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Application of Wavelet Transform to measure the voltage sag in Power line

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Abstract— In this work, a new voltage sag detection method based on wavelet transform is developed. Voltage sag detection algorithms, so far have proved their efficiency and computational ability .Using several techniques take long computational times for disturbance detection. Due to increasing power quality standards new high performance disturbance detection algorithms are necessary to obtain high power quality standards. For this purpose the wavelet technique is used for detecting starting and ending points of voltage sags by energy coefficient. This technique is very useful and important to know the disturbance zone of the voltage, so that we can monitor the voltage sags occurs in the particular area with there begining and ending points. The developed voltage sag detection algorithm is implemented with a high speed MATLAB results shows that the new approach provides very accurate and satisfactory voltage sag detection.

Index Terms- : Power Quality, Wavelet transform

1 Introduction

The definitions of sags have evolved over the past fifteen years, as have the power quality instruments that measure them. Sags, or dips as they are referred to in the European communities, were initially any reduction in voltage below a user defined low limit for between one cycle and 2.55 seconds. Swells, originally referred to as surges, were similar to sags, except that the voltage exceeded a user-defined high limit. While various definitions relative to the amplitude and duration are still in use, the IEEE 1159-1995 Recommended Practice on Monitoring Electric Power Quality has defined them as follows:

Sag [dip] a decrease to between 0.1 and 0.9 p.u in rms voltage or current at the power frequency for durations of 0.5 cycles to 1 minute. Sags is the most common types of power quality disturbances. Millions of dollars are lost in productivity each year in the United States due to these disturbances. A simple understanding of the causes will allow for effective solutions to mitigating these disturbances in most applications.

The importance of power quality is increasing due to the fact that the equipments in power system is much more sensitive to power quality problems. Processes are interrupted and productivity is haulted due to these disturbances. To avoid this, the power quality problems such as voltage sag need to be identified first recent advances in signal analysis have led to the development of new methods for characterizing and identifying various power quality problems. Today one of the most power quality problems is voltage sag [1].

Voltage sags are the main cause of more than 80% of the problem experienced in power systems. Voltage sag is a short time (10ms to 1min) event during which a reduction in RMS voltage magnitute occurs [2]. Despite of a short duration, a small deviation from the rated voltage can result in lots of cost effect disturbances, the same production process comes to a hault.The disturbance may be over within one second, but the restorstion process may take several hours. For many power system equipments, the effect of voltage sag is the as the effect of the interruption. The number of voltage sag is about 80-90 per year, where the number of interruption is on average round one per year. So, the consequences due to voltage sags are more significant than due to interruptions [2].

Voltage sag often sets only by two parameter, magnitude and duration [3]. Wavelet decomposition technique provide a powerful tool, which can be used to detect and localize voltage sags [4]. Wavelet analysis is becoming a common tool for analysing localized variation of power within a time series. localized variation of power within a time series into time-frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time?

By decomposing a time series into time-frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time [5]. In the power system analysis, wavelet transform have received attention because its efficiency for the analysis of transients compared to other types transforms. The wavelet transform have been used for numerous studies in power system protection, power quality, power system transients, load forecast and power system measurement [6].

Several studies have been done to show the identification and classification of power quality problems using wavelet transform. Most of them use sampled voltage and current waveforms, based on the Parseval's theorem[7-10] .

Ref 10 is an excellent introduction to voltage sag detection techniques for dyanamic voltage restorers, which are used to protect sensitive loads from the effect of voltage sags . But this did not provide all of the necessary details for wavelet analysis and avoided the issue for practical use with a MATLAB. Unfortunately, many studies using wavelet analysis have suffered from an apparent lack of quantitative results. The analysis are done via simulation and the theoretical results of the detection methods with wavelet analysis are not compared with practical results.

This project a new algorithm to detect the starting and ending points and the magnitude of voltage sag.The Discrete Wavelet Transform (DWT) is used to detect fast changes in the voltage signals, which allows the time localization of differences frequency components of a signal with different frequency wavelets. The algorithm is demonstrate via case studies.

2 Wavelet Transform

Wavelets are short-duration oscillating waveforms with zero mean and fast decay to zero amplitude, especially suited to analysis of non-stationary signals. Contrary to the use of DFT analysis, the use of wavelets allows the simultaneous evaluation of a signal in the time and frequency domains with different resolutions, making it very attractive for the analysis of electrical power quality disturbances. Wavelets are used in power quality when it is not important to know the exact frequency of a disturbance in voltage or current waveforms, but the time information is important. Wavelet analysis is a technique for carving up function or data into multiple components corresponding to different frequency bands. This allow one to study each component separately. The main idea existed since the early 1800s when Joseph Fourier first discovered that signals could be represented as superposed sine and cosine waves, forming the basis for the in famous Fourier analysis.

A different wavelet analysis can be applied on the input signal depending on the type of power quality disturbance under study; Real-time or off-line application of wavelet transforms can be applied. A partial implementation of wavelet transforms can be used to study only the time–frequency characteristics of the specific frequency band in the input signal selected by the user.

2.1 Discrete Wavelet Transform (DWT)

The discrete wavelet transform (DWT) is the digital representation of the continuous wavelet transform (CWT). DWT can be implemented using a multi-stage filter bank with the wavelet function as the low-pass filter (LP) and it's dual as the high-pass filter (HP) for a two-level decomposition tree-bands of the signal. Down sampling by two at the output of the low-pass and high-pass filters scales the wavelet by two for the next stage. The output coefficients of the low-pass filter (the approximation coefficients) are again decomposed to produce a new representation of the signal and so on, producing a logarithmic decomposition of the frequency spectra of the input signal for the wavelet decomposition tree (fs/2 is the Nyquist frequency for fs sampling rate). High time resolution is obtained in higher frequency bands whereas low time resolution is provided in the lower frequency band of a signal.

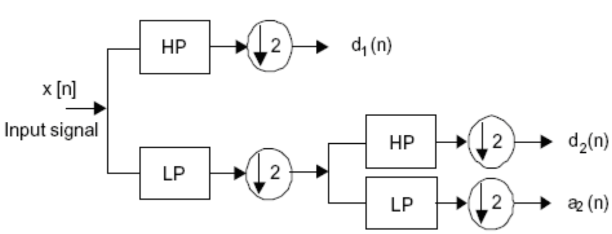


Fig.1. Two level wavelet decomposition tree for DWT analysis

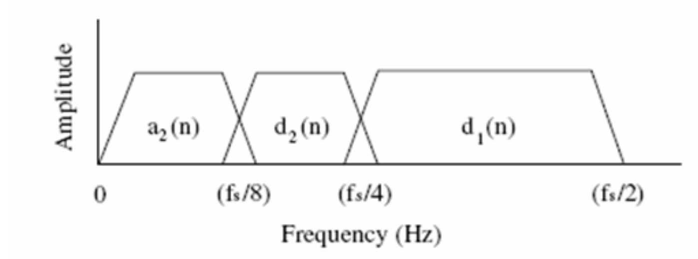
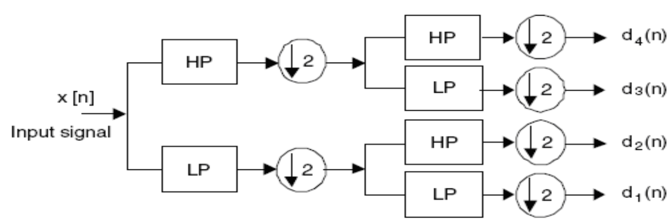


fig 2 Output frequency bands of the wavelet decomposition in fig 1 for f sampling rate

2.2 Wavelet-Packet Transform

The wavelet-packet transform (WPT) can be used to overcome the limitations of the DWT and to obtain a uniform frequency decomposition of the input signal. In the WPT, the output of both, the low-pass and the high-pass filters (the detail and the approximation coefficients) are decomposed to produce new coefficients for a two-level wavelet decomposition tree, in this way enabling a uniform frequency decomposition of the input signalUsing the wavelet-packet transform instead of DWT and adequately selecting the sampling frequency and the wavelet decomposition tree, the uniform output frequency bands can be selected to correspond with the frequency bands of the different harmonic groups in the input signal, as defined in the IEC standard 61000-4-7 [14].



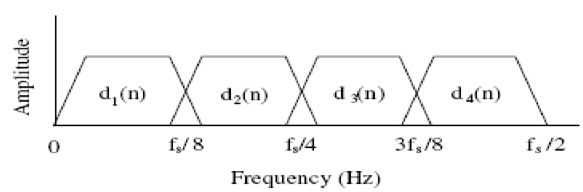


Fig 3 Two level wavelet decomposition tree for WPT analysis

Fig 4 Output frequency bands of the wavelet decomposition tree in fig 3 for f sampling rate

Two main factors affect the successful application of wavelets in power quality applications: first, the extraction of specific features for detection and identification of the different power quality disturbances and second, the selection of the most adequate wavelet mother function and the selection of the decomposition tree and sampling frequency to obtain the time–frequency resolution required. In general, WPT provides more information for signal discrimination than DWT

Wavelet analysis is a technique for carving up function or data into multiple components corresponding to the different frequency bands. The main idea existed since the early 1800s when Joseph Fourier first discovered that signals could be represented as superposed sine and cosine waves, forming the basis for the infamous Fourier analysis. From the beginning of 1990s, it began to be utilized in science and engineering, and has been known to be particularly useful for analyzing signals that can be described as aperiodic, noisy, intermittent or transient. With these traits, it is widely used in many applications including data compression, earthquake prediction, and mathematical applications such as computing numerical solutions for partial differential equations. In recent year it is widely applied in power quality measurement and assessment. Wavelet analysis is a form of time-frequency technique as it evaluates signal in the time and frequency domains simultaneously. The Fourier transform is a frequency domain approach which converts a continuous time signal into frequency domain. Fourier representation X (f) which is calculated by the Fourier transforms integral shown by

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-i2\pi f t} dt \tag{1}$$

The disadvantage of frequency-domain analysis approach is that a significant amount of information may be lost during the transformation process. This information is non retrievable unless a permanent record of the raw vibration signal has been made. The problem of Fourier transform is overcome up to some extent using Short Term Fourier Transform. STFT is simply the result of multiplying the time series by a short time window and performing a discrete Fourier transform. Mathematically for a signal $x(t)$, it is written as,

$$\{x(t)\} \equiv X(\tau, w) = \int_{-\infty}^{\infty} x(t)\omega(t-\tau) e^{-j\omega t} dt \tag{2}$$

For discrete signals, this transform is known as Short Term Discrete Fourier Transform (STDFT) expressed mathematically with signal $x[n]$ & window $\omega[n]$ as

$$\mathrm{STFT}\{x[n]\} \equiv X(n,m) = \sum_{n=-\infty}^{\infty} x[n]\omega[n-m] e^{-j\omega n} \tag{3}$$

Application of STFT have been used to for analyzing different vibration signals for different application but having problem that time resolution is same for all spectral components. This problem is reduced by using the wavelet transform. It is a technique which allows the time-frequency place to be divided in a more flexible way such that a smaller time is use for higher frequencies & larger time is used for lower frequencies. It is calculated by convolving the wavelet with the original signal, multiply the shifted wavelet with the original signal, then sum the result to produce a single value.

(A) Continuous Wavelet

Wavelets, “small waves” which are functions with limited energy and zero average,

$$\int_{-\infty}^{\infty} \varphi = 0 \tag{4}$$

The functions are typically normalized, $\|\psi\| = 1$ and centered in the neighborhood of $t = 0$. The continuous wavelet transform (CWT) was introduced in 1984 by Morlet and Co-workers to analysis geophysical signals with some kind of modified windowed Fourier transform (WFT), which reads,

$$F_h[S](t,w) = \frac{1}{\sqrt{2\pi}} \int_R s(y) \overline{h(y-t)} e^{-twy} dy$$

For $s \in L_2(R)$ a time – continuous signal and $h \in L_2(R)$ a window function. Hence $L_2(R)$ denotes the space of square Integral functions on R. The modification of the WFT was established by combining window function and Fourier mode e^{-twy} into one window function ψ that can be scaled. This modification become the CWT given by,

$$W_\phi[s](a,b) = \frac{1}{\sqrt{a}} \int_R s(t) \overline{\psi\left(\frac{t-b}{a}\right)} dt.$$

The continuous wavelet transform is defined as the convolution between the original signal s(t) and a wavelet $\Psi_{a,b}$ (t).

$$W_{\downarrow}((a,b) = \int_{\downarrow(-\infty)}^{\uparrow(+\infty)} S(t) \; (\!\!\lnot_{\downarrow} ab \; (t) dt$$

$$= \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} s(t) \overline{(\left(\frac{t-b}{a}\right)} \, dt \tag{5}$$

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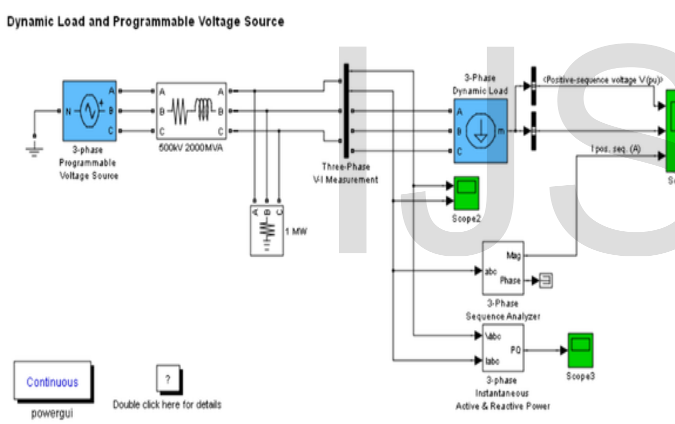
Where s(t) is the input signal; 'a' is the scaling factor; 'b' is the translation parameter; and Ψ(t) is called mother wavelet.

(B) Discrete Wavelet

An important property of discrete wavelet transform is the MSD technique which decomposes a signal into scales with different time and frequency resolution. The MSD technique decomposes a given signal x(t) into its detailed and smoothed versions. In power quality (PQ) disturbance signals, many disturbances contain sharp edges, transitions, and jumps. By using the MSD technique, the PQ disturbance signal is decomposed into two other signals; one is the smoothened version of the PQ signal and the other, the detailed version of the PQ disturbance signal that contains the sharp edges, transitions, and jumps. Through dyadic filter banks MSD can easily achieved. So, the MSD technique discriminates disturbances from the original one and analyses them separately. We will consider the smoothed version of the PQ signal and investigate its filtering property to make the signal disturbance notch free.

3 Dynamic load and programmable voltage source



Circuit description

A dynamic load is connected on a 500 kV, 60 Hz power network . The network is simulated by its Thevenin equivalent (voltage source behind a R-L impedance corresponding to a 3-phase short circuit level of 2000 MVA). The source internal voltage is modulated in order to simulate voltage variation during a power swing. As the dymamic load is a nonlinear model simulated by current sources, it cannot be connected to an inductive network (R-L in series). Therefore, a small resistive load (1 MW) has been added in parallel with the dynamic load.

The dynamic load power is a function of its terminal positive-sequence voltage V. Open the Dynamic Load menu and notice that both exponents np and nq are set to 1 and that the specified minimum voltage Vmin is 0.7 pu . It means that the load active power P and reactive power Q are defined by the following equations:

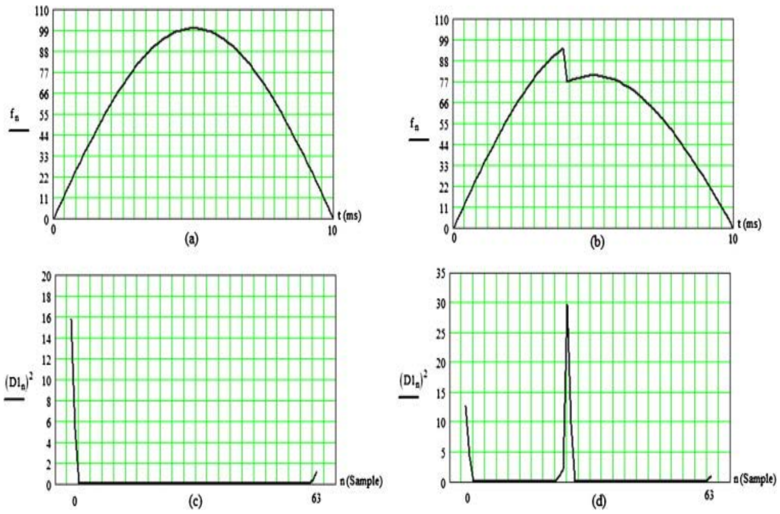
If V >Vmin
P = Po*(V/Vo); Q = Qo*(V/Vo)
If V <Vmin
P = Po*(V/Vo)^2; Q = Qo*(V/Vo)^2

In other words, as long as voltage is higher than 0.7 pu, the load current is constant. When voltage falls below 0.7 pu the load behaves as a constant impedance. In order to demonstrate the variation of P and Q as function of voltage, the source internal voltage is controlled by the 3-Phase Programmable Voltage Source block. Open the source menu and notice that the specified type of amplitude variation is a sinusoidal modulation (Amplitude of the modulation = 0.5 pu, Frequency of the modulation = 1 Hz). Therefore, the source positive-sequence voltage varies between 0.5 pu and 1.5 pu. The initial source voltage is 1 pu. Modulation starts at t = 0.2 s and stops after 1 cycle at t = 1.2 s. A 3-Phase Sequence Analyzer block (from the Extras/Measurement library), is used to monitor the positive-sequence component of load current. Another block from the Extras/Measurement library is used to compute the load active and reactive powers.

4 Wavelet based detection of voltage sags

As mentioned in [13], the high frequency resolution of transformed can detect transient disturbances better than low resolutions. The scaling (A5) and wavelet signals (D1-D4) of a voltage signal S , when it is subjected to sag for 4 cycles are shown in fig. below with the starting and ending point.It can be seen that the first level of the transformed signal clearly shows a peak at the begining and end of the voltage sag. The other wavelet levels have also experienced variation at this same instant. Therefore it can said that the disturbance can be detected with high frequency wavelet levels better , the starting and ending point of voltage sag is also detected.

Fig(a). shows a pure sine wave and (c) its D1 wavelet .The horizontal axis presents sampling point ant the vertical point axis presents the magnitude of wavelet coefficient. The first four points and last sample magnitudes are different are different from zero.The pure sine wave will be used as a reference in comparison with sag cases. Fig(b). shows a voltage signal disorted with sag and (d) shows its first decomposition level. It is clear from the figure that there is a decrease in the voltage signal, the wavelet coeffients around sag starting points differs from zero. A sike is seen at the initial point in wavelet. The sag can occur at any point of voltage signal. To determine the effects of voltage sag starting point and ending point on the magnitude of the spike in the wavelet, the same magnitude of sags were applied to different points on voltage wave.



Fig(a) Pure sine wave Fig(b) Voltage signal disorted with sag
Fig(c) its D1 wavelet Fig(d) Shows its first decoposition level

4 Results

To recognize the disorted signal with begining and ending point and test the proposed algorithm a voltage sag identifier system is developed. A test is performed by using MATLAB. The voltage sag occur and detection of that signal with the begining and ending point of decomposition at 4 level is shown in the fig 5

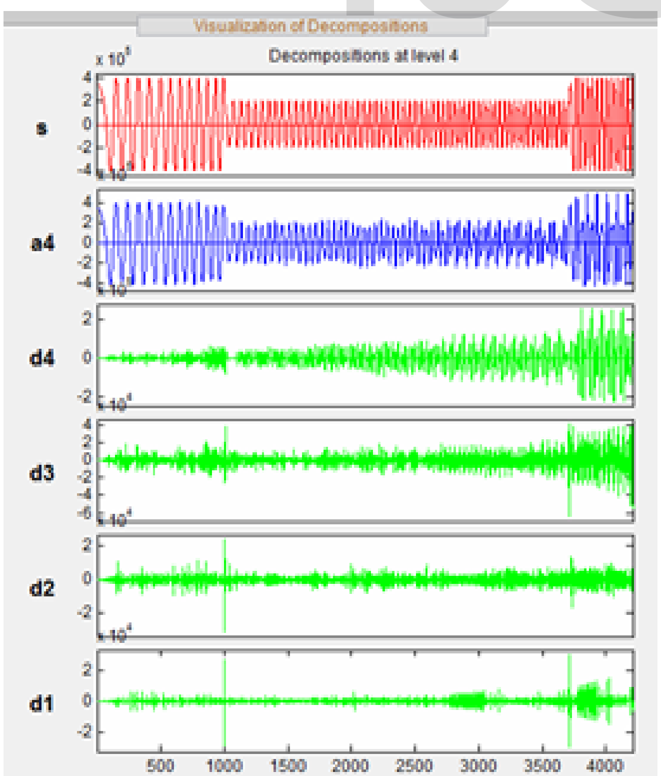


Fig 5 Detecxtion of beginning and Ending point of Voltage Sag

The percentage of energy coefficient in this decomposion is shown in Fig 6, this can be detected by different selection of data.

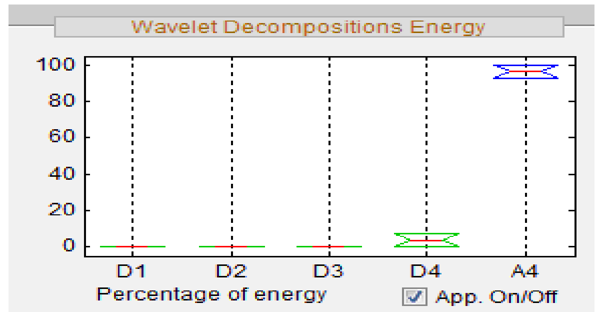


Fig 6 Wavelet Dcomposition Energy

5 Conclusion

Utilities record power quality data, especially voltage, to identify the origins of power quality problems in order to improve the reliability of electrical systems. This paper presents a practically effient method for the starting and ending point of voltage sag detection. The method uses discrete wavelet transforms to determine beginning and ending of the voltage sag with sag magnitute. A MATLAB software is used for this purpose. The proposed method is successfully tested for different voltage sags instants of voltage. It has a advantage of finding voltage sag magnitude and duration in low cost implementation.

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