DETECTION AND CATEGORIZATION OF POWER QUALITY EVENTS: A REVIEW

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Abstract : Power quality issue has evolved as an interesting topic for researchers since last few years due to a large utilisation of loads based on power electronics and controlled by microprocessors. In different papers, different classification techniques have been proposed for recognition of power quality disturbances so far. A broad overview of signal processing techniques used for power quality analysis is presented in this paper. Various intelligent techniques used for classification such as artificial neural network, fuzzy logic, support vector machine as well as their hybrid models are reviewed. This paper may be used by researchers to know about different methods for classification and feature extraction of power quality(PQ) disturbances used so far, which may help for further improvement and better result.

Index Terms- PQ disturbances, Signal Transformation techniques, Intelligent techniques, Optimization methods, Signal feature extraction, PQ event classifier

1. INTRODUCTION

There is a continuous expectation of undistorted and rated sinusoidal power supply from the consumers. PQ problems[1] have sharpened due to continuous addition of large number of sources of power, lines for transmission , different type of transformers, and responsive loads. Environmental disturbances are also come in contact with these exposed systems. Furthermore, one of main causes of degradation of quality are the nonlinear responsive loads[2]. Different power line disturbances characterise Power quality[3,4] . Data loss, memory and equipment malfunction of responsive loads ; and abnormal operation of electronic controls[5] can be caused by PQ problems. Therefore, there is a necessity of monitoring of these disturbances.A continuous monitoring is required as there is a increasing demand of distortion and noise free power [6-8]. Standards of monitoring are given in [9].

Disturbances existing for microseconds, if recorded needs a large volume of data to be stored, necessitating the development of a competent technique to squeeze the data volume. Data monitoring has important involvement in the field of PQ[10]. Data compression has received importance as the volume of to be recoded and examined data is so large[11]. If unnecessary changes in the voltage and current signal are not checked properly[12], they can lead to breakdown or impairments of many responsive loads connected to the system, which may cost heavily the end users. It is necessary to identify the incidents through PQ events detection and classification system to carry out the mitigation action. In past several years, analysis of PQ is becoming the most fascinating area of research for characterization[13, 14] and classification of events[15].

The extraction of feature from the input PQ disturbances is required for PQ event detection. For efficient representation of the signal, better set of feature is required. Extracted set of feature can be used for the classification process.

Review on methods for events classification of PQ described earlier, have little observation into the extensive analysis of different techniques. For the investigation of PQ events , modern and powerful tools are currently available.

2. THE REALIZATION OF POWER QUALITY EVENTS

2.1 POWER QUALITY

One of the most popular word in the power industry is the term PQ.The study of causes for various PQ disturbances may be worthy in the context of PQ[16-18]. Electrical systems functioning in an efficient manner according to a set of limits of electrical properties, this set of limits of electrical properties is PQ. PQ describes the interdependency of electric power and the load's ability to function properly. Without proper power, malfunctioning, premature fail or permanent shutdown may occur of an electrical load. Due to the non-stationary disturbances, the major malfunctioning of the electrical equipment occurs. Many multidisciplinary researchers are attracted in this provocative field for the analysis of non-stationary disturbances. Non-stationary signals defined by broad dimensions of the frequency spectrum with components of sub-harmonic and transient are difficult to analyze as in[19]. These disturbances can be monitored as in[20] and classified on the basis of time-variant statistical characteristics of the voltage and current waveforms as in[21-23] and they could be sinusoidal or non-sinusoidal. Dominating frequency components have been used as features for recognition of events only in case of non-stationary PQ events[24]. Evaluating the electric power quality becomes very essential for both utilities and consumers especially when moving towards smart grid. The increasing use of renewable energy source and distributed generation may lead to research in the field of PQ events analysis. Research in the field of PQ events analysis can also play a vital role in smart grid.. Therefore, the area of PQ attracts many more researchers because it is of futuristic use in the power system.

2.2 TYPES OF POWER QUALITY DISTURBANCES

The PQ disturbances are broadly classified into three categories namely, the magnitude variations, sudden transients and steady state harmonics. Due to inception of line faults and penetration of heavy or light loads, the voltage/current magnitude variations such as sag, swell and interruption have been observed in power system networks. Spikes or impulsive and oscillatory transients may be caused due to the sudden changes in the operating conditions such as switching of capacitor banks and lightning. Due to the applications of non-linear loads and power electronic converters[25], the steady-state PQ disturbances such as harmonics, flickers, notches are created. The power quality disturbances depend on amplitude or frequency or on both frequency and amplitude. Events can be divided into short, medium or long type, based on duration of existence of PQ disturbances. Inigo Monedero et al.[26] defined PQ disturbances, which is given in Table I, based on the UNE standard in Spain which defines the ideal signal as a single-phase or three-phase sinusoidal voltage signal of 230 V_{RMS} and 50 Hz. D. Saxena et al[27] classified various PQ events into five groups viz. Short duration variation, long duration variation, transients, voltage imbalance and waveform distortion. S. Edwin Jose et al[28] classified PQ disturbances on basis of values of tails of histogram obtained from simulation results.

TABLE I

TYPES OF DISTURBANCES

Types of disturbances	Disturbance subtype	Time	Min. value	Max. value
Frequency	Slight deviation	10s	49.5 Hz	50.5 Hz
Frequency	Severe deviation	10s	47.0 Hz	52.0 Hz
Voltage	Average voltage	10 min	0.85 Un	1.1 Un
Voltage	Flicker	-	-	7 %
Voltage	Sag-Short	10ms-1s	0.1 U	0.9 U
Voltage	Sag-Long	1s-1min	0.1U	0.9 U
Voltage	Sag-Long-time disturbance	> 1min	0.1 U	0.9 U
Voltage	Under Voltage-short	< 3min	0.99 U	0.99 U
Voltage	Under Voltage-long	> 3min	0.99 U	0.99 U
Voltage	Swell-Temporary Short	10ms-1s	1.1 U	1.5 KV
Voltage	Swell-Temporary Long	1s-1min	1.1 U	1.5 KV
Voltage	Temporary Long-time	> 1min	1.1 U	1.5 KV
Voltage	Over-voltage	< 10ms	1.1 U	6 KV
Harmonics	Harmonics	-	THD>8%	THD>8%

3. FEATURE EXTRACTION TECHNIQUES IN POWER QUALITY

The feature extraction process is most important to find the distinctive features from the obtained transform coefficients of the original signals. By using a feature extraction technique, the PQ disturbances can be detected and classified. The extracted features are used for the classification of PQ disturbances. From the original signals or from some time frequency transformation techniques, features can be extracted.

Information in time and frequency domain are obtained by using this transformation. In order to achieve the highest accuracy of the classification, the section of the most suitable pictures of the PQ events is of extreme importance [29]. The extracted picture vector greatly influences the performance of a classifier [30]. The distinctive pictures of the buttons are the main focus of the pattern recognition system instead of the dining a complicated classifier. In order to reduce the data size and to obtain distinctive features of the PQ disturbances, the statistical parameters of the transformed coefficients of the PQ disturbances can be calculated. The most widely used statistical parameters for the classification of PQ disturbances are energy, entropy, minimum, maximum, standard deviation, mean, rms value, etc. and their combination.

3.1 Fourier transform based feature extraction

The most widely used computational algorithm for the steady state analysis of the stationary signals by extracting spectrum at specific frequencies is, the Fourier transform(FT). The, to be analysed signal can be represented as a sum of constituent sinusoids of different frequencies[31]. The detection of the existence of certain frequency component in a signal without any information of time at which this

frequency component appears is done by the FT. In transformation of the signal to frequency domain, the time information is ignored. The FT of a continuous time signal x(t) is defined as

$$X(f) = \int_{-\infty}^{\infty} x(t)\, e^{-j\omega t}\, dt \qquad (1)$$

The Discrete Fourier Transform (DFT) that is used for computer analysis can be expressed

$$X[k] = \sum_{n}^{N-1} x[n] e^{-j2\pi Kn/N} \qquad (2)$$

The DFT is inappropriate to detect the PQ disturbances signals, which are usually non stationary and transitory in nature. However,it is suitable for the stationary PQ disturbances. The discrete signals that repeat themselves periodically can be represented by the DFT.

The same result as the DFT can be obtained by the Fast Fourier Transform (FFT) algorithm in much less time. The widely used technique for harmonic analysis of a PQ event is the FFT [32]. In [33], the windowed FFT is used for power quality assessment. The window FFT [34] is a time version of the discrete time FT. Due to leakage, picket fence, and aliasing effects produced by FFT [35], the signal parameters (frequencies, amplitudes, phases) can not be obtained accurately.

An alternative of FFT, the Short- Time Fourier- Transform (STFT), analyses the time-frequency decomposition of non-stationary signals by splitting the signals into small sections where each section is assumed stationary. The discrete STFT is multiplied by a window function w[n-m] whose position is translated in time by m:

$$STFT[k,m] = \sum_{n}^{n} x[n] w[n-m] e^{-\frac{j2\pi kn}{N}} \qquad \ldots(3)$$

Where w[[n-m] in its simplest form is the rectangular window function

$$w[n] = \begin{cases} 1 \; if \; 0 \le n-m \le N-1 \\ 0 \qquad otherwise \end{cases} \qquad \ldots(4)$$

The sinusoidal frequency and phase contents of local sections of signals are determined by the STFT, as they change over time.Also, it extracts several stationary and rotating frames of signals with a window moving with time. In [36], the discrete STFT has been applied for time-frequency analysis of non-stationary PQ disturbances by decomposing the time-varying signals into time-frequency domain components. The transients positions in disturbance data can be detected by the STFT on choosing a small window size. Once the size of the window is chosen, the STFT enables an easier analysis for harmonic signals, although it has a fixed resolution for all frequencies. With STFT operating in a fixed window size, it is difficult to analyse non-stationary signals. The deficiency of the STFT is the selection of the size of the window. Large window size selection results in a good frequency resolution and a bad time resolution and as the window size reduces, the frequency resolution decreases and the time resolution increases.

3.2 Methods Based on S-Transform

The S-transform was created through the blend of STFT and WT which is a time-frequency tool [43]. The Gaussian modulated co-sinusoids is the primary function of S-transform, it creates a time-frequency representation of a time series. In this frequency-dependent resolution combines exclusively that simultaneously localizes imaginary and the real spectra [44]. While in [45]this method features are extracted through S-transformation of the voltage signal which uses fewer features and little memory. The S-transform provides a pattern in case of non-stationary disturbance with boisterous information (noisy data) that resemble closely to the distress type which may necessitate an uncomplicated classification course of action [46]. In [47]a particular feature with a favorable value is determined for the width factor by estimating the classification accuracy. The Author presented in [48]an efficient and straightforward method for power quality disturbances while using S-transform for quantification and classification into ten typical kinds. While in [49]the author used the dynamics to reduce the run time by introducing the amalgam techniques on S-transform & dynamics for real-time classification of power quality disturbances. The automatic classification of power quality disturbance is presented in [50]via S-transform supported neural networks configuration; it integrates neural networks and S-transform techniques to construct a classifier for multiple level observation. Discrete orthogonal S-transform is use for power quality analysis in [51]. In [52]for power quality events the multi-resolution S-transform is propose which is supported by the fuzzy recognition system, which changes the variable width of widow analysis concerning frequency subject to a user-defined function. In [53]to extract accurately the localized time of spectral characteristics for non-stationary signals the discrete S-transform (FDST) algorithm is proposed. In this paper [54]for detection and classification of PQ two clustering decision trees methods has been compared which are S-transform & fuzzy C-means while other is S transform with rule-based in line with Std IEEE 1159 using software of Matlab. While in [55]the author presented a rule-based tree with the help of ANN and S-transform which further improved in [56]to rule based tree with the only S-transform.

3.3 Methods Based on Wavelet Transform

The Wavelet transform (WT) relies on a group theory and a square-integral representation, in other words, it's a mathematical instrument, in similar to FT, which expand a signal prototype function by decomposition of a signal into multiple levels of resolution. It provides frequency and time local representation of a given signal. In disturbances of power quality such as transition where time-frequency

analysis are required it's more beneficial [57][58]. The Wavelet transform is classified into continuous wavelet transforms (CWT) and discrete wavelet transform (DWT) [59]. In this [60]paper DWT based techniques for operational events of power system detection along with all associated disturbances is presented. The signals decompositions of multi-resolution are introduced as prevailing investigation apparatus for Power quality event in [61]. In [62], a wavelet-based method is used for detection, classification and quantifying along with localizing is presented. A compression method for power quality disturbances data is introduced via wavelet packet transform (WPT) and DWT in [63]. The architectural model which is a two-layer probabilistic wavelet network is proposed in [64]which includes the probabilistic network and a wavelet layer for disturbance detection of voltage harmonics. Consequently, in [65], self-organizing learning array system with Wavelet transform novel approach is used for the power quality disturbance classification. A unique viewpoint for the IEEE standards 1459-2000 definitions is brought in by the author in [66]by using the SWT for defining pollution factor, power factors and control components. The time-frequency domains are redefined while using WPT in [67]which PQ was recommended in [68][69]. In [70]wavelet norm entropy for power disturbance classification is presented based on effective feature extraction method. WT and S-transform based method is proposed by the author in [71]which detect the interference in distributed generation hybrid system due to load rejection in islanding. The author presented a method by using complex wavelet coefficients to the un-decimated wavelet transform to compute Power qualities in [72], to use wavelet method is a critical issue because the selection of suitable wavelet is an important task because with the increase in filter length the computational cost increases. In this paper [73]the features are extracted by discrete wavelet transform with (MRA) multiresolution Analysis through an optimal feature selection of Power quality disturbances through (PNN-ABC) probabilistic neural network supported by artificial bee colony. In the system due to the severity of the faults many long and short duration events are caused by the power quality [74]. To accurately extract the component of fundamental frequency from the distorted input signal the filter design and its Q-factor and redundancy are more important [75]. These machines sometimes contradict with actual system conditions [76]. In [77]a classifier of power quality is proposed which is supported by WT and SVM to analyze complex events via a combination of binary classifiers which contains real signals magnitude comprising of events within the analyzed temporal window. In [78]mapping power quality events which are momentary variation regarding disturbances are crucial aspect while in [79]power quality events which are non-stationary are analyzed via MRA and Discrete wavelet transform. In this paper [80]for the wavelet-based feature extraction techniques is used via these three methods which are SVM (support vector machine), DT (decision tree), and RF (random forest). The primary challenges are concerning the researchers are due to the changing regulation, because the distribution market is liberalize with the increase of equipment based on power electronics. The issue of the day is to extract features from the limited measurements [81]. While in [82]the Author presented for detection and localization MODWT technique which is time-series based maximal overlap. The author proposed in [83]an integrated rule base approach of DWT and FFT for the detection of power quality. To achieve the detail coefficient features the discrete wavelet coefficients are utilized to get the average energy entropy of squared.

3.4 Miscellaneous Feature Extraction Techniques

The methods mentioned in section A-D apart from that there are some other methods for detection and classification which also played a unique function in the improvement of power quality. In [99]for monitoring of power quality, an author demonstrated de-noising method supported by change point impends regarding wavelet base power quality. In [100]the author presented feature extraction of power quality disturbances by parallel computing for time-frequency. In [101]frequency shifting decomposition with Hybrid wavelet and HT for Power quality analysis is presented. Many other techniques such as short-time correlation transform [102]. Curve fitting [103], linear combiners [104], Adeline [105], digital filters [106], parametric spectral estimation method [107], Gabor-Wigner transform (GT) [108], TT Transform [46], Fuzzy-ARTMAP-wavelet network [109], Kalman filter [110][111], extended Kalman filtering [112], DWT Transform and wavelet network [113], Hybrid soft computing technique [114], higher order statistics and case-based reasoning [115]. In [116]the advantage of deep learning is utilized on image file classification, the image files are of three-phase power quality events data, while in [117]a staked autoencoder is used as a deep learning framework for the classification of power quality distribution. In [118]the proposed method decouples the signal of the power system into independent components and then classifies power quality disturbances by specialized classifiers. The anomalies in power quality time series are presented in this paper [119]. This article is based on MMG (multi-resolution morphology gradients) [120], but its process uses half the MMG strategy. In [121]paper k-mean optimization algorithm is presented which classify PMU (Phasor measurement units) into different power quality classes. In [122]the author tried to use different models to get results with the help of Multi agent system . These authors have co-operated a vital role in recent years to improve event detection and classification of Power quality.

4. Classification Techniques of Artificial Intelligence

Artificial intelligence (AI) can be defined as the activities such as detection of a problem then the problem salvation with a valid reason in a keen perception and learning after making a decision that is associate with human thinking is a broad definition defined in [123]. In the recent years, there is enormous research going on to meet the interest of the electric power Community.

4.1 Classification Based on the Neural Network

The neural networks (NN) are good at Optimization and data clustering, pattern matching, classification, function approximation. It represents the new era of information processing system [124]. Artificial neural networks function's approximation capabilities were

employed in harmonic source classification, faults, and power quality studies. The Time delay neural network (TDNN) and feed-forward neural network (FFNN) are the two different Paradigms of neural networks for the classification of power system disturbance waveforms which are presented in [125]. In [126]Wave-shape fault is displayed for automatic detection, localization and to classify various types of disturbances. In [127]a neural network based approach is proposed to identify the non-intrusive harmonic source. In [128]ANN and Wavelet-based a novel method is proposed for fault detection in line transmission and its classification by using data of oscillographic. Studies are carried out for classification and detection based on some DWT patterns for both high and low-frequency disturbances such as sags, transient, and harmonics, flickers simultaneously in [129]. Power quality disturbances recognition based on wavelet and artificial neural network classifier is tested and implemented in [130]. Feature extraction on center clustering is obtained and fed to the artificial neural network as an input for power quality event classification is presented in [131], while in [132]the author presented a novel method based on S transform and Probabilistic neural network for power quality event classification. In [133]the balanced neutral tree is given by the author for classification of Power quality. To classify and detect single & combined Power quality disturbance based on a dual neural network based methodology is presented in [134], while in [135][136][137]the author introduced the radial basis function (RBF) neural network for classification and recognition of power quality events. In this paper [138]a dual neural network methodology is proposed which detect and classify single and combined power quality which computes the root mean square for harmonic and inter harmonic estimation via an adaptive linear system. In [139]a multilayer perception neural network is presented for classification of power quality. As in most research, the authors used frequency domain as an analysis tool, but in this paper [140]the author presented an approach in the time domain for detection and classification of power quality. In this paper hybrid detection and classification method is shown in which quantity characteristics are introduced then recognition algorithm is used for signal and multiple disturbances recognition [141]. In [142]for real-time power quality evaluation, an artificial neural network is proposed conjugate gradient back-propagation. In recent years the latest developments are FPGA based smart sensors which integrate with HOS (higher order statistic) processing cores for analysis of signals which further classify the power quality by artificial neural networks [143].

4.2 Classification Based on Neuro-Fuzzy System

The information handling such as imperfect, vague, partial or managed imprecise is one of the biggest advantages of Neuro-fuzzy based methods. It resolves conflicts with capabilities of self-tuning, self-learning, aggregation, self-organizing and collaboration. The operation uses fuzzy numbers for fast computation it doesn't require human imitate decision-making processes or prior knowledge of relationships of data [144][145]. In [146]the author presented a fuzzy-neutral network as a classifier to extract feature by using morphological filtering and contour extraction while describing a cork stopper, quality classification system principal component analysis along with neuro-fuzzy based automatic classification is presented by four steps algorithm approach with the combination of 3-D space referential representation in [147]. Transmission line faults and its location are proposed via adaptive-neuro-fuzzy-interface system approach in [148][149]. In [150]the author presented an adaptive neuro-fuzzy system with PSO (Particle-swarm optimization) with phase jumps by UPQC for mitigation of Voltage sags. In this paper [151]FAT (fuzzy assessment tree) supported by SIM HT (short-time modified Hilbert transform) is utilized for detection and classification of multiclass. While low and high limit detection is evaluated against measured data by a fuzzy logic classification system via member functions which are two inputs and one output [152]. Furthermore, in [153]fuzzy logic and ANN for classification of disturbances are s-transform and wavelet such as DTCWT (Dual tree complex wavelet transform).

4.3 Classification Based on Support Vector Machine

Vapnik laid the foundation of Support Vector Machine [154]; in this new-fangled pattern recognition is provided by statistical learning theory approach. SVMs belong to the generalized linear combiners which are used for regression and classification via a set of related supervised learning methods [155]. The author presented N-1SVMs' classifier for the identification of PQ event in [156], which works more efficiently in the voltage disturbance via automatic classification [157]. SVM based one-versus-one approach is presented in [158]which can process multiple classifications of Power quality disturbance. The SVM technique is a low convolution event classifier and far better than Optimal time-frequency Representation (OTFR) [159]. In [160]the author presented Wavelet multi-class SVM based an integrated model for recognizing PQ disturbances. In [161]the SVM and DWT combined classifier is shown to recognize the type of Power quality of a system. In the comparison of ANN-based methods & Kamel-based learning method with the direct, a cyclic SVM shows that linear a cyclic SVM have less testing time, less training and with a high degree of accuracy [162]. The power quality events classification based on SVM and wavelet transform is presented in [163][164][165]. The modified SVM and TT-transform are used in non-stationary power signals for classification with modified immune optimization algorithm by enhancing the compactness of different clusters of some SVM [166]. The author presented higher order statistical feature along with SVM is used for classification of power quality events in [167]. In this paper the Author presented for the single and multi power quality disturbances a new SVM model which overcomes the limitation of employing a number of binary support vector machines [168]. Where as in [169]the support vector machine as classifier core discriminated the power quality events to perform a satisfactory test in terms of accuracy and speed even in noisy conditions. In [170]the TDR (time-domain reflectometry) technique with PRBS (pseudorandom binary sequence) is used for data set as an appropriate input for PSO based SVM to increase the parameters for classification accuracy. In [171]FIR-DGT and T2FK-SVM is used to enhance the accuracy of classification by reducing the feature size so that less time and memory is required for classification.

4.4 Classification Based on Genetic Algorithm

By natural genetics and natural selection mechanism Genetic Algorithm (GA) is a search Algorithm which joins survival of the vigorous among string structures for information exchange with a structured yet randomized to form a search algorithm with some of the innovative flairs of human [172]. It used probabilistic, random, multipoint and guided search mechanism for optimization the GA is considered as one of the intelligent Paradigm [173]. A fuzzy-based adaptive approach is used in [174]to the metering of RMS voltage, power, and current employing GA. In [175]the author presented a validation of power system model for power quality assessment application while using GA. During the dynamic performance of power system, the GA is introduced for monitoring and supervising as a powerful tool [176]. In [177]GA is proposed for the power voltage control optimization system in hierarchical format via a jumping genes paradigm. In [178]the author introduced a new technique while using enhanced GA for placement of Power quality monitors. The extension of GA and wavelet transform is presented in [179]as an analytical technique of power quality. The design of a GA is presented in [180]which optimize the S-transform in perturbation of electrical signals for classification and analysis. In this paper [181]the author presented a model which can perform the disturbance analysis in one step instead of two stages as other types usually do, While in [182]GA is designed as a crossover operator based on particular direction-based.

4.5. Classification Based on the Fuzzy Expert System

Classical two-valued logic is a generalized logic system which is referred to fuzzy logic in uncertainty for reasoning. It is motivated by the knowledge and concepts which have no defined boundaries but still can be utilized for human reasoning [183]. In [184][185]the author presented the Mamdani type rules for a fuzzy classification system to evaluate linguistic variable inputs information. In [186]the author presented than a fuzzy expert-system utilizes a collection of fuzzy sets for reasoning about data instead of Boolean sets. A fuzzy set along with wavelet is used by the author to design a tool to quantify Power quality parameters in [187]. While in [188], a fuzzy expert system with linear Kalman filter is used for characterizing power quality events as a hybrid technique. In [189]a particle swarm optimization algorithm along with fuzzy logic approach is for detection & classification of single and multiple power quality disturbances. Fuzzy clustering using the technique of decision tree and chemo-tactic differential evolution is presented as an approach for the classification of power quality data in [190]. In [191]the author showed a fuzzy expert system based on S transform using power data of quality time series. A variety of window techniques are presented in [192]for various stationary power signals visual localization, detection, and classification. In the electrical system, the transient disturbance classification is proposed in [193]by a using fuzzy expert system with Fourier linear combiner as a hybrid scheme. A wavelet-based extended fuzzy reasoning approach is proposed in [194]for identification a recognition to power quality disturbances, while the abnormal operation of an electrical system is introduced with a technique of an adaptive fuzzy self-learning in [195]. In [196]the author presented a data compression method for a power waveform while using adaptive fuzzy logic. In this paper, the author utilized the MM (mathematical morphology) and FDT (fuzzy decision tree) which is a new contribution to detection and classification [197]. While in [198][199][200]the author used different combinations such as automatic, Kalman, Hilbert transforms with a fuzzy expert system for power quality disturbances recognition and classification. In [201]the Author presented a new model which is immune to noise and different which is further modified through Fuzzy C-means based foraging optimization algorithm for improvement in detection and classification.

4.6. Miscellaneous Classification Systems

The Important consideration in electric utilities is the detection, and its classification of power quality events. The features of S transform are used to design a Rule-based system for intelligent classification of Power quality disturbances [202][203]. In [204]the author presented for the classification of power quality events Rule-based wavelet multiresolution decomposition. In this paper [205]by Gaussian window, a simple rule base is created under various non-stationary signal conditions for selecting a suitable window for a reasonable time-frequency localization of the disturbance signal. This rule base uses statistical base entropy measure. Furthermore, in [206]a rule-based method with the help of CS (compressive sensing) and ML (maximum likelihood) are used for classification of Power quality disturbances. In [207][208]the author presented an expert system for the power quality classification. Many other power quality classification methods such as Easy VI program [209]Digital filtering and mathematical morphology [210], Warping Classifier [211], Multi-way principal component analysis [212], Phasor data records and sequence of events [213], inductive inference approach [214], Hardware and software architecture [215][216][217], as Hidden Markov models and vector quantization [218], nearest neighbor rule [219], Transient-meter [220], recurrence quantification analysis [221], fault current limiting high-temperature superconductor cable [222]In this paper [223]the two successive stages space and times are achieved by the extension of K-mean algorithm to identify the faults with space-time solution. Furthermore, in [224], a mathematical model is developed for describing waveforms which contains power quality disturbances simultaneously. They have shown significant role in power quality event classification in recent years.

5. CONCLUSION

Detection and classification are two of the key aspects of the electrical power system on which this comprehensive and critical literature review is carried out. All recent publications on detection and classification are presented in this paper; the literature survey uses detection/feature extraction methods such as Fourier transform, S-transform, wavelet transform, Hilbert-Huang transform and artificial

intelligence methods for power quality classification such as artificial neural network, SVM, GA and fuzzy logic. It also includes the classification power quality events effect due to different types of noises. Furthermore, in the end, the future research scope is indicated in the field of power quality and classification methods. As per developed review most commonly used methods for power quality disturbances are HHT, FT, ST, and WT while regarding event classification the commonly used algorithm trend is based on SVM, ANN, FS, ES, and GA.The future major thrust is in four aspects, Economical, Fast & Accurate, Secure & Reliable and Miniature & Safe while the Present thrust in Power quality is real-time analysis, many scientists and researchers work day and night for the mitigation and enhancement of real-time power quality detection. The new era needs new techniques out of the box which can work on real-time power quality events for mitigation ad classification. In other words, the standards are still far away from the targeted standards as the power system is expanding day by day with numerous & anonymous power devices which generate an advance version of Power quality errors which are still to discover. Single and multiple Power quality errors need a generalized approach for detection and classification. On the basis, it is possible that blackout conditions can be improved.

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