EXPERT SYSTEM FOR CLASSIFICATION OF POWER SYSTEM EVENTS

نظام متخصص لتمييز أحداث منظومة القوى

Amany El-Zonkoly
Arab Academy For Science & Technology, Faculty of Engineering,

ملخص:
تقدم هذه الورقة نظام متخصص قادر على التمييز بين الأحداث المختلفة و المرتبطة بجودة منظومة القوى. و هذا النظام يعتمد على موجات الجهد للتمييز بين الأنواع المختلفة من نقصان و زيادة الجهد. و قد تم تطبيق كل من تحليل فورير و تحليل الويفلت للحصول على الخواص المميزة لكل نوع من الأحداث و بالتالى تحديد نوعها.

ABSTRACT:
This paper presents an expert system that is able to classify different types of power quality (PQ) events. The expert system uses the voltage waveforms and distinguishes the different types of voltage dips and swells. Both Fourier and Wavelet analyses are applied for extracting distinct features of various types of events as well as for classifying the events.

KEYWORDS:
Power Quality (PQ) – Wavelet Transform – Fourier Transform – Expert System

1- INTRODUCTION:

In power systems, faults, dynamic operations, or non-linear loads causes various types of power quality disturbances such as voltage sags, voltage swells, impulses, flickers, outage, etc. [1,2]. On the other hand, the increased use of sensitive electronic circuitry by industrial and residential customers as well as the progress of utility deregulation and competition has imposed greater demand on the quality of power. Consequently, the studies aimed at detecting and analyzing as well as eliminating or minimizing the effects of power quality disturbances on industrial and residential customer loads have assumed greater importance.

The increased requirements on supervision, control, and performance in modern power systems make power quality monitoring a common practice for utilities. With the growth of the number of monitors installed in the system, the amount of data collected is growing, making individual inspection of all wave shapes no longer an option. New tools are required to extract all relevant information from the recordings in an automatic way. Such automatic analysis tools can be applied to large existing databases, but can also be implemented in a monitor. Several approaches for automatic classification of power system disturbances have been proposed in a number of papers [3,4].

Generally speaking, the PQ event detection and classification problem consists of two steps. The first step may include feature extraction, during which the distinct and dominant features of various events are selected and obtained using appropriate

Accepted September 30, 2004.

techniques. The second step is called decision-making: the extracted features are further processed to determine the types of events. Appropriately chosen features are essential for both simplification of the decision-making system (DMS) and improving the correct identification rate of the system [5,6].

Various approaches for both feature extraction and DMS have been proposed previously for PQ event detection and classification. For feature extraction, both Fourier transform and wavelet analysis have been suggested. Fourier transform is suitable for stationary signals while wavelet transform more adapts to dynamic signals. For decision-making, neural networks based approaches have been developed. The neural network fundamentally realizes a non-linear functional mapping. However, the correct identification rates resulting from existing approaches are still low and not quite satisfactory [5-7]. Fuzzy logic techniques have been also used for classifying PQ disturbances [8-10].

The paper is arranged as follows. First, the different types of power system events (considered by the expert system) are presented. Second, the structure and most important parts of the expert system are described. The expert system is then tested using different events waveforms and the results are presented and discussed.

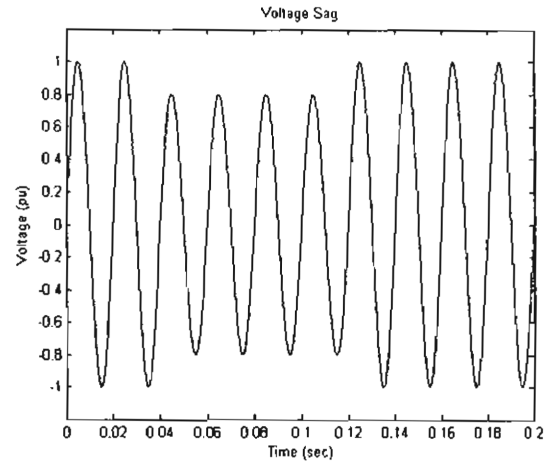
2- DIFFERENT TYPES OF POWER SYSTEM EVENTS:

In a power system, there are various kinds of power quality disturbances. The most common variations and events are given below (see Fig.1 for examples).

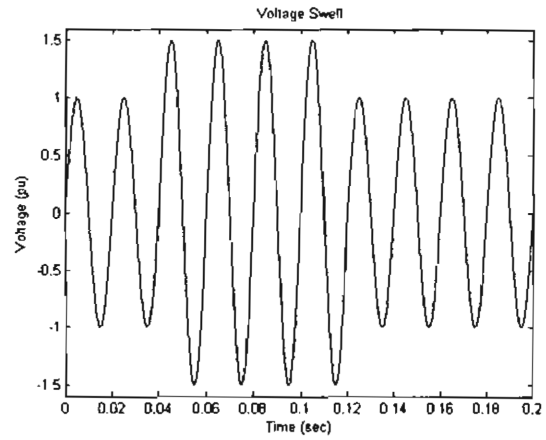
a- *Voltage Sag:* voltage sag is characterized as having a short-term decrease in line voltage. According to EN50160 standard [11], the rms voltage during the sag is 90% or less of the normal voltage with duration between 10 ms to 60 ms. Voltage sag is often caused by starting of large loads such as motors or by faults in power system [5,12].

b- *Voltage Swell:* it is a short increase in rms voltage. According to EN50160, the rms voltage is 110% or more of the nominal voltage. The duration is between 20 ms and 120 s (for 50 Hz) [5,12]. Voltage swell could be caused due to fault initiation such as single-phase faults in ungrounded systems or due to fault clearing [13,14].

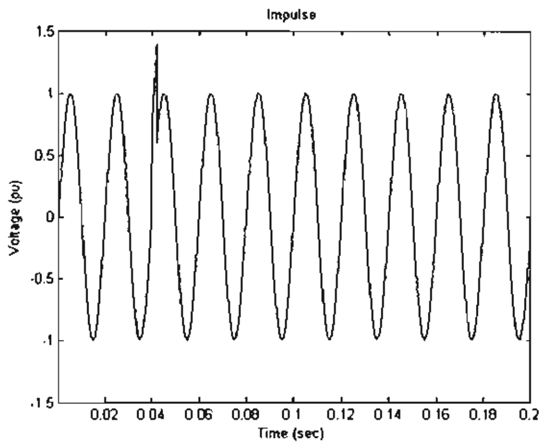
c- *Impulse*: waveforms in this class are described as high frequency voltage transients. They typically occur due to capacitor switching, load start up and lightning [5].



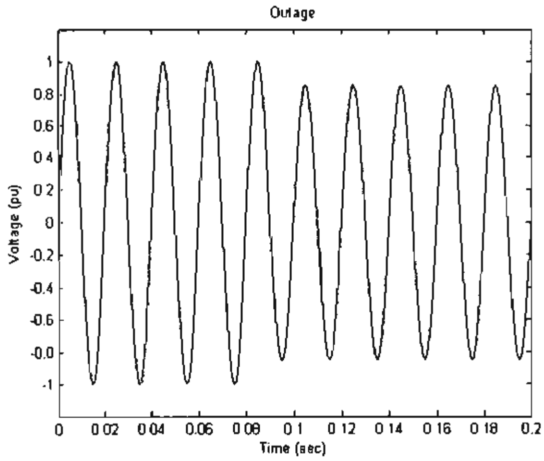
(a)



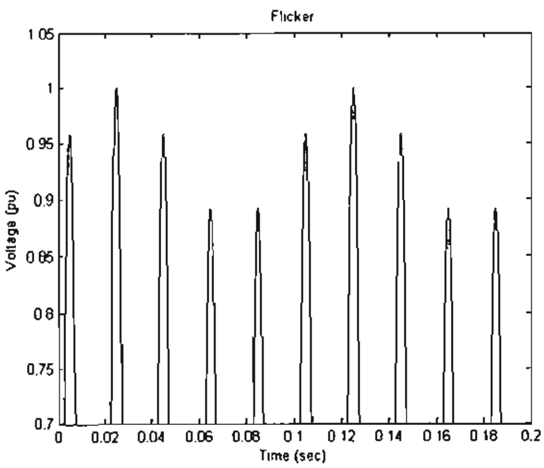
(b)



(c)



(d)



(e)

Fig.1: Typical waveforms used.
(a) Voltage sag. (b) Voltage swell.
(c) Impulse. (d) Outage. (e) Flicker.

d- *Outage*: an outage is the absence of usable power at some point. Outages are typically caused by system faults and circuit breaker operation [5].

e- *Flicker*: heavy loads like arc furnaces, pumps, motors, etc. will increase the level of voltage fluctuations in the network. In many cases these fluctuations are repeated with a low frequency (2-25 Hz). This phenomenon is called flicker [12]. The standard IEC-61000-4-15 (International Electrotechnical Commission)[15] states how to measure flicker.

Identifying the different types of events, the next step is to detect the event when it happen and classify its type.

3- AUTOMATED POWER QUALITY DISTURBANCE DETECTION AND CLASSIFICATION:

Largely speaking, the detection and classification problem consists of two steps [16,17]. The first step is feature extraction and the second one is the decision-making or classification step. The flow chart of the proposed solution is shown in Fig.2.

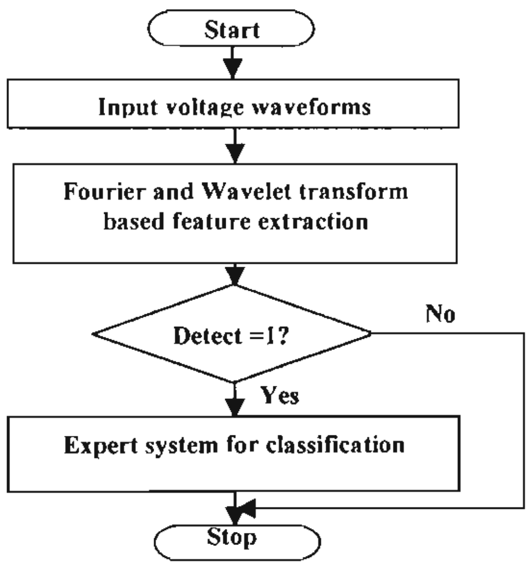


Fig. 2: Flow chart of the proposed expert system.

3.1 Fourier and Wavelet Analysis Based Feature Extraction:

A number of power quality events of various types have been simulated and corresponding waveforms are obtained. The following five distinct features inherent to different types of power quality events have been extracted: the fundamental component (Vn), number of peaks of the wavelet coefficients (Nn), energy of the wavelet coefficients (EW_n), oscillation number of missing voltage (OSn), and oscillation number of the rms variations (RN). The formula for computing these features are given as follows [8]:

$$Vn = \sqrt{2}\, abs(V^n[1])/N \qquad (1)$$

where

$V^n[k]$ is the Discrete Fourier Transform (DFT) for the samples contained in the n^{th} data window defined as

$$V^n[k] = \sum_{i=1}^{N} v[i+(n-1)*N]\, e^{-j\frac{2\Pi ki}{N}}$$

v[i] presents the sampled input signal, i= 0,1,….,L-1, with L the length of the signal

N is the number of samples in one data window (one cycle)

n = 1,2,….,10.

$$EW_n = \sum_{k=1}^{le} abs(WC^n[k]) \qquad (2)$$

where

WC^n is the wavelet coefficients for the samples contained in the n^{th} data window.

$$Nn = peak(abs(WC^s)) \qquad (3)$$

where

WC^s is defined as an array composed of $WC^n[k]$ for k=1,2,…,le, with le the length of WC^n.

$$OSn = root(v^s_{miss}) \qquad (4)$$

$$RN = root(V^s_{rms} - mean(V^s_{rms})) \qquad (5)$$

where

$v_{miss}[i] = v[i] - v_{ref}$, with v_{ref} is the reference or fundamental voltage waveform

v^s_{miss} is defined as an array composed of $v_{miss}[i]$, i= 0,1,…,L-1

$$V^n_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v^2[1+(n-1)N]}$$

V^s_{rms} is defined as an array composed of V^n_{rms}, n = 1,2,..,10

abs(.) gives the absolute value of the argument

root(.) returns the number of zero-crossings of the argument

peak(.) returns the number of peaks of the argument

mean(.) gives the mean of the argument

In our work, ten cycles of samples of voltage signal (in per unit) are used. The Daubechies-4 wavelet family and the second scale wavelet detail coefficients are utilized. Detailed analysis on the wavelet transform and multiresolution decomposition techniques is referred to in [7,18]. Next, the statistical properties of the parameters for various power quality events can be obtained.

3.2 Expert System for Detection and Classification:

Identification of power quality disturbance waveforms usually requires significant amount of expertise in power quality. A trained engineer in power quality can easily identify the cause of the disturbance from a given voltage and/or current waveforms. Identifying a handful of disturbance waveforms should not be a problem and can be performed with a high degree of accuracy. However, identifying thousands of disturbance waveforms are certainly overwhelming and tedious. In addition to human error, manual procedures in identifying power quality events are obviously not practical and costly [4].

It is therefore desirable that the expertise of power engineers be reproduced and encoded into a set of computer programs. The set of computer programs behaves as if it were an expert in power quality and processes artificial intelligence to identify disturbance waveforms. This kind of artificial intelligence system is known as expert system in power quality domain.

A basic structure for the PQ expert system is shown in Fig.2. The input to the system is a voltage waveforms and the output is the power quality event associated with the disturbance waveform. The needed knowledge is stored in the form of if-then rules relevant to PQ events.

4- PERFORMANCE EVALUATION:

4.1 Application of the Expert System:

The system is developed in Matlab and applied in two steps:

1- *Detection step:*
The system will detect an event on the bases of change in the rms value of the fundamental component of the voltage. Voltage dips lower than 0.95 pu or overvoltages higher than 1.05 pu are considered by the expert system.

2- *Classification step:*
Based on more than a 100 test waveforms of different types of power quality events it was noticed that the classification could be made according to the following set of rules.

Rule 1: classification of the event as a flicker according to the EW parameter.

For the flicker event it was noticed that the difference between the maximum values of the EW parameter of the test waveform (EW_m) and the reference waveform (EW_{mr}) was less than or equal to 1.

Rule2: classification of the event as an impulse according to the OSn parameter.

For the impulse event it was noticed that $EW_m - EW_{mr} > 1$ but $OSn < 1$.

Rule 3: classification of the event as an outage according to the RN and Nn parameters.

For the outage event it was noticed that

$EW_m - EW_{mr} > 1$

$OSn > 1$

$RN = Nn = 1$

Rule 4: classification of the event as voltage sag according to the Vn parameter.

For the voltage sag event it was noticed that

$EW_m - EW_{mr} > 1$

$OSn > 1$

$RN \neq Nn \neq 1$

Maximum rms value of the fundamental component of the test waveform (V_{nmax}) is equal to that of the reference waveform (V_{nr}).

Rule 5: classification of the event as voltage swell according to the Vn parameter.

For the voltage swell event it was noticed that

$EW_m - EW_{mr} > 1$

$OSn > 1$

$RN \neq Nn \neq 1$

Minimum rms value of the fundamental component of the test waveform (Vn_{min}) is equal to that of the reference waveform (Vn_r).

4.2 Results:

The proposed expert system was applied to 20 waveforms of different types of power quality events and it managed to detect and identify all of the 20 cases successfully (100%) which is an improved result over other classification methods previously used where the best one of them [4] identified only 94.6% of the events successfully. The following cases show different waveforms and the response of the expert system to it.

Case 1: Normal operation:

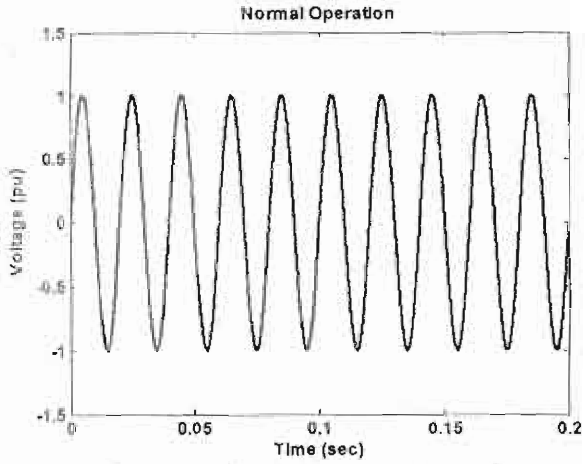


Fig.3 Voltage waveform during normal operation

In that case the detection step the system detected no change between the maximum and minimum rms values of the fundamental component of the voltage.

$Vn_{max} = Vn_{min} = 1$ pu

Case 2: Voltage Sag:

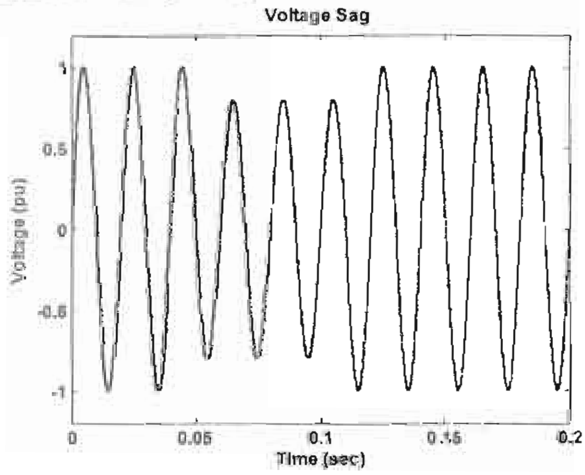


Fig.4 Voltage waveform during sag event

In the detection step the system detected changes between the maximum and minimum rms values of the fundamental component of the voltage as follows

$Vn_{max} = Vn_r = 1$ pu $\qquad Vn_{min} = 0.8$ pu

and the voltage parameters were as follows

$EW_m - EW_{mr} = 2082 > 1$

$OSn = 1$

$RN = 2 \qquad Nn = 2$

Case 3: Voltage Swell:

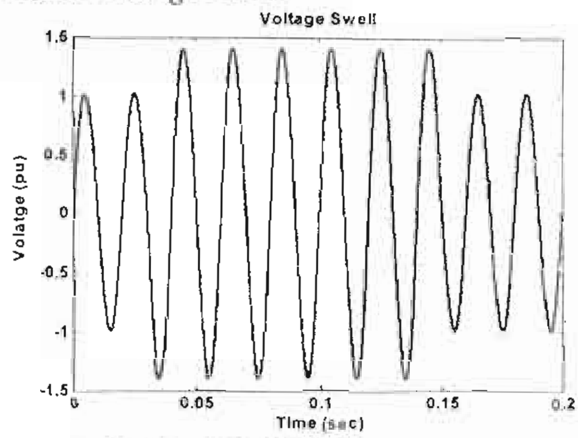


Fig.5 Voltage waveform during swell event

In the detection step the system detected changes between the maximum and minimum rms values of the fundamental component of the voltage as follows

$Vn_{max} = 1.4$ pu $\qquad Vn_{min} = Vn_r = 1$ pu

and the voltage parameters were as follows

$EW_m - EW_{mr} = 4164 > 1$

$OSn = 1$

$RN = 2 \qquad Nn = 2$

Case 4: Impulse:

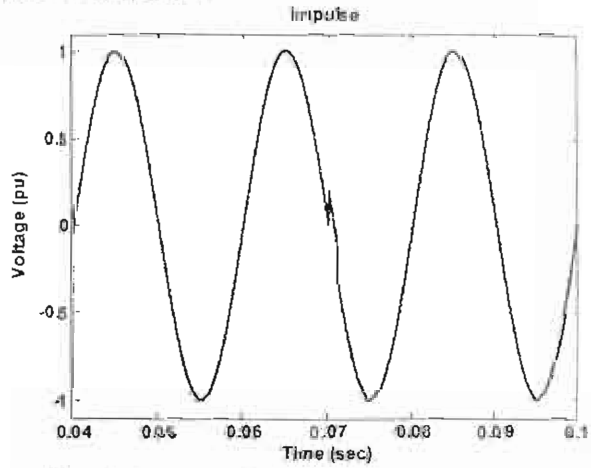


Fig.6 Voltage waveform during impulse event

In the detection step the system detected changes between the maximum and minimum rms values of the fundamental component of the voltage although it was not a great change as follows

$Vn_{max} = Vn_r = 1$ pu $Vn_{min} = 0.99$ pu

and the voltage parameters were as follows

$EW_m - EW_{mr} = 2809380 > 1$

$OSn = 0.5$

$RN = 2$ $Nn = 1$

Case 5: Outage:

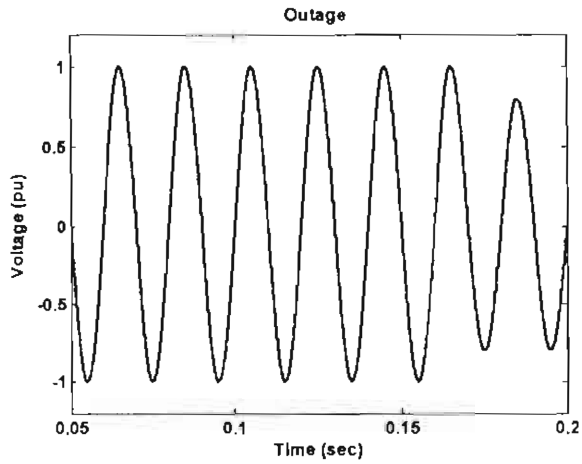


Fig.7 Voltage waveform during outage event

In the detection step the system detected changes between the maximum and minimum rms values of the fundamental component of the voltage as follows

$Vn_{max} = Vn_r = 1$ pu $Vn_{min} = 0.8$ pu

and the voltage parameters were as follows

$EW_m - EW_{mr} = 2082 > 1$

$OSn = 1$

$RN = 1$ $Nn = 1$

Case 6: Flicker:

In the detection step the system detected changes between the maximum and minimum rms values of the fundamental component of the voltage as follows

$Vn_{max} = Vn_r = 1$ pu $Vn_{min} = 0.88$ pu

and the voltage parameters were as follows

$EW_m - EW_{mr} = 0 < 1$

$OSn = 1$

$RN = 3$ $Nn = 10$

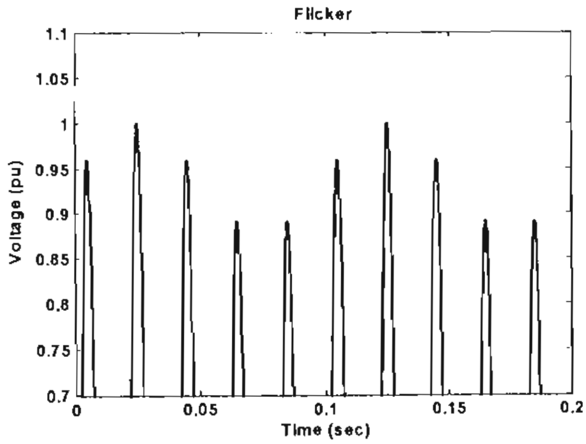


Fig.8 Voltage waveform during flicker event

5- CONCLUSION:

This paper presents an expert system for automatic detection and classification of power quality recordings. The main objective of the system is to distinguish between the different types of power system events. The expert system considers events that present a considerable change in voltage. The expert system enables fast and accurate classification of the recordings in term of the origin. Event classification offers the means for better understanding and description of the operation of the power system in term of power quality.

REFERENCES:

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

[2] IEEE Std. 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, IEEE Inc. New York (1995), pp 1-59.

[3] P.K.Dashand, M.M.A.salama and S.Mishra, " Classification of power system disturbances using fuzzy expert system and a Fourier linear combiner", IEEE Trans. Power Delivery, Vol.15, Apr.2000.

[4] S.Santoso, J.Lamoree, W.M.Grady, E.J.Powers, and S.C.Bhatt, "A scalable PQ event identification system", IEEE Trans. Power Delivery, Vol.15, Apr.2000.

[5] K.A.Ghosh and D.L.Lubkeman, "Classification of power system disturbances using a neural network approach", IEEE Trans. Power Delivery, Vol.10, Jan. 1995.

[6] B.Perunicic, M.Mallini, Z.Wang and Y.Liu, "Power quality disturbance detection and classification using wavelets and artificial neural networks", Proceedings of the 8th International Conference on Harmonics and Quality of Power, Vol.1, 1998.

[7] Santoso, Syrya, Powers, Edward, Grady, W.Mack and Hofmann Peter, "Power quality assessment via wavelet transform analysis", IEEE Trans. Power Delivery, Vol.11, No.2 Apr.1996.

[8] M.Kezunovic and Y.Liao, "Advanced framework for power quality assessment", Proceedings of the 15th International Conference on Electricity Distribution, CIRED'99, Nice, France, June 1999.

[9] J.Yen and R.Langari, Fuzzy Logic: Intelligence, Control and Information, Printice Hall, 1999.

[10] W.R.Anis and M.M.Morcos, "Artificial intelligence and advanced mathematical tools for power quality applications: a survey", IEEE Trans. Power Delivery, Vol.17, No.2, Apr.2002.

[11] CENELEC EN50160, Voltage characteristics of electricity supplied by public distribution systems, CENELEC publications 1999.

[12] P.Aelberg, Measurement methods for calculating the direction to a flicker source, Technical report No.463L, Charlmers University of technology, Sweden, 2003.

[13] M.A.Chapman, A.Martinez, E.Sabir, K.Wang and Y.Liu, " Switching and fault caused transients in electric power systems", Proc. IEEE Power Eng. Soc. Winter Meet., Vol.2, 1999.

[14] L.A.Kojovic, S.P.Hassler, K.L.Leix, C.W.Willims and E.E.Barker, "Comparative analysis of explosion and current limiting fuse operation in distribution systems for improved power quality and protection", IEEE Trans. Power Delivery, Vol.13, July 1998.

[15] IEC, Flickermeter-Functional and design specifications, IEC 61000-4-15 standard, 1999.

[16] E.Styvaktakis, M.H.J.Bollen and I.Y.H.Gu, "Classification of power system events: Voltage dips", Proc. 9th Conf. Harmonics and Power Quality, Vol.2, Orlando, FL, Oct., 2000.

[17] M.H.J.Bollen and E. Styvaktakis, "Characterization of three-phase unbalanced dips (as easy as one-two-three?)", Proc. 9th Conf. Harmonics and Power Quality, Vol.2, Orlando, FL, Oct., 2000.

[18] D.C.Ropertson, O.I.Camps, J.S.Mayer and W.B.Gish, "Wavelets and electromagnetic power system transients", IEEE Trans. Power Delivery, Vol.11, No.2, April 1996.