.

7. CONCLUSION

This paper presents investigate Complex power quality disturbances, these generated power quality signals are decomposed using Discrete Wavelet transform and plots of detail and approximation coefficients are obtained. Various features obtained from these plots are used to recognize the complex power quality disturbances. It is concluded that proposed method is found to be effective in the investigation of complex power quality disturbances.

REFERENCES

[1] Iyer Shiv Kumar, Ghosh Arinand, Joshi Avinash," Inverter topologies for DSTATCOM applications – a simulation study," Electric Power Systems Res 2005;75:161-170.

[2] P. Kanirajan, and V. Suresh Kumar, "Power quality disturbance detection and classification using wavelet and RBFNN," Applied Soft Computing, Vol. 35, pp. 470-481, 2015.

[3] JayaramanMeenakshi, Sreedevi VT, Balakrishnan Rajkiran, "Analysis and design of passive filters for power improvement in stand -alone PV systems," IEEE international conference on engineering, Ahmedabad, Nov 2013.

[4] Murat Uyar, Selcuk Yildirim, Mushsin Tunay Gencoglu, "An expert system based on S-transform and neural network for automatic classification of power quality disturbances," Expert Systems with Applications, Vol. 36, pp. 5962-5975, 2009.

[5] O. P. Mehla, A. G. Shaik and N. Gupta, " a criticl review on detecton and classification of power quality events," Renewbale and sustainable Energy reviews, vol. 41, pp 495-505, 2015.

[6] Om Prakash Mahela, Abdul Gafoor Shaik, and Neeraj Gupta, "A critical review of detection and classification of power quality events," Renewable and Sustainable Energy reviews, Vol. 41, pp. 495-505, 2015.

[7] Murat Uyar, Selcuk Yildirim, Mushsin Tunay Gencoglu, "An expert system based on S-transform and neural network for automatic classification of power quality disturbances," Expert Systems with Applications, Vol. 36, pp. 5962-5975, 2009.

[8] Ming Zhang, Kaicheng Li, and Yisheng Hu, "A real-time classification method of power quality disturbances," Electric Power Systems Research, Vol. 81, pp. 660-666, 2011.

[9] D. Granados-Lieberman, R. J. Romero-Troncoso, R. A. Osornio-Rios, A. Garcia-Perez, and E. Cabal-Yepez, "Techniques and methodologies for power quality analysis and disturbances classification in power system: a review," IET Generation, Transmission & Distribution, vol. 5, no. 4, pp. 519-529, 2011.

[10] Wang Zhan, Zeng Xiangjun, Hu Xiaoxi, and Hu Jingying, "The Multi-disturbance Complex Power Quality Signal HHT Detection Technique," Innovative Smart Grid Technologies - Asia (ISGT Asia), 2012 IEEE, pp. 1-5, 2012.

[11] Suhail Khokhar, Abdullah Asuhaimi B. Mohd Zin, Ahmad Safawi B. Mokhtar, and Mahmoud Pesaran, "A comprehensive overview on signal processing and artificial intelligence techniques applications in classification of power quality disturbances," Renewable and Sustainable Energy reviews, Vol. 51, pp. 1650-1663, 2015.

[12] P. Kanirajan, and V. Suresh Kumar, "Power quality disturbance detection and classification using wavelet and RBFNN," Applied Soft Computing, Vol. 35, pp. 470-481, 2015.

[13] B. Perunicic, M. Mallini, and Z. Wang, "Power Quality Disturbance Detection and Classification Using Wavelets and Artificial Neural Networks," 8th IEEE International Conference on Harmonics and Quality of Power.

[14] Ying-Yi Hong, and Cheng-Wei Wang, "Switching Detection/ Classification Using Discrete Wavelet Transform and Self-Organizing Mapping Network," IEEE Transactions On Power Delivery, Vol. 20, No. 2, pp. 1662-1668, April 2005.