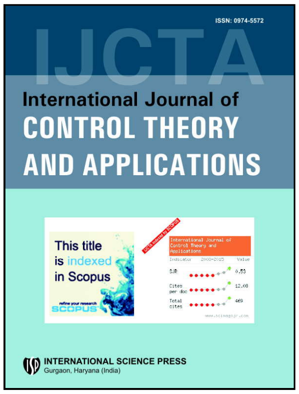

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Wavelet Packet Transform Based Disturbance Detection in Renewable Energy Integrated Power System

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Abstract: Quality of power is one of the most vital factors in modern power system which needs to be taken care of. Power quality problems lead to voltage swell, sag, flicker, harmonic distortion, electromagnetic transients etc. Traditionally the power quality signals are analyzed through time domain but the signal to be analyzed is not always in time domain. Many techniques such as Fourier transform were applied but it has its own limitations. Therefore a new technique called Wavelet Transform (WT) is used in order to localize the information in time-frequency analysis, so it is the best method for analysis of non stationary signals. And to get the information about power quality disturbances, Wavelet packet transform (WPT) is implemented. In this paper the detection of power quality disturbances in a signal is done through Wavelet transform and Wavelet packet transform.

Keywords: Power Quality, Wavelet Transform, Wavelet Packet Transform, Voltage Sag, Swells, Interruption.

1. INTRODUCTION

Power quality (PQ) has become the most important issue which has direct impact on the consumers in this deregulated power supply. Power Quality is the quality of the power exchanged at the point of common coupling (PCC) .It depends on the quality of the voltage, current, power etc. quality of power and voltage are the two important parameters of electric power system network. Due to the impedance of the power system, any current or voltage waveform results in harmonics and affects the entire power system. Power quality (PQ) disturbances have the maximum impacts on the grid as well as load side. Recent industrialization leads to the wide use of power electronic devices such as rectifiers, inverters, converters etc and non linear loads such as electric arc furnaces in the electrical system introduces power quality disturbances such as harmonics, high frequency variation etc, which affects the safe and reliable operation of the supply system. Therefore power quality analysis and monitoring has become one of the most challenging aspects for the power engineers.

Analyzing, monitoring and identifying the hidden PQ problems become necessary, so that adequate counter measures can be taken for the improvement of power quality. Analysis of the PQ problems requires detection, localization and classification in time and frequency domain. Extraction of information for the detection of Power quality disturbances requires estimation of duration in time domain, accurate transformation, and observation and analysis of the signals after transformation. Several methods of transformation has been proposed for the detection of disturbance occurring related to power quality such as Short-Time Fourier Transform (STFT), Discrete Fourier Transforms (DFT) etc. In this paper Wavelet Transform (WT) and Wavelet Packet Transform (WPT) has been purposed for the detection of PQ problems. Power harmonics analysis in steady state can be done by using Discrete Fourier Transforms (DFT). In Discrete Fourier Transforms (DFT), Problem related to harmonics leading to power quality events can be detected related to the frequency content of the signals. But due to its constant bandwidth, DFT fails to detect the short term transient signals. Fourier transform fails to detect the amplitude of the harmonic signal that fluctuates with time; therefore Fourier transform needs to be modified. It is a mostly used method to window a signal into a sufficiently small sequence so that it will be approximated as a stationary waveform. This method is called Short Time Fourier Transform (STFT). Though, this approach giving both time as well as frequency resolution for detecting the disturbances of power quality, width of the window is fixed which is the main limitation for analyzing transient non stationary signals. The STFT works well for short window with lower fluctuation rate. But, with increase in fluctuation rate can give rise to significant detection errors. Wavelet transforms (WTs) and Wavelet packet transforms (WPTs) [1-3] are the solutions to the problems of DFT and STFT. Non stationary signal analysis is done by both the Wavelet transforms (WTs) and Wavelet packet transforms (WPTs).With the emergence of Wavelet Transform (WT), characterization of Power Quality (PQ) disturbances has become more efficient and effective Wavelet transforms (WTs) are very fast and effective for the detection of PQ disturbances, in power system. Discrete wavelet transform (DWT) has the advantage of multi resolution analysis (MRA) based signal decomposition (MSD) which analyzes signal of different frequencies with different resolutions. From the multi resolution analysis (MRA), information about time and frequency can be achieved from the high and low frequency component respectively. Detection of disturbances in a power system can be done by wavelet transform. WT has gained popularity due to its wide range of applications. Concept of Wavelet transform depends upon some basic information related to signals in time and frequency format [1]-[2]. WT uses short windows and long windows for low frequencies and high frequencies; wavelet transform can extract information related to time and frequency at the same time. So transients and discontinuities present in time-varying signals are supervised in a better way. This motivates to upgrade the application for the detection of islanding study. Detection of disturbances and extraction of the signals in islanding condition can be done by Wavelet transform as it is sensitive to signal irregularities and insensitive to the regular signal behavior. Batch processing step is the biggest demerit of wavelet transform, which leads to the problem of delay.

2. SYSTEM CONFIGURATION AND POWER QUALITY

Power Quality is one of the important aspect which impacts on many costumers like small or residential customers and big costumers like industrial or commercial customers. Much consideration has been given to power quality issues in the recent times due to large scale penetration of power electronically controlled loads, but these devices has power quality issues which leads to mal-operation, problems related to stability, efficiency etc. Power quality refers to current quality, voltage quality, power factor, frequency, proper sinusoidal waveform etc. Power quality issues are mostly due to the various types of loads and sources. Disturbances like voltage swell, sag, momentary interruption and transients create problems that lead to disoperation, failure of electrical equipments etc. Power quality problem also arises due to switching of large non-linear loads such as induction motors, transformers etc .leads to variation in voltage signal, distortion, and notch in both current and voltage signal. When the linear and non linear loads are switched suddenly it leads to the

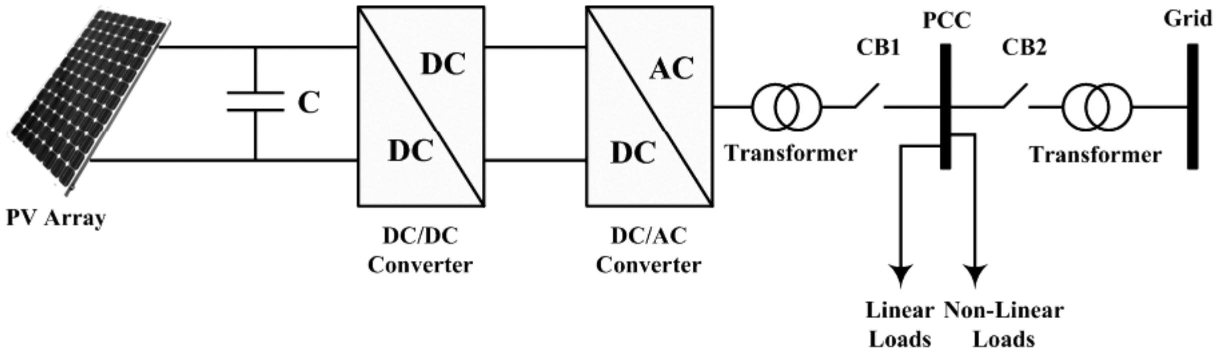

Figure 1: Grid-connected PV system

interruption of voltage for a long period of time. Significantly due to the increase in both embedded generation and distributed resources which create PQ problems such as flicker, waveform distortion, voltage variation etc. Therefore classification and detection of these power quality events has become very much necessary. The purposed grid connected PV system shown in Figure 1. consists of PV System feeding a 3-Φ load through a boost converter. A suitable Maximum Power Point Tracking (MPPT) algorithm has been applied in order to extract maximum power from the PV system. A 3-Φ inverter with PWM technique is also applied in order to convert AC to DC.

3. METHODS OF DETECTION OF PQ DISTURBANCES

3.1. Continious wavelet transform

Power quality disturbances are analyzed by using signal processing tool like Wavelet Transform (WT). Every disturbance signal can be decomposed into series of wavelet components using a set of filters. Every wavelet corresponds to a signal in time domain having a specific frequency band containing more detailed information. Signals which are non stationary in nature are analyzed by wavelet transform in time frequency domain. For the analysis of low frequency, the signal is passed through a series of low pass filters and for the analysis of high frequency components, the signal is passed through a series of high pass filters. Detail (D) and approximation (C) coefficient are the two components of the signal (S) after decomposition [3]. Low-frequency high scale component is called approximation coefficient (C) and high frequency low scale component is called detail component (D). This process of decomposition can be iterated and in every stage of decomposed approximation,

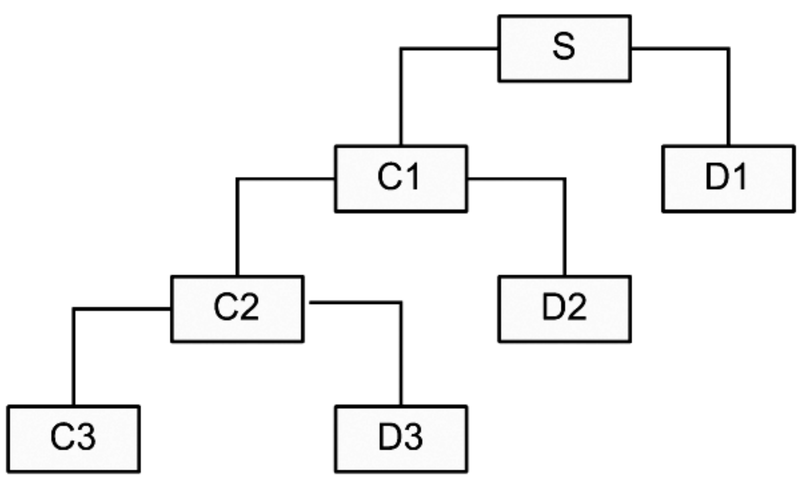

Figure 2: Wavelet Decompositiojn Tree

the signals are divided into many components of lower resolution scale. From this process we get the wavelet decomposition tree which is shown in Figure 2.

Because of higher level decomposition, components of lower frequency are filtered out gradually. In addition to decomposition of signal, wavelet transform also provides frequency resolution unlike Fourier transform. (i.e., shorter windows for higher frequency and longer window for low frequency is used in Wavelet Transform). Basics functions are generated from the operation of translation and dilatation of mother wavelet. Non stationary signals by using Wavelet Transform (WT) give time scale analysis [4]-[7]. Using dilation and translation, the signal expands into different frequency regions of fixed wavelet function called mother wavelet. Because of its ability of extracting frequency and time information at the same time, wavelet transform is one of the best methods for analyzing the power quality disturbances [3]. Wavelet Transform (WT) is divided into two type's i.e Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT). Discrete WT (DWT) is a subset of Continuous WT (CWT). As per the property of band pass filters, for investigation of the phenomenon of transient, the continuous wavelet transform has been proposed. DWT is generally used for practical applications such as PQ and fault analysis. High-pass g(k) and low-pass h(k) filters are used to divide the input signal f(k) in respective low- and high-frequency components into octave bands [3]. Scaling function gives h(k) low-pass filter. From the scaling and wavelet function high-pass filter g(k) is determined. From the scaling function the low pass filter h(k) and from both wavelet and scaling function high pass filter g(k) can be determined. The wavelet function $\psi(k)$ and scaling function $\phi(k)$ are given as,

$$\psi(k) = \sqrt{2}\sum_{n} g(n)\phi(2k-n), \tag{1}$$

$$\phi(k) = \sqrt{2}\sum_{n} h(n)\phi(2k-n) \tag{2}$$

Here n is the number of samples. While the approximations (A_j) and details (D_j) coefficients are obtained after decomposition. Different types wavelet functions are there such as Haar, Morlet, Coiflet, Symlet and Daubechies wavelets [3]. Choosing mother wavelet is one of the vital factors because every mother wavelet has its own characteristics.

3.2. Wavelet Packet Transform

Wavelet Packet Transform (WPT) is one of new method used for the classification of fault and for the identification of the faulted section in the power system. In Wavelet Packet Transform (WPT) feature extraction is done by decomposing the signal into different frequency bands of both low and high pass components by low and high pass filters [4]-[5]. For getting the desired information, feature extraction method is used. The WPT decomposes the disturbance signals into frequency bands.WPT has the ability to decompose the signals into different resolutions, for this reason precise feature extraction is possible from non-stationary signals [6]- [7]. Features like energy, entropy are extracted from the signal after decomposition. Decomposition of signals through WPT is shown in Figure 3. Continuous wavelets are functions generated from one single function called mother wavelet $\psi(t)$.

$$\psi_{ab}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right), a,b \in \Re, a \neq 0 \tag{3}$$

Here a, b and t is are the scale, translation parameters and time respectively. The function set $\psi_{a,b}(t)$ is called wavelet family. For the transform representation both the scaling and wavelet functions is used. Generally, discrete wavelet family parameters scale and shift parameters are given by a = a^{j}0 and b = kb0 aj0, Here j and k are integers. Discretized parameters function family becomes:

$$\psi_{j,k}(t) = a_0^{-j/2}\psi(a_0^{-j}t - kb_0) \quad (4)$$

Where $\psi_{j,k}$(t) is called the discrete wavelet transform (DWT) basis.

Discrete wavelet transform decompose the signal at different resolution into different frequency band for getting the detailed and approximation information. Two different set functions such as scaling functions φ(t) and wavelet function ψ(t) are employed for DWT. These are related to processing through high-pass and low-pass filters.

The original signal *x*(*t*) can be decomposed to:

$$x(t) = \sum_k c_j(k)\varphi_{jk}(t) + \sum_{j=1}^{j}\sum_k d_j(k)\varphi_{jk}(t) \quad (5)$$

Where j is the level number of the wavelet decomposition, j = 1, 2, ... J with J the time of the wavelet decomposition. c_j and d_j are the approximation coefficients and detail coefficients of x(t), respectively.

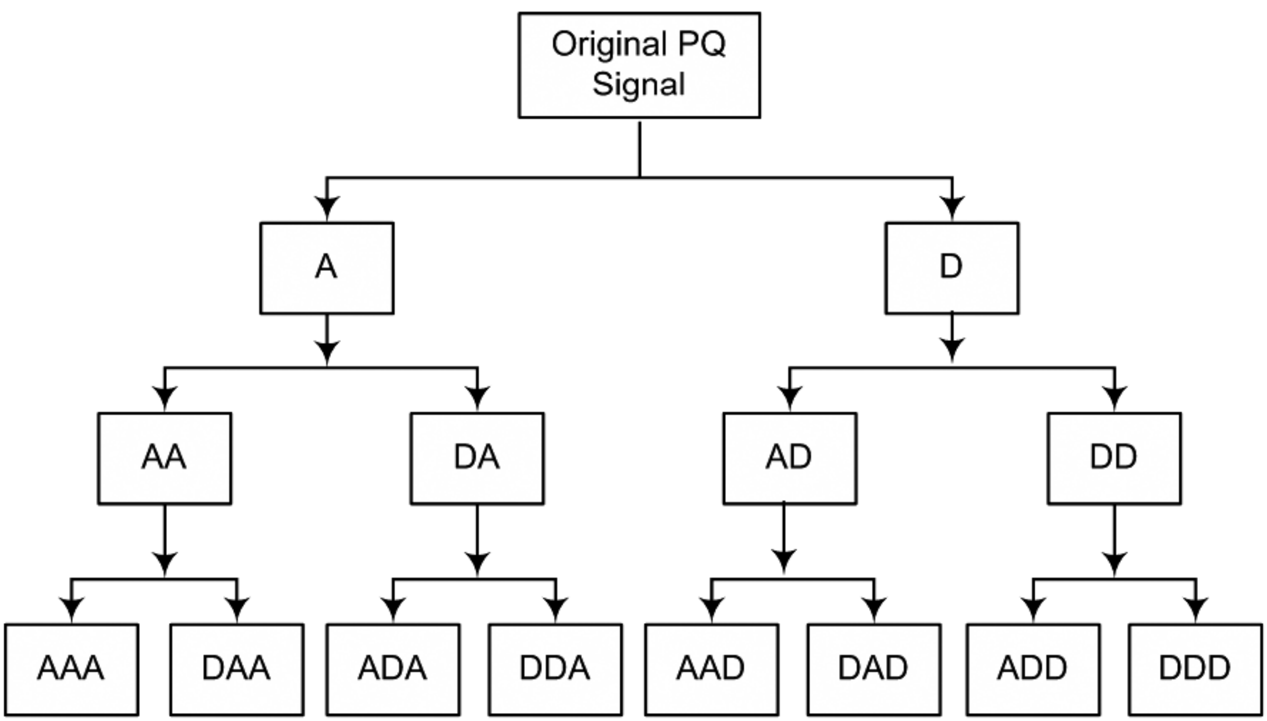

Figure 3: Wavelet packet decomposition tree.

4. SIMULATION RESULTS

This section describes the detection of power quality events using wavelet transform as well as wavelet packet transform. Different types of PQ disturbances are created in the considered grid-connected PV system by switching load operation. The voltage signal at point of common coupling is retrieved and is being passed through the wavelet packet as well as wavelet transform. The detection results as shown in Figures. 4-7, clearly shows that the voltage sag as well as voltage swell disturbances in PV system is nicely detected by both wavelet and

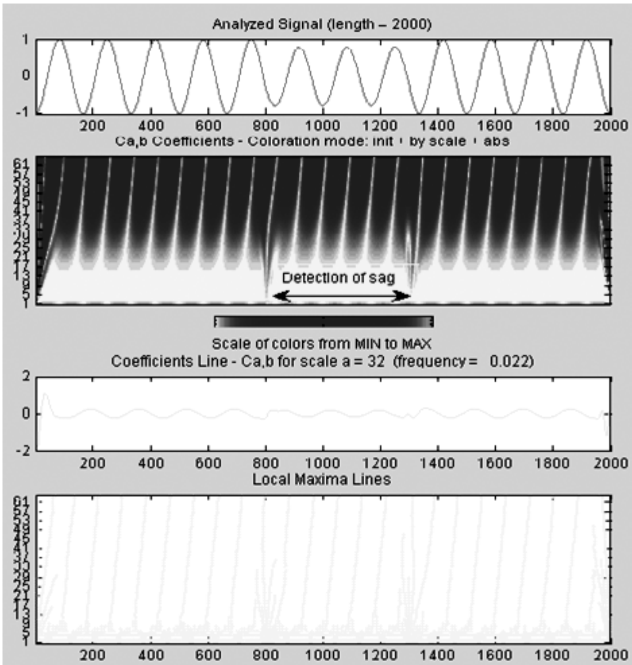

Figure 4: Wavelet transform decomposition for V_{sag} with decomposition level 4.

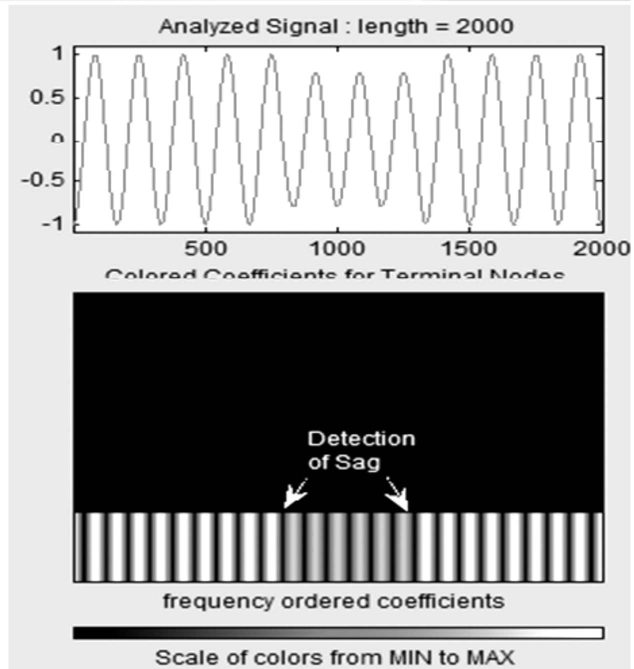

Figure 5: Wavelet PacketTransform decomposition for V_{sag} with decomposition level 4.

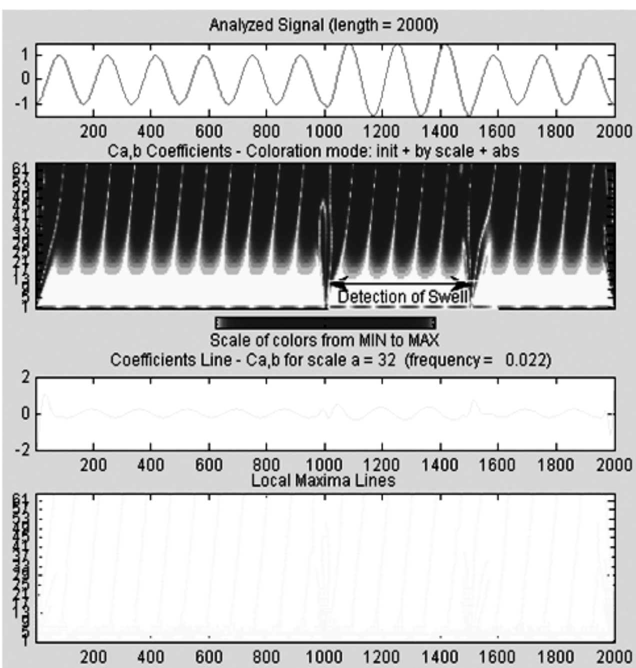

Figure 6: Wavelet transform decomposition for V_{swell} with decomposition level 4.

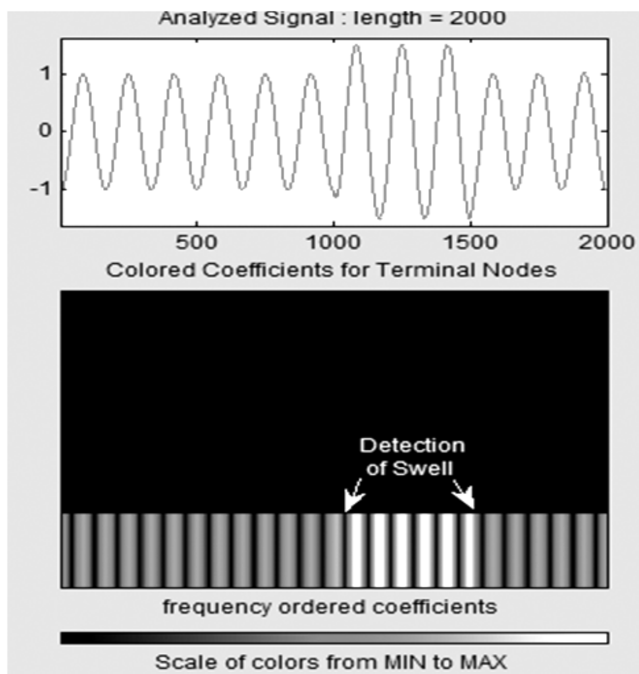

Figure 7: Wavelet PacketTransform decomposition for V_{swell} with decomposition level 4.

wavelet packet transform. The results reflect that wavelet packet transform shows better detection performance because of the detail decomposition of various frequency ranges. In addition, performance indices such as mean, standard deviation, RMS value and entropy are calculated so that threshold values can be selected such

Table 1
PQ Performance Indices

PQ Disturbance	*Mean*	*Standard Deviation*	*RMS Value*	*Entropy*
Sag	4.1314e-06	0.6749	0.6747	4.8492
Swell	2.4869e-06	0.8100	0.8098	4.4993
Normal	0.0428	0.7281	0.7279	4.1527

that the corresponding PD events can be classified. The values are presented in Table I.

4. CONCLUSION

This paper presented a study on PQ events in a grid-connected PV system. Different power quality disturbances such as sag, swell in the voltage waveform are created by load switching in the PV system and the voltage signal obtained from the point of common coupling is passed through wavelet and wavelet packet transform for detection analysis. The transforms correctly detect the disturbances because of its multi-resolution analysis. Further, mean, RMS value, standard deviation and entropy is calculated as indices in order to detect the disturbances as well as normal operating scenarios.

REFERENCES

[1] S.J. Huang, C.T. Hsieh, Coiflet, "Wavelet transform applied to inspect power system disturbances-generated signals," IEEE Trans. Aero Electron. Syst. Vol.38 (1), pp. 204–210, 2002.

[2] C.-T. Hsieh, J.-M. Lin, S.-J. Huang, "Enhancement of islanding-detection of distributed generation systems via wavelet transform-based approaches," Electr. Power Energy Syst, vol. 30, pp. 575–580, 2008.

[3] Prakash K. Ray, Soumya R. Mohanty, Nand Kishor, "Disturbance detection in grid-connected distributed generation system using wavelet and S-transform," Electric Power systems Research, vol. 81, pp. 805–819, 2011.

[4] G. S. Hu, F. F. Zhu and Z. Ren, "Power Quality Disturbance Identification Using Wavelet Packet Energy Entropy and Weighted Support Vector Machines," Expert Systems with Applications, vol. 35, No. 1-2, pp. 143-149, 2008.

[5] Ming Zhang, Kaicheng Li, Yisheng Hu,"Classification of Power Quality Disturbances Using Wavelet Packet Energy Entropy and LS-SVM," Energy and Power Engineering, vol. 2, pp. 154-160, 2010.

[6] Gauda, M., Salama, M.A.,Sultam, M.R. and Chikhani A.Y., "Power quality detection and classification using wavelet multi-resolution signal decomposition", IEEE Tansn. On Power delivery, vol. 14, pp. 1469-1476, 1999.

[7] Mallat, S.G. "A Theory for Multi-resolution Signal Decomposition: The Wavelet Representation", IEEE Transn. Pattern Recognition and Machine Intelligence, 11, pp. 674-693, 1989.