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A Virtual Instrument for Electrical Power Quality Analysis using Wavelet Technology in Real-time

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A Virtual Instrument for Electrical Power Quality Analysis using Wavelet Technology in Real-time

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Abstract - This paper discusses the design of a virtual instrument for detection and analysis of power quality disturbances in Power System using Wavelet Packet Transform with the help of LabVIEW® algorithm. The virtual instrument designed can operate in different working modes depending on the type of power quality disturbances to be detected and analyzed. Different wavelet analysis (discrete or wavelet-packet transform), with different mother wavelet, decomposition tree and different sampling rate is performed on the input signal either in real-time or off-line. The instrument also permits the partial implementation of a wavelet decomposition tree when we are only interested in a specific frequency band in the input signal. The real signals from chroma programming are used in LabVIEW® algorithm by Data Acquisition (DAQ) card to acquire and digitize the input line signal to obtain the results. The results obtained in simulation using real signals demonstrate good performance of the instrument developed for the detection and analysis of different power quality disturbances with proper time information of the signal. This helps us to analyze the power quality problems to improve the supply quality of the power system effectively by taking proper preventive measures
Key words— CWT, DFT, DWT, Power quality, STFT, WFT, WPT.

I. INTRODUCTION

Electrical Power quality plays an important role in smooth operation of sensitive loads, appliances & sophisticated plant processes. Most of the manufacturing industries face difficulty due to the distortion of the power supply which results to both manufacturing & production losses. Because all kinds of transducers, PLC apparatuses and automatic production processor based on computers are sensitive to small distortion of supply voltage. More attention has been given in the power quality problems.[1] Since power quality distortion has harmful effects on the electric power system, and everyone is concern about quality of products & services as those are paid for. Hence there is a need to analyze the power quality disturbances by proper instrument for accurate detection and localization so as to take proper preventive measures to assure qualitative power to the consumers.

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Electrical power quality disturbance is a general term used to designate a number of electromagnetic phenomena that cause voltage supply to deviate from its constant magnitude and frequency of ideal sinusoidal wave shape.

Table 1: *Classification of Power Quality Disturbances* [2]

Sl. No.	Categories	Typical spectral content	Typical duration	Typical Voltage magnitude
1.0	Transients			
1.1	Impulsive			
1.1.1	Nanosecond	5 ns rise	<50 ns	
1.1.2	Microsecond	1□s rise	50 ns–1 ms	
1.1.3	Millisecond	0.1ms rise	>1 ms	
1.2	Oscillatory			
1.2.1	Low frequency	<5 kHz	0.3–50 ms	0–4 pu
1.2.2	Medium frequency	5-500 kHz	20□s	0–8 pu
1.2.3	High frequency	0.5-5 MHz	5□s	0–4 pu
2.0	Short-duration variations			
2.1	Instantaneous			
2.1.1	Interruption		0.5–30 cycles	<0.1 pu
2.1.2	Sag (dip)		0.5–30 cycles	0.1–0.9 pu
2.1.3	Swell		0.5–30 cycles	1.1–1.8 pu
2.2	Momentary			
2.2.1	Interruption		30 cycles – 3 s	<0.1 pu
2.2.2	Sag (dip)		30 cycles – 3 s	0.1–0.9 pu
2.2.3	Swell		30 cycles – 3 s	1.1–1.4 pu
2.3	Temporary			
2.3.1	Interruption		3 s – 1 min	<0.1 pu
2.3.2	Sag (dip)		3 s – 1 min	0.1–0.9 pu
2.3.3	Swell		3 s – 1 min	1.1–1.2 pu
3.0	Long-duration variations			
3.1	Interruption, sustained		>1 min	0.0 pu
3.2	Undervoltages		>1 min	0.8–0.9 pu
3.3	Overvoltages		>1 min	1.1–1.2 pu
4.0	Voltage unbalance		Steady state	0.5 – 2%
5.0	Waveform distortion			
5.1	DC offset		Steady state	0 – 0.1%
5.2	Harmonics	0 – 100th harmonic	Steady state	0 – 20%
5.3	Interharminics	0 – 6 kHz	Steady state	0 – 2%
5.4	Notching		Steady state	
5.5	Noise	Broadband	Steady state	0 – 1%
6.0	Voltage fluctuations	<25 Hz	Intermittent	0.1 – 7%
7.0	Power frequency variations		<10 s	

Two main groups of power quality disturbances can be defined: stationary (or quasi-stationary) and transient disturbances. Harmonic and interharmonic distortion, voltage fluctuation, voltage flicker and voltage unbalance make up the first group, whereas voltage transients, voltage dips, voltage swells, short interruptions in voltage supply and other high-frequency disturbances constitute the latter group. Categories and Characteristics of Electromagnetic Phenomena responsible for Power Quality disturbances are given in Table-1.

In power quality it is important to know the time information rather than the exact frequency of a disturbance. Wavelet Transform Analysis allows the simultaneous evaluation of a signal in the time and frequency domains with different resolutions. Wavelets are especially suited for analysis of non-stationary signals with exact time information. [3]

The Discrete Fourier Transform(DFT) should be used when we want to know the magnitude and phase-angle of the different frequency components of a periodic and stationary voltage or current waveform. DFT analysis provides information in the frequency domain with a resolution that depends on the time window width. The time information of the signal is not obtained.[4]

Wavelets are short-duration oscillating waveforms with zero mean and fast decay to zero amplitude, especially suited for analysis of non-stationary signals.

Wavelet of Daubechies (4db) is very useful for detection & localization of electrical power quality disturbances & applied to detect voltage sag, voltage swell, and voltage interrupt. The proposed algorithm is simple and proves to be accurate when applied to different power quality distortion levels

II. WAVELET TECHNOLOGY

FFT analysis only provides information in the frequency domain with a resolution that depends on the time window width. No time information about the signal is provided. It is very difficult for the analysis of electrical power quality disturbances. In order to overcome this limitation the Windowed Fourier Transform (WFT) is used to provide frequency-time spectrum. The Windowed Fourier Transform (WFT) is also called Short Time Fourier Transform (STFT). But STFT has the limitation of fixed window size. So window resizing flexibility cannot be achieved in the STFT, which greatly affects both frequency and time resolution. To overcome the resolution problem the continuous wavelet transform is developed as an alternative approach to the short time Fourier transform. Wavelet Transform (WT) method provides frequency-time spectrum along with flexible resizing of the window, therefore preserving time and frequency information. It is especially suited to analysis of non-stationary signals. So wavelet allows the simultaneous evaluation of a signal in the time and frequency domains with different resolutions.[5-6]

Continuous wavelet transform (CWT) is defined as

$$CWT_X^{\Psi(\tau,s)} = \Psi_X^{\psi}(\tau,s) = \frac{1}{\sqrt{|s|}}\int X(t)\Psi^*\left(\frac{t-\tau}{s}\right)dt$$

Where τ is the translation parameter.

s is the Scale parameters

CWT Ψ (t) is the mother wavelets.

A signal can be better analysed by expressing as a linear combination of a set of orthogonal functions $\Psi_l(t)$

$$f(t) = \sum_{l \in z} c_l \Psi_l(t)$$

Where l is an integer index

c_l is the expansion coefficient

For continuous signal the expansion coefficient c_l is calculated by inner product (or scalar product)

$$c_l = \langle f, \Psi_l \rangle = \int_{-\infty}^{\infty} f(t)\Psi^*_l(t)dt$$

For discrete signal the expansion coefficient c_l is

$$c_l = \langle f, \Psi_l \rangle = \sum_{k=-\infty}^{\infty} f(k)\Psi^*_l(k)$$

In the above equation "*" is denoted by complex conjugate.

For the wavelet expansion

$$f(t) = \sum_j \sum_k c_{j,k}\Psi_{j,k}(t)$$

Where j, k are integer indices

The orthogonal basis is formed by the wave let function $\Psi_{j,k}(t)$

The set of Coefficients $c_{j,k}$ is called discrete wavelet transform (DWT) of f(t) function. $c_{j,k}$ Can be calculated as

$$c_{j,k} = \int f(t)\Psi_{j,k}(t)dt = \langle f(t), \Psi_{j,k}(t) \rangle$$

In Wavelet analysis, Discrete Wavelet Transform (DWT) provides different sized frequency bands and less tree branches. Therefore less computational time is required. On the other hand, Wavelet Packet Transform (WPT) is considered as the generalization of the wavelet decomposition. It provides the full tree of decomposition for the analyzed signal. Although it provides uniform frequency bands or levels, it requires a large amount of calculations. [7]

Wavelet and Fourier transforms represent a signal through a linear combination of their basis functions. The basis functions are dilations of cosine and sine signals (each spanning the entire time interval) for Fourier transforms. For wavelet transforms the basis functions are translations and dilations of function. The function is termed as Mother Wavelet along with a scaling function (each spanning a logarithmically reduced subinterval). The dilations of both sets of basis functions are possible because of their frequency localization. So it allows us to obtain frequency information. But the most important difference between the two sets of basis functions is time localization. The basis functions of wavelet transform are compact, or finite in time. This feature allows the wavelet transform to obtain time information as well as frequency information.[

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III. ALGORITHM OF WPT

The wavelet-packet transform (WPT) can be used to obtain a uniform frequency decomposition of the input signal. In the WPT both the output low-pass and high-pass filters (the detail and the approximation coefficients) are decomposed to produce new coefficients. Fig.1 shows the two-level wavelet decomposition tree. The WPT have the same frequency bandwidths in each resolution but DWT does not have this property. It does not increase or lose the information during the mode of decomposition. So the signal contains the original information. Therefore, the signal with great quantity of middle and high frequency components can offer superior time-frequency analysis. For non stationary signals WPT is a suitable signal processing tool. Unlike high and low frequencies, the same frequency bandwidths can provide good resolution.

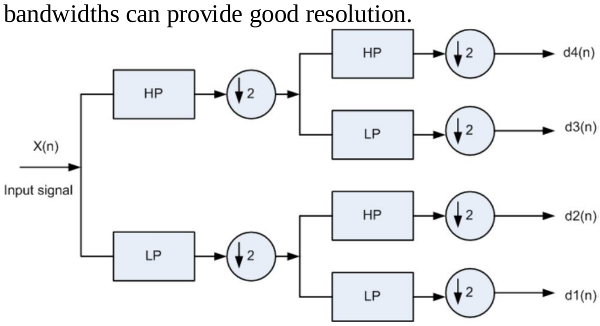

Fig. 1 Two-level wavelet decomposition tree for WPT analysis.

Fig. 2 shows the uniform frequency decomposition of the input signal. According to IEC standard 61000-4-7 the wavelet-packet transform is used instead of DWT for selecting the sampling frequency and the wavelet decomposition tree. The uniform output frequency bands can be selected for corresponding frequency bands of the input signal [9]

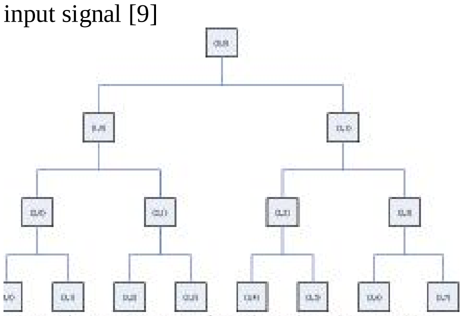

Fig. 3. The tower structure of wavelet package decomposition

IV. TEST RESULTS BY USING CHROMA PROGRAMMING AND LABVIEW®

The proposed Virtual instrument is modelled in LabVIEW®

for demonstration. For offline demonstration of the virtual instrument the block diagram is developed for generating AC voltage (sine waves) with Swag, Swell & Interruption in

3-phases simultaneously as shown in the fig.4, and the output is viewed in the front panel as shown in fig.5. The power quality disturbances can be detected & analysed by the help of Wavelet packet Analysis block connected to each

phase which gives exact location of the disturbance with duration of occurrence & intensity.

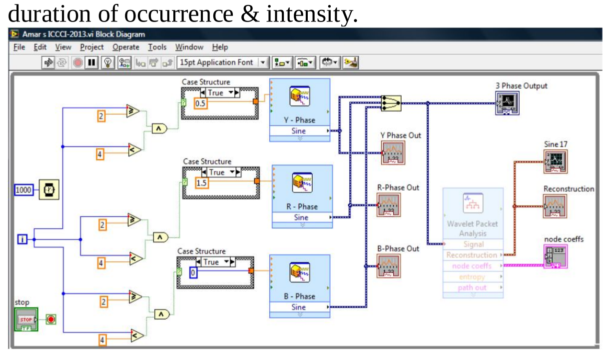

Fig. 4. Block diagram of the virtual instrument modelled in LabVIEW®.

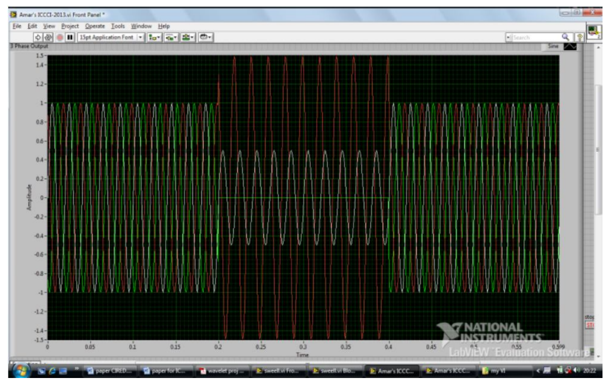

Fig. 5. Front Panel showing generation of Swag, Swell & Interruption in 3-phases simultaneously.

Continuous monitoring of Power quality in real time can also be possible with this virtual instrument with the help of Data acquisition (DAQ) board, PC, I/O Connector , cable and demo-box with terminals as shown in Fig. 6. Demo-box contains 6 analog inputs from A0-A5, 4 digital outputs from D0-D3, and Ground terminal. Model 8112 clamp adaptor current probe or voltage probe real time signal data were collected from Chroma 615XX Series programme and given to analog input terminal of the Demo-box. From Demo-box the signal was sent to LabVIEW® algorithm by Data Acquisition hardware. Results were displayed on front panels of the computer screen in LabVIEW® software. Single phase voltages and currents were continuously sampled at a sampling rate of 3.2 KHz, which correspond to 64 samples per cycle with 50 Hz fundamental frequency. The proposed monitoring technique detected and localized all the transient disturbances in the distorted signal using db4 (Daubechies) level 4 decomposition. The information about the position and duration of a power system disturbance was obtained from the detail coefficients d1. When disturbance exist the signal coefficient d1 (n) is non-zero.

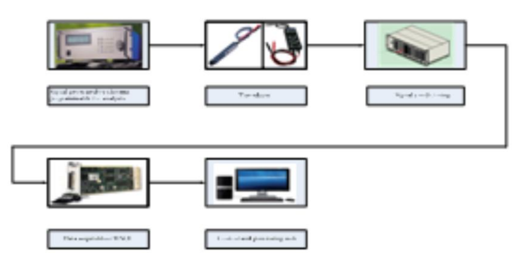

Fig. 6. Hardware architecture of the Chroma and LabVIEW

A. Detection of Voltage interrupts using WPT in real time

Circuit breaker tripping, faults in power system, equipment failures and control malfunctions cause interruption in power network. So during Voltage interrupt, magnitude of the voltage decreases to 0.0 p.u of the rated value for duration of time greater than 1 minute and then resumes the normal value based on IEEE standard 1159.[10] Voltage interrupt signal is generated in chroma programming (Fig.7) and simulated in LabVIEW® programming as shown in **Fig.8.**

Fig. 7. Voltage interrupt signal generated in chroma programming

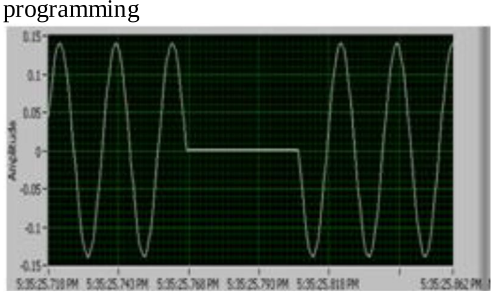

Fig. 8. Voltage interrupt signal shown in the front panel of LabVIEW®.

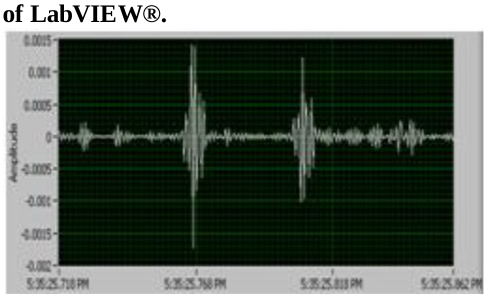

Fig. 9. Detection and localization of interrupt wave using WPT

The wave form interrupts from 5:35:25:766 to 5:30:25:807. The sampling frequency and supply frequency are 3.2 KHz and 50 Hz respectively. The coefficients of details at level 4 are shown in Fig. 9. A spike is seen at the starting and end point of the interrupt in WPT at times from 5:35:25:766 to 5:30:25:807, from which, we can obtain the beginning time and the ending time of voltage interrupt accurately.

B. Detection of Voltage Swell using WPT in real time

Load switching, capacitor switching and system voltage regulation cause swell formation in a pure sine wave. During voltage swell magnitude increases from 1.1 to 1.8 p.u of the rated value in the time duration of 0.5 to 30 cycles continuously, and then resumes the normal value.

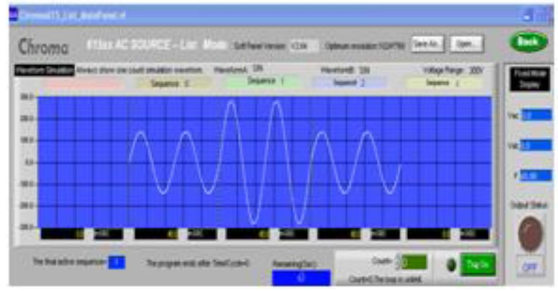

Fig. 10. Swell signal generation in chroma programming

Fig.11. Swell voltage signal shown in the front panel of LabVIEW®

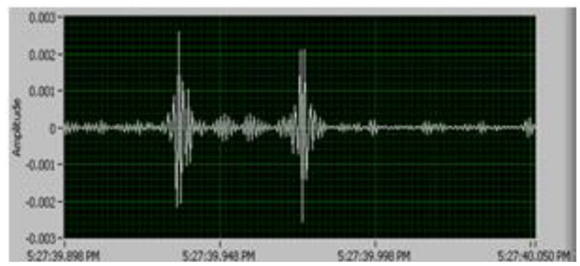

Fig. 12. Detection and localization of swell using WPT

Fig.10 shows swell signal is generated in chroma programming. The swell magnitude is increased to 220V over an interval of 2 cycles. Then it resumes to normal sine wave magnitude of 150V. As shown in Fig.11 the signal of voltage swell is simulated in LabVIEW® programming. The wave form contains disturbance of swell from time 5:27:39:934 to 5:27:39:974. The sampling frequency and supply frequency are 3.2 KHz and 50 Hz respectively. It is assumed that the lifting wavelet of Daubechies (db4) is decomposed to level 4. The coefficients of details at level 4 are shown in Fig. 12. A spike is seen at the starting and end point of the swell in WPT from time 5:27:39:934 to 5:27:39:974, from which, we can obtain the beginning time and the ending time of voltage swell accurately.

C. Detection of Voltage Sag using WPT in real time

Fig.13 shows generation of sag disturbances in chroma programming. The voltage decreases to 120V for 2 cycles and then resumes the normal sine wave voltage of 220V. The wave form contains disturbance of sag from time 5:59:35:721 to 5:30:00:768.

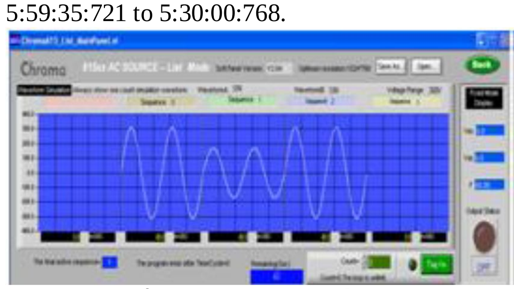

Fig 13. Waveform generation in chroma programming with sag disturbances

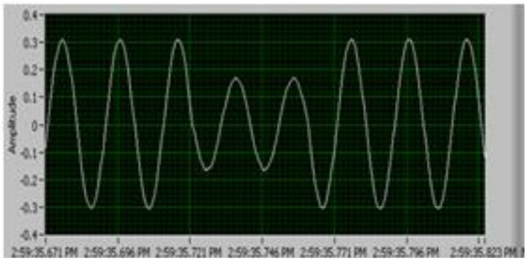

Fig. 14. Sag voltage signal shown in the front panel of LabVIEW

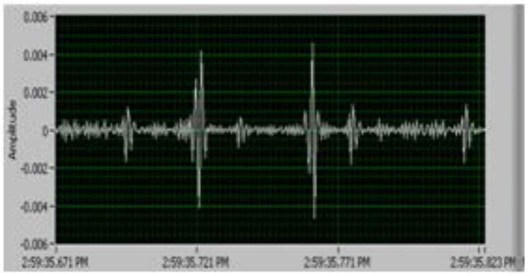

Fig.15. Detection and localization of sag by using WPT.

The signal of voltage sag is simulated in LabVIEW® programming as shown in Fig. 14. The sampling frequency and supply frequency are 3.2 KHz and 50 Hz respectively. It is assumed that the lifting wavelet of Daubechies (db4) is decomposed to level 4.The coefficients of details at level 4 are shown in Fig. 15. A spike is seen at the starting and end point of the sag in WPT from time 5:59:35:721 to 5:30:00:768, from which, we can obtain the beginning time and the ending time of voltage sag accurately.[11]

V. CONCLUSION

The virtual instrument designed using WPT algorithm in LabVIEW®. Wavelet Packet Transform is an advanced & economic technique for detection & localization of Electrical Power quality problems in both Distribution & Transmission of Electrical Power with accurate time information. That is further referred for mitigation of power quality problems to improve the supply power quality with optimal control using appropriate FACTS devices.[12] By choosing the most suitable wavelet family and mother wavelet, and then applying the Wavelet packet transform the problem of spectral leakage can be minimized when analyzing power system disturbances. The main advantage of the proposed method is the separation of power quality problems that overlap in both time and frequency. Now a day's virtual measurement instrument is very efficient for detection and analysis of power quality disturbances in a low voltage distribution system using wavelets. Wavelet packet transform is the faster transform for detection and compression purpose in non-stationary signal to identify the origins of power quality problems by utilizing power quality data, especially voltage signal. So it helps to improve the reliability of power systems. This may improve the computational efficiency of the system. It has the advantage of finding the duration of disturbances in real time operation with low cost implementation

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