A HYBRID CLASSIFIER FOR POWER QUALITY (PQ) PROBLEMS USING WPT AND ANFIS

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Abstract-This paper introduces a novel automatic hybrid classifier to detect and classify the Power Quality(PQ) problems in power systems using Wavelet Packet Transform(WPT) and Adaptive network based fuzzy inference system(ANFIS).Various PQ events like Normal, Sag, Swell and Interruptions are obtained by modeling three phase distribution system using MATLAB simulink. For classification, the selection of suitable features from the disturbance signal is extremely important. Recent literature survey deals with various signal processing techniques like Fast Fourier Transform (FFT), Discrete Wavelet Transform (DWT) and Wavelet Packet Transform (WPT) were used for feature extraction. From the above techniques, the main issues addressed are selection of optimal feature subset and the design of ANFIS architecture model. To build a competent and robust classifier, it is essential to extract the utilizable feature vectors from the disturbance signal that can optimize data size as well as incorporate the main characteristics of the signal. This paper addresses these issues, and the distinctive feature vectors are obtained with reduced number of coefficients by using Energy Entropy based WPT. From these, the best discriminative feature vectors with reduced number of coefficients are obtained and are used as input to ANFIS, so that the burden over classification can be reduced. The classification performance is compared with WPT based ANN. The simulation results obtained have significant improvement over existing methods. Thus the proposed hybrid classifier provides the most excellent detection among PQ problems that arises in real time by improving classification accuracy in terms of both computation time and means square error.

I. INTRODUCTION

Power Quality (PQ) is an issue that is becoming more and more paramount for both customers and utilities. Power Quality (PQ) problems mainly come up due to the proliferation in utilization of non linear loads, power electronic equipments and solid state switches which are perceptive to small distortions of supply voltage. The major PQ problems are voltage sag, swell, momentary interruptions and harmonics that can cause breakdown or faulty of electrical equipments, thus affects the performance and life expectancy of the equipments. To enhance PQ, it is crucial to identify and discriminate PQ problems.

In many research papers [2-4], Fast Fourier Transform (FFT) is used as a signal processing technique for the detection of PQ problems, which provides information in frequency domain and is not fitted for analyzing non stationary signals. Many of the researchers use Wavelet Transform (WT) [5-6] which has a fully scalable window that allows precise separation of signal characteristics that are used to extract features from the disturbance signal in terms of both time and frequency, so that it is more suitable for analyzing non stationary signals. In many research papers, the combined WT and ANN is used as a classifier for Power Quality problems [7-10]. But the classification accuracy mainly depends on the extraction of specific features from the disturbance signal, choice of mother wavelet and the design of ANN architecture. The other improved schemes STFT, S-Transform have been developed for detecting PQ events [11-14].To overcome the limitations of Wavelet Transform, Wavelet Packet Transform (WPT) is used in many research papers [15-17] for the detection of PQ problems.

Adaptive Neuro Fuzzy Inference System (ANFIS) is a combination of fuzzy systems and neural network. In ANFIS, neural network is used to decide parameters of the fuzzy system. Necessity for manual optimization of the fuzzy system parameters is mainly removed by ANFIS. The system parameters are adjusted automatically with use of Neural network. e.g.… adjusting the membership functions bounds, leading to improved performance without operator intervention. "The neuro fuzzy system with the learning capability of neural network and with the benefits of the rule-base fuzzy system can improve the performance considerably and can provide a mechanism to incorporate past observations into the classification process. In neural network the training basically builds the system. However, using a neuro fuzzy scheme, the system is built by fuzzy logic definitions and is then refined using neural network training algorithms

Advantages of ANFIS:

A. *To define the behaviour of a complex system. ANFIS improves fuzzy if-then rules. It does not require prior human expertise*
B. *Larger choice of membership functions to use.*

C. It uses membership functions

D. It has very fast convergence time.

E. Desired dataset to approximate

The results obtained prove that this proposed hybrid classifier provides the most excellent classification in terms of both accuracy and time.

II. WAVELET PACKET TRANSFORM

The wavelet packet transform (WPT) provides a multi resolution and time–frequency testing for non-stationary signals. For breakdown a low (L) and high (H) pass filter is perpetually applied to the function f, with decimation 2, to engender a consummate sub-band tree decomposition to acquire the desired depth as shown in Fig .1. WPT decomposes both approximations and details of the signal; it embraces the consequential information placed in higher frequency apparatus. A WPT is represented as a function

$$\Psi_{(j,k)}^{i}(t)=2^{-j/2}\,\Psi^{i}[2^{-j}x(t-k)] \quad (1)$$

Where i is the modulation parameter, j is the dilation parameter and k is the translation parameter i=1, 2,...,j,.. n , and n is the level of breakdown in wavelet packet tree. The number of decompositions from a signal in dissimilar ways may be profoundly and astronomically immense.

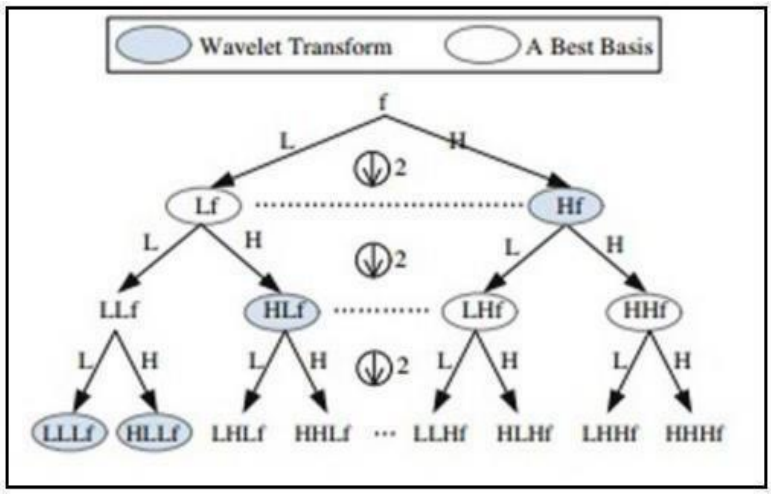


Fig.1:Wavelet Packet Decomposition

To attain an optimal decomposition the concept of Wavelet Packet Energy is introduced which grant valuable information about the signal. In this paper, Shannon entropy is used to compute signal density to wavelet coefficients engendered by WPT where high entropy values represent higher process uncertainty consequently higher complication. The Shannon entropy is defined as

$$E(s) = \sum s_i \log(s_i) \quad (2)$$

Where S_i represents coefficients of signal S in an ortho normal basis. If the entropy value is greater than one, the component has a capability to expose more information about the signal and it is needed to be decomposed further in order to obtain simple frequency component of the signal.

III. THE ADAPTIVE NETWORK BASED FUZZY INFERENCE SYSTEM (ANFIS)

The adaptive network based fuzzy inference system (ANFIS) is a data driven procedure representing a neural network approach for the solution of function approximation problems. Data driven procedures for the synthesis of ANFIS networks are typically based on clustering a training set of numerical samples of the unknown function to be approximated.

The architecture of multi layered ANFIS network is shown in Fig.2.

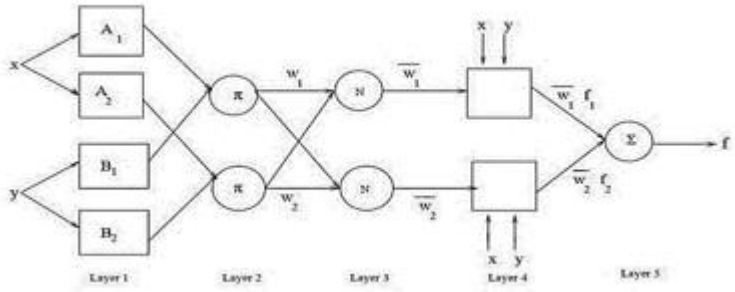


Fig.2:ANFIS Architecture

ANFIS was built on the three main components, namely basic rules, where it consists of the selection of fuzzy logic rules "If-Then;" as a function of the fuzzy set membership; and reasoning fuzzy inference techniques from basic rules to get the output. FIS will work when the input that contains the actual value is converted into fuzzy values using the fuzzification process through its membership function, where the fuzzy value has a range between 0 and 1. The basic rules and databases are referred to as
this network has different functions and tasks, and the output depends on the incoming signals and parameters that are available in the node. A learning rule that was used can affect the parameters in the node and it can reduce the occurrence of errors at the output of the adaptive network.

IV. PROPOSED SCHEME

The detection and relegation of different Power Quality problems that may occur in a distribution system is crucial for PQ assessment. To achieve this, the proposed hybrid classifier is developed which consist of Energy Entropy based Wavelet Packet Transform (WPT) and ANFIS for automatic detection and discrimination of different Power Quality disturbances. The different stages involved in this work are shown as a block diagram in Figure.3. will be explained in the following sections. the knowledge base, where both are key elements in decision-making. Normally, the database contains definitions such as information on fuzzy sets parameter with a function that has been defined for every existing linguistic variable. The development of a database typically includes defining a universe, determination of the number of linguistic values to be used for each linguistic variable, as well as establish a membership function. Based on the rules, it contains fuzzy logic operators and a conditional statement "If-Then." The basic rules can be constructed either from a human or automatic generation, where the searching rules using input– output data numerically Adaptive network is one example of feed forward neural network with multiple layers In the learning process, these networks often use supervised learning algorithm. In addition, adaptive network has the architecture characteristics that consists of a number of adaptive nodes interconnected directly without any weight value between them. Each node in Disturbance Signal Generation

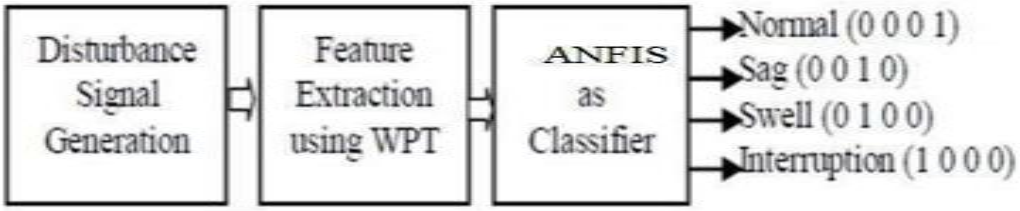


Fig.3.: Block Diagram of the Proposed Scheme

Fig.4 Different Power quality disturbance signals Normal, Sag, Swell and Interruption have been obtained using MATLAB simulink by create single phase to ground fault between the instance 0.2s to 0.4s in a 440V ,50 Hz three phase distribution system connected with linear load as shown in Fig. 4.The simulated PQ events obtained are shown in fig.5. (a-d). 100 samples of data for each PQ disturbance signals normal, sag, swell and interruption are generated for various distribution voltages by the creation of fault at different instances

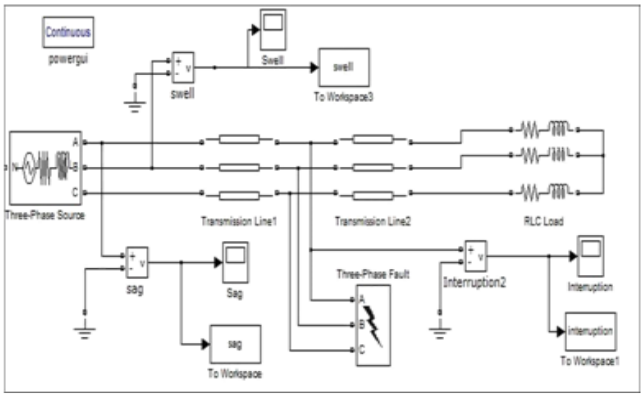
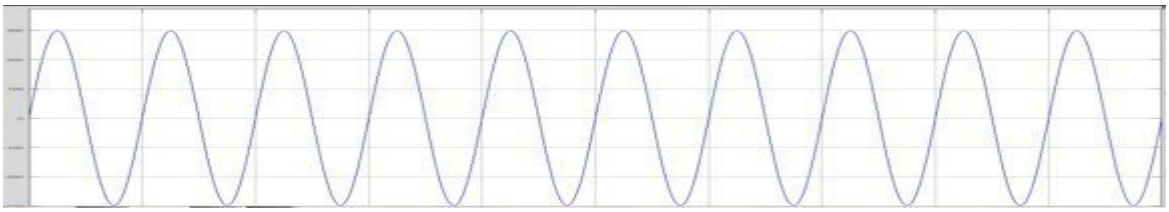
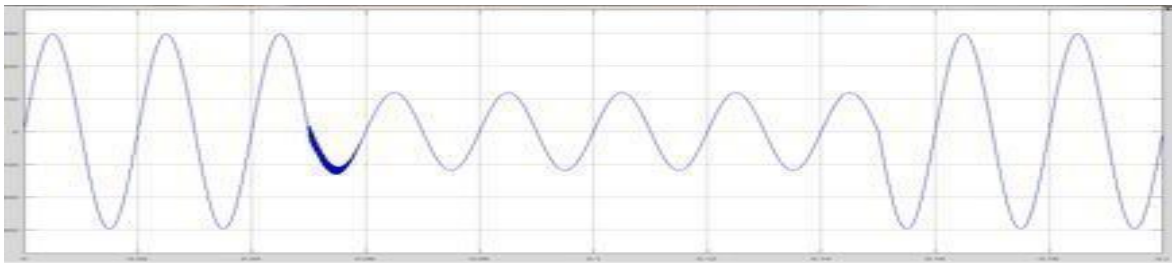


Fig.4:Simulation model for the generation of disturbance signal



(a)



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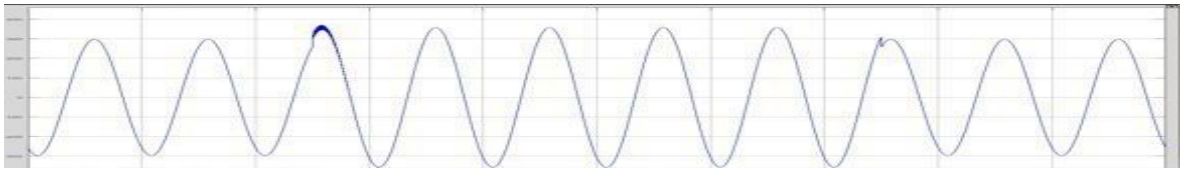
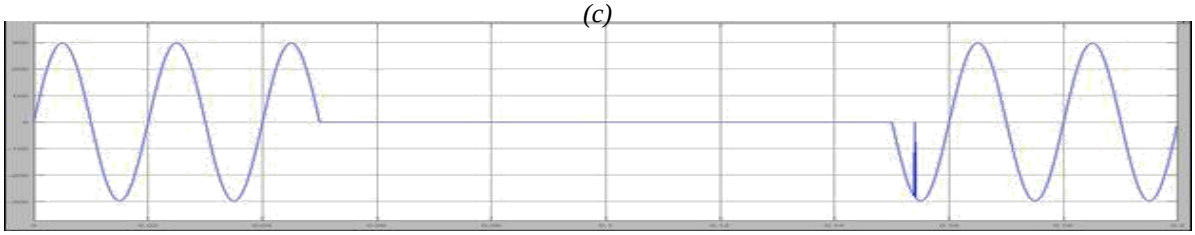


(c)



(d)

Fig.5:(a)Normal;(b)Voltage sag;(c)Voltage swell; (d)Interrupti

Feature Extraction using WPT

Feature extraction is the key for pattern apperception should reduce the dimension of pattern vector (i.e., the original waveform) to a lower, which contains most of the utilizable information from the pristine vector. Wavelet Packet Transform is used to decompose the PQ disturbance signal with an excellent resolution. During WPT decomposition each signal is decomposed up to level 3, and the mother wavelet chosen is "Db2".The WPT decomposition for voltage sag is shown in Fig. 6.

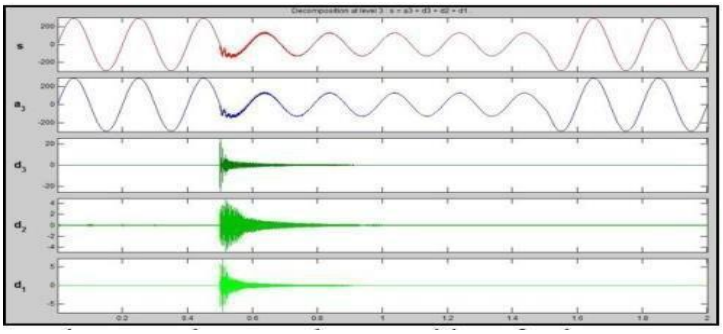


Fig.6: Level 3 WPT decomposition of voltage sag

After decomposition shanon energy entropy based principle is applied to optimize the size of the feature vector so that the useful information from the disturbance signal is obtained with reduced dimension feature vector. Development of ANN Architecture In this proposed scheme, the feature vectors from the disturbance signal are obtained by using FFT and Energy entropy based WPT so that two different ANN architectures FFT based ANN and WPT based ANN have been considered.

In FFT based ANN, FFT is worn to get the input characteristic vectors from the disturbance signal so that 35 samples are obtained for each disturbance signal, the number of neurons in the input layer is 35.

One hidden layer is taken and the number of neurons are different from 18 to 70 and the optimum results are obtained with 35 neurons. If the number of neurons in the hidden layer is increased further than 35, the system complexity increases but the results are not getting much improved. One output layer with four outputs is selected. therefore, the final FFT based ANN architecture consist of one input layer with 35 neurons, one hidden layer with 35 neurons and one output layer with 4 neurons.

In WPT based ANN, the feature vectors from the disturbance signal are obtained by using Wavelet Packet Transform. The obtained optimum feature vectors consist of 8 samples for each disturbance signal which are given as input to ANN. Thus the number of neurons in input layer is 8. One unknown layer was taken and the number of neurons is chosen as 8. One output layer with four outputs was selected. Hence, in the final WPT based ANN architecture consists of one input layer with 8 neurons, one hidden layer with 8 neurons and one output layer with 4 neurons. Thus, the proposed hybrid classifier will provide best configuration topology.

V. SIMULATION RESULTS AND ANALYSIS

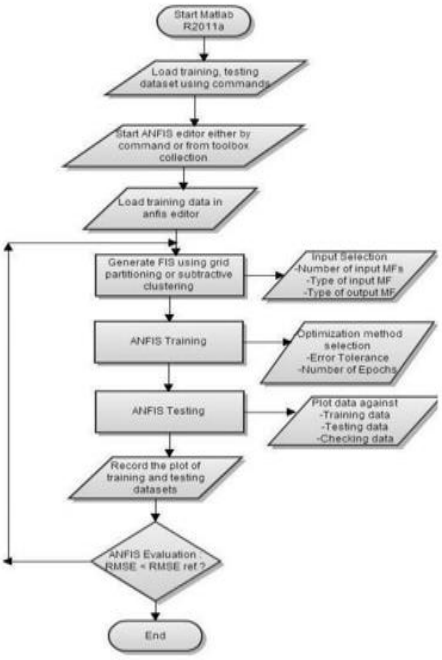
In order to validate the presentation of the future classifier, 200 disturbance signals for normal, sag, swell and interruption are generated in the three phase distribution system by varying input voltage and creating fault at different instances using matlab. Then the signal processing techniques WPT and the proposed energy entropy based WPT are used to obtain the characteristic vectors from the disturbance signal. Based on the size of the feature vectors obtained, two different ANFIS classifier model is developed, one for WPT based ANFIS and the another for WPT based ANN. In both the classifiers. The detailed flow chart for the implementation of ANFIS is shown in fig.7.

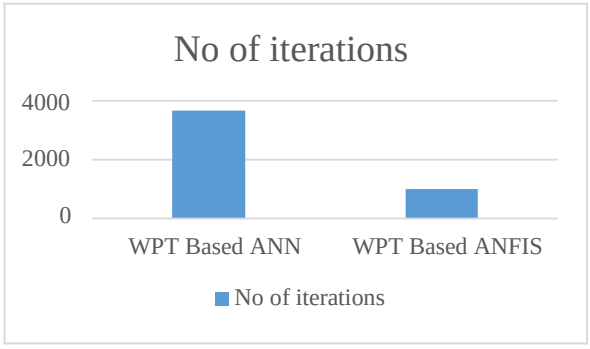
0 0 0 1 ---- Normal.
0 0 1 0 ---- voltage sag.
0 1 0 0 ---- voltage swell.
1 0 0 0 ---- Interruption

The momentum factor used is 0.90. The obtained simulation results of WPT based ANFIS are given in Table1.Both the ANFIS classifiers have four outputs. The outputs of both the network are shown below

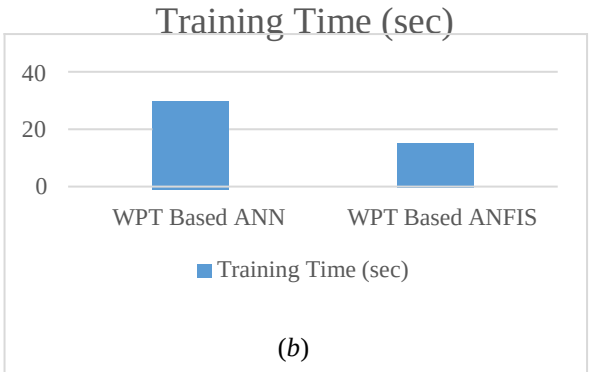
Subsequent to adequate training both ANFIS models were tested with all achievable set of dataunder different power quality events. The performance comparison of WPT based ANFIS and WPT based ANN classifiers are shown in table1,2

As compared to WPT based ANFIS, the proposed WPT based ANN classifier gives faster (in terms of number of iterations shown in Fig.8.(a) and simulation time shown in Fig.8.(c)) and more accurate (in terms of mean average error shown in Fig.8.(b)). Thus the proposed classifier is a promising tool for the precise detection and classification of different power quality problems.





(a)



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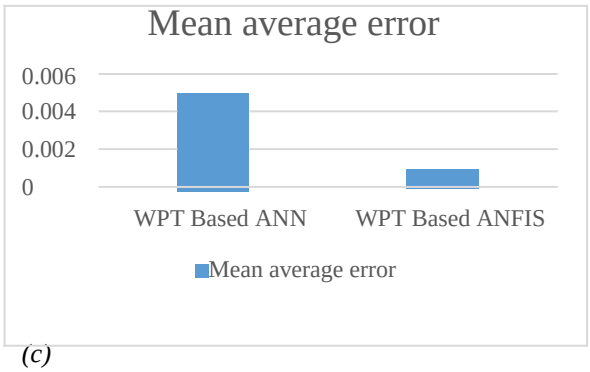

(c)

Fig.8: (a-c).Performance Comparison of a proposed classifier

Table.1: WPT Based ANN

Different PQ Problems	Architecture	Output for training and testing								Error
		1		2		3		4		
		A	T	A	T	A	T	A	T	
Normal	8-8-4	0.0000	0	0.0195	0	0	0	0.9752	1	0.019
Sag	8-8-4	0.0045	0	0.0000	0	0.9903	1	0.0057	0	0.012
Swell	8-8-4	0.0000	0	0.9961	1	0	0	0.0054	0	0.0066
Interruption	8-8-4	0.9951	1	0	0	0.0044	0	0	0	0.0065

Table.2 WPT Based ANFIS

Different PQ Problems	Architecture	Output for training and testing								Error
		1		2		3		4		
		A	T	A	T	A	T	A	T	
Normal	8-8-4	0.0000	0	0.009021	0	0000	0	0.988255	1	0.014810
Sag	8-8-4	0.0000	0	0.0000	0	0.995655	1	0.002655	0	0.005092
Swell	8-8-4	0.0000	0	0.998525	1	0.0000	0	0.0000	0	0.001475
Interruption	8-8-4	0.998201	1	0.0000	0	0.0000	0	0.0000	0	0.001799

Table . 3: Performance comparison of WPT Based ANN and WPT Based ANFIS Classifiers

Parameters	WPT Based ANN	WPT Based ANFIS
No of Iterations	3653	1000
Training Time(sec)	30	15
Mean Average Error	0.005	0.001

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