Classification of Power Quality Disturbances using Wavelet-Transform & Fuzzy Base Expert System

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Abstract— A system for power quality (PQ) disturbance (event) analysis is proposed using wavelet feature (WF) based fuzzy classification method. Wavelet transform (WLT) has been proven to be an effective tool for extracting inherent features through time- frequency analysis of these events. In this work WLT is used for detection and/or localization of PQ events and to decompose the PQ event signals for extracting unique features. These WF are fed into fuzzy classifier for making decision regarding the type of events. Varieties of PQ events which include voltage sag, swell, momentary interruption, flicker, oscillatory transient and harmonics are considered to test the performance of proposed approach.

Key words: Power Quality, Wavelet Transform, Fuzzy Classifier

I. INTRODUCTION

Modern power systems are complex networks of generating stations and load centers interconnected through transmission & distribution lines. The main concern of consumers is the quality and reliability of power supplies at various load centers. Poor power quality is normally caused by power-line disturbances, such as voltage sag/swell, harmonic distortion, flicker, momentary interruptions, impulses and so on. The poor power quality can have a large detrimental effect on both the industrial process and commercial users [6]. To solve power quality problems it is necessary to know the sources and causes of such disturbances. When the disturbance type has been classified accurately, the power quality engineer can define the major effects at the load and analyze the source of the disturbances. Thus it is desirable to develop the method for detecting, identifying and analyzing all kinds of disturbances. The discrete wavelet transform technique is integrated with the fuzzy logic model to build the classifier [9]. Firstly, the wavelet decomposition based on Mallat algorithm and the Parseval's theorem are introduced. Secondly, to extract disturbance features, the energy distribution of the wavelet at each decomposition level is calculated. Thirdly, the fuzzy-expert system is employed to classify disturbance according to the wavelet decomposition level and the numerical values of the energy distribution. Based on the energy distribution patterns the membership functions of inputs and rule base are generated. Finally, the fuzzy set of the output variable will be mapped into a crisp number, in terms of which the disturbances are classified.

II. WAVELET TRANSFORM AND FEATURE EXTRACTION

A. *Wavelet Transform Decomposition*

The wavelet transform is a mathematical tool which has its energy concentrated in time and analyzes transient non-stationary or time varying phenomenon [4]. The main characteristic in discrete wavelet transform (DWT) is the Mallat algorithm which can decompose the original signal into several other signals with different scales. The high frequency part is called the detail version which contains sharp edges, transition, and jumps, while the low frequency part is called the smoothed version. Decomposed signal at scale j are $a_j(n)$ and $d_j(n)$, where $a_j(n)$ is the approximation coefficients which represent the smoothed part of signal f(n), and $d_j(n)$ is the detail coefficients. The definitions are shown as [10]

$$a_j(n) = \sum_k h(k-2n) f_{j-1}(k) \quad (1)$$

$$d_j(n) = \sum_k g(k-2n) f_{j-1}(k) \quad (2)$$

Where, h(n) and g(n) are the associated filter coefficients that decomposed f(n) into $a_j(n)$ and $d_j(n)$.

In this proposal, the Daubechies wavelet is chosen to analyze different power quality disturbances, because of its sensitivity to irregular and non-stationary signal. Among Daubechies wavelets, the Db 4 is the only wavelet that can detect the small fluctuation of signal compared with others. Therefore, Db4 could be the optimal choice because it is the most localized in time [4]. In order to ensure all disturbance features in both high and low frequency are extracted, 9-scale signal decomposition is used.

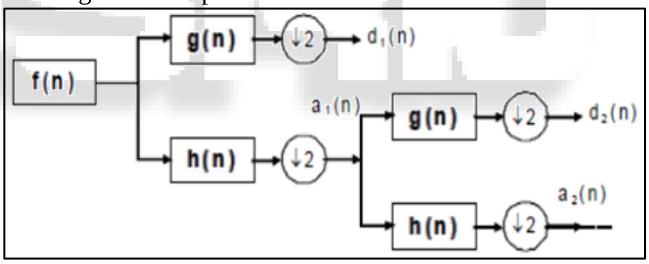


Fig. 1: Two Level Wavelet Decomposition of a Signal f(n) bsased on Mallat Algorithm

B. *Parseval's Theorem in DWT Application*

According to Parseval's theorem, the energy of the distorted signal is related to the energy in each of the expansion components and their wavelet coefficients. It means that the energy of the signal can be separated according to the following expansion [1]:

$$\int |f(t)|^2 d(t) = \sum_k |a(k)|^2 + \sum_{j=0}^{j-1} \sum_k |dj|^2 \quad (3)$$

Therefore, the energy of distorted signal E_{signal} can be defined by wavelet coefficient as formula:

$$E_{signal} = E_{a0} + \sum_{j=0}^{j-1} E_{dj} \quad (4)$$

$$E_{a0} = \sum_k |a(k)|^2 \quad (5)$$

$$E_{dj} = \sum_k |dj(k)|^2 \quad (6)$$

Where, E_{ao} is the energy of the approximated version of the decomposed signal and E_{dj} is the disturbance energy at the detail version. The energy distribution features of the detailed version from distorted signal will be utilized to extract the features of power disturbances. Therefore, the detailed energy will be calculated at each decomposition level to extract the feature curve [3][8].

C. Feature Extraction

In general, it is possible to categorize three properties of energy distribution of the distorted signal based on wavelet decomposition levels.

- When a sag or swell or interruption occurs, the great variations of energy will show in normal frequency sag and swell zone.
- When the voltage suffers a disturbance of the high frequency elements, the obvious variations of energy will show in high frequency disturbance zone.
- When the voltage suffers a disturbance of the low frequency elements, the obvious variations of energy will show in low frequency disturbance zone.

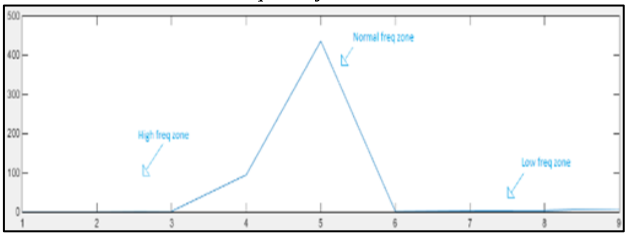


Fig. 2: Generalized Power Quality Feature Extraction Curve (Pure Sine Wave)

The amplitude of the feature extraction curve is the numerical value of the energy distributions at each wavelet level. The peak value of feature extraction curve generated by pure sine wave could be viewed as the fundamental. The fundamental is used to compare with other peak value of feature extraction curve generated by the other kind of distorted signals. They can become the features for classifying the disturbances.

III. FUZZY-EXPERT SYSTEM FOR PQ DISTURBANCE CLASSIFICATION

Fuzzy logic refers to a logic system which represents knowledge and reasons in an imprecise of fuzzy manner for reasoning under uncertainty. A fuzzy-expert system is an expert system that utilizes a collection of fuzzy sets and rules for reasoning about data. In this proposal, a 9-level decomposition of each distorted signal to obtain the detailed coefficients d1~d9 is used. Using Equation (6), one can obtain energy distribution. The wavelet decomposition levels of feature extraction curve and energy in feature extraction curve will be applied to the fuzzy-expert system for classifying the distorted signals [3].

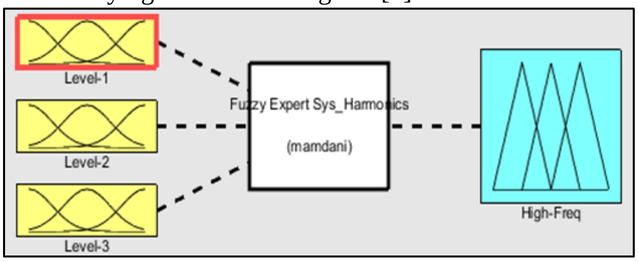


Fig. 3: Proposed Fuzzy-Expert System Based on Mamdani Type Fuzzy Implication

The fuzzy-expert system is designed using Fuzzy Logic Toolbox (FIS) in Matlab. The frequency is 50Hz, amplitude is 1p.u. Parameters of electrical components are changed in order to generate different disturbance waveforms.

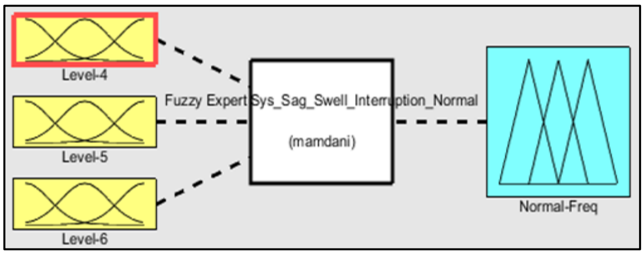
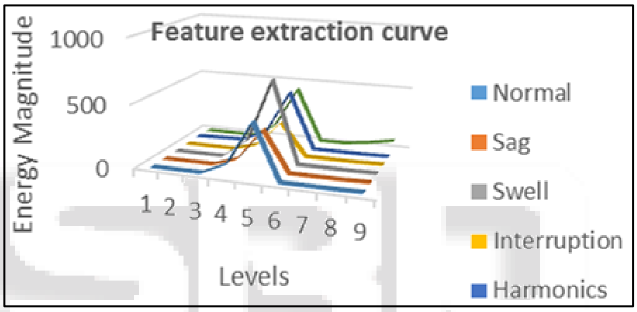


Fig. 4: Differences in Feature Extraction Curve of all Signals

- In voltage sag or swell or momentary interruption occurs, the energy in 5th and 6th wavelet decomposed levels will show obvious variation.
- For harmonic distorted voltage, the energy in 2nd, 3rd, and 4th wavelet decomposed levels shows obvious variation.
- For voltage flicker, transient the energy in 7th, 8th, and 9th wavelet decomposed levels will show obvious variation.



Base on the fuzzy set of input variables and the output variables. If-Then rules are made for classifying power quality disturbances [8].Once the fuzzy-expert system is designed, the classification of different disturbances can then be made. To test the accuracy of the proposed fuzzy-expert system, 10 new distorted voltage waveforms for each event are randomly generated and which has a different time of occurrence, duration, and amplitude. After calculating the energy on each wavelet decomposition level, the feature extraction curve is obtained, and then the classification of each waveform into different category by using the fuzzy-expert system is performed. The classification results of the generated disturbances using the proposed system in shown in Table-I.

Type of disturbance	Number of disturbance	Number of Case Correctly classified
Normal	10	10
Sag	10	9
Swell	10	10
Interruption	10	9
Harmonics	10	10
Transient	10	10
Sum	60	58

Table 1: Classification Results by using the Proposed Fuzzy-Expert System

It can be seen that the proposed fuzzy-expert system has classified correctly 58 disturbances of the total number of 60 tested disturbances, thus having a classification accuracy of 96.7%. Although only six types of waveform are classified, it is possible to classify more than six types. To classify new type of power quality disturbance new rule base will need to be developed based on the feature extraction curve of the new disturbances.

IV. CONCLUSION

In this paper, a fuzzy-expert system has been developed for classifying power quality disturbances. The energy distribution patterns in the wavelet domain are used to extract features. Based on the feature extraction curve, the membership functions of inputs and rule base are generated. Finally, the fuzzy set of the output variable is mapped into a crisp number, in terms of which the disturbances are classified according to the numerical value. The proposed fuzzy-expert system has been tested with ten unseen new distorted voltage waveforms to verify its classification accuracy. Results show that the proposed fuzzy-expert system has correctly classified 96.7% of the tested waveform. Also accuracy can be further increased by other AI techniques like Artificial Neural Network (ANN) etc. integrated with fuzzy based expert system.

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