Techniques for Detection of Power Quality Disturbance Waveform – A Review

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Abstract— **An exponential increase of nonlinear loads in power-system, mostly consisting of power electronic devices, hampered the quality of power supply. Deterioration of power quality often termed as Power Quality Disturbance. This paper aims to briefly depict the issues related to power quality disturbances and it further discusses the methodologies adopted for recognition of power quality disturbances. These disturbances are observed in electrical parameters like voltage, frequency and it includes voltage sag, voltage swell, harmonics, notching, d. c. offset etc. Diagnostic tool for power quality disturbances underwent an evolution of phases. Details regarding conventional transform techniques like discrete and fast fourier transform along with advanced mathematical tool like wavelet and s-transforms are characterized in this paper. Also, the application of artificial intelligence and their combined approach with mathematical techniques reported by researchers in this domain is stated in this work.**

Keywords*— *Power Quality, Fourier transform, Wavelet transform, Artificial intelligence.

I. Introduction

With advent of an era demanding a power-system to supply high-rate increase of end users as well as loads with high efficiency and large productivity, it raised a concern pertaining to the quality of power supply feeding them. Extensive use of sensitive automated control strategies along with sophisticated power electronics equipment for improving system stability and operational efficiency deviates supply from its normal values. The growing complexity of industrial processes as well as system interconnections lead to high inter-dependability, thus results in severe consequences such as huge economic losses if any component fails. In general, the term used to address this quality of supply is ‘Power Quality’ (PQ). PQ, like quality in other goods and services, is difficult to quantify. In an attempt to define PQ, the views of utilities, equipment manufacturers, and customers might be completely different. Utilities consider PQ from the system reliability point of view. Equipment manufacturers, on the other hand, consider PQ as being that level allowing for proper operation of their equipment, whereas customers consider good PQ that ensures the continuous running of processes, operations and businesses. Thus, a PQ problem is ultimately a consumer-driven issue, and the problem related with PQ can be defined as being “any power problem manifested in voltage, current or frequency deviations that result in failure or misoperation of customer equipment”. [1]

There are certain standards for voltage and other measurable electrical parameters as laid by recognized institutes like IEEE, ANSI (American National Standard), British Standards (BS), European Norms (EN) etc. [2]-[5]. The main function of these standards are to provide uniform terminology and test procedures, to set limits, standardized measures and values, and to provide a common basis on which a wide range of engineering is referenced. However, ultimate significance of PQ is determined by performance and productivity of end-user equipment.

Horizon of PQ problem covers a wide spectrum which involves harmonics, voltage sag, voltage swell and momentary interruptions. [6], [7] These disturbances cause problems such as overheating, motor failures, inaccurate metering and malfunctioning of protective equipment. It is important for further understanding and improving power quality to extract features of disturbances from a large number of power signals and to recognize them automatically. Researchers working in this domain adopted variety of methodologies for PQ analysis such as fast fourier transform (FFT), fractional fourier transform [8] and wavelet transform [9,10]. Artificial neural networks ANNs, fuzzy logic and support vector machines are also used for event. [11]

Details regarding PQ problems and feature extraction techniques are further discussed in following sections.

II. PQ Disturbance

Depending on the statistical characteristics of voltage and current waveforms PQ disturbances can be broadly classified as stationary and non stationary. Waveforms of stationary disturbance exhibit time-invariant statistical characteristics, while in case of non-stationary disturbance, these waveforms have time-variant statistical characteristics and they could be sinusoidal or non-sinusoidal. In a general view of power-system engineering these disturbances are further classified as short-duration and long duration voltage variations, voltage imbalance and fluctuations, waveform distortion, power frequency variation. These PQ problems are discusses as below:

i) Short-duration voltage variations: Any variation in the supply voltage for duration not exceeding one minute is known as Short-duration voltage variations. This is further classified as:

- Voltage Sags: It is a fundamental decrease in the supply voltage for duration varying between 0.1 second to a minute.
- Voltage Swell: It is an increase of fundamental frequency voltage for a short duration.
- Interruption: It occurs when the supply voltage or load current decrease to less than 0.1 p.u. for period of time not exceeding 60 seconds.

ii) Long-duration voltage variations: Any variation in the supply rms voltage at fundamental frequency for duration exceeding one minute is known as Long-duration voltage variations. This is further classified as:

- Overvoltage (or Undervoltage): It is a 10% or more increase (or decrease) in rms voltage for more than one minute.
- Sustained interruption: In case of zero supply voltage for time period exceeding one minute, it is termed as 'Sustained interruption'.

iii) Voltage imbalance and voltage fluctuation: Condition in which the voltages of three-phase supply are not equal in magnitude and may not even be equally displaced in time is called as voltage imbalance. Voltage fluctuation is defined as a systematic random variation in supply voltage whereas very rapid change in supply voltage is called as voltage flicker.

iv) Waveform distortion: This is the steady state deviation in voltage or current waveform from an ideal sine wave. These are observed in following forms:

- D.C. offset: Presence of a d.c. voltage or current in a.c. power-system is termed as D.C. offset.
- Harmonics: A sinusoidal waveform with frequencies that are multiples of frequency at which the supply voltage is designed to be delivered. Its measure is total harmonic distortion (THD) is given as:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \quad (2.1)$$

  Where; V_n= magnitude of n^{th} harmonic voltage, V_1= magnitude of fundamental voltage
- Notching: Notches are steady state power disturbances containing sudden spikes which naturally give rise to high frequency content.

v) Power frequency variation: These are usually caused by rapid changes in load connected to the system.

Detail description of these faults is as represented in table 2.1 below. [11], [12]

TABLE I
TYPES, CAUSES AND EFFECTS OF PQ DISTURBANCES

PQ disturbances	Types	Causes	Effects
Short-duration voltage variation	Voltage Sag, Swell Interruptions	System Faults, Energization of large loads	Ripple in A.C. Motor,
Long-duration voltage variation	Overvoltages Undervoltages Sustained Interruptions	Switching of a large load, Energization of large capacitor bank	Premature equipment failure due to increase of electrical stress
Voltage imbalance and fluctuation		Rapid variation in load-current magnitude, High inrush current	Voltage dip Brown-out
Waveform Distortion	D.C. offset Harmonics Notching	Geomagnetic disturbances, Poor grounding,	Increase in Transformer losses

III. DIAGNOSIS OF PQ DISTURBANCES

Diagnosing a power quality disturbance means identifying the type and cause of the disturbance. Fast diagnosis of PQ disturbances is important so as to assist network operators in performing counter measures and implementing suitable PQ mitigation actions. To analyze power signals, various signal processing techniques such as Fourier transformation methods, wavelet transform and S-transform are commonly applied. Also, artificial intelligence (AI) techniques have found their application in this field of power system. Application of hybrid methodology by embedding above two techniques for diagnostic purposes is also successfully practiced by some researchers. This section further discusses each of these methodologies as follows:

A. Fourier transform (FT):

The connection between time and frequency domains is made by the FT that use orthogonal sinusoidal basis function showing the signal as an expansion. Complicated periodic function are written as the sum of simple waves mathematically represented by sine and cosines using FT. [13] Various forms of FT applied for PQ analysis are as follows:

i)Discrete Fourier Transform (DFT): Fourier Transform applied to signals that repeat themselves in a periodic fashion from negative to positive infinity is most often called the Discrete Fourier Transform. For a finite length discrete signal x[n], it's DFT and frequency function is given as in equation (3.1) and (3.2) respectively;

$$X(f) = \frac{1}{N}\sum_{n=0}^{N-1} x[n] e^{\frac{-j2\Pi nf}{N}} \quad (3.1)$$

$$x(n) = \sum_{n=0}^{N-1} X[f] e^{\frac{j2\Pi nf}{N}} \quad (3.2)$$

For non-uniform DFT, Goertzel's algorithm is most popular. [14]

ii) Fast Fourier Transform (FFT): FFT exhibit advantage over DFT that it reduces the computational complexity from N in DFT to N logN multiplications with same results. Cooley and Tukey (1948) came up with a computational breakthrough of FFT which allows the computation of N point DFT as a function of only 2N instead of N^2. The FFT of signal x[n] decomposed into odd and even part can thus be written as,

$$FFT(x,f) = \frac{1}{2N}\sum_{n=0}^{N-1} x[2n] e^{\frac{-j\Pi(2n)f}{N}} + \frac{1}{2N}\sum_{n=0}^{N-1} x[2n+1] e^{\frac{-j\Pi(2n+1)f}{N}} \quad (3.3)$$

FFT is still one of the most commonly used operations in digital signal processor and all modern signals processing to provide a frequency spectrum analysis. [15]

iii) Short Time Fourier Transform (STFT): This technique is applied to improve the analysis for signals whose spectrum changes with time. It is calculated by repeatedly multiplying the time series with shifted short time windows and performing a DFT on it. Here the window helps to localize the time-domain data before obtaining the frequency domain information. STFT for continuous time signal is given as;

$$X(\tau,\omega) = \int_{-\infty}^{\infty} x(t)\omega(t-\tau) e^{-j\omega t} dt \quad (3.4)$$

Where; x(t)= signal to be transformed, w(t)=window function, $X(\tau,\omega)$ = FT of $x(t)\omega(t-\tau)$. In case of discrete signal with 'm' as discrete time-shift, it can be expressed as in equation 3.5; [16], [17]

$$X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n]w[n-m]e^{-j\omega n} \qquad (3.5)$$

However, STFT of a signal has constant window length which limits non-stationary signal resolution. To overcome this resolution problem using STFT, a signal processing tool, Wavelet Transform (WT), had been widely implemented in PQ analysis. This technique is as discussed further. [18]-[23]

B. *Wavelet transform:*

WT use wavelets to decompose any signal for detailed analysis with multiple time–frequency resolution. [24,25]. In the decade of 90's WT technique was first practiced for analysis of non-stationary signals in power-system. [26-33] Unlike STFT, the length of the smoothing window of the WT depends on the frequency analyzed: long windows are used at low frequencies, and short windows at high frequencies. Also, WT have infinite sets of possible basis function often known as 'Mother Wavelet'. WT is commonly observed in mainly two forms namely: Continuous wavelet transform (CWT) and Discrete wavelet transform (DWT). CWT is given as in equation (3.6).

$$XWT(\tau,s) = \frac{1}{\sqrt{s}} \int x(t).\Psi(\frac{t-\tau}{s})dt \qquad (3.6)$$

Where; x(t)=signal to be analysed, $\psi(t)$ is the mother wavelet, s and τ represent scale and translational parameters respectively.

DWT is a discrete counter of CWT which implements the WT using a discrete set of the wavelet scales and translations obeying some defined rules. DWT decomposes the signal into mutually orthogonal set of wavelets. [35], [36]

C. *S-transform:*

S-transform is an extension of ideas of CWT. S-transform that provides a time-frequency with frequency-dependent resolution while, at the same time, maintaining the direct relationship, through time-averaging, with the Fourier spectrum.[36] The basis functions for the S-transform are Gaussian modulated cosinusoids, so that it is possible to use intuitive notions of cosinusoidal frequencies in interpreting and exploiting the resulting time-frequency spectrum. S-transform has unique properties uniquely combines frequency dependent resolution with absolutely reference phase, so that the time average of the S-transform equals the Fourier spectrum. It simultaneously estimates the local amplitude spectrum and the local phase spectrum, whereas the CWT approach is only capable of probing the local amplitude and power spectrum. S-transform of signal h(t) is given as;

$$s(\tau, f) = \frac{|f|}{\sqrt{2\Pi}} \int_{-\infty}^{\infty} h(t) e^{\frac{-(\tau-t)^2 f^2}{2}} e^{-i2\Pi ft} dt \qquad (3.7)$$

Where; t and τ represent time whereas f represent frequency.

D. *Artificial Intelligence (AI):*

AI can be the automation of activities that are associated with human thinking, such as decision making, problem solving, learning, perception, and reasoning. The AI tools of interest to the electric power community include fuzzy logic (FL), adaptive fuzzy logic (AFL), expert system (ES), artificial neural networks (ANN) and genetic algorithms (GA).[37] These AI techniques had been extensively applied in different domains of electric power system. [39]-[40] Due to its inherent advantages these AI techniques are also implemented for analysis of PQ disturbances. [41]-[43]

ES which emulate human thought process through knowledge representation and inference mechanism are applied for detection of PQ problems like harmonics as well as for classification of PQ disturbances. [44], [45] Researchers have also reported the integrated approaches with other techniques for PQ disturbances. [46]

ANN has capability of non-linear function approximation and had been widely implemented in this domain. [47]-[50]. As ANN is self-learning system, along with conventional training algorithms, an approach for hybrid algorithms as well as combined approach of ANN with wavelet and s-transform had been adopted. [51] -[56]. For industrial applications and recent concepts like distributed generation, ANN has found its application for PQ analysis and improvement. [57], [58]

FL is a variation of crisp logic and provides a strong technique for natural knowledge representation. [59] FL embedded with transform techniques in PQ diagnose issues like allocating capacitor banks while maintaining harmonic distortion levels within acceptable limits, estimating power quality indices using fuzzy constraints, locating sources of disturbances in power systems and power-factor improvement [60]-[62]. Recent work by researchers focuses on implementation of combined approach using the transform and AI techniques so as to utilize special characteristic of each technique as in [63].

GA is an excellent intelligent paradigm for optimization using a multipoint, probabilistic, random, guided search mechanism. Thus, it is generally applicable as tool for optimal selection so as to reduce total contents of harmonics of system. [64], [65] Further [66] reports its implementation for ANN parameter optimization to avoid trapping of ANN in local minima and hence to improve accuracy of PQ level determination.

IV. CONCLUSIONS

In recent time, maintaining power quality standards had been a major concern for electric utilities. Researchers in power quality domain confronted a challenge of accurately analyzing the disturbances in it. Transform techniques like discrete and fast fourier transform gave a basic tool for this purpose. However, to overcome limitations of these transform techniques in case of non-stationary signals, windowed techniques like Wavelet and S-transform, which suits better for feature extraction of waveforms were implemented. Recent approaches implement the artificial intelligence techniques for automating the analysis process. Techniques like artificial neural network and fuzzy logic in combination with mathematical tools improved the diagnostic accuracy to a remarkable level. Also application of optimization tool like genetic algorithm helped to optimize the process parameters and hence further improvement of accuracy.

REFERENCES

[1] Dugan RC, Mcgranaghan MF, Santoso S, Beaty HW. Electrical power systems quality. Mc Graw-Hill; 2002. pp. 28–9.

[2] IEEE Std. 1366. IEEE standard guide for power distribution reliability (2003).

[3] IEEE 1159.3. IEEE recommended practice for the transfer of power quality data

[4] ANSI IEEE 1159.3 Recommended Practice for the Transfer of Power Quality Data (2009)

[5] BS 5750 Recommended Practice for the Quality Assurance (1996)

[6] Suresh Kumar. K. S, Dr. Ashok. S, National Institute of Technology Calicutm, Kerala, India , 2000.

[7] US–Canada power system outage task force. Final report on the Aug, 14, 2003 blackout in the United States and Canada: causes and recommendations; Apr,04.

[8] Hamid EY, Kawasaki ZI. Wavelet-based data compression of power system disturbances using the minimum description length criterion. IEEE Trans Power Deliv 2002;17(2):460–6

[9] Dash PK, Panigrahi BK, Sahoo DK, Panda G. Power quality disturbance data compression, detection, and classification using integrated spline wavelet and S- transform. IEEE Trans Power Deliv 2003;18(2):595–600.

[10] Poisson O, Rioual P, Meunier M. New signal processing tools applied to power quality analysis. IEEE Trans Power Deliv. 1999;14(2):561–6.

[11] Fanibhushan Sharma, A. K. Sharma, Ajay Sharma, Nirmala Sharma "Recent Power Quality Techniques A Comparative Study", Canadian Journal on Electrical & Electronics Engineering Vol. 1, No. 6, October 2010.

[12] IEEE Recommended Practice for Monitoring Electric Power Quality, IEEE Inc.,New York, USA, 1995.

[13] Bracewell, R. N. (2000). The Fourier Transform and its Applications. McGraw- Hill Book Co, Singapore.

[14] Bhim Singh,Kamal Al-Haddadf,"A Review of Active Filters for Power Qualit Improvement",IEEE Transactions on Industrial Electronics Vol 46 (5) Oct 1999.

[15] Chassaing, R. (2005). Digital Signal Processing and Applications with the C6713 and C6416 DSK. John Wiley & Sons. Inc., Hoboken, New Jersey.

[16] Qian S., Chen D., "Understanding the nature of signals whose power spectra change with time-joint analysis", IEEE Signal Processing Magazine, 1999.

[17] Qian S., Chen D., "Discrete Gabor Transform", IEEE transaction signal processing, Vol. 41(7), pp. 2429-2439.

[18] Hlawastch F and Krattcnthaler W., "Bilinear Signal Synthesis", IEEE transaction Signal processing, Vol. 40(2), pp. 352-363

[19] P. Pillay, P. Ribeiro, and Q. Pan, "Power quality modeling using wavelets," in IEEE Proceedings of the 7th International Conference on Harmonics and Quality of Power (ICHQP), Las Vegas, NV, USA, October 16–18, 1996, pp. 625–631.

[20] S. Santoso, E. J. Powers, W. Mack Grady, and P. Hofmann, "Power quality assessment via wavelet transform analysis," IEEE Transaction on Power Delivery, vol. 11, no. 2, pp. 924–930, April 1996.

[21] D. C. Robertson, O. I Camps, J. S. Mayer, andW. B. Gish, "Wavelet and electromagnetic power system transients," IEEE Transaction on Power Delivery, vol. 11, no. 2, pp. 1050–1058, April 1996.

[22] N. S. Tunaboylu and E. R. Collins, "The wavelet transform approach to detect and quantify voltage sags," in Proceedings of the 7th International Conference on Harmonics and Quality of Power (ICHQP), Las Vegas,NV, USA, October 16–18, 1996, pp. 619–623.

[23] L. Angrisani, P. Daponte, M. D'Apuzzo, and A. Testa, "A new wavelet transform based procedure for electrical power quality analysis," in Proceedings of the 7th International Conference on Harmonics and Quality of Power (ICHQP), Las Vegas, NV, USA, October 16–18, 1996, pp.608–614.

[24] O. Rioul and M. Vetterli, "Wavelets and signal processing," IEEE Signal Processing Magazine, pp. 14–38, October 1991.

[25] A. Grossmann, J. Morlet, Decomposition of Hardy functions into square integrable wavelets of constant shape, SIAM J. Math. Anal. 15 (1984) 723–736.

[26] S.G. Mallat, A theory for multiresolution signal decomposition: the wavelet representation, IEEE Trans. Pattern Anal. Mach. Intell. 11 (1989) 674–693.

[27] P.F. Ribeiro, Wavelet transform: an advanced new tool for analyzing nonstationary harmonic distortion in power systems, IEEE Int. Conf. Harmonics Power Syst. (1994) 365–369.

[28] S. Santoso, E.J. Powers, W.M. Grady, Electric power quality disturbance detection using wavelet transform analysis, in: IEEE – SP Int. Symposium on Time–Frequency and Time Scale Analysis, 1994, pp. 166–169.

[29] Robert D. Nowak and Richard G. Baraniuk, "Wavelet-Based Transformations for Nonlinear Signal Processing", IEEE transactions on Signal Processing, 47(7) (1999) 1852–1865.

[30] L. Agrisani, P. Daponte, M.D. Apuzzo, and A. Testa, "A measurement method based on the wavelet transform for power quality analysis", IEEE Trans. Power Delivery, vol. 13, 990-998, Aug 1998.

[31] P. Pillay, A. Bhattacharjee, Application of wavelets to model short-term power system disturbances, IEEE Trans. Power Syst. 11 (1996) 2031–2037.

[32] W.A. Wilkinson, M.D. Cox, Discrete wavelet analysis of power system transients, IEEE Trans. Power Syst. 11 (1996) 2038–2044.

[33] G.T. Heydt, A.W. Galli, Transient power quality problems analyzed using wavelets, IEEE Trans. Power Deliv. 12 (1997) 908–915.

[34] O. Rioul and M. Vetterli, "Wavelets and signal processing," IEEE Signal Processing Magazine, pp. 14–38, October 1991.

[35] M.B. Hughes, J.S. Chan and D.O. Koval: Distribution Customer Power Quality Experience,IEEE Trans. Ind. Applicat., Vol. 29, pp. 1204-1211, Nov./Dec. 1993.

[36] Stockwell, R.G.; Mansinha, L.; & Lowe R. P. (1996). Localization of the complex spectrum: the S-Transform. IEEE Transactions on Signal Processing 44(4),pp. 998-1001.

[37] Wael R., Anis Ibrahim and Medhat M. Morcos, "Artificial Intelligence and Advanced Mathematical Tools for Power Quality Applications: A Survey", IEEE transactions on power delivery, VOL. 17(2), pp. 668-673, APRIL 2002.

[37] S. Madan and K. E. Bollinger, "Applications of artificial intelligence in power systems," Elect. Power Syst. Res., vol. 41, pp. 117–131, 1997.

[38] C.-C. Liu, "Intelligent systems applications to power systems," IEEE Comput. Appl. Power, vol. 10, pp. 21–24, 1997.

[39] M. E. El-Hawary, "Electric Power Applications of Fuzzy Systems" New York: IEEE Press, 1998.

[40] M. Kezunovic and I. Rikalo, "Automating the analysis of faults and power quality," IEEE Comput. Appl. Power, vol. 12, pp. 46–50, 1999.

[41] M. Kezunovic, G. T. Heydt, J. Schilleci, G. Lambert-Torres, T. Key,and D. G. Kreiss, "Intelligent system applications to power quality and substation automation," in IEEE Power Eng. Soc. Summer Meeting, Edmonton, AB, Canada, 1999.

[42] S. Naoussi, et al., "FPGA Implementation of Harmonic Detection Methods Using Neural Networks", 13th International Conference on European Power Electronics and Applications, pp. 1–10, 2009.

[43] D. D. Shipp, W. Vilcheck, M. E. Swartz, and N. H. Woodley, "Expert system for analysis of electric power system harmonics," IEEE Conference on Annual Pulp Paper Industry, pp. 12–19,1993.

[44] D. D. Shipp, W. Vilcheck, M. E. Swartz, and N. H. Woodley, "Expert system for analysis of electric power system harmonics," IEEE Conference on Annual Pulp Paper Industry, pp. 12–19,1993.

[45]J. Schlabbach, "Expert System Measures Harmonics and EMC," IEEE Comput. Appl. Power, vol. 7, pp. 26–29, 1994.

[46]M. Faisal, A. Mohamed, H. Shareef, A. Hussain, "Power Quality diagnosis using time frequency analysis and rule based techniques ", Expert System with Applications, vol. 38, pp. 12592-12598, 2011.

[47] A. K. Ghosh and D. L. Lubkeman, "Classification of power system disturbance waveforms using a neural network approach," IEEE Trans. Power Delivery, vol. 10, pp. 109–115, Feb. 1995.

[48] P. K. Dash, S. K. Panda, A. C. Liew, B. Mishra, and R. K. Jena, "New approach to monitoring electric power quality," Elect. Power Syst. Res., vol. 46, no. 1, pp. 11–20, 1998.

[50] Hongzhi Zang, Jinan, Yishu Zhao, "Intelligent Identification System of Power Quality Disturbance" WRI Global Congress on Intelligent Systems, Vol. 1, pp. 258 – 261, 19-21, May 2009.

[51] Elango M.K., Kumar A.N., Duraiswamy K, "Identification of power quality disturbances using Artificial Neural Networks", IEEE Conference on Power and Energy Systems, pp. 1 – 6 , 2011.

[52] Huang, N.T. , Zhang, Y.J. Xu, D.G., Liu, X.S. , Qi, J.J. "Power quality disturbances classification by ensemble and hybrid Neural networks", International Conference on Power System Technology, pp.1-7 , 24-28 Oct. 2010.

[53] Liu Hua; Wang Yuguo; Zhao Wei, " Power Quality Disturbances Detection and Classification Using Complex Wavelet Transformation and Artificial Neural Network Control",Chinese Digital Object Identifier, pp, 208 – 212, 2007.

[53] Guo-sheng Hu, Feng-feng Zhu, You-zhi Zhang , "Power Quality Faint Disturbance Identification Using Wavelet Packet Energy Entropy and Weighted Support Vector Machines", Third International Conference on Natural Computation, Vol. 5, pp. 649 – 653, 2007.

[54] Yinghui Kong, Jinsha Yuan , Tianshu Bi , Tiefeng Zhang, " Online power quality disturbances identification using incremental wavelet decomposition and support vector machine", Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, pp. 1841 – 1846, 6-9 April 2008..

[55] Yuliang Liu , Li Zhao , Shigang Cui , Qingguo Meng , Hongda Chen, "Quantum-behaved particle swarm optimization -ANN based

identification method for typical power quality disturbance", China,pp. 1103-1108.

[56] Wei Liao, Hua Wang, Pu Han, " Neural network-based detection and recognition method for power quality disturbances signal", International Conference on Control and Decision, China, pp.1023–1026,26-28 May 2010.

[57] Ipinnimo. O., Chowdhury S., Chowdhury S. P. " ANN-based voltage dip mitigation in power networks with distributed generation", IEEE Power Systems conference and Exposition, pp. 1-8, 20-23 March ,2011.

[58] Manke P.R., Tembhurne S.B., "Artificial Neural Network Classification of Power Quality Disturbances Using Time-Frequency Plane in Industries", First International Conference on Emerging Trends in Engineering and Technology, pp. 564 – 568, 2008.

[59] E. Cox, "Fuzzy fundamentals," IEEE Spectrum, vol. 29, pp. 58–61, Aug. 1992.

[60] R. M. Martins, A. de Oliveira, and S. F. de Paula Silva, "New proposal to capacitor bank allocation using fuzzy logic," in Proc. 2nd IEEE Int. Conf. Power Electron., Drives Energy Syst. Industrial Growth, vol. 2, Perth, Australia , pp. 598–603,1998.

[61] Morsi W.G., El-Hawary M.E., "A new fuzzy-wavelet based representative quality power factor for stationary and nonstationary power quality disturbances", IEEE Conference, pp.1 – 7, 26-30 July 2009 .

[62] Ming Zhang, Kai-Cheng Li, Wei-Bing Hu, "Automated classification of power quality disturbances using the S-transform", International Conference On Wavelet Analysis and Pattern Recognition, pp 321-326, 2008.

[63] Sulaiman, M.S., Mohd Yasin, F.Kamada, M., Reaz , "Expert System for Power Quality Disturbance Classifier", Power Delivery, IEEE Transactions Vol 22, Issue 3,pp 1979 – 1988. July 2007.

[64] M.A.Choudhry and S. Rahman, "Generic algorithm to select building lighting technologies for minimizing total harmonic distortion," Energy, vol. 20, no. 10, pp. 1027–1036, 1995.

[65] G. Levitin, A. Kalyuzhny, A. Shenkman, and M. Chertkov, "Optimal capacitor allocation in distribution systems using genetic algorithm and a fast energy loss computation technique," IEEE Trans. Power Delivery, vol. 15, pp. 623–628, Apr. 2000.

[66] Shuai Yuan, Autom., Weiming Tong,Chengde Tong, Zhongwei Li " A Novel Method for Power Quality Comprehensive Evaluation Based on ANN and subordinate Degree" Fourth International Conference, Vol. 4, pp 62 – 65, 18Oct. 2008.

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