Power Quality Assessment using Change Detection and DFT

K. Deepthi

Abstract: ***Uninterrupted examination of Power Quality (PQ) problems in electrical power distribution network has become a significant problem for consumers at different levels. For maintaining accurate performance of electrical and electronic equipment, assessment of PQ disturbances is required. This paper introduces a new technique for PQ disturbances detection and classification with minimum computational complexity. The presence of disturbance in the sinusoidal signal is identified using Voltage slope detection method and the type of disturbance is classified using Discrete Fourier Transform (DFT). Results proves that the proposed method is optimum and the overall accuracy is high compared to other methods.***

Keywords: Classification, Disturbance detection, Discrete Fourier Transform, Power Quality (PQ), PQ Disturbances, signal model.

I. INTRODUCTION

Power Quality (PQ) has eventually be a big task for customers. Widening usage of non linear loads such as power converters, lightning controls, adjustable speed drives and arcing devices contribute to poor PQ [1]. Poor PQ may cause equipment deterioration and reduce the life of load. To provide good power quality, the power must be free form disturbances. Power Quality is defined as the study of powering and grounding sensitive electronic equipment in a manner suitable for the equipment [2]. Electrical equipments such as a motor, a transformer, a desktop computer, or a refrigerator are inclined to deficiency when exposed to single or multiple PQ disturbances. In a power distribution network, some PQ disturbances like surges, voltage sag or dip,undervoltage, voltage swell, interruption, transients, flicker, harmonics and voltage unbalance result in deterioration of quality of electric power. These are mainly caused by faults, switching of heavy loads and non-linear loads [1]. These PQ disturbances weaken the performance of customer equipment. So, PQ improvement has a positive impact on the distribution system for its continuous profits. IEEE deals with the definition, detection, mitigation and classification of PQ events [2]. Digital signal processing tools like Fourier Transform (FT), Short Time Fourier Transform (STFT), Slantlet Transform (SLT), Wavelet Transform (WT), Hilbert transform, Kalman Filter (KF) and Stockwell Transform (ST) are used to abstract frequency and time information of different PQ disturbances. Fourier transform [3] provides only the frequency resolution and it is not suited for non-stationary signals.STFT [4] well known as sliding window version of FFT exhibits better results with regard to resolution and frequency sensitivity. For non-stationary signals, STFT unable to track the mobility of the signal accurately due to rigid window width. Wavelet transform [5]-[7] is used for analyzing non-stationary signals. Both time and frequency domains information are extracted using WT. The accuracy of WT depends on the wavelet chosen. It deteriorates from the drawbacks of computational complication and affected by the noise level. Using SLT [8], single and multiple disturbances are identified. But due to the presence of noise in the signals, the performance of SLT technique is degraded. A combination of Kalman filter and fuzzy expert system [9] has been proposed for PQ analysis. The solution of KF are based on model of the scheme used and choice of filter parameters. S-transform [10]-[12] is a varying window of STFT or an extension of WT. It depends on the scalable localizing Gaussian window and presents the frequency dependent resolution. ST has the capacity to observe the disturbance in the existence of noise also. But the disadvantage is its complicated calculation, because every time the frequency is multiplied by gaussian window and then by inverse Fourier transform. In [13], Empirical mode decomposition (EMD) with Hilbert transform (HT) for PQ assessment is used. From non-stationary and non-linear signals, EMD technique generates Intrinsic mode functions (IMF). The major drawback is mode mixing, where the wanted data will be reduced.

In this paper, a new power quality assessment technique is proposed for identification and classification of PQ problems. To detect the disturbance present in the sinusoidal signal, a new Voltage Slope Detection technique is proposed. This method detects the disturbances within a short period of time. Using one of the Phasor estimation technique, Discrete Fourier Transform (DFT), the features of different PQ disturbances are obtained and are classified. The advantage of the proposed method is its less computational complexity, because it detects the disturbance in the signal when there is change in the signal only. The proposed method is proved with signals having varying amplitude, time and frequency to show their effectiveness under noisy conditions. Results demonstrate the robustness of this method.

This paper is standardized into four sections. Section II describes the representation of PQ signal model. Proposed algorithm for power quality assessment is discussed in Section III. In Section IV, MATLAB results of the proposed technique and comparison results are shown. Finally, in Section V Conclusion is presented.

Revised Manuscript Received on June 01, 2019.

K.Deepthi, Department of Electrical & Electronic Engineering, Sagi RamaKrishnam Raju Engineering College, Bhimavaram, Andhra Pradesh, India (Email:-katarideepthi37@gmail.com)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

II. SIGNAL MODEL

In this section, modelling of simulated power quality disturbances(PQD) are described. Various PQD are generated in MATLAB software using parametric equation model or mathematical model. In this paper, using parametric equation models eleven types of PQD are created as shown in Table I. Advantages of using parametric equations are the parameters of the signal can be varied easily in a controlled manner and are used for real time classification. PQD like undervoltage, overvoltage, voltage sag or dip, spike, voltage swell, interruption, notch and transients are created by applying step functions for duration between $t_1$and t_2. Harmonic signals have greater than three frequency elements and are uneven multiples of primary frequency element. Amplitudes of harmonic signal given by parameters $\alpha_1, \alpha_3, \alpha_5$ and α_7 are varied from 0.05 to 0.15 and square of sum of all these elements not to go beyond unity magnitude [14]-[17]. Transients have rapid changes which occur for a small period of time is controlled by parameter τ. The parameters $\boldsymbol{\alpha}$ represents the magnitude of different PQD and $t_2 - t_1$ represents the duration of disturbances as presented in Table I. By varying parameters $\boldsymbol{\alpha}$, $t_1$and t_2, a large number of PQ disturbance signals can be generated. The signals produced by parametric equation model can be easily used in the detection and classification of PQD.

III. PROPOSED ALGORITHM

The proposed method has two stages:

A. *Disturbance Detection*

Voltage slope detection is a new method to detect the disturbance present in the signal. It is a process that measures how the characteristics of a signal have changed between two or more time periods. In this method, the difference of voltage between two values of sample is considered for the detection of disturbance. The pure value of the sum of the slopes of the voltage signal for a window of oneentire cycle isallotted as disturbance index. Under normal conditions, the disturbance index value is zero. At the initiation of disturbance, the disturbance index raises to a bigger value. This value of disturbance index is tested with a prearranged threshold parameter.

Mathematically this can be written as,

$$l(i) = (v(i) - v(i-1))/\Delta t \quad (1)$$

$$S(i) = \sum_{j=i-N+1}^{i} l(j) \quad (2)$$

At the instant i, the slope of the signal is $l(i)$, sampling interval is given by Δt, $S(i)$ is the value of disturbance index using the proposed method, N is number of samples per cycle and $v(i)$ is the present voltage signal sample value.

The disturbance is identified,

$$\text{if } |S(i)| > T_1 \quad (3)$$

Where T_1 is the threshold value.

TABLE I
SIGNAL MODELAND THEIR PARAMETERS [16]

PQ Disturbance	Signal Model	Parameters
Pure sine	$v(t) = A\sin(wt)$	*A = 1(pu), f=50 Hz*
Undervoltage	$v(t) = A\left(1 - \alpha_u\left(u(t-t_1) - u(t-t_2)\right)\right)\sin(wt)$	$0.1 \le \alpha_u \le 0.9$, $T \le t_2 - t_1 \le 9T$
Overvoltage	$v(t) = A\left(1 + \alpha_o\left(u(t-t_1) - u(t-t_2)\right)\right)\sin(wt)$	$0.1 \le \alpha_o \le 0.8$, $T \le t_2 - t_1 \le 9T$
Interruption	$v(t) = A\left(1 - \alpha_i\left(u(t-t_1) - u(t-t_2)\right)\right)\sin(wt)$	$0.9 \le \alpha_i \le 1.0$, $T \le t_2 - t_1 \le 9T$
Flicker	$v(t) = A(1 + \alpha_f \sin(\beta wt))\sin(wt)$	$0.1 \le \alpha_f \le 0.2$, $5 \le \beta \le 20\ Hz$
Voltage sag or dip	$v(t) = A\left(1 - \alpha_d\left(u(t-t_1) - u(t-t_2)\right)\right)\sin(wt)$	$0.1 \le \alpha_d \le 0.9$, $T \le t_2 - t_1 \le 9T$
Voltage swell	$v(t) = A\left(1 + \alpha_s\left(u(t-t_1) - u(t-t_2)\right)\right)\sin(wt)$	$0.1 \le \alpha_s \le 0.8$, $T \le t_2 - t_1 \le 9T$
Oscillatory transients	$v(t) = A(\sin(wt) + \alpha_t e^{-\frac{t-t_1}{\tau}} sinw_n(t-t_1)\{u(t_2) - u(t_1)\})$	$0.1 \le \alpha_t \le 0.8, 0.5T \le t_2 - t_1 \le 3T$
Harmonics	$v(t) = A(\alpha_1\sin(wt) + \alpha_3\sin(3wt) + \alpha_5\sin(5wt) + \alpha_7\sin(7wt))$	$0.05 \le \alpha_3, \alpha_5, \alpha_7 \le 0.15$, $\sum \alpha_i^2 = 1$
Notch	$v(t) = A(\sin(\text{wt}) - sign(\sin(wt)) \times \left[\sum_{n=0}^{9} K \times \{u(t-(t_1+0.02n)) - u(t-(t_2+0.02n))\}\right])$	$0.1 \le K \le 0.4, 0 \le t_1, t_2 \le 0.5T$, $0.01T \le t_2 - t_1 \le 0.05T$
Spike	$v(t) = A(\sin(wt) + sign(\sin(wt)) \times [\sum_{n=0}^{9} K \times \{u(t-(t_1+0.02n)) - u(t-(t_2+0.02n))\}])$	$0.1 \le K \le 0.4, 0 \le t_1, t_2 \le 0.5T$, $0.01T \le t_2 - t_1 \le 0.05T$

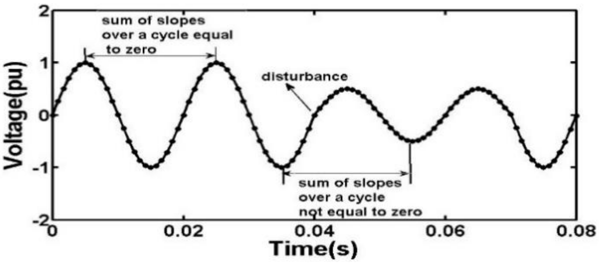


Fig. 1. Voltage slope detection example.

A suitable threshold value is essential for disturbance detection because of noise, sudden load changes as faults and other uncertainties. Fig.1 shows the example of disturbance detection using voltage slope detection method.

B. Phasor Estimation Technique

Discrete Fourier transform is a phasor estimation technique used for reconstructing discrete time rule information into its equivalent discrete frequency rule information. It is widely used in digital communication, signal processing, linear filtering, spectral analysis and wireless communication. Using DFT, the amplitude and phase angle of distinctive signal frequency components are determined.

for the given series, the M-pointDFT is shown as

$$x(i) = \sum_{m=0}^{N-1} x(m)\, e^{-j2\pi mi/M} \quad (4)$$

Where i=0,1,2,………..M-1

Here, the discrete time rule signal is expressed as $x(m)$as$m$ be the discrete time rule index and the frequency rule components is taken as $x(i)$ where i is the normalized frequency rule index. Benefits of using DFT are high speed operation, high efficiency and low computational complication.

The flowchart for the detection and classification of power quality disturbances is shown in Fig. 2.

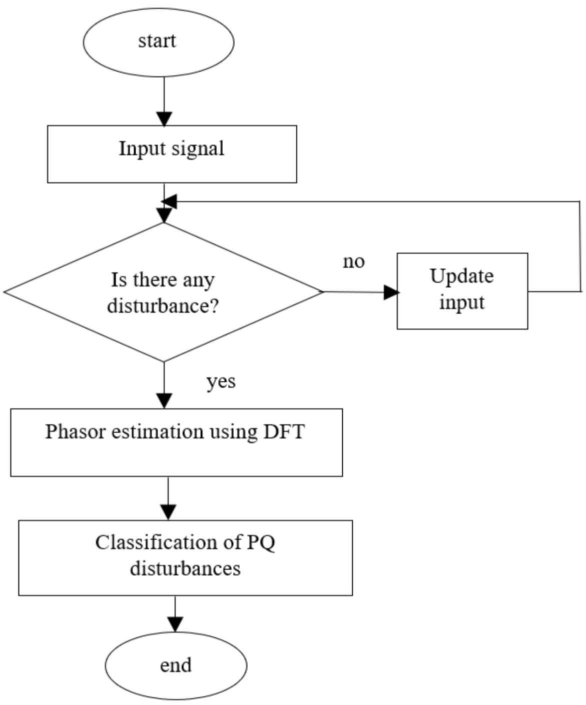


Fig. 2. Flowchart of the proposed algorithm

In the present work, DFT is used for the classification of eleven PQ disturbance signals. By observing the magnitude and duration in the plots, the type of disturbance is classified as per definitions[1].

IV. RESULTS

The proposed power quality assessment method presented is designed to detect and classify the eleven PQ disturbances such as undervoltage, overvoltage, voltage sag or dip, voltage swell, flicker, interruption, harmonics, oscillatory transients, notch and spike. The fundamental frequency of each signal is 50 Hz and the sampling frequency is 3200Hz, i.e., 64 samples for each cycle [2]. Considering the overall duration of the signals as 0.2 seconds except for long duration voltage variations. The input signal is voltage signal, the disturbance is detected by voltage slope detection method and then processed for classification using phasor estimation technique DFT by calculating their magnitude.

Fig. 3. shows the amplitude versus time of normal voltage signal with maximum amplitude of 1pu.Considering the duration greater than 1 min for disturbances like undervoltage and overvoltage are shown in Figs. 3-4, where the maximum amplitude obtained is 0.5 pu for undervoltage and 1.5 pu for overvoltage [1]. Figs. 6(a)-13(a), clearly describes the amplitude versus time of different PQ disturbances generated by using signal models as shown.

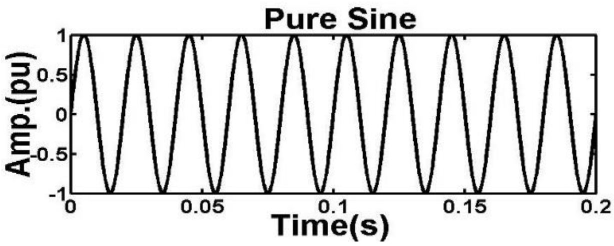


Fig. 3. Pure sine

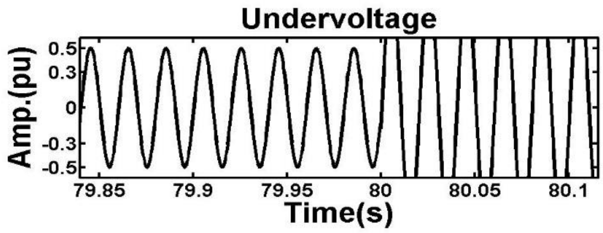


Fig. 4. Undervoltage.

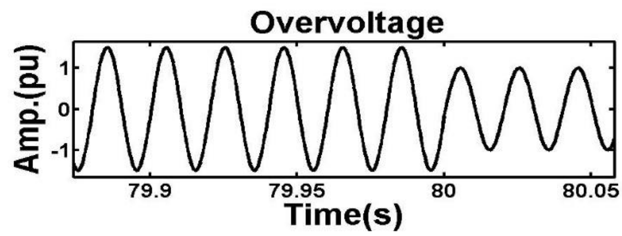
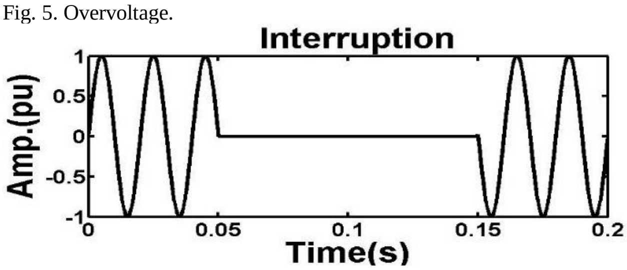
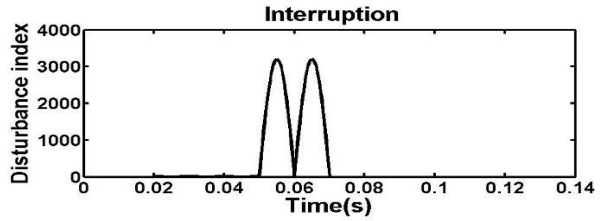


Fig. 5. Overvoltage.



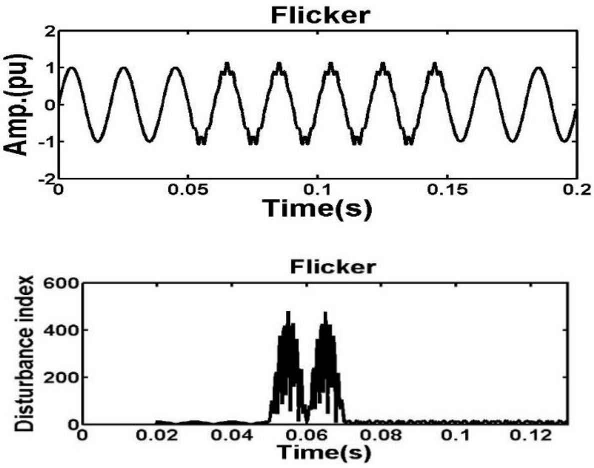
(a)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication



(b)

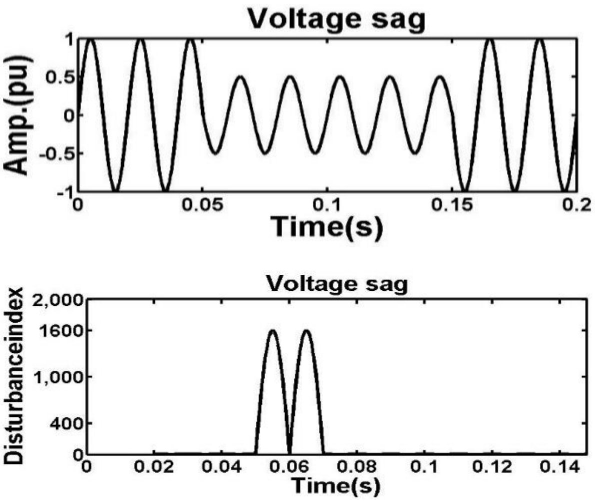
Fig. 6.(a) Interruption. (b) Detection occurs at time, t=0.05 sec.



(a)

(b)

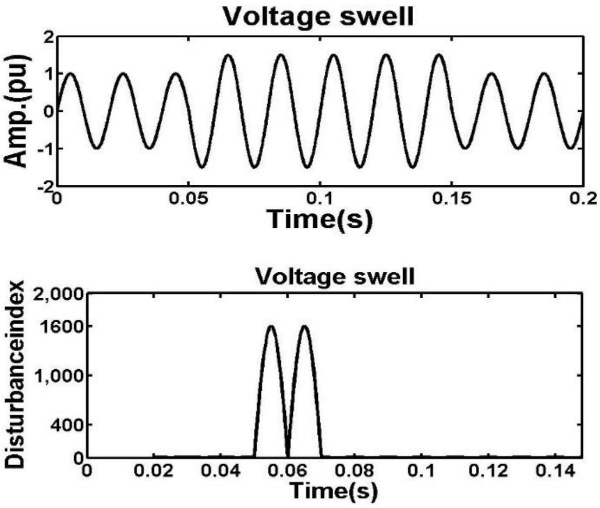
Fig. 7.(a) Flicker. (b) Detection occurs at time, t=0.05 sec.



(a)

(b)

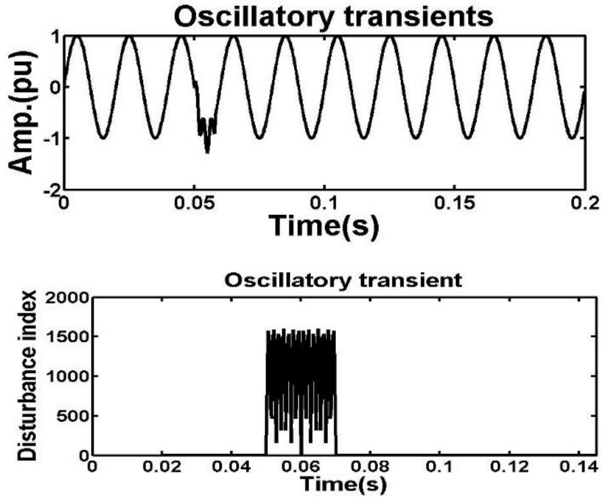
Fig. 8. (a) voltage sag. (b) Detection occurs at time, t=0.05 sec.



(a)

(b)

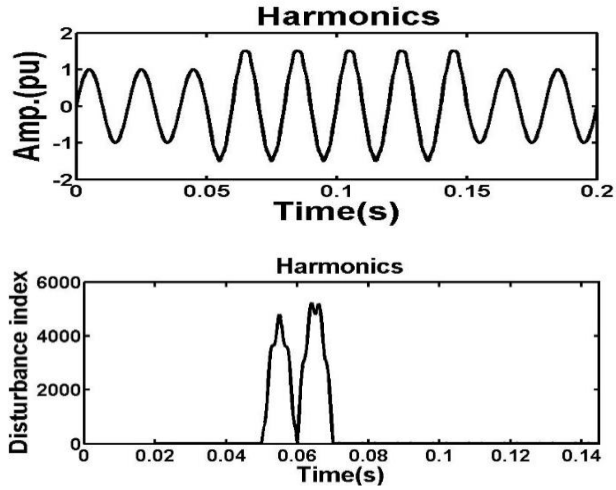
Fig. 9.(a) Voltage swell. (b) Detection occurs at time, t=0.05 sec.



(a)

(b)

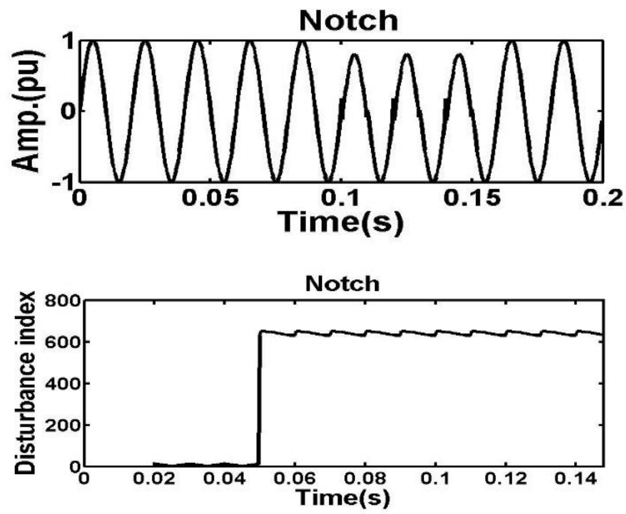
Fig. 10.(a) Oscillatory transients. (b) Detection occurs at time, t=0.05 sec.



(a)

(b)

Fig. 11. (a) Harmonics. (b) Detection occurs at time, t=0.05 sec.



(a)

(b)

Fig. 12. (a)Notch. (b) Detection occurs at time, t=0.05 sec.

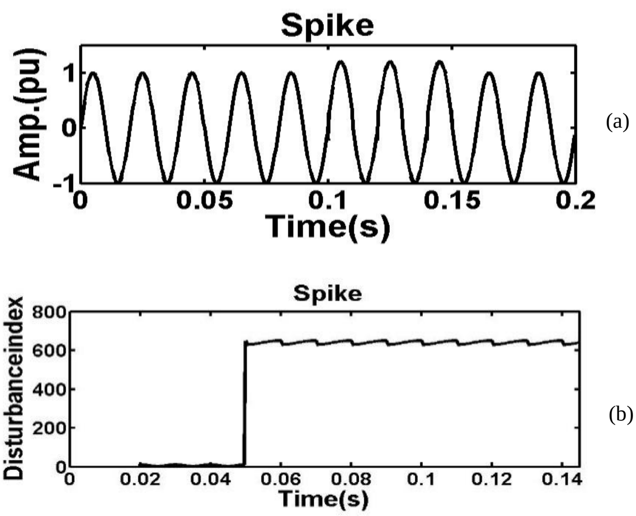


Fig. 13.(a) Spike. (b) Detection occurs at time, t=0.05 sec.

These figures clearly illustrates the magnitude and time of its occurrence. As per definitions[1], the type of disturbance is classified using DFT by observing their magnitude. Figs. 6(b)-13(b) show the results of disturbance detection method, by observing the index value and the time at which disturbance is identified. When there is no disturbance, the disturbance index value is zero. By observing the figures, the disturbance occurs at time t=0.05sec, for signals interruption, flicker, voltage sag, voltage swell, oscillatory transients, harmonics, notch and spike.

A total of 275 signals with 25 signals of each class are generated using signal models by varying parameters such as starting time, end time, amplitude and frequency. In the case of signals with amplitude less than unity, the overall accuracy is reduced to 96% due to disturbances flicker and spike.This is due to rapid changes in voltage signal, these flicker and spike signals may be misclassified. Otherwise, the proposed method works well for these disturbance signals also.

TABLE II
RESULTS OBTAINED USING PROPOSED METHOD, WITHOUT NOISE

PQ disturbances	**Accuracy(%)**				
	Starting time	***End time***	***Amplitude***	***Frequency***	***Magnitude***
Pure sine	100	100	100	100	100
Undervoltage	100	100	100	100	100
Overvoltage	100	100	100	100	100
Interruption	100	100	100	100	100
Flicker	100	100	96	100	100
Voltage sag	100	100	100	100	100
Voltage swell	100	100	100	100	100
Oscillatory transients	100	100	100	100	100
Harmonics	100	100	100	100	100
Notch	100	100	100	100	100
Spike	100	100	96	100	100
Overall accuracy	100	100	99.27	100	100
Overall accuracy=99.85					

TABLE III
RESULTS OBTAINED USING PROPOSED METHOD, WITH NOISE

PQ Disturbances	**Accuracy(%)**		
	SNR 30dB	***SNR 40 dB***	***SNR 50 dB***
Pure sine	100	100	100
Undervoltage	100	100	100
Overvoltage	100	100	100
Interruption	100	100	100
Flicker	100	100	100
Voltage sag	100	100	100
Voltage swell	100	100	100
Oscillatory transients	100	100	100
Harmonics	100	100	100
Notch	100	100	100
Spike	100	100	100
Overall accuracy=100			

TABLE IV
THE OVERALL ACCURACYOF THE PROPOSED METHOD

PQ Disturbances	**No. of cases**	**Disturbance detection accuracy(%)**	**Classification accuracy(%)**
Pure sine	25	100	100
Undervoltage	25	100	100
Overvoltage	25	100	100
Interruption	25	100	100
Flicker	25	100	96
Voltage sag	25	100	100
Voltage swell	25	100	100
Oscillatory transients	25	100	100
Harmonics	25	100	100
Notch	25	100	100
Spike	25	100	96
	Total=275	Overall accuracy=99.63	

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

TABLE V
COMPARISON RESULTS OF PROPOSED METHOD WITH OTHER METHODS

References	No. of PQ Disturbances	Overall accuracy(%)
ST+FUZZY [18]	07	98
ST+PNN [19]	11	97.4
ST+PNN [12]	10	94.7
ST+FUZZY [20]	13	92.7
Proposed method	11	99.63

The overall accuracy is 99.85% for all eleven types of disturbance signals without noise as presented in Table II. To know the performance of the proposed method under noisy condition, the signals are combined with white Gaussian noise of signal to noise ratio (SNR) varying from 30 to 50 dB. Table III demonstrates the results obtained for signals at different SNR using the proposed method and the overall accuracy is 100%. For a complete set of 275 signals, the individual and overall accuracy results are shown in Table IV. In this, the overall accuracy of disturbance detection is 100% and the overall classification accuracy is 99.27%. Table V show the proposed method accuracy comparison with other methods[18]-[20].

The proposed method is able to detect and classify the 11 types of PQ disturbances with an accuracy of 99.63% which is higher than other methods. The proposed method results obtained show that this method is suitable for disturbance detection and the classification of PQ signals.

V. CONCLUSION

A new power quality assessment technique based on voltage slope detection and Discrete Fourier Transform has been developed for PQ disturbance signals detection and classification. It is observed that this method correctly detects and classifies the eleven types of PQ disturbances with higher accuracy, in the presence of noise environment also. The overall accuracy obtained is 99.63% which is higher than other methods. The advantage of this method is less computational complexity. The obtained results show the best performance and high accuracy of the proposed method.

REFERENCES

1. R. C. Dugan, M.MC Granaghan, H. Beaty “Electrical power system quality”, McGraw-Hill companies, 1996.
2. IEEE Recommended Practice for monitoring Electric Power Quality, IEEE Std. 1159, 2009.
3. Emanuel Fuchs, BetiTrajanoska, Sarah Orhouzee, and Herwig Renner, “Comparison Of Wavelet and Fourier Analysis in Power Quality”, IEEE certified Journal, 2012.
4. Y. H. Gu and M. H. J. Bollen, :Time-frequency and time-scale domain analysis of voltage disturbances”, IEEE Trans. Power Del., vol. 15, no. 4, pp. 1279-1284, oct. 2000.
5. F. Jurado, N. Acero, B.Ogayar, “Application of signal processing tools for power quality analysis:, Canadian Conference on Electrical and Computer Engineering, IEEE CCECE 2002. Vol. 1, 12-15 May 2002.
6. S.Santoso, E. J. Powers, W. M. Grady, and P. Hofmann, “Power quality assessment via wavelet transform analysis”, IEEE Trans. Power Del., vol. 11, no. 2, pp. 924-930, Apr. 1996.
7. A. M. Gaouda, M. M. A. Salama, M. R. Sultan, and A. Y. Chikhani, “Power Quality Detection and Classification Using Wavelet-Multiresolution Signal Decomposition”, IEEE Transactions on Power Delivery, Vol. 14(4), pp. 1469-1176(1999).
8. G. Panda, P. K. Dash, A. K. Pradhan, and S. K. Meher “Data Compression of Power Quality Events Using the Slantlet Transform”, *IEEE Transactions on Power Delivery,* Vol. 17, No. 2, April 2002.
9. A. Abdelazeem, A. AbdelsalamAzza, “Classification of power system disturbances using linear Kalman filter and fuzzy-expert system” Electrical Power and Energy Systems 43 (2012) 688-695.
10. P. K. Dash, B. K. Panigrahi, G. Panda, “Power quality analysis using S-transform”, IEEE Trans. Power Deliv. 2003, 188, 406-411.
11. Raj Kumar, Bhim Singh, Ambrish Chandra, and Kamal Al-Haddad “Recognition of Power Quality Disturbances Using S-Transform-Based ANN Classifier and Rule-Based Decision Tree”, *IEEE Trans. Ind. Electron.*, vol. 50, no. 2, pp. 1249-1258, March/April 2015.
12. I. W. C. Lee and P. K. Dash, “S-transform-based intelligent system for classification of power quality disturbance signals”, *IEEE Trans. Ind. Electron.*, vol.50, no. 4, pp. 800-805, Aug. 2003.
13. S. Shukla, S. Mishra, B. Singh, “Empirical-Mode Decomposition with Hilbert Transform for Power-Quality Assessment”, *IEEE Transactions on Power Delivery,* vol. 24, no. 4, pp. 2159-2165, Oct.2009.
14. Nermeen Talat, W. R. Ibrahim, George L. Kusic, “New Technique for Categorization of Power Quality Disturbances”, Power Quality and Supply Realibility Conference, 2008, IEEE, pp. 11-16.
15. B. K. Panigrahi, V. R. Pandi, “Optimal feature selection for classification of power quality disturbances using wavelet packet based fuzzy k-nearest neighbor algorithm”, IET Gener. Transm. Distrib., 2009, Vol. 3, Issue. 3, pp. 296-306.
16. R. H. G. Tan and V. K. Ramachandramurthy, “Numerical model framework of power quality events,” *Eur. J. Sci. Res.*, vol. 43, no. 1, pp. 30-47, Jun. 2010.
17. W. P. Khaing, T. Zin and H. M. Tun, “Detection and Localization of Electrical Power Quality Disturbances”, International Journal of Engineering Trends and Technology, Vol. 11, no.4, May. 2014.
18. M. V. Chilukuri and P. K. Dash, “Multiresolution S-transform-based fuzzy recognition system for power quality events,” *IEEE Trans. Power Del.*, vol. 19, no.1, pp. 323-330, Jan. 2004.
19. S.Mishra, C. N. Bhende and B. K. Panigrahi, “Detection and classification of power quality disturbances using S-transform and probabilistic neural network,” *IEEE Trans. Power Del.*, vol. 23, no.1 pp. 280-287, Jan. 2008.
20. M. Biswal and P. K. Dash, “Detection and characterization of multiple power quality disturbances with a fast S-transform and decision tree based classifier,” *J. Digit. Signal Process.*, vol. 23, no.4, pp. 1071-1083, Jul. 2013.

AUTHORS PROFILE

K.Deepthi is a student of Masters of Technology in Power systems and Automation, JNTUK University, Andhra Pradesh, India. She has received the Bachelor of Technology degree in the department of Electrical and Electronics Engineering from JNTUK University, Andhra Pradesh in the year 2017. Her research interest includes Power Quality, Power System Optimization techniques, Flexible AC transmission systems, Digital Signal Processing and AI techniques.