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A Three Decades of Marvellous Significant Review of Power Quality Events Regarding Detection & Classification

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Abstract

Around the globe, the necessity of green supply with a dedicated standard quality thrust of consumers is increasing day by day. The advancement in technology urges the electrical power system to deliver a high-quality rated undistorted sinusoidal current, the voltage at a constant desired standard frequency to its consumers. The present paper reveals a complete and inclusive study of power quality events, such as automatic classification and signal processing via creative techniques and the noises effect on the detection and classification of power quality disturbances. It's planned to make a possible list for quick reference to obtain an extensive variety on the condition & status of available research for detection and classification for young engineers, designers and researchers who enter in the power quality field. The current extensive study is supported by a critical review of more than 200 publications on detection and classification techniques of power quality disturbances.

Keywords

Power Quality, Feature Extraction, Power Quality Disturbances, Power Quality Events Classifier

1. Introduction

The economy of any stable country is mainly dependent on the power generation and its demand and supply. It greatly suffers from massive losses when in the power delivery there are some abnormalities such as disturbance/deviation in the frequency, current, voltage from the official rating. These power qualities result in malfunctioning failure of electronic and electrical equipment. The sizes and smartness in the business environments required more sensitive components such as computers, protection relay equipment and PLCs which are the biggest sources of power consumption [1]. Power quality is discussed in researchers/scientist on a daily basis worldwide since 1970 and it's one of the hot topic in all decades due to upcoming new trends and technologies [2] [3]. Consumers are expecting un-interrupted and high-quality power for their household and business equipment. The integration of resources of renewable energy in distribution grids according to user's expectation is the central focusing area of smart grid and a great challenge for all engineers & scientists [4]. Sometimes huge and small blackouts happen due to the interdependencies of associated dynamical propagation and its sub-networks because of different power quality disturbances [5]. To prevent such issues consumers are investing huge investment in personal, uninterrupted power supplies though they are very costly; it shows the importance of commercial energy distribution regarding power quality [6]. Problems such as swell/sag, harmonics, flickers, voltage regulation, deviation in phase, unbalancing loads and frequency errors are exaggerated in the distribution system due to the increase of electronically switched and nonlinear devices which well equipped the smart transmission systems and renewable energy integration. In the last two decades, the international scientific community studied, proposed and developed several solid-state power electronic devices to improve power quality [7] [8]. The induction of these devices in the system attracts the attention of engineers towards the complexity of networks for planning and operation of electrical supply with the quality of power [9]. In electrical systems during the operating conditions such as network contingencies, load disturbances, renewable energy resources which output the power sinusoids and harmonics are observed at low-frequency signals while across the bus/node when electronically controlled capacitors are switch, and the transient oscillation is glimpsed in power network [10] [11] [12] [13] [14]. The consumer's bears ancillary services costs due to these unwanted events such as load curtailment loss, reactive power cost, disturbance removing cost and re-dispatch cost. Therefore PQ events need to maintain standards of the power supply and to be monitored and mitigated in operating conditions. The Large power system is complex during operations for monitoring and analysis to measure all PQ events. Therefore under sudden changes of operating conditions an elegant tactics & tools are requisite for detection and its classification also to understand smartly the utilities, regulators, and consumers operating requirements [15]. Power quality issues can be created from any reason that can be minor to major but in all cases it affects the system with prodigious losses. In the next generation of power grid networks the premier task is to localize the proximity of problem regardless of its nature, secondly how to respond reliably and securely to the detected regions which has been impacted by faults. Power quality becomes more challenging and complex in the presence of dual and multi disturbances. There are many challenges to focus specially to achieve integration of multi-platforms, diagnostic modular designs to achieve flexibility, precision, fast & accurate results with reliability. It is important to note that due to the introduction of nanotechnology the systems are getting more and more complex which needs a system which can automatically detect, classify and reserve power quality. In this aspect maybe in future the Multi agent system can take a leading role to achieve the accuracy and computational time on the basis of Control & Decision integration with support of Power Quality Decision Data Bank (PQDDB). The PQDDB is a new term introduced here on the basis of Power quality verities which are introduces every day via numerous researchers. These verities can be combined in the form of Power quality directory with decision and to feed to data bank of system as ready reference. This single platform will directly impact the approach, computational time and the accuracy. However, to make analysis more efficient requires reason of event occurrence and foremost from these disturbances feature extractions are requisite for precise and accurate detection [7]. After that these extracted features can be used for classification process in a sophisticated way.

2. The Realization of Power Quality Events

2.1. Power Quality

In Power network system the term "Power Quality" is used for the occurrence of electromagnetic Phenomena as wide variety [5]. Quality of Power supply is term as the ability of the system to deliver a signal containing undistorted current, voltage, and frequency [16]. The power quality sensitivity is classified in a highly evolved electrical system in three categories: 1) digital economy; 2) continuous processing economy; 3) essential services economy. The loads vary from 03-120 KVA per event, and there is a liability cost incurred on all above categories to operate. The variation in characteristic of current and voltage can shutdown or damage the electrical equipment which is critically design for specific tasks. Such continuous changes in the power supply with such frequency can despise the image in a competitive environment [16]. To PQ issues significantly affects Energy industries and their economic operations. To mitigate these problems the consumers apart from grid supply are equipped with backup instruments [17]. IEEE standard 1159-1995 [18] includes a broad variety of power quality disturbances such as Impulsive transients, oscillatory transients, sag, swell, interruption (with short duration variations) flickers, notch, harmonics (steady state variations) large period variation, frequency variation. In [19] the disturbances of power quality are defined in standards of UNE which is given in **Table 1**. Power quantities under balance & unbalance conditions sinusoidal & nonsinusoidal measurement definitions are include in IEEE Std. 1459-2010 [20]. As a part of a power quality Improvement structure, the power magnitude measurement system was presented in IEEE Std. 1459 [21] [22], while in [23] for the electrical power quantities measurements standard definitions under sinusoidal, balanced and non-sinusoidal, unbalanced conditions given as per revision IEEE Std. 1459-2010; March 2010 by the Author. In [24] the author presented a real power quality measurement via an adaptive algorithm subject to IEEE std.1459-2000.

Table 1. Classification of PQ disturbances [19].

Sr-No	Subject	Type of Disturbance		Time Duration	Range	
					Minimum Value	Maximum Value
1	Frequency	Slight deviation		10 s	49.50 Hz	50.50 Hz
		Sever deviation			47 Hz	52 Hz
2	Voltage	Average Voltage		10 min	0.85 Un	1.1 Un
		Flicker		-	-	7%
		Sag	Short	10 ms - 1 s	0.1 U	0.9 U
			Long	1 s - 1 min		
			Long-Time Disturbances	>1 min		
		Under Voltage	Short	<3 min	0.99 U	-
			Long	>3 min		
		Swell	Temporary short	10 ms - 1 s	1.1 U	1.5 kV
			Temporary Long	1 s - 1 min		
			Temporary-Long Time	>1 min		
			Over Voltage	<10 ms		6 kV
3	Harmonics & Miscellaneous Signals	Harmonics		-	THD > 8%	-
		Miscellaneous Signals		-	Including in Other Disturbance	-

2.2. Classifier's Based on Automatic Power Quality Events

Before 1990's due to the unavailability of advanced techniques such as signal processing few physical pattern systems were brought into play for managing & monitoring of power supply qualities. With the passage of time, the technology evolved as smart technologies and was adopted with time to time such as artificial intelligence Internet-networking, pattern-recognition, data mining as a smart signal processing techniques. The smart gadgets, such as digital signal processors in computers, information & communications buffers, mass storage, etc. Segmentation and feature extraction are the two function blocks of an automatic PQ event classifier as shown in **Figure 1** [25] the signal is pass through the pre-processing unit for classification, and the post-processing gives the decision about types of disturbance.

2.3. The Segmentation

Segmentation is a process which breaks up the information succession into stationary as well as non-stationary parts [26]. In between transition-segment events and the segments is to distinguish between the disturbances into different types the information of feature extraction from the event part is important because the information is unique during signal is stationary. To get the episode of

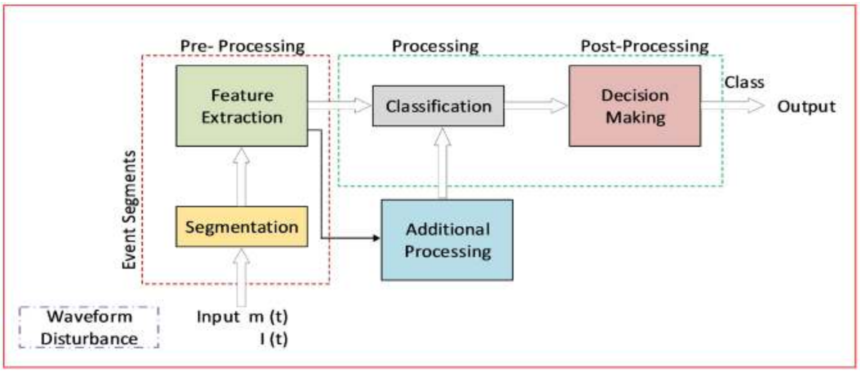

Figure 1. Block diagram of automatic power quality event classifier.

disturbance waveform a technique of triggering need compulsory to acquire the start and end spots of the power quality events [27] [28]. The method in current scenario utilized for identifying Power classes is supported on next cycle point to point comparison or RMS values spot to spot assessment to the distorted signal with its transformed frequency domain data or pure signal. The recently proposed methods are classified as model-based (Parametric) or transform supported as (nonparametric). The Auto-regressive (AR) and Kalman filter (KF) are parametric methods while Wavelet transform (WT) and Short-term Fourier transform (STFT) is nonparametric methods [29].

3. The Feature Extraction

Detection of disturbance is also known as the extraction of features from power quality disturbances. The human brain is liable source of the interface which extracts the electrical features from Electroencephalogram signals [30]. In the same way, these extracted features are use in the classification of Power quality events. A post-processing unit is use for making a final judgment via the information of the classifier's [25]. In classification the selection of suitable extracted features play a major role, it may be derived from the parameter of signal model or the original dimension or to get it from some malformed sphere [31]. In subsection, the current progress concerning the feature extractions practices is present in detailed.

3.1. Methods Based on Hilbert Huang Transform

In 1998 Dr. Huang proposed a novel signal processing algorithm known as Hilbert Huang transform (HHT) which includes two processes [32]. The empirical mode decomposition (EMD) and Hilbert transform works in a combination that empirical mode decomposition process into IMF (intrinsic mode function) which has significant instantaneous amplitude and frequency [33]. The empirical mode decomposition disbands the signals into different intrinsic mode roles in an approach that these frequencies were arranged from higher to lower. To achieve instantaneous frequency and amplitude versus time curve the Hilbert transform is applied once the signal is dissolve into different IMF's [34] [35]. In the development of different circumstance of PQ detection and classification numerous HHT variants are establish, even for the assessment of power events the EMD and Hilbert transform combination based method is developed in [36]. Furthermore an approach of using Relevance Vector machine along with HHT is presented in [37] for power quality disturbances classification. The HHT algorithm is utilize for the sophisticated power quality through multi-disturbances signal HHT detection method in [38]. In the scrutiny of non-stationary and non-linear signals the HHT cannot be used, so to analyze a voltage flicker the Orthogonal Hilbert Huang transform (OHHT) was use in [39]. By HHT and Mathematical morphology, the author presented a novel method for power quality disturbances detection and analysis' in [40], while the author introduced the time-frequency analyses with the support of Hilber-Haung modified method for distorted power signals [41]. An improved methodology in radial basis function (RBF) neural network is used to classify while to extract proficient features of the power quality via Hilbert Transform is presented in [42].

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. **Table 2** provides the characteristics of commonly use wavelets.

3.4. Methods Based on Fourier Transform

Fourier transform (FT), is the frequency domain analysis technique where the signal has represented a combination of multiple frequencies of different terms of sinusoidal [84]. Fourier transform is use in extracting spectrums for stationary signals at specific frequencies; however with fluctuation some temporary information is associated which is yet unable to resolve [84]. The short time Fourier transform (STFT) is one of the FT variants which divides the signal into small segments and considers that it is in stationary [85]. As for the signal changes over time, the STFT determines the Phase contents and the sinusoidal frequency of local sections. It also analyzes several frames of an extracted signal a window which moves with time. The time and variance of frequency relation can be determined through a moving window [86] [87]. It is complicated for STFT to scrutinize non-stationary signals [88]; however, it has been applied in a fixed window size to non-stationary signals while operating [89]. Non-stationary signals are analyze via time-frequency analysis through Discrete STFT. The Discrete STFT putrefies the signals of varying Time in components of time-frequency domain [90]. The discrete signals which were symbolized by DFT (Discrete Fourier transform) go over themselves from positive to negative infinity in a periodic fashion while the same results exhibit by fast Fourier transform (FFT) in less time than DFT [91]. The author is using Wavelet Transforms (WT) & Fourier methodologies in [92] to extract recorded current and voltage waveform.

Table 2. Wavelet characteristics.

Sr. No	Wavelet Name	Filters Length	Compact Support	Width Support	Orthogonal Properties	Symmetry
1	Coiflets	6N	YES	6N-1	YES	NO
2	Daubechies	2N	YES	2N-1	YES	Near to Symmetry
3	Symlets	2N	YES	2N-2	YES	Near to Symmetry
4	Haar	2	YES	1	YES	YES

In [93] the author for the judgment of power quality used "Windowed FFT" which is the time version of discrete time Fourier transform [94]. In this paper [95] the author presented a method which analyzes the disturbances of power quality via FFT which suffer spectral leakage phenomenon which results in invalid assessment in the existence of power quality which is non-stationary, while this paper calculates and analyzes synthetic signals while offline [96]. In this article, a modified FNN (Fourier neural networks) and HST (hyperbolic S-transform) are presented better time-frequency resolution [97]. In this article [98] the FRFT (Fractional Fourier transform) which is a new technique, offers multi-domain feature extractions. It is verified through different research that WT is healthier than STFT. Many schemes have been developed to detect power quality based on STFT, Kalman filter, and S-transform.

3.5. 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 the results are shown in Figure 2 and Figure 3. These authors have co-operated a vital role in recent years to improve event detection and classification of Power quality.

3.6. Detection Techniques Comparative Study of Power Quality Event's

In Table 3 all the main detection techniques of power qualities computational efficiency is presented to detect Power quality, while in Table 4 the analysis of all the main methods of power quality comparison is presented. By the publication [32]-[121], critical review comparative study of detection techniques of power quality events is carried out.

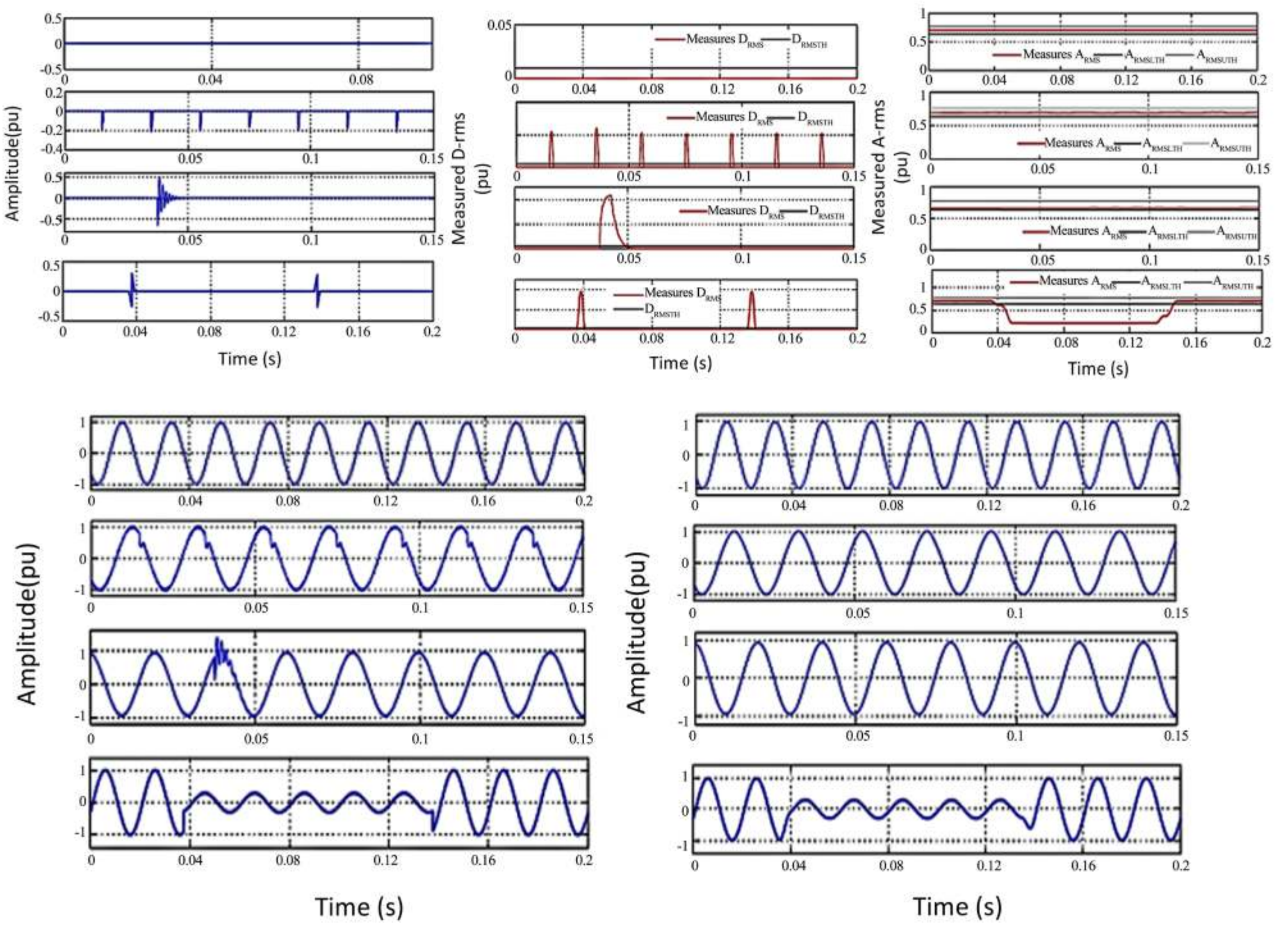

Figure 2. Fundamental, normal, oscillatory transients, voltage sag, and notch sag. Signals with extracted feature along with signal feature measured rms envelope, with extracted approximation and approximation signal measured rms envelope.

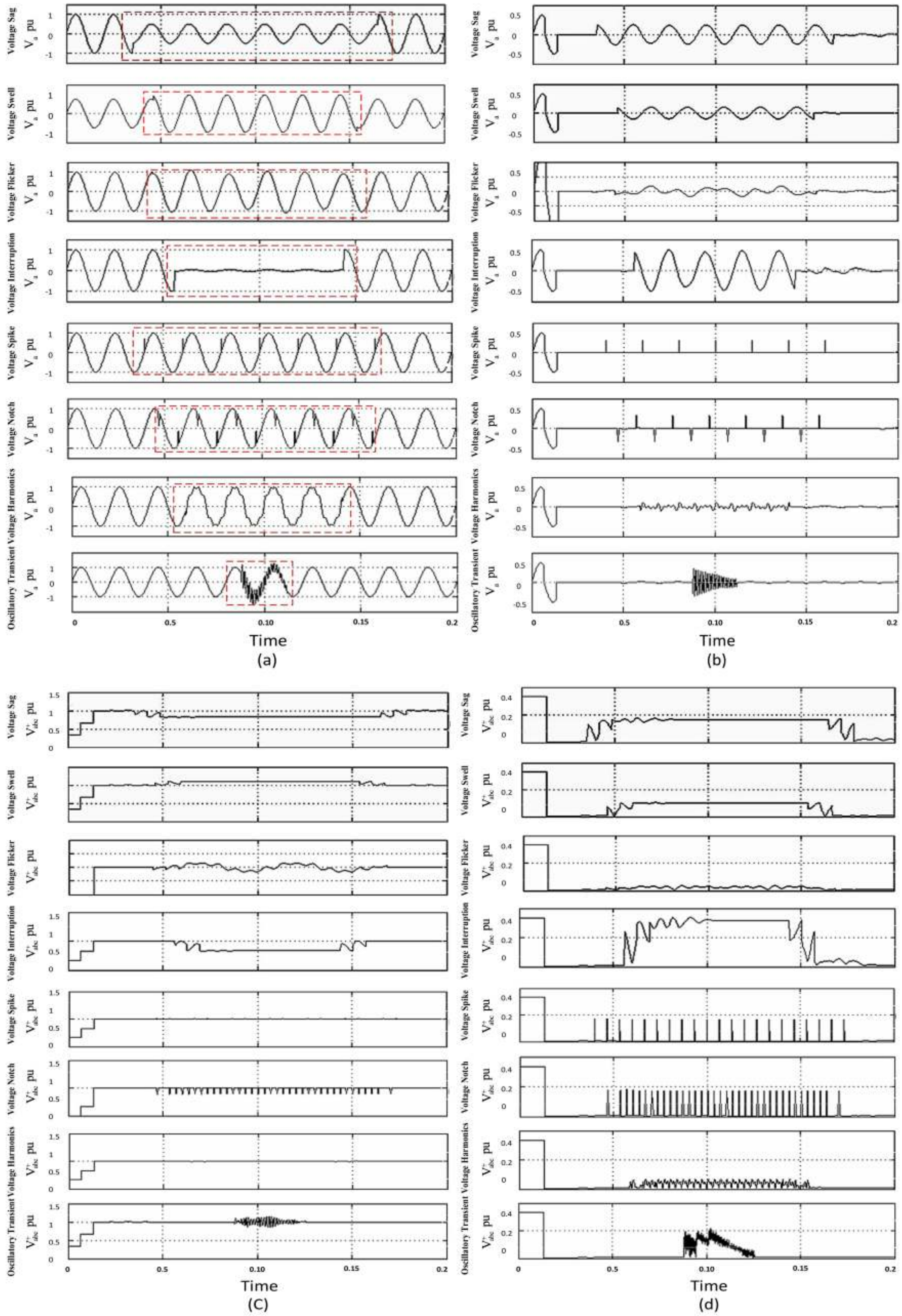

Figure 3. (a) Different power quality disturbances; (b) Phase disturbances; (c) Positive instantaneous peak contour; (d) Negative instantaneous peak contour.

Table 3. Power quality techniques computational efficiency.

SR-No.	Power Quality Disturbance	Power Quality Detection Techniques Efficiency in Percentage			
		Discrete Wavelet Transform [36]	Fast Fourier Transform [36]	S-Transform [113]	Hilbert Haung Transform [218]
1	Flicker	98.67	89	100	100
2	Notch	97.33	-	83	100
3	Sag	98.67	95	100	100
4	Swell	99.33	98	100	100
5	Transient	98.67	100	100	98
6	Harmonics	99.33	100	100	95
7	Spike	-	-	77	95
8	Sag + Harmonics	98.18	-	100	98
9	Swell + Harmonics	98.18	-	100	89
10	Sag + Transients	98.36	-	-	-
11	Swell + Transients	98.18	-	-	-

Table 4. Power quality primary methods comparison analysis.

Sr. No	**Power Quality Analysis Techniques**	**Advantages**	**Disadvantages**
1	**Short Time Fourier Transform**	It's simple in implementation; it is used in stationary signals successfully whose properties do not change in time.	It has a fixed window width limitation which does not follow signals dynamics appropriately therefore it's not suitable for non stationary signals.
2	**Hilbert Huang Transform**	Phase and instantaneous amplitude can be simply assessed due it generation of quadrature signals. It's very useful in distorted waveforms to extraction of features.	It used to works only in narrow band conditions which is very limited.
3	**S-Transform**	It's very flexible it can easily convertible in 2-D frequency translation domain from time domain and even to Fourier frequency domain.	The reliance of frequency window width on central frequency generates inaccurate measurements of harmonics. It also does not gratify real-time necessities subject to block processing manner.
4	**Wavelet Transform**	It is suitable in an excellent time-frequency resolution it also provides in time as well as frequency the local representation.	It's anguishing due to the picket fence effect and spectral leakage and also sturdily affected due to presence of noises in the signal.
5	**Gabor-Wigner Transform**	It has good time-frequency resolution as well as high signal to noise ratio.	The time computational span is on high complexity as it's directly associated to sampling frequency. As well as it has a very limited availability at high frequencies.

4. Classification Techniques of Artificial Intelligence

Artificial intelligence (AI) can be define 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.

4.7. Power Quality Events Comparative Cram of Classification Techniques

A critical review has been carried out of classification methods of power quality events in [123] [224], this comparative study presents the strengths and weakness for different power qualities by various AI techniques are provided in **Table 5** to classify and analyzed. While in **Table 6** various classification methods for various Power quality disturbances are shown.

5. Effect of Noise on PQ Event Classifiers

Noise is the unwanted sound which is accompanied by signals when the monitoring devices captured; it has an adverse effect while extracting relevant features from the signal. Wavelet-based even detection performances are affected more adversely by noises in time localization, event detection and its classification due to the difficulty in separation of noises from the disturbances [225]. In the wavelet-based power quality monitoring system the detection capability is degraded with the presence of noises because when wavelet transform decomposes the power quality data, then multiple frequencies usually reveals at high bands due to noise present in the disturbances. So if compare to the fundamental component the level of noise magnitude is not very high, so it can easily be comparable to disturbance energy at these bands [226]. In [227], the change-point approach is introduced with the help of de-noising technique for monitoring wavelet-based power quality. Consequently, in [228], the author presented a new de-noising technique for the performance improvement of power quality disturbance classification. Power quality events which are influenced with noises can be recognized with the extraction of its integrated features via a neuro-fuzzy network as presented in [229]. Inter-scale & intra-scale wavelet coefficients dependencies are proposed as a technique to de-noise power quality waveform data to improve time localization and detection of Power quality disturbances in

Table 5. Weaknesses and strengths of artificial intelligence techniques.

Sr-No	Artificial Intelligence Techniques	Knowledge Representation	Explanation Ability	Data Mining	Learning Ability	Imprecision Tolerance	Uncertainty Tolerance	Adaoptability	Maintainability	Overall Generalized Performance
1	Neural Network	Satisfactory	Satisfactory	Very good	Very good	Very good	Very good	Very good	Very good	Very good
2	Artificial Neural Network	Outstanding	Good	Very good	Excellent	Very good	Very good	Very good	Very good	Very good
3	Support Vector Machine	Satisfactory	Satisfactory	Very good	Excellent	Excellent	Excellent	Very good	Very good	outstanding
4	Fuzzy Logic	Very good	Very good	good	Satisfactory	Very good	Very good	good	good	Satisfactory
5	Genetic Algoritum	Satisfactory	Satisfactory	good	Very good	Very good	Very good	Very good	good	Satisfactory
6	Expert System	Good	Very good	Satisfactory	Satisfactory	Satisfactory	good	Satisfactory	Satisfactory	Satisfactory

Table 6. Power quality event classification techniques comparison.

Sr-No	Artificial Intelligence Techniques	Advantages	Disadvantages
1	**Neural Network**	It exhibits high level of accuracy for diverse and mixed power quality disturbance classification.	In noisy conditions its efficiency is very limited or in other words it's less.
2	**Artificial Neural Network**	It offers mathematical suppleness with high accuracy in real time applications.	Its accuracy and convergence depends on its network architecture and also dependent on noises in the signal.
3	**Support Vector Machine**	It has a high learning process with a prospective to grip hefty features; it also provides a stable solution in quadratic optimization.	Its total dependent on training samples if they are minimum, the classification accuracy is poor and vice versa.
4	**Fuzzy Logic**	It has a fascinated accuracy in analyzing complex systems and it's accurate in modeling.	It cannot accommodate new disturbances as its training set is limited for every case.
5	**Genetic Algorithm**	It classifies accurately power quality disturbances which are generated due to damped sub harmonic signals and dynamic performance of the power system.	It has a very high computational time.
6	**Expert System**	It has the facility that it can be used with/without limited data.	In this, the actual situation and assumptions do not match exactly and the extract of conclusion is very difficult furthermore its execution is very slow, moreover the system is very expensive.

[230], which is simple but yet effective de-noising method. In [231] wavelet-based Power quality monitoring is proposed a method of spatial noise-suppression as a de-noising technique. In this paper [232] the proposed is a quantile smoothing techniques to noisy signal, while in [233] the EMD based method for de-noising is proposed to align common frequency through multiple channels for facilitating the de-noising data. Furthermore [234] suggest the algorithm to the complex-valued differential for signal separation problems. The usage of SVM and ANN for the classification of power quality due to the presence of noise is presented in **Table 7** as a brief comparative study.

6. The Prospect Possibility

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

Table 7. The noise effect on the classification techniques of power quality.

Sr. No	Power Quality Classification Techniques	Notch	Transients	Voltage-Sag	Voltage-Swell	Sinusoidal Waveform
1	SVM	3.74	4.69	4.63	5.65	8.87
2	ANN	3.24	5.47	7.49	7.49	9.66

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.

7. 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 compressive review literature will help authors for selecting the particular method/techniques for their specific application/task and as well as the effectiveness of the particular methods with their significant advantages and disadvantages as outlined.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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