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A Survey on Classification of Power Quality Disturbances in a Power System

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ABSTRACT
Nowerdays, due to the penetration of power electronics based loads and microprocessor based controlled loads. We have to give more importance to power Quality problems. In order to improve the power quality, the sources of power quality disturbances should be recognized and classified earlier. So many techniques are proposed so far in many research papers under feature extraction and classification. This paper gives a survey of the various papers and it will be use full for the researchers to know about the various methods discussed and helps to do the further work in this area.
Keywords-Power Quality, Support Vector Machine, Fuzzy Expert System, Wavelet Transform.

I. INTRODUCTION

The increasing number of disturbing loads in industrial and public sectors cause power quality disturbances. These power quality (PQ) disturbances degrade the characteristics of power system. Power quality is defined as" set of parameters defining the properties of power quality as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage". There are multiple sources of disturbances, it is must to detect and classify them automatically to take appropriate mitigating actions and for power quality monitoring.

Power quality disturbances identification includes two steps mainly; they are extracting features of different disturbance signals and then classifying the disturbances signals .Basically signal processing techniques are used to extract features from the disturbance signal, such as Fourier transform (FT), short-time Fourier transform (STFT) S-transform (ST), Kalman filter (KF), Gabor-Wiger transform and wavelet transform (WT) for useful feature extraction from signals. In classification approach both conventional and artificial intelligence (AI) based classification methods are present. Where the limitations of conventional methods are overcome by the AI based methods. Some frequently used AI based classifiers are rule-based expert systems, fuzzy classification systems, artificial neural networks, kernel machines, and support vector machines.

In this work, various PQ issues, types of PQ disturbances, automatic power quality recognition system, feature extraction techniques and classification methods proposed by more researchers are analyzed and presented.

II. POWER QUALITY ISSUES AND DISTURBANCES

The power quality events/disturbances can further be classified according to the nature of the waveform distortion, in an electrical power system the various kinds of power quality disturbances

1. Transients
2. Interruptions
3. Sag/Under voltage
4. Swell/Overvoltage
5. Waveform Distortion
6. Voltage Fluctuations
7. Frequency Variation

Table: 1 Classification of various power quality events

Category	Duration	Voltage/ magnitude
<u>short Duration Variation</u>		
Sag	0.5-30 cycle.	0.1-0.9 pu.
• Instantaneous	30 cycles-3 sec.	0.1-0.9 pu.
• Momentary	3sec-1min.	0.1-0.9 pu.
• Temporary		
Swell	0.5-30 cycle.	
• Instantaneous	30 cycles-3 sec.	1.1-1.8 pu.
• Momentary	3sec-1min.	1.1-1.4 pu.
• Temporary		1.1-1.2 pu.
Interruption	0.5cycles-3sec.	
• Momentary	3sec-1min	<0.1pu.
• Temporary		<0.1 pu.

Long Duration Variation Under voltage Over voltage	 >1min >1min	 0.8-0.9 pu. 1.1-1.2 pu
Transients Impulsive • Nanosecond • Microsecond • millisecond Oscillatory • low frequency • medium frequency • high frequency	 <50nsec. 50-1msec. >1msec. 0.3-50msec. 20µsec. 5µsec	 0-4 pu. 0-8 pu. 0-4 pu
Voltage Imbalance	Steady state	0.5-2%
Waveform Distortion Harmonics Notching Noise	 Steady state Steady state Steady state	

III. SIGNAL PROCESSING METHODS

In order to improve the power quality it is essential to classify the source of disturbances .There are two groups of classification. the first group is called the disturbance classification such as voltage sag, voltage swell interruption etc, and second group is the event classification and the causes are faults, capacitor switching and transformer energizing .Signal processing techniques are used to extract the features of the disturbance waveforms. The feature can be extracted directly from its RMS value, total harmonic distortion values, harmonic magnitudes, energy values of WT coefficients , WT coefficients obtained from event signals and from transformed domain or from parameters of signal models.RMS method is a easy method but it does not give information on the wave where it begins. Now the commonly used feature extraction techniques are discussed below.

1. FOURIER TRANSFORM

The Fourier Transform(FT) is time dependent and tells about frequency contents in the signal and does not contain information on when they exist and for how long it exist.

Fourier transform (FT) is used to process and analyze only stationary signals, But most PQ signals are non stationary, so we need a technique that not only provide frequency information but also capture the timing of occurrence of the disturbance. Since FT is not an efficient analyzing tool for extracting the transient information of the non-stationary signals. P.Kailasapathi et al [1] described that FT can be applied to both continuous signal and discrete signal. It can be either periodic or aperiodic.

2. SHORT TIME FOURIER TRANSFORM

Short Time Fourier Transform (STFT) divides the full time interval into a number of small/equal – time intervals .it extracts several frames of the signal to be analyzed with a window that moves with time. Nonstationary signals characterized by wide range of frequency spectrum with transient and sub harmonic components are difficult to analyze with STFT. For nonstationary signals, the STFT does not track the signal dynamics properly due to the limitations of fixed window width [2].

Discrete Fourier transform (DFT) is used for analysis of frequency content in steady state periodic signal and is suitable for harmonic analysis .It is the widely used discrete signal processing algorithm. The Fast Fourier transform (FFT) produces the same result as evaluating the DFT but the only difference is FFT is much faster[3].

2. S-TRANSFORM

S-transform(ST) is a hybrid of STFT and wavelet analysis, bridges the gap between them containing the elements of both but having its own characteristic properties[4]Gaussian window makes S-T a powerful tool in power quality analysis.[5] proved ST has high tolerance and satisfactory accuracy on classification.[6] proposed a modified ST with Gaussian window on ST. The disadvantage of S-transform is the heavy computation, because each frequency point in the Fourier spectrum needs to be multiplied by the Gaussian window and then by inverse Fourier transform. Therefore the run time of s-transform is more.

4. HILBERT-HUANG TRANSFORM:

B. Biswal et al [7] presented Hilbert transform (HT) together with Empirical mode Decomposition (EMD).It is a new method of analyze non stationary signals .The significant use of EMD is to prepare a signal for the input of HT.EMD will generate a collection of intrinsic mode functions (IMF), then decomposition is based on the direct extraction of energy associated with various intrinsic time scales. The idea of EMD is repeatedly applying a process of shifting out the fastest oscillatory mode then separating the next fastest and so on until the signal entirely broken down into simple oscillatory component called IMF

5. KALMAN FILTER

Abdelazeem.A et al [8] presented a Kalman filter which is used to evaluate a value of the amplitude and slope of the captured waveform. If there is any change in the magnitude of the fundamental component, kalman filter is used to analyze the voltage event. The results of kalman filter depend on the model of the system and suitable selection of filter parameters. If the filter parameters are not suitable, the rate of convergence will be slow or the results will diverge. Advantage of kalman filter in [9] is the time varying analysis and noise tolerance. But the disadvantage is KF based approach depend wholly on the model of state and measurement matrixes. Any mismatch of signal and filter model brings error and divergence occur if nonlinear filter model is employed.

6. WAVELET TRANSFORM

Wavelet transform (WT) is an important tool used for feature extraction in power quality disturbance identification [10]. WT traces the signal change in time domain and simultaneously decompose the signal in frequency domain. In wavelet based approach, a mother wavelet is employed for finding the wavelet coefficients of the signal that affects the effectiveness in identifying the disturbance present in the signal. WT prepares a window that automatically adjusts to give proper resolutions of both the time and frequency. Here a large resolution of time is provided to high frequency components of a signal and larger resolution of frequency to low frequency components. These features makes WT well suited for the analysis of power system transients caused by various PQ disturbances.

IV. POWER QUALITY CLASSIFIERS

1.ARTIFICIAL NEURAL NETWORK

Neural network is a non linear, data driven self adaptive method and a promising tool for classification of power quality disturbance [11].The neural network recognizes a given pattern by experience which is acquired during the learning or training phase when a set of finite examples is presented in the network. This set of finite examples is called the training set and it consists of input patterns (i.e. input vector) along with their label of classes (i.e. output).In this phase, neurons in the network adjust their weight vectors according to certain learning rules. After the training process is completed, the knowledge needed to recognize patterns is stored in the neurons weight vectors. The network is then presented to another set of finite examples .i.e., the testing data set, to assess how well the network performs the recognition tasks. This process is known as testing or generalization.ANN is a universal function approximator i.e., this can approximate any function with arbitrary accuracy. All the above mentioned attributes make ANN flexible in modeling real world complex problems [12].

2. FUZZY-EXPERT SYSTEM

Fuzzy logic refers to a logic system which represents Knowledge and reasons in an imprecise or fuzzy manner for reasoning under uncertainty. Fuzzy logic system has strong inference capabilities of expert system as well as power of natural knowledge representation. The rules of this AI technique are based on modeling human experience and expertise. A membership function provides a measure of the degree of similarity of an element in the fuzzy subset. Unlike the classical logic systems, it aims at modeling the imprecise modes of reasoning that play an essential role in the human ability to infer an approximate answer to a question based on a store of knowledge that is in exact, incomplete, or not totally reliable. It is usually appropriate to use fuzzy logic when a mathematic model of a process does not exist or does exist but is too difficult to encode and too complex to be evaluated fast enough for real time operation. The accuracy of the fuzzy logic systems is based on the knowledge of human experts, hence it is only as good as the validity of the rules.

Ortiz et al [13] have proposed a fuzzy expert system for detection and classification of voltage sag. Abdelsalam et al [14] proposed a new algorithm for power system disturbance classification. It is a two stage system that employs the great potentials of the discrete wavelet transform. Kalman filter and a fuzzy expert system. For the first stage, the captured voltage waveform is passed through the DWT to determine the noise inside it. The covariance of this noise is then calculated and fed together with the captured voltage waveform to the kalman filter to provide the amplitude and the slope of this waveform. These are considered as an input to the fuzzy expert system in the second stage to determine the class to which the waveform belongs.

3. ADAPTIVE NEURO FUZZY SYSTEM

Adaptive neuron fuzzy system (ANFS) is a hybrid system incorporating the learning abilities of ANN and excellent knowledge representation and inference capabilities of fuzzy logic that have the ability to self modify their membership function to achieve a desired performance. ANFS utilizes the hybrid learning rule and manage complex decision making or diagnosis system. ANFS has proved as the effective tool for tuning the membership functions of fuzzy inference system [15].

4. GENETIC ALGORITHM

Genetic Algorithm (GA) is a probabilistic search method. The Principle of GA is the survival of fittest solution among a population of potential solutions for

a given problem. Thus the new generations produced by the surviving solutions are expected to provide better approximations to the optimum solution.

Upender et al [16] proposed a technique consisting of a preprocessing unit based on discrete wavelet transform in combination with genetic algorithm for classifying the power system fault disturbances.DWT extract the features from the input current signals and fed to GA for classifying the faults.

Brahmodesem et al [17] proposed an efficient Genetic Algorithm based data mining for feature subset selection in a power quality pattern recognition application. Wavelet transform and S-transform are utilized to produce feature vectors and genetic wrapper based approach integrator multi-objective genetic algorithm to evolve optimal subsets of features for pattern classification.

5. SUPPORT VECTOR MACHINE

Support Vector Machine (SVM) can be treated as a recently developed special neural network. A SVM model is equivalent to a two layer perceptron neural network with using a kernel function.SVM is an alternative training method for multilayer perceptron classifiers in which the weights of the network are identified by solving a quadratic programming problem under linear constraints rather than by solving a unconstrained minimization as standard neural network training.[18].SVM is based on minimization of misclassification probability of unseen patterns with an unknown probability distribution of data

SVM is based on minimization of the misclassification probability of unseen patterns with an unknown probability distribution of data and have solid theoretical foundation rooted in statistical learning theory. Read world problems often require hypothesis spaces that are more complex than those using linear discriminents. SVM's are able to find non linear boundaries if classes are linearly non-separable the main issue of interest in using SVM for classification is its generalization

Axelberget et al [19] proposed SVM based algorithm for common type of voltage sag disturbances. The results show high accuracy which implies SVM classification technique an attractive choice for classification of voltage sag and other PQ disturbances. It has been found that the accuracy of the proposed method is also dependent on the features given to the classifier.

Karthikeyan et al [20] presented a wavelet transform and support vector machine based algorithm for classification of power quality disturbances. The features extracted through the wavelet transform are trained by SVM for classification of power quality disturbances. Five types of disturbances are considered for the classification problem.

V. CONCLUSION

Due to increased use of power electronic devices in modern power system, power quality becomes an important and challenging issue. In this paper a survey on power quality disturbances and techniques for detection, classification is done. There is no unique model to access the power quality problem and to identify and classify them properly. So we need improvement in different areas of classification in terms of reliability and accuracy.

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