Classification of Power quality problems by wavelet Fuzzy expert system

N.Karthik
Electrical and Electronics Engineering, Bapatla Engneering college
Bapatla, India,
karthik_21199@yahoo.co.in

Dr.Shaik Abdul Gafoor
Electrical and Electronics Engineering, Bapatla Engneering college
Bapatla, India

Dr.M.Surya Kalavathi
JNTU college of Engineering,Kukatpally,
Hyderabad, India

Abstract: Electric power quality, which is a current interest to several power utilities all over the world, is often severely affected by harmonics and transient disturbances. There is no unique model which can assess the power quality problem and to identify and classify them properly. Existing automatic recognition methods need improvement in terms of their versatility, reliability, and accuracy. The FUZZY LOGIC based tools have been applied for the PQ classification. This paper addresses Power quality problem classification by wavelet and fuzzy expert system. Major Key issues and challenges related to these advanced techniques in automatic classification of PQ problems are highlighted. New intelligent system technologies using DSP, expert systems, AI and machine learning provide some unique advantages in intelligent classification of PQ distortions.

INTRODUCTION

Modern power systems are complex networks, where hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks. The main concern of consumers is the quality and reliability of power supplies at various load centers where they are located at. Even though the power generation in most well-developed countries is fairly reliable, the quality of the supply is not so reliable. Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality problems.

Power quality problems are associated with an extensive number of electromagnetic phenomena in power systems with broad ranges of time frames such as long duration variations, short duration variations and other disturbances. Short duration variations are mainly caused by either fault conditions or energization of large loads that require high starting currents. Depending on the electrical distance related to impedance, type of grounding and connection of transformers between the faulted/load location and the node, there can be a temporary loss of voltage or temporary voltage reduction (sag) or voltage rise (swell) at different nodes of the system. Therefore, these power quality problems can be improved in distribution system by using custom power devices like DVR, D-STATCOM, and SSTC.

SHORT-DURATION VOLTAGE VARIATIONS: Voltage variations, such as voltage sags and momentary interruptions are two of the most important power quality concerns for customers.

Voltage Sags (dips) : One of the most common power quality problems today is voltage sags. Voltage sag is a short time event during which a reduction in r.m.s voltage magnitude occurs. Despite a short duration, a small deviation from the nominal voltage can result in serious disturbances.

Definition of Voltage Dips : Voltage sag is defined as a sudden reduction of supply voltage down 90% to 10% of nominal, followed by a recovery after a short period of time. A typical duration of sag is, according to the standard, l0 ms to 1 minute. Voltage sag can cause loss of production in automated processes since voltage sag can trip a motor or cause its controller to malfunction. An appearance of r.m.s voltage sag is shown in Figure 2.1

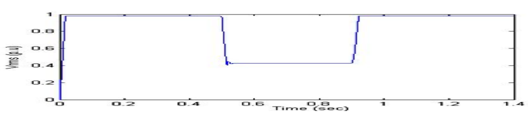

Figure 1: Voltage Sag

A three-phase voltage study of voltage dips results in two main groups, balanced and unbalanced voltage dips. A balanced voltage dip has an equal magnitude in all phases and a phase shift of 120^0 between the voltages, as shown in Figure 2

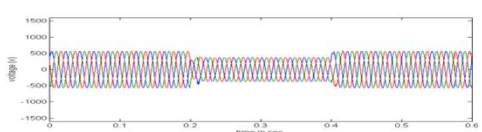

Figure 3: A Balanced 3-Phase Voltage Sag

Unbalanced voltage dips do not have the same magnitude in all phases or a phase shift of 120^0 between the phases. An example of unbalanced voltage dip caused by LLG fault is shown in Figure 2.3

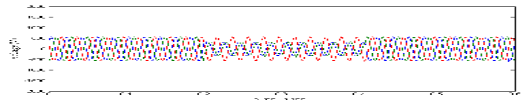

Figure 4: An Unbalanced 3-Phase Voltage Sag

Sources and Occurrences Voltage Sag : A voltage dip is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing. Typical faults are single-phase or multiple-phase short circuits, which leads to high currents. The high current results in a voltage drop over the network impedance. At the fault location the voltage in the faulted phases drops close to zero, whereas in the non-faulted phases it remains more or less unchanged (solidly grounded system). Many short circuits are initiated by over voltages.

Voltage Swells : Voltage swell, on the other hand, is defined as a sudden increasing of supply voltage up 1l0% to 180% in rms voltage at the network fundamental frequency with duration from 10 ms to 1 minute. Switching off a large inductive load or energizing a large capacitor bank is a typical system event that causes swells [4]. An appearance of r.m.s voltage swell is shown in Figure 2.4

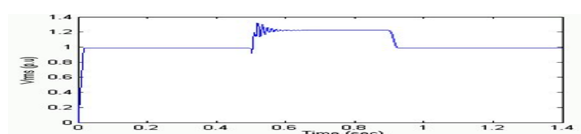

Figure 5: Voltage swell

Sources and Occurrences Voltage Swells: As with sags, swells usually associated with system fault conditions, but they are not as common as voltage sags. A swell can occur due to a single line-to ground fault on the system, which can also result in a temporary voltage rise on the un-faulted phases. This is especially true in ungrounded or floating ground delta systems, where the sudden change in ground reference result in a voltage rise on the ungrounded phases. Swell can also be caused by switching off a large load or energizing a large capacitor bank. Swells are characterized by their magnitude (rms value) and duration. The severity of a voltage swell during a fault condition is a function of fault location, system impedance, and grounding.

Voltage Interruptions

An interruption occurs when the supply voltage or load current decrease to less than 0.1 pu for a period of time not exceeding one minute. The interruptions are measured by their duration since the voltage magnitude always less than 10 percent of nominal. An appearance of r.m.s voltage swell is shown in Figure2.5.

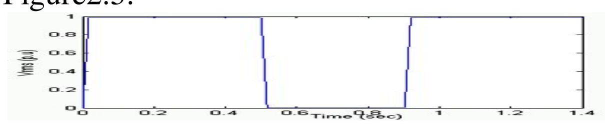

Figure 6: Voltage Interruptions

Sources and Occurrences of Voltage Interruptions

Interruptions can be result of power system faults, equipment failures, and control malfunctions. Delayed re-closing of the protective devices may also cause a momentary or temporary interruption. The duration of an interruption due to equipment malfunctions or loose connections can be irregular.

Effects of Voltage Sag and Interruptions

Slow down or stopping of induction motors, tripping of contactors or CBs, Mal-operation or tripping of adjustable speed drive, Failure of inverters, Incorrect operation of control and protective devices, Crashing of computers & Communication systems.

The collapse of computer system, loss of control, shut down of drives, mal-operation of devices may result in problems in certain critical applications,

Effects of Voltage Swells

The major effect of swell is on semiconductor devices, and the insulation of the system. This is further aggravated by the ageing effects of equipments. The life of the lamps and tubes is reduced, and the working of computers, IT and communication equipment is affected and have ageing effect on them. Voltage swell upsets the working of electrical control and variable speed drives.

The main objective of this paper is to classify the power quality problems using wavelet transformation with fuzzy logic. First, the wavelet transformation is described. Then, the paper describes the structure of wavelet transformation with fuzzy logic and, the performance of wavelet transformation with fuzzy logic is evaluated by simulation.

WAVELET TRANSFORMATION

Recently wavelet analysis is proposed in the literature as a new tool for monitoring power quality problems. Wavelet transformation has ability to analysis different power quality problems simultaneously in both time and frequency domains. The wavelet transform is useful in detecting and extracting disturbance features of various types of electric power quality disturbances because it is sensitive to signal irregularities but insensitive to the regular-like signal behavior. Wavelet analysis deals with expansion of functions in terms of a set of basis functions, like Fourier analysis. However, wavelet analysis expands functions not in terms of trigonometric polynomials but in terms of wavelets, which are generated in the form of translations and dilations of a fixed function called the mother wavelet. Compared with Fourier transform, wavelet can obtain both time and frequency information of signal, while only frequency information can be obtained by Fourier transform. The signal can be represented in terms of both the scaling and wavelet function as follows:

$$f(t) = \sum_n c_J(n)\, \emptyset(t-n) + \sum_n \sum_{j=0}^{J-1} d_j(n)\, 2^{j/2} \varphi(2^j t - n) \quad (1)$$

where c_j is the J level scaling coefficient,
d_j is the j level wavelet coefficient,
$\emptyset(t)$ is scaling function,
$\varphi(t)$ is wavelet function,
J is the highest level of wavelet transform,
t is time.

Continuous Wavelet Transformation

Each wavelet is created by scaling and translation operations in a special function called mother wavelet. A mother wavelet is a function that oscillates, has finite energy and zero mean value. Wavelet theory is expressed by continuous wavelet transformation as

$$CWT_{\varphi}X(a,b) = W_X(a,b) = \int_{-\infty}^{\infty} X(t)\, \varphi_{a,b}^{*}(t)\, dt \quad (2)$$

$$\varphi_{a,b}(t) = |a|^{\frac{1}{2}} \varphi\left(\frac{t-b}{a}\right)$$

a (scale) and b(translation) are real numbers.

Discrete Wavelet Transformation

Equation (2) has great theoretical interest for the development and comprehension of its mathematical properties. However, its discretization is necessary for practical applications. For discrete-time systems, the discretization process leads to the time discrete wavelet series as

$$CWT_{\varphi}X(a,b) = W_X(a,b) = \int_{-\infty}^{\infty} X(t)\, \varphi_{a,b}^{*}(t)\, dt \quad (3)$$

$$\varphi_{m,n}(t) = a_0^{\frac{-m}{2}}\, \varphi\left(\frac{t - nb_0 a_0^m}{a_0^m}\right)$$

a= a_0^m and b= $nb_0 a_0^m$

In power quality problem analysis, discrete wavelet transformation is adequate to classify the power quality problems.

Multiresolution Analysis

In multiresolution analysis (MRA), wavelet functions and scaling functions are used as building blocks to decompose and construct the signal at different resolution levels. The goal of MRA is to develop representations of a signal at various levels of resolution. MRA is composed of 2 filters in each level which are low pass filter and high pass filter. MRA can be shown as in Fig.7 Suppose signal co(n) is discrete time signal distributed in 2 level. This signal is filtered into high frequency component level 1 (d1(n)) by using high-pass filter (g(n)) and low frequency component level 1 (c1(n)) by using low-pass filter (h(n)). This signal is passed through down sampling as relation in eq. (4)-(5).

$$c_1(n) = \sum_k h(k-2n)\, c_0(k) \quad (4)$$

$$d_1(n) = \sum_k g(k-2n)\, c_0(k) \quad (5)$$

where g(n) is high-pass filter,
h(n) is low-pass filter.

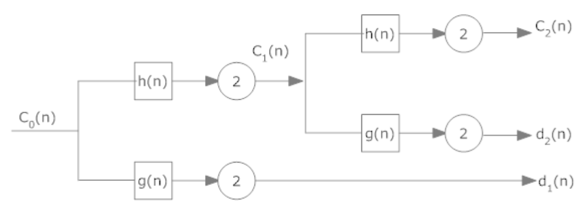

Fig. 7. Multiresolution of signal in 2 level.

In MRA level 2, the component in level 1 is used as initial signal. This signal is passed through High-pass filter and low-pass filter. The outputs of filter are the high frequency component and low frequency component in level 2 as relation in eq. (6)-(7).

$$c_2(n) = \sum_k h(k-2n)\, c_1(k) \quad (6)$$

$$d_2(n) = \sum_k g(k-2n)\, c_1(k) \quad (7)$$

Feature Extraction

MRA can detect and diagnose defects, and provide early warning of power quality problems. Furthermore, using standard deviation multiresolution analysis curve (Std_MRA) one will have the ability to quantify the magnitude of variation within the signal. The extracted features help to distinguish one disturbance event from another. The standard deviation is used to represent data
in each level of multiresolution analysis. However, the standard deviation is always positive value. In power quality problem, the graph of standard deviation of multiresolution analysis is very similar in some cases such as swell, notching, interruption, and voltage These signals change only magnitude but not change frequency. Hence, the features of these signals at level 7-8 are very similar which are difficult to classify each others. In order to extract feature of these signals, the standard deviation of power quality problem signals are subtracted from standard deviation of pure sinusoidal waveform.

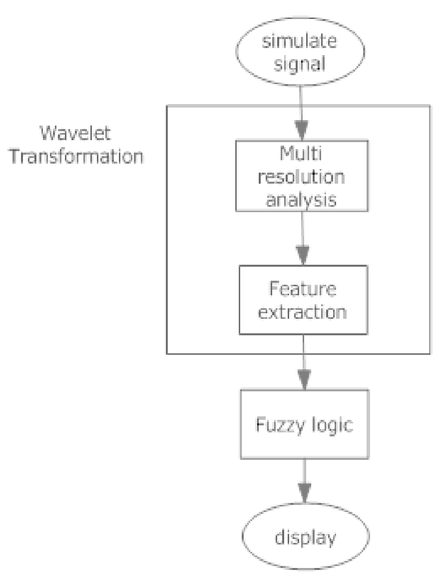

Fig. 8. Procedure in power quality analysis

POWER QUALITY PROBLEM CLASSIFICATION

Automatic classifiers used for classification of different power quality disturbances can be broadly classified into deterministic and statistical classifiers as described below:
Deterministic Classifiers: These classifiers can be designed with limited amount of data with sufficient power system expert knowledge. Rule based expert system and fuzzy expert system come under deterministic classification method.
Statistical Classifiers: Statistical methods are suitable when a large amount of data from training of the classifiers is available. Artificial neural network (ANN) and support vector machines (SVM) are the statistical based classifiers. The artificial neural network is more popular in literature and often combined with set of wavelet filters for feature extraction and fuzzy logic for decision making.Both conventional and artificial intelligence (AI) based classification methods are reported in the literature. 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. The artificial neural network is the most popular method in literature often combined with other AI techniques.
The main drawback of ANN technique is the need of training cycle and requirement of retraining the entire ANN for every new PQ event. With the use fuzzy logic based classifiers the drawbacks of ANN technique can be eliminated.

Fuzzy Expert System Based PQ Classifiers

Fuzzy logic with rule based expert system has emerged as a powerful categorization tool for PQ events that is computationally simple and fairly accurate. Fuzzy logic system (FLS) 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. The basic block diagram of fuzzy logic system is shown in Fig. 3.

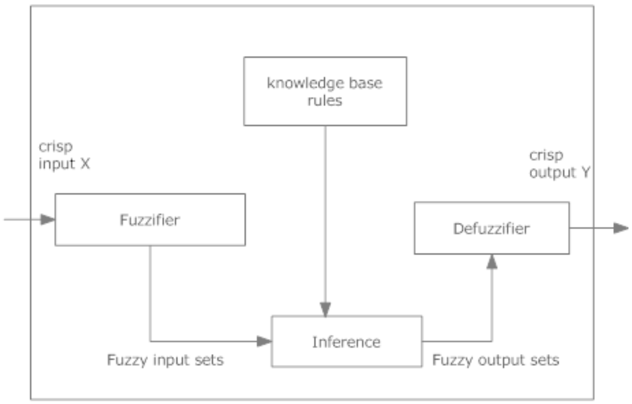

Figure 3. Fuzzy logic system

The proposed fuzzy expert system used for detection and classification of voltage sags. The extended fuzzy reasoning scheme used for identifying eight kinds of power quality disturbances. The extracted features in wavelet domain and fast Fourier transform (FFT) are used to form the linguistic rules. Simple disturbances such as outage can be detected without the use of DWT and FFT. A hybrid scheme using a Fourier linear combiner and fuzzy expert system has been presented. The captured waveforms have been passed through a Fourier linear combiner block to extract amplitude and phase of the fundamental signal. The proposed method was found to be accurate and robust in presence of noise. It is computationally simple and gives classification result in less than a cycle as compared to the proposed ANN based classifier in which produces large error in presence of noise and is computationally intensive.

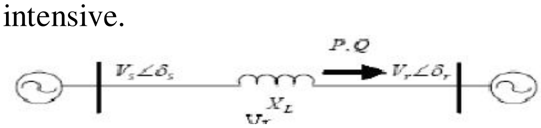

Fig4: system under study

Various power quality problems are simulated on system given in fig. various power quality problems can be defined by following features. Fundamental component of voltage, Phase angle shift, Harmonic distortion, number of wavelet coefficients, energy of wavelet coefficients and osilllations in RMS voltages. Proposed fuzzy wavelet expert system is simple to detect and classify various power quality problems. Mamdani type of expert system is proposed here.

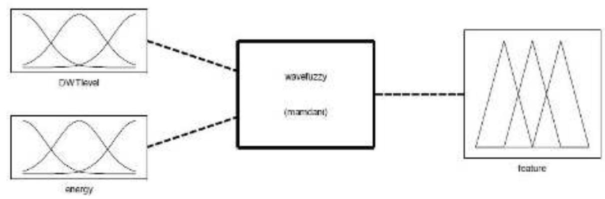

Fig5. Fuzzy expert system

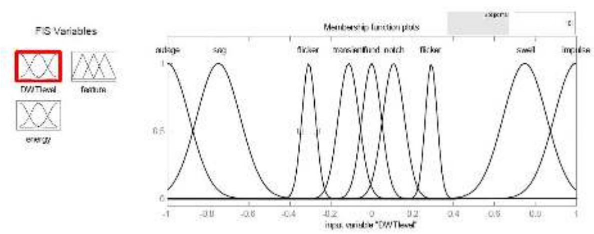

Fig6. Membership functions for DWT levels

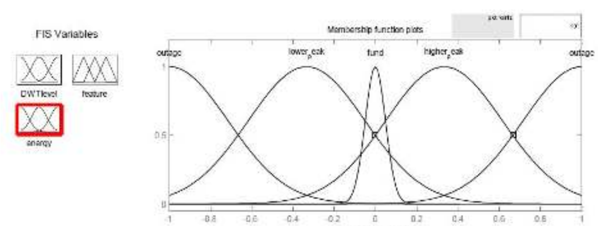

Fig7. Membership functions for energy levels

Rule base for fuzzy expert system

1) If DWT level is fund and energy level is fund then fundamental
2) If DWT level is transient and energy level is lower peak then transient
3) If DWT level is notch and energy level is lower peak then notch
4) If DWT level is flicker and energy level is fund then flicker

5) If DWT level is fund and energy level is outage then sag
6) If DWT level is sag and energy level is lower peak then sag
7) If DWT level is sag and energy level is higher peak then fund
8) If DWT level is swell and energy level is higher peak then sell
9) If DWT level is sell and energy level is lower peak then fund
10) If DWT level is outage and energy level is outage then outage
11) If DWT level is impulse and energy level is outage then impulse

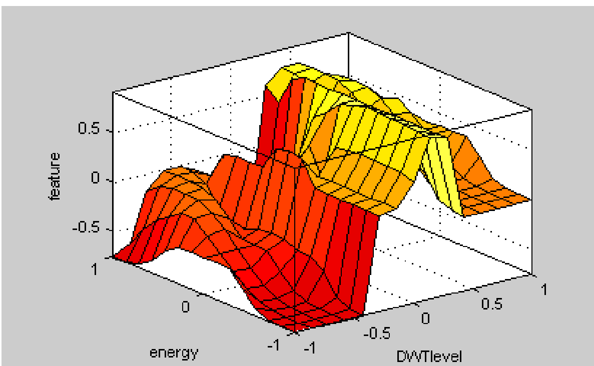

Fig8. Surface viewer of fuzzy expert system Simulation results

Table-1

classification	Output of fuzzy model
fundamental	**0.053**
Transients	**0.2584**
Impulse	**-0.21365**
Flicker	**0.5854**
Sag	**-0.8542**
Swell	**0.762**
Outage	**-0.9817**
Notch	**0.95162**

By observing table 1 various problems of power quality are classified by fuzzy expert system and it showing the values of fuzzy output for particular power quality problems. Fuzzy classifier in the system time response slows down with the increase in number of rules. If the system does not perform satisfactorily, then the rules are reset again to obtain efficient results. The accuracy of the system is dependent on the knowledge and experience of human experts. The rules should be updated and weighting factors in the fuzzy sets should be refined with time. Neural networks, genetic algorithms, swarm optimization techniques, etc. can be used to for fine tuning of fuzzy logic control systems.

CONCLUSION

Electric power quality, which is a current interest to several power utilities all over the world, is often severely affected by harmonics and transient disturbances. Due to increased use of various power electronic devices in modern power systems, power quality is becoming an important and challenging issue for the power engineers. There is no unique model which can assess the power quality problem and to identify and classify them properly. Existing automatic recognition methods need improvement in terms of their versatility, reliability, and accuracy. The FUZZY LOGIC based tools have been applied for the PQ classification. This paper addresses different PQ classification approaches in general and FUZZY logic tools are reviewed in particular. Major Key issues and challenges related to these advanced techniques in automatic classification of PQ problems are highlighted. New intelligent system technologies using DSP, expert systems, AI and machine learning provide some unique advantages in intelligent classification of PQ distortions.

To build an ideal PQ classification system, various issues have to be addressed.

- The new algorithms should be able to classify voltage or current transients due to different power system events, such as
- Motor starting, transformer inrush currents, capacitor switching, and high impedance faults.

- The new methods need to be capable of implementing cause-based classifications, in addition to phenomenon-based classifications.
- The new methods should classify the multi PQ events occurring simultaneously.
- The new methods should be noise tolerant as PQ signals are normally accompanied with noise.

REFERENCES

[1] R. C. Dugan, M. F. McGranaghan and H. W. Beaty, "*Electrical Power Systems Quality*", McGraw-Hill, 1996.

[2] A. M. Gaouda, M. M. A. Salama, M. R. Sultan and A. Y.Chikhani, "Power Quality Detection and Classification Using Wavelet-Multiresolution Signal Decomposition**",** *IEEETransactions on Power Delivery,* Vol.14, No.4, October 1999, pp. 1469 – 1476.

[3] A. M. Gaouda, M. M. A. Salama, M. R. Sultan and A. Y.Chikhani, "Application of Multiresolution Signal Decomposition for Monitoring Short-Duration Variations in Distribution Systems", *IEEE Transactions on Power Delivery,* Vol.15, No.2, October 2000, pp.478 – 485.

[4] S. J. Huang, C. T. Hsieh and C. L. Huang, "Application wavelets to classify power system disturbances", *Electric Power System Research*, Vol.47, Issue2, October1998, pp.87 –93.

[5] S. J. Huang, C. T. Hsieh and C. L. Huang, "Application of Morlet Wavelets to Supervise Power System Disturbance", *IEEE Transactions on Power Delivery,* Vol.14, No.1, January 1999, pp. 235 – 243.

[6] N. S. D. Brito, B. A. Souza and F. A. C. Piers, "Daubechies Wavelets in Quality of Electrical Power*", 8th International Conference on Harmonics and Quality of Power ICHQP'98,* October 14 – 16, 1988, pp. 511 – 515.

[7] S. Santoso, E. J. Power and P. Hofmann, "Power Quality Assessment via Wavelet Transform Analysis", *IEEETransactions on Power Delivery*, Vol.11, No.2, January 1996,pp. 924 – 930.

[8] Ibrahim W.R. Anis and Morcos M.M., 2000. Preliminary application of an adaptive fuzzy system for power quality diagnostics, *IEEE Power Engineering Review*, vol. 20, pp. 55-58.

[9] Ibrahim W.R.A. and Morcos M.M., 2001. An adaptive fuzzy technique for learning power-quality signature waveforms, *IEEE Power Engineering Review*, vol. 21, no.1, pp. 56-58.

[10] Ibrahim W.R.Anis and Morcos M.M., 2002. Artificial intelligence and advanced mathematical tools for power quality applications: a survey, *IEEE Trans. on Power Delivery*, vol. 17, pp. 668-673.