IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

ANALYSIS OF ELECTRICITY SUPPLY IN THE DISTRIBUTION NETWORK OF POWER SECTOR

Rajender Kumar Beniwal[1], Akanksha Aggarwal [*1], Rohit Saini[2], Sunita Saini[3]

[*1] Department of Electrical Engineering, DCR University of Science & Technology, Murthal, India
[2] Department of Electronics & Comm. Engineering, Hindu College of Engineering, Sonipat, India
[3] Department of Management Studies, DCR University of Science & Technology, Murthal, India

DOI: 10.5281/zenodo.1173535

ABSTRACT

Nowadays, consumers of electricity are demanding for better quality of services and this creates competition in power utility companies to provide better services which are reliable as well as efficient and less costly also to their consumers. Assessment of PQ problems is a tedious task and the various aspects of power system and equipment modelling, disturbance mitigation and data analysis are involved in it. The majority of the work is focused on the distribution system where the sensitive equipments experience interference under different kinds of power disturbances from the system and the local network. For the effective mitigation of these disturbances, some knowledge about PQ events and its effects on equipment is important. So, in this concern PQ is a challenging issue in current scenario. The main aim of this review paper is to investigate different techniques reported by the researchers for detection and classification of PQ events.

KEYWORDS: Power quality, Distribution network, Power sector.

I. INTRODUCTION

All PQ can be defined in different ways but most of the time it is related with voltage quality [1, 61, 65-70]. In other words, it is only the interaction of electric power with electric equipments. Now, if the equipment works properly without any malfunctioning or damage, then it will be said that the quality of power is good and vice-versa [54, 56, 60]. There may be some symptoms which show that the quality of power is bad, such as if any electric equipment frequently fails to operate in a proper manner, failure of equipment during cloud burst or thunderstorm, or if regularly equipment mis-operates during the same time of the day. In another sense, PQ is any deviation from normal of either a DC or AC voltage source or any change in the magnitude, frequency or wave shape can be classified as a PQ issue. Voltage sag, swell, impulsive & oscillatory transient, flicker, noise, harmonics, inter-harmonics, outage, notching, and interruption are some type of PQ disturbances [48-52]. There is also possible occurrence of more than one type of disturbance at the same time.

The need of regular monitoring of PQ in sensitive industrial and commercial plants arises due to extensive use of power electronics in every field, such as residential, commercial and industrial [1]. Electronic devices and nonlinear loads are very much sensitive to the disturbances and thus cause malfunctioning and reduced life of the equipments directly and degradation of PQ indirectly [2]. Hence, the need of disturbance free electricity at all levels of its usage is growing which makes detection and classification of PQ events vital for the power system.

Another problem is that these events are highly varying in time and frequency domain which makes their automatic classification difficult [63, 64]. To solve such problems, the interest is growing in the development of new approaches and methodologies for detection and classification of PQ disturbances [59]. Signal processing techniques make the analysis easier [3].PQ events are not only restricted to energy efficiency but strictly related with continuity of supply to the end-users. Thus, it is a major thrust point for electric companies and consumers.

Further before their mitigation, the sources of disturbance and their possible causes should be in knowledge. The sources, those are generally responsible for PQ problems cannot be easily detected. They may be user load, utility generation system, utility transmission and distribution system, and weather related problems. Some PQ problems are related to frequency deviations. These problems are generally harmonics or inter-harmonics and caused by

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

converters, reactors, and nonlinear loads whereas problems related to voltage magnitude deviations which are flicker, sag, and transient-overvoltage, are resulted from the arc furnaces operation and heavy load starting.

II. LITERATURE REVIEW

Power demand is increasing day by day so as the complexity and PQ problems in the network [47, 58]. For detection and classification of PQ events various signal processing tools have been proposed by the researchers in [5]. Further intelligent techniques used for classification were also discussed along with some optimization techniques [53-57]. Different strategies for analysis of non-stationary signals have been compared such as STFT, GT, ST, WT, KF etc. [4]. These techniques have been compared on the basis of frequency and time resolution, convergence, signal-to-noise ratio. Similarly, the algorithms used for classifying power disturbances were compared such as ANN, SVM, FL, BC, MLP, k-NN and BPNN. These classifiers have been compared on the basis of classification accuracy, flexibility and time consumed. Some more techniques other than traditional techniques as discussed above are also used by the researchers in some of the reported articles such as HHT, 3-D space representation and TT-transform based for analyzing of PQ events.

WT is an effective technique for feature extraction of non-stationary signal. Combination of WT with artificial intelligent methods can be used for the classification purpose. WT have been used by researchers in various applications other than PQ. The applications of wavelets in analysis of PQ have been described in [6]. In [6], authors described the wavelet based methods for feature extraction. Wavelets are also used in combination with the advanced classification algorithm to improve the classification performance as in the literature. Various de-noising approaches based on wavelet have been reported.

In the wavelet-based methods it is necessary to use de-noising scheme because in case of noise high frequency components overlap with the noise, and it is difficult to understand the difference between noise and the disturbance. Another form of wavelet i.e., multiwavelet approach has been also used for detection and analysis of PQ events in [7, 8]. In comparison with all single wavelets, Multiwavelets resolve the signal better as they are based on two or more than two scaling functions. Dempster-Shafer (DS) classifier, an intelligent classifier along with two sub-classifiers i.e., heuristic classifier and statistical classifier have been used. Performance of the algorithm has been compared with ST and WT.

PQ events and the disturbances (which occur after a fault event) have been classified in [9]. Three-phase voltage signals are first passed to normalization and segmentation techniques. And then two stage feature extraction process have been suggested for feature extraction from such signal by applying WT. Now to classify the PQ events, the extracted features of reduced size have been applied to SVM classifier. In the last, the type of disturbance related to each fault event has been recognised using decision tree algorithm.

A different approach based on image processing (gray scale image and binary image) is used to detect the single PQ disturbances. First, gray scale image of the disturbed voltage waveform is represented and this detects the disturbance area by comparing it with gray scale pattern of pure voltage waveform. In the next step, image enhancement techniques are applied on the feature sets of the disturbances to make them livelier. For the classification purpose, binary image analysis has been performed in [10].

Optimal feature set play a vital role in analysis of PQ events. The performance of selected features for a particular classifier has been noticed in [11]. This started with large number of features and finally by using feature selection technique, useful feature subset has been extracted. The feature selection technique also depends on the classifier used. Hence, features optimized according to the classifier used which further helps in efficiently classifying the PQ events. Eight feature selection methods have been described and used along with Bayes and SVM classifier.

In [12], ST and TT-Transform are used for the purpose of feature extraction from the power signal. Probabilistic neural network based feature selection has been used for eliminating the non-essential features and combined of the fully informed particle swarm and an adaptive probabilistic neural network techniques. Out of 62 features only five features selected for classification. Hence, the use of feature selection technique gave the optimal feature set. The classifiers used by the authors were MLP, k-NN and adaptive probabilistic neural network techniques. The results indicate that this optimal feature selection technique enhanced the performance of the classifiers even in the noisy environment.

In some cases, only short-duration disturbances such as sag, swell, transient have been considered. In [13], short-duration disturbances were detected using modified potential function approach. By using potential function, a fast real-time track and detection algorithm has been developed which gives the diffusion matrix. This parameter detects the presence of disturbance in the signal. On the basis of threshold value, the algorithm is able to classify the short-duration disturbances.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

In [14], another suggested a technique for detection of short-duration disturbances. Here, discrete wavelet transform (DWT) is used for detecting the starting and ending point along with magnitude of the voltage sag and also for detecting the rapid change in the signal that allows time localization of different frequency components of a signal. The sag detector developed using DWT is mainly consists of zero-crossing detector and dsPIC microcontroller unit. When AC line voltage falls to zero, zero-crossing circuit generates pulse and dsPIC calculates critical value using DWT. The calculating process of dsPIC takes 32 µs for 64 samples; hence it is less than the sampling time. If the calculated critical value is less than the desired value, voltage sag has occurred.

Another different method for the classification of the like sag, swell, transient, spikes, harmonics, interruption, notches is without using any classifier but by using the S-transformed module time-frequency matrix (MTFM). This technique is based on MTFM for various short-duration disturbances and then calculating the similarity among the MTFMs of standard and tested short-duration disturbances and classified as per the similarity scheme [15].

To detect and then classify PQ disturbances, an energy difference multiresolution analysis (EDMRA) approach is developed by the authors in [16]. Sampled signal has been decomposed to several levels by using MRA. At each level of decomposition, squared value of detail information is calculated as their energy and then it is used to construct the feature vectors which are used for analysis. To make it more effective and for reduction in unnecessary computational cost, it's preferred to find the minimum decomposition level. The employed technique has been also tested under noisy condition.

In [17], authors proposed an approach which was 3D-space representation. In this method, PQ disturbances characterized in terms of variance, sample matrix, eigen value, correlation matrix, eigen vector and normalized error signal. Principle Component Analysis approach used for classification purpose. Authors focus on the use of statistical estimator to detect anomalies which mainly preserve the power line frequency. Variance, skewness and kurtosis estimators were used for detection. In such a way higher-order statistical estimators has been used for classification of PQ events [18].

Authors reported a method based on independent component analysis (ICA) for separation of multiple disturbances. It is an analysis technique blindly used for source separation and it finds components that are as independent as possible hence had application in the field of signals having multiple disturbances, but the ambiguities also arises with ICA such that we cannot determine the variance and order of the independent components. As ICA is originally applied to multivariate data, a pre-processing step is also employed for ICA which includes filter banks. The performance of employed technique has been compared with DWT, for decomposition of combined PQ disturbances [19].

KF provides the information regarding any change in phase angle and magnitude of the voltage during an event. Filter response depends upon the signal-to-noise ratio, system model and filter parameters. Its extension to EKF reduces the limitation of KF regarding nonlinearity, but computational complexity increases as well as convergence problem arises if proper tuning of filter is not done. In [20], authors reported a technique of using three KFs to estimate the RMS magnitude and phase angle of three phase voltage signal in real-time [62, 65]. KF and DWT also used jointly by the authors to identify power system disturbances [21]. KF only works for linear system models and its nonlinear version is known as Extended KF. DWT and EKF jointly also used in [22], to provide accurate starting and ending of voltage event along with proper estimation of magnitude and phase angle of voltage supply during the event. In this, DWT has been used to extract the noise from the analyzed signal. Then, the covariance of this noise along with analyzed signal fed to KF which further enhanced the performance of the reported system.

A rule–based method for the classification of the PQ disturbances single as well as multiple considered. Here, multiresolution S-transform used for the purpose of feature extraction from the signal and rule-based classification algorithm used for identification of disturbance. Several sources are considered to obtain distorted signals i.e., synthetic signals obtained from MATLAB, simulated signals using PSCAD/EMTDC, real signals obtained by a data acquisition system. The suggested framework classifies the complex disturbances in noise [23].

In [24], authors suggested EMD in combination with HT which becomes HHT for detecting the causes of voltage sag. EMD is a process of decomposition applied on non-stationary and nonlinear signals to achieve various IMF components. For extraction of features, HT is applied on these IMF components. And finally, PNN classifier used to classify the causes of voltage sag. With EMD, problem of mode mixing has been arrived. To handle this problem, authors of [25] investigated the performance of ensemble EMD (EEMD) and then its performance has been compared with the EMD. Hence, HHT becomes combination of HT and EEMD. Features for first IMFs, instantaneous amplitude and instantaneous frequency have been calculated. Further singular value decomposition (SVD) has been used to calculate the singular values and to improve the exact classification rate of SVM.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

In [26], authors suggested the PQ disturbance assessment using chaos synchronization-based detector. It has been designed such that it can track the dynamic error. These dynamic error equations used for feature extraction and construction of various butterfly patterns. The trajectories of these patterns show motions in various bounded regions for disturbances. Such a motion gives an idea about starting and ending point of the disturbance occurrence. In addition to this, particle swarm optimization (PSO) algorithm and PNN classifier have been used.
Another analysis performed by hybrid demodulation concept described in four major steps [27]. In the first step, multiple PQ events have been differentiated from single events using correlation and threshold values. The threshold values of Cross-correlation (XCF) distinguish the difference between single and multiple PQ events. In the next step, single PQ events are analyzed and in the third step, multiple PQ events have been analyzed. Afterwards in the last step, separate knowledge bases have been designed for such events using hybrid demodulation and multiple signal classification (MUSIC) algorithm concept. These knowledge bases are then utilized by the fuzzy classifier. Two fuzzy classifiers fuzzy product aggregation reasoning rule classifier and fuzzy explicit have been used for the better suitability of this approach in classification of overlapped and ill-defined PQ events.
For detection as well as for classification of disturbances, intelligent method i.e. fuzzy systems have been used along with particle swarm optimization algorithm [28]. First, fuzzy system was expertise for detection purpose and second one for classification work. Feature extraction performed using FT and WT. Extracted features have been given to fuzzy systems as their inputs. To further improve the accuracy, PSO technique was used for optimization of membership function of fuzzy systems. Another form in which FL has been used fuzzy-C-means algorithm. This algorithm used for grouping of data into clusters and then the class of data identified. But it suffered from various issues such as trial and error method for choice of initial cluster centers. Hence to avoid this and to refine the cluster centers, various optimization techniques were used. In [29], hyperbolic S-transform as feature extractor tool and GA based fuzzy-C-means algorithm has been used for classifying disturbances. Hence it found from the results that hybrid fuzzy C-means and GA gave better results than the fuzzy C-means algorithm alone.
FL when aggregated with ART (adaptive resonance theory) and neural network gave fuzzy-ARTMAP-NN, used in [30] to classify the voltage type disturbance with high accuracy rate. In this paper, DWT, multiresolution analysis and entropy norm concepts were used for extracting the features. Mathematical models and simulation using ATP software have been used to obtain various PQ events, single as well as combined.
Wavelet based analysis performed in [31], for both type of events, single as well as multiple. DWT used to de-noise the distorted waveform and to extract feature vectors. De-noising technique consists of three tasks, decomposition, selection of threshold and reconstruction. DWT's de-noising performance is depends on the value of threshold chosen. To optimize the combination of feature vectors, PCA approach preferred. After this, feature vectors applied to the wavelet network (WNs) classifier for its training. This works well even in the presence of noise. Various advantages of WNs over ANN have been given in the article.
The ST based fuzzy expert system (FES) has been suggested by the authors for PQ time series data mining. Data mining approach has been associated with fuzzy system to provide a certainty factor for each classification rule. Analyzed signals have been processed by ST and hence features were extracted. They were then fuzzified using proper membership function and then passed to FES in [32]. In [33], authors reported framework of automatic classification of PQ events with the use of WPT and SVM along with optimization techniques. WPT used for feature extraction from the disturbed signal. Afterwards the GA and simulated annealing have been used to get the desired feature sets. These selected features were act as input to SVM classifier. The performance of the method have been compared with PNN and fuzzy k-NN classifier and hence outperformed.
In [34], generalized form of TT-transform [35] used to accommodate arbitrary scalable windows and it resolves the times of event initiation, when it is jointly used with generalized ST. Now the extracted features from TT-transform are used to classify the disturbance through Fuzzy-C-means algorithm. Out of various extracted features clustering has been done of variance and normalized values. To enhance the classifier accuracy Adaptive Ant colony optimization (ACO) technique has been used.
In [36], authors proposed a scheme for classification and characterization of PQ events. This technique is based on multiresolution S-transform and Parseval's theorem. The instantaneous frequency vector obtained from the multiresolution S-transform afterwards based on Parseval's theorem, energies of these vectors are utilized in distinguishing the type of disturbance. Using these energies, simple rules have been developed and then by using these rules, classification of disturbances have done.
In [37], a simple method of classification and representation of voltage sags and short interruption has been proposed. This method classifies the events according to a rule which calculates the characteristics of the three-

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

phase voltages during the disturbance. This method provides individual phase voltages information during the disturbance, rather than just a single magnitude and duration. In [38] the PQ events have been divided into two groups and respective to these groups; different methods for their detection and classification were used. Digital filtering and mathematical morphology have been used for detection of transients and waveform distortions. On the other hand short and long-duration disturbances are detected using RMS value. But this method is unable to differentiate some disturbances like harmonics and inter-harmonics hence marked it under the group of waveform distortion.

Some statistical methods were also used by the researchers for analysis of PQ events. In [39] deviation from the Gaussian behaviour of the voltage waveform has been evaluated. Non Gaussianity is a sign of having disturbance in the signal because for normal sinusoidal voltage waveform, Gaussian behavior is present. Feature extraction has been done using higher order cumulants and quadratic classifiers for classification. In [40] covariance behaviour of several features has been analyzed to classify the PQ event. Prior to this analysis, it is required to develop a feature set. The common vector classifier which is covariance based has been used for classifying the type of the PQ event.

In [41], WT based multiresolution has been applied on the analyzed signals. After multiresolution analysis, detailed and approximation coefficients of each decomposition level is find out and then used for constructing the feature vector. This feature vector has been used for training and testing of self-organizing learning array (SOLAR). SOLAR has several advantages such as data driven learning scheme, local interconnections of neurons and entropy based self-organization.

In [42], the problem of switching of load/capacitor has been addressed, as the transient caused by this is the one of the major PQ problem. For their detection and classification, WT and hybrid self-organizing mapping neural network has been used. This hybrid SOMNN is a combination of supervised and unsupervised training algorithms. By using DWT, features were extracted from the transients caused by the switching of load/capacitor. Now the wavelet coefficients then serve as input to hybrid SOMNN for detecting the switching and phase angles, and also classifying the type of switching.

In [43], TT-transform is applied with modified Gaussian window to provide better time-time resolution. The window used is a function of frequency, from which time-time distributions were generated. The time-time contours have obtained for PQ disturbances from TT-transform. From this significant features have been derived. SVM clustering algorithm is also used in association with Modified Immune algorithm to provide good classification accuracy.

To avoid the misinterpretation of artifacts, sometimes S-transform and TT-transform are used side by side. In [44] ST and TT-transform of various PQ disturbances have been obtained. As TT transform is the 2 D time-time representation of a 1 D time series based upon the ST. In this 3 D representation of the power signal disturbances has used. The pattern obtained for various disturbances signals are unique and hence these are helpful in accurate identification of disturbance.

In [45], SVM has been used by authors to provide automatic classification of PQ disturbance. A RBF network based classifier is also used to ensure the better performance of SVM. And for the training and testing of classifier, features were extracted. Space phasor has been used to extract features from the three phase signals and hence build various different patterns for the classifiers.

In [46], detection and classification of PQ events and PQ disturbances has been presented. In this PQ events are detected under two main categories. One is the category of fault event and other is of switching events. PQ disturbances occurred in the system after a fault event. The extracted features from WT are classified by SVM classifier, which uses RBF kernel and their classification results are compared with ANN which shows that their decision time is almost same but the training time of SVM is much lesser than ANN.

III. CONCLUSION

In this work a number of papers from literature are reviewed. Discussion of each paper about the different PQ events, signal processing techniques, optimization as well as classification method has been presented. Causes and the effects of each event have also mentioned. From the exhaustive survey of literature, it is clear that the field of PQ has been divided into four major parts: data acquisition system, characterization of events, classification and mitigation. The need of detection and classification of PQ events leads towards the development of different signal processing and soft computing tools

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IV. REFERENCES

[1] M. H. J. Bollen, "What is Power Quality?," Electric Power Systems Research, vol. 66, pp. 5-14, 2003.
[2] A. Thapar, T. K. Saha and Z. Y. Dong, "Investigation of Power Quality Categorisation and Simulating it's Impact on Sensitive Electronic Equipment," IEEE Power Engineering Society General Meeting, vol. 1, pp. 528-533, 2004.
[3] M. H. J. Bollen and I. Y. H. Gu, Signal Processing of Power Quality Disturbances. Hoboken, NJ: Wiley-IEEE Press, 2006.
[4] D. G. Liberman, R. J. R. Troncoso, R. A. O. Rios, A. G. Perez and E. C. Yepez, "Techniques and Methodologies For Power Quality Analysis and Disturbances Classification in Power System: A Review," IET Generation, Transmission, and Distribution, vol. 5, pp. 519-529, 2011.
[5] M. K. Saini and R. Kapoor, "Classification of Power Quality Events – A Review," International Journal of Electrical Power & Energy Systems, vol. 43, no. 1, pp. 11-19, 2012.
[6] J. Barros, R. I. Diego and M. D. Apraiz, "Applications of Wavelets in Electric Power Quality: Voltage Events", Electric Power Systems Research, vol. 88, pp. 130-136, 2012.
[7] R. Kapoor and M. K. Saini "Multiwavelet Transform Based Classification of Power Quality Events," European Transactions on Electrical Power, vol. 22, no. 4, pp. 518-532, 2012.
[8] R. Kapoor and M. K. Saini, "Classification of Nonlinear Power Quality Events Based on Multiwavelet Transform," International Journal of Nonlinear Science, vol. 10, no. 3, pp. 279-286, 2010.
[9] H. Eristi and Y. Demir, "Automatic Classification of Power Quality Events and Disturbances Using Wavelet Transform and Support Vector Machines," IET Generation, Transmission, and Distribution, vol. 6, no. 10, pp. 968-976, 2012.
[10] H. Shareef, A. Mohamed and A. A. Ibrahim, "An Image Processing Based Method for Power Quality Event Identification," International Journal of Electrical Power & Energy Systems, vol. 46, pp. 184-197, 2013.
[11] S. Gunal, O. N. Gerek, D. G. Ece and R. Edizkan, "The Search for Optimal Feature Set in Power Quality Event Classification," Expert Systems with Applications, vol. 36, no. 7, pp. 1026-1027, 2009.
[12] C-Y Lee and Y-X Shen, "Optimal Feature Selection for Power Quality Disturbances Classification," IEEE Transaction Power Delivery, vol. 26, pp. 2342-2351, 2011.
[13] R. Kapoor and M. K. Saini, "Detection and Tracking of Short-duration Variations of Power System Disturbances Using Modified Potential Function," International Journal of Electrical Power & Energy Systems, vol. 47, pp. 394-401, 2013.
[14] O. Gencer, S. Ozturk and T. Erfidan, "A New Approach to Voltage Sag Detection Based on Wavelet Transform," International Journal of Electrical Power & Energy Systems, vol. 32, pp. 133-140, 2010.
[15] X. Xiao, F. Xu and H. Yang, "Short-duration Disturbance Classifying Based on S-Transform Maximum Similarity," International Journal of Electrical Power & Energy Systems, vol. 31, pp. 374-378, 2009.
[16] H. He, X. Shen and J. A. Starzyk, "Power Quality Disturbances Analysis Based on EDMRA Method," International Journal of Electrical Power & Energy Systems, vol. 31, pp. 258-268, 2009.
[17] V. F. Pires, T. G. Amaral and J. F. Martins, "Power Quality Disturbances Classification Using 3-D Representation and PCA based Neuro-fuzzy Approach," International Journal of Expert System With Applications, vol. 38, pp. 11911–11917, 2011.
[18] A. Aguera-Perez, J. C. Palomares-Salas, J. J. G. D. L. Rosa, J. M. Sierra-Fernandez, D. Ayora-Sedeno and A. Moreno-Munoz, "Characterization of Electrical Sags and Swells Using Higher-Order Statistical Estimators," Measurement, vol. 44, pp. 1453-1460, 2011.
[19] M. A. A. Lima, A. S. Cerqueira, D. V. Coury and C. A. Duque, "A Novel Method for Power Quality Multiple Disturbance Decomposition Based on Independent Component Analysis," International Journal of Electrical Power & Energy Systems, vol. 42, pp. 593–604, 2012.
[20] J. Barros and E. Perez, "Automatic Detection and Analysis of Voltage Events in Power Systems," IEEE Transaction on Instrumentation and Measurement, vol. 55, no. 5, pp. 1487-1493, 2006.
[21] A. Moschitta, P. Carbone and C. Muscas, "Performance Comparison of Advanced Techniques for Voltage Dip Detection," IEEE Transaction on Instrumentation and Measurement, vol. 61, no. 5, pp. 1494-1502, 2012.
[22] E. Perez and J. Barros, "A Proposal for On-line Detection and Classification of Voltage Events in Power System," IEEE Transaction on Power Delivery, vol. 23, no. 4, pp. 2132-2138, 2008.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[23] A. Rodriguez, J. A. Aguado, J. J. Lopez, F. Munoz and J. E. Ruiz, "Rule-based Classification of Power Quality Disturbances Using S-Transform," International Journal of Electrical Power & Energy Systems, vol. 86, pp. 113-121, 2012.
[24] M. Manjula, S. Mishra and A. V. R. S. Sharma, "Empirical Mode Decomposition with Hilbert Transform for Classification of Voltage Sag Causes Using Probabilistic Neural Network," International Journal of Electric Power & Energy Systems, vol. 44, pp. 597-603, 2013.
[25] O. Ozgunenel, T. Yalcin, I. Guney and U. Kurt, "A New Classification for PQ Events in Distribution System," Electric Power Systems Research, vol. 95, pp. 192-199, 2013.
[26] C. H. Huang, C. H. Lin and C. L. Kuo, "Chaoc Synchronization Based Detector for Power Quality Disturbances Classification in a Power System," IEEE Transaction Power Delivery, vol. 26, pp. 944-953, 2011.
[27] R. Kapoor and M. K. Saini, "Hybrid Demodulation Concept and Harmonic Analysis for Single/Multiple Power Quality Events Detection and Classification," International Journal of Electrical Power & Energy Systems, vol. 33, pp. 1608-1622, 2011.
[28] R. Hooshmand and A. Enshaee, "Detection and Classification of Single and Combined Power Quality Disturbances Using Fuzzy Systems Oriented by Particle Swarm Optimization Algorithm," Electric Power Systems Research, vol. 80, pp. 1552-1561, 2010.
[29] B. Biswal, P. K. Dash and B. K. Panigrahi, "Non-stationary Power Signal Processing for Pattern Recognition Using HS-Transform," Applied Soft Computing, vol. 9, pp. 107-117, 2009.
[30] J. G. M. S. Decanini, M. S. Tonelli-Neto, F. C. V. Malange and C. R. Minussi, "Detection and Classification of Voltage Disturbances Using a Fuzzy-ARTMAP-Wavelet Network," Electric Power Systems Research, vol. 81, pp. 2057–2065, 2011.
[31] M. A. S. Masoum, S. Jamali and N. Ghaffarzadeh, "Detection and Classification of Power Quality Disturbances Using Discrete Wavelet Transform and Wavelet Networks," IET Science, Measurement & Technology, vol. 4, pp. 193-205, 2010.
[32] H. S. Behera, P. K. Dash and B. Biswal, "Power Quality Time Series Data Mining Using S-Transform and Fuzzy Expert System," Applied Soft Computing, vol. 10, pp. 945–55, 2010.
[33] K. Manimala, K. Selvi and R. Ahila, "Optimization Techniques for Improving Power Quality Data Mining Using Wavelet Packet Based Support Vector Machine," Neurocomputing, vol. 77, pp. 36-47, 2012.
[34] B. Biswal, P. K. Dash and S. Mishra, "A Hybrid Ant Colony Optimization Technique for Power Signal Pattern Classification," Expert Systems with Applications, vol.38, pp. 6368-6375, 2011.
[35] C. R. Pinnegar and L. Mansinha, "A Method of Time–Time analysis: The TT-transform," Digital Signal Process, vol. 13, pp. 588–603, 2003.
[36] A. M. Gargoom, N. Ertugrul and W. L. Soong, "Automatic Classification and Characterization of Power Quality Events," IEEE Transaction on Power Delivery, vol. 23, No. 4, pp. 2417-2425, 2008.
[37] S. Z. Djokic, J. V. Milanovic and D. J. Chapman, "A New Method for Classification and Presentation of Voltage Reduction Events," IEEE Transaction on Power Delivery, vol. 20, no. 4, pp. 2576-2584, 2005.
[38] T. Radil, P. M. Ramos and M. Janeiro, "PQ Monitoring System for Real-Time Detection and Classification of Disturbances in a Single-Phase Power System," IEEE Transaction on Instrumentation and Measurement", vol. 57, no. 8, pp. 1725-1733, 2008.
[39] O. N. Gerek and D. G. Ece, "PQ Event Analysis Using Higher Order Cumulants and Quadratic Classifiers," IEEE Transaction on Power Delivery, vol. 21, no. 2, pp. 883-889, 2006.
[40] O. N. Gerek, A. Barkana and D. G. Ece, "Covariance Analysis of Voltage Waveform Signature for PQ Event Classification," IEEE Transaction on Power Delivery, vol. 21, no. 4, pp. 2022-2031, 2006.
[41] H. He and J. A. Starzyk, "A Self-Organizing Learning Array System for PQ Classification Based on Wavelet Transform," IEEE Transaction on Power Delivery, vol. 21, no. 1, pp. 286-295, 2006.
[42] Y. Hong and C. Wang, "Switching Detection/Classification Using Discrete Wavelet Transform and Self-Organizing Mapping Network," IEEE Transaction on Power Delivery, vol. 20, no. 2, pp.1662-1668, 2005.
[43] B. Biswal, M. K. Biswal, P. K. Dash and S. Mishra, "Power Quality Event Characterization Using SVM and Optimization Using Advanced Immune Algorithm," Neurocomputing, vol. 103, pp. 75-86, 2013.
[44] S. Suja and J. Jerome, "Pattern Recognition of Power Signal Disturbances Using S and TT transform," International Journal of Electrical Power & Energy Systems, vol. 32, pp. 37-53, 2010.

[45] P. Janik and T. Lobos, "Automated Classification of Power Quality Disturbances Using SVM and RBF Networks," IEEE Transaction on Power Delivery, vol. 21, no. 3, pp. 1663-1669, 2006.
[46] H. Eristi and Y. Demir, "Automatic Classification of Power Quality Events and Disturbances Using Wavelet Transform and Support Vector Machine," IET Generation, Transmission and Distribution, vol. 6, no. 10, pp. 968-976, 2011.
[47] R. Singh, Satpal and S. Saini, "Power Sector Development in Haryana," International Journal of Science, Technology and Management, vol. 5, no. 3, pp. 278-285, 2016.
[48] S. Saini, "Social and behavioral aspects of electricity theft: An explorative review," International Journal of Research in Economics and Social Sciences, vol. 7, no. 6, pp. 26-37, 2017.
[49] S. Saini, "Scenario of Distribution Losses – A Case Study from Haryana", International Journal of Research in Economics and Social Science, vol. 8, no. 1, pp. 163-175, 2018[a].
[50] S. Saini, "Malpractice of Electricity Theft: A major cause of distribution losses in Haryana," International Research Journal of Management and Commerce, vol. 5, no. 1, pp. 284-313, 2018[b].
[51] S. Saini, "Expectancy-disconfirmation based assessment of customer Satisfaction with electric utility in Haryana," International Research Journal of Human Resources and Social Sciences, vol. 5, no. 1, pp. 320-335, 2018[c].
[52] S. Saini, "Electricity Theft – A primary cause of high distribution losses in Indian State," International Research Journal of Management and Commerce, vol. 8, no. 1, pp. 163-175, 2018[d].
[53] S. Saini, "Service quality of electric utilities in Haryana – A comparison of south and north Haryana," International Journal of Research in Engineering Application & Management, Accepted, 2018[e].
[54] S. Saini, "Rationale behind developing awareness among electricity consumers," International Journal of Research in Engineering Application & Management, Accepted, 2018[f].
[55] S. Saini, "Analysis of service quality of power utilities," International Journal of Research in Engineering Application & Management, Accepted, 2018[g].
[56] S. Saini, "Difference in Customer Expectations and Perceptions towards Electric Utility Company," National Journal of multidisciplinary research and management, Accepted, 2018[h].
[57] S. Saini, "Appraisal of Service Quality in Power Sector of NCR," National Journal of multidisciplinary research and management, Accepted, 2018[i].
[58] S. Saini, "Evolution of Indian Power Sector at a Glance," National Journal of multidisciplinary research and management, Accepted, 2018[j].
[59] S. Saini, R. Singh, Satpal, "Service quality assessment of utility company in Haryana using SERVQUAL model," Asian Journal of Management, Accepted, 2018[k].
[60] S. Saini, "Influence of gender on service quality perceptions", Kaav International Journal International Journal of Economics, Commerce & Business Management, Accepted, 2018[l].
[61] R. Kumar, A. Aggarwal, R. K. Beniwal, S. Saini, R. Paul and S. Saini, "Review of voltage management in local power generation network," International Journal of Engineering Sciences & Research Technology, Submitted, 2018.
[62] S. Saini, R. K. Beniwal, R. Kumar, R. Paul and S. Saini, "Modelling for improved cyber security in Smart distribution system," International Journal on Future Revolution in Computer Science & Communication Engineering, Accepted, 2018[m].
[63] R. K. Beniwal, A. Aggarwal, R. Saini and S. Saini. "Detection of anomalies in the quality of electricity supply," International Journal on Future Revolution in Computer Science & Communication Engineering, Accepted, 2018.
[64] M. K. Saini, R. Dhiman, A. N. Prasad, R. Kumar and S. Saini, "Frequency management strategies for local power generation network," International Journal on Future Revolution in Computer Science & Communication Engineering, Accepted, 2018.
[65] R. Kumar, S. Saini, A. Aggarwal, R. Paul, R. Saini and S. Saini, "Complete management of smart distribution system," International Journal of Engineering Sciences & Research Technology, Submitted, 2018.
[66] M. K. Saini and R. Kapoor, "Multiwavelet transform based classification of PQ events," International Transactions on Electrical Energy Systems, vol. 22, no. 4, pp. 518-532, 2012.
[67] R. Kapoor R and M. K. Saini, "A new signal processing technique for power system disturbance detection and classification," Institution of Engineers India Part-EL, vol. 88, pp. 9-14, 2007.
[68] M. K. Saini, R. Kapoor, B. B. Sharma, "PQ events classification and detection – a survey, 2nd IEEE International Conference on Sustainable Energy and Intelligent system, Chennai, 2011, pp. 490-495.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[69] M. K. Saini and R. Kapoor, "Classification of nonlinear power quality events based on multiwavelet transform," International Journal of Nonlinear Science, vol. 10, no. 3, pp. 279-286, 2010.
[70] M. K. Saini and R. Beniwal, "Recognition of Multiple PQ issues using Modified EMD and Neural Network Classifier," Iranian Journal of Electrical and Electronics Engineering, 2018, In Press.