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A Short Time Discontinuity and Voltage Disturbance Detection Using HAAR and Daubechies Wavelet

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Abstract

The objective of this paper is to present the simulation results obtained, the conclusions drawn and the approach used to detect the discontinuities using the basic Haar wavelet and the typical power quality disturbance such as voltage sag, swell, interruption, impulse and voltage notching using the Daubechies wavelet on the disturbances generated using MATLAB/SIMULINK environment and also the same verified on the real data captured i.e. sag occurred during intermittent operation of welding machine.

1. Introduction

In engineering terms, power is the rate of energy delivery and is proportional to the product of the voltage and current. The power supply system can only control the quality of the voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits. Hence the power quality is nothing but the voltage quality. The quality of electric power has become an important issue for electric utilities and their customers. Customers, in particular, have become less tolerant of power quality disturbances because these disturbances degrade the performance and efficiency of customer loads, especially power electronics loads. [1]

2. Wavelet Transform

A wavelet is a waveform of limited duration that has an average value of zero. These have a beginning and an end. Wavelets are irregular and often non-symmetrical. Wavelet transforms are exciting because they too are comparisons; they use smaller and shorter waveforms that can start and stop. Wavelet transforms compares many stretched and shifted wavelets to the original pulse.

3. Wavelet Decomposition

The wavelet decomposition produces a family of hierarchally organized decompositions. It consists of calculating "resemblance index" between the signal and the wavelet located at position 'b' and scale 'a'. If the index is large, the resemblance is strong otherwise it is slight. The index C (a, b) are called coefficients. The level is chosen based on desired lowpass cut-off frequency. The scale 'a' is related to level 'j' by $a=2^j$. Resolution =1/a, then resolution increases as scale decreases. The greater the resolutions, the smaller and finer are the details that can be accessed. The size of the revealed details for any level 'j' is proportional to the size of the domain in which the wavelet or analyzing function of the variable x. One dimensional analysis is based on one scaling function and one wavelet.

Wavelet functions $w_{a,s}(t) = |a|^{-1/2}\, w\left(\frac{t-s}{a}\right)$

The mother wavelet w(t) is $w_{1,0}(t)$ at unit scale a=1 and position s=0. The factor $|a|^{-1/2}$ assures that the rescaled wavelets have equal energy $||w_{a,s}||=||w||$. Its normalized so that all these functions have unit norm $||w_{a,s}||=1$.

4. Choice of Analyzing Wavelets

The choice of analyzing wavelets plays a significant role in detecting and localizing various types of power quality disturbances. This is especially true when considering one- or two-scale signal decompositions. For short and fast transient disturbances, Daub4 and Daub6 wavelets are better, while for slow transient disturbances, Daub8 and Daub10 are particularly good.[1] The wavelet transforms are performed by dilating (expanding) a mother wavelet in the course of analysis, rather than by contracting the mother wavelet. Therefore, we choose Daub4 (Daub6 is a good candidate **as** well) because it is the most localized, i.e. compactly supported, in time.

5. Haar Wavelet

The haar wavelets are the simplest, shortest and the first to be used. Although a "continuous" haar wavelet doesn't exist in the real world of digital computers, a good estimation can be produced by upsampling and lowpass filtering the simple wavelet function filter (the highpass reconstruction filter) to produce a multiple point estimation. They have a support width of 1.0. Haar wavelets have outright discontinuities and are thus not smooth or regular. It is the only non-continuous function with three points of discontinuity (0, 0.5, 1). Haar wavelets (filters) have only one vanishing moment. Stretched versions of the haar wavelet will of course also have one vanishing moment. They are not strictly symmetric, but are anti-symmetric. With a basic filter length of only two points they are excellent for time resolution but poor for resolution in frequency.

6. Experimental Results using Haar Wavelet

Several experimental simulations where done using HAAR wavelet for thorough understanding, the test data used was a series of random numbers.

1. a = [60 60 60 60 60 60 60 0]

As shown in Figure 1(a) the input signal consists of 8 samples with the discontinuity at 7th sample. Figure 1(b) shows the approximation A1 which indicates the nature of disturbance and also the level of the disturbance which is found to be the average of the two adjacent samples. Figure 1(c) shows the Detail D1, which detects the disturbance.

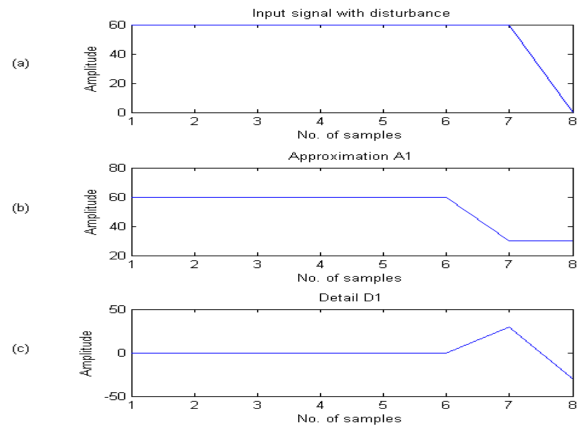

Figure 1. Detection of discontinuities in an array of data of size eight with discontinuity at a single point

2. a = [0 60 60 60 60 60 60 0]

As shown in Figure 2(a) the input signal consists of 8 samples with the discontinuity at 1st and 7th sample. Figure 2(b) shows the approximation A1 which indicates the nature of disturbance and also the level of the disturbance which is found to be the average of the two adjacent samples. Figure 2(c) shows the Detail D1, which detects the disturbance.

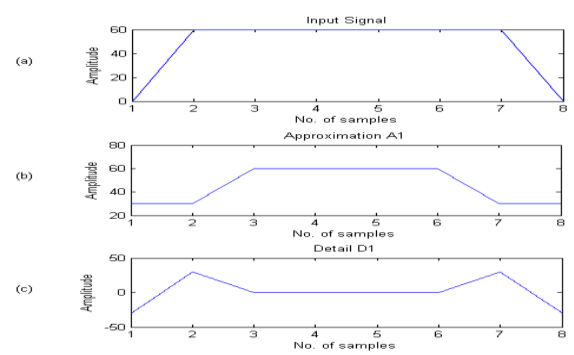

Figure 2. Detection of discontinuities in an array of data of size eight with discontinuities at points

3. a = [60 60 0 60 60]

As shown in Figure 3(a) the input signal consists of 5 samples with the discontinuity at 3rd sample. Figure 3(b) shows the approximation A1 which indicates the nature of disturbance. Figure 3(c) shows the Detail D1, which indicates the detection of the disturbance.

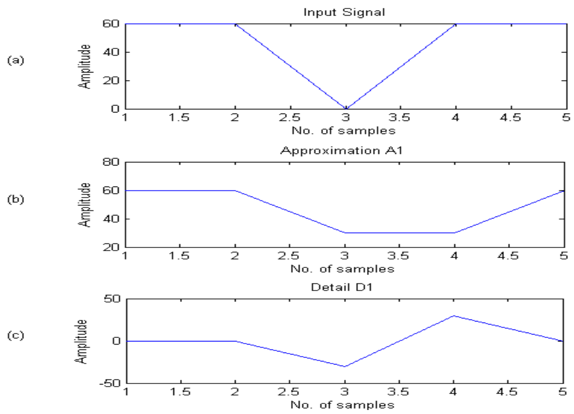

Figure 3. Detection of discontinuity in an array of data the point of discontinuity being at an odd position

4. a = [60 0 60 0 60 0]

As shown in Figure 4(a) the input signal consists of 6 samples with the disturbance at every alternate sample. Figure 4(b) shows the approximation A1 which indicates the type of disturbance and also the level of the disturbance which is found to be the average of the two adjacent samples. Figure 4(c) shows the Detail D1, which detects the disturbance.

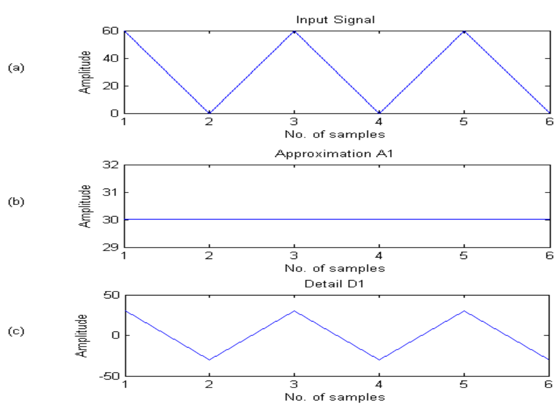

Figure 4. Detection of discontinuity in array with discontinuities at consecutive positions

5. a = [60 60 60 60 60 60 0]

As shown in Figure 5(a) the input signal consists of 7 samples with the disturbance from 6th sample to 7th sample. Figure 5(b) shows the approximation A1 which indicates the type of disturbance and also the level of the disturbance which is found to be the average of the two adjacent samples.

Figure 5(c) shows the Detail D1, it is evident from the detail D1 that when the no. of samples are odd and the disturbance is from even sample to odd sample the HAAR wavelet doesn't detect the disturbance. It is one of the limitations of HAAR wavelet.

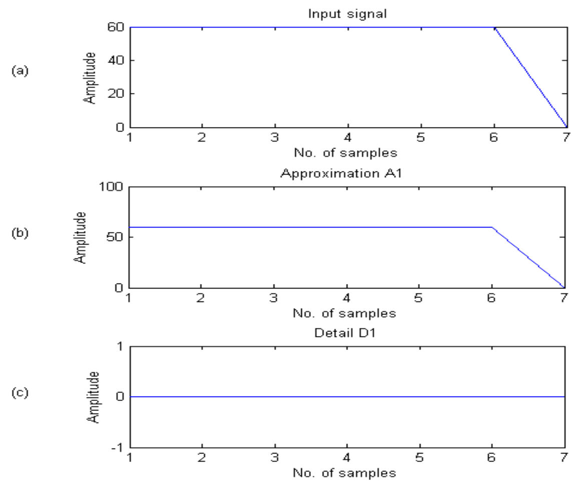

Figure 5. Non –detection of discontinuity in an array when the position of discontinuity is in an even –odd point

7. Haar Wavelet application to Power Quality Disturbance

1. Impulse transients:

The HAAR wavelet applied to detect the recurring impulsive transient which may be caused due to the lightning. From Figure 6 it is evident that the HAAR wavelet successfully detects the same.

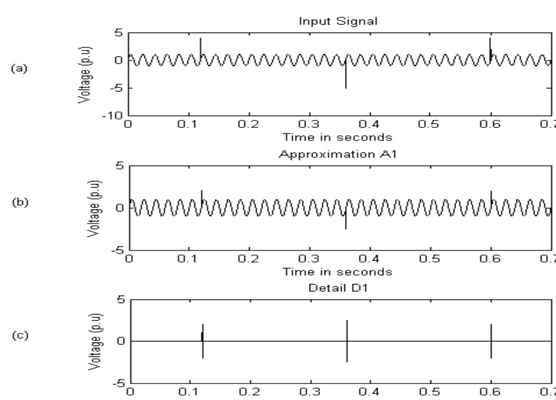

Figure 6. Detection of Impulsive transients using HAAR wavelet

2. Daubechies Wavelet

Ingrid Daubechies, called to be as one of the brightest stars in the world of wavelet research, invented what are called compactly supported orthonormal wavelets - thus making discrete wavelet

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analysis practicable. The names of the Daubechies family wavelets are written dbN, where N is the order, and db the "surname" of the wavelet. The db1 wavelet is the same as Haar wavelet. Here are the wavelet functions, psi of the next nine members of the family:

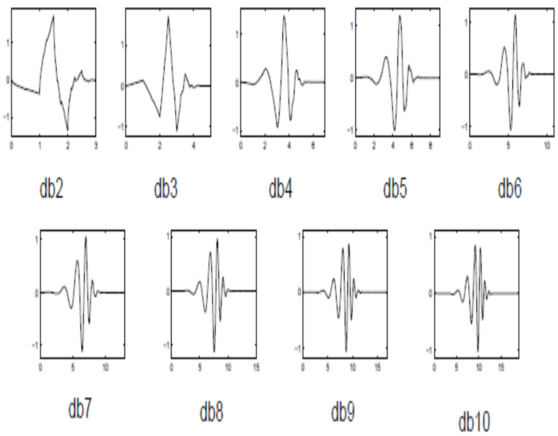

Figure 7. Wavelet functions db2 to db10

8. Experimental Results for Typical Power Quality Disturbances Using Db4 Wavelet

1. Voltage Sag/Dip

Voltage sags are regarded as one of the most relevant issues in power quality due to their high cost impact on sensitive industrial loads. Also, they are more common than complete interruptions to the supply.

Figure 8(a) shows the 80% voltage sag in the single phase supply system. The input signal is passed through the discrete wavelet transform which produces the detail and approximation of the signal. Figure 8(b) shows the detail D1 which clearly detects the instant of occurrence of the sag and also the instant of recovery of the sag. Figure 8(c) shows the approximation A1 which indicates the type of disturbance and also the level of the disturbance.

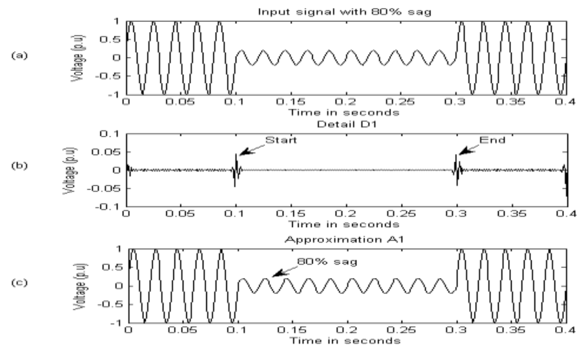

Figure 8. Detection and quantification of voltage sag using Db4

2. Multiple sag levels during occurrence of disturbance

Multiple sag levels may occur in the single phase supply system due to reclosing of circuit breakers before the clearance of fault. Figure 9(a) shows the phenomenon of repeated sags in the input signal. As shown in figure the system has voltage sag of 30% and after some time duration the level of sag is increased to 60% leading to multiple sags.

Figure 9(b) shows the Detail D1 indicating the instant of occurrence of the sags and the instant of recovery. Figure 9(c) shows the Approximation A1 which indicates the type of disturbance and its level.

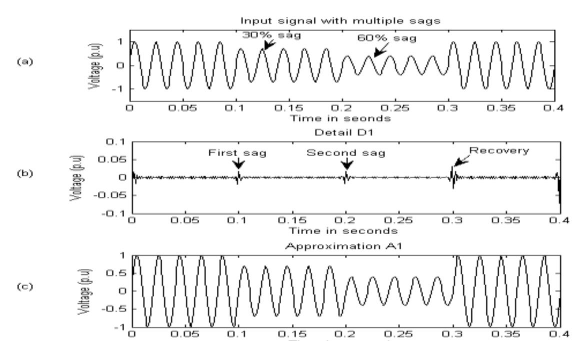

Figure 9. Detection of Multiple sag levels

3. Voltage Swell

Voltage swells are generated when loads are transferred from one utility power source to another, or when some types of loads are used such as welding machines, and also due to single or double phase to ground fault on one of the connected feeders.

Figure 10(a) shows the input signal of single phase supply system with 70% swell. Figure 10(b) shows the Detail D1 indicating the instant of occurrence and instant of recovery of the swell. Figure 10(c) shows the approximation A1 clearly indicating the type of disturbance and also the level of swell.

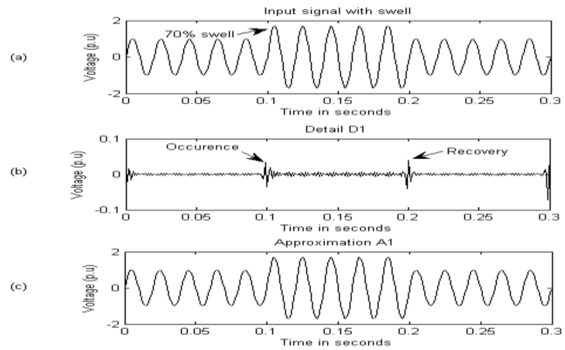

Figure 10. Detection of Voltage swell

4. Voltage Interruption

The interruption can occur due to instant tripping of a transformer breaker, and also due to consecutive tripping after the occurrence of a ground fault which leads to complete interruption.

Figure 11(a) shows the input signal with the complete interruption with the voltage of magnitude 0.05p.u. Figure 11(b) shows the Detail D1 indicating the occurrence and recovery of the instant of interruption. Figure 11(c) shows the approximation A1 indicating the interruption.

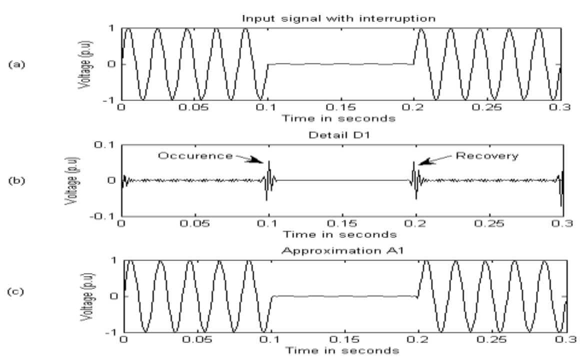

Figure 11. Detection of Voltage Interruption

5. Voltage Notches

Typically, voltage notches are associated with the adjustable speed drives and also common with the operation of power electronic devices when current is commutated from one phase to another. This phenomenon leads to improper operation and failure of equipment.

Figure 12(a) shows the voltage notch in the input signal. Figure 12(b) shows the Detail D1 indicating all the instances of occurrence of the notch. Figure 12(c) shows the type of disturbance as voltage notch.

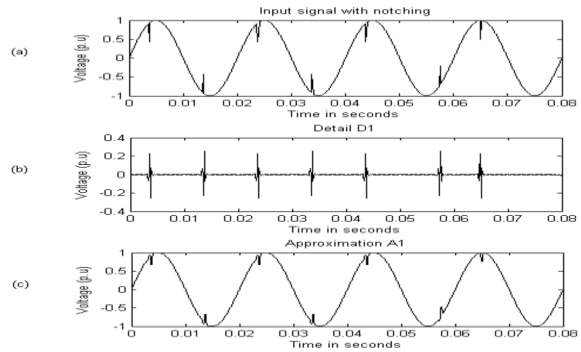

Figure 12. Detection of Voltage Notch

6. Impulsive Transients

Impulsive transients are spikes that occur for a very short duration (less than a cycle) in voltage, current or both.

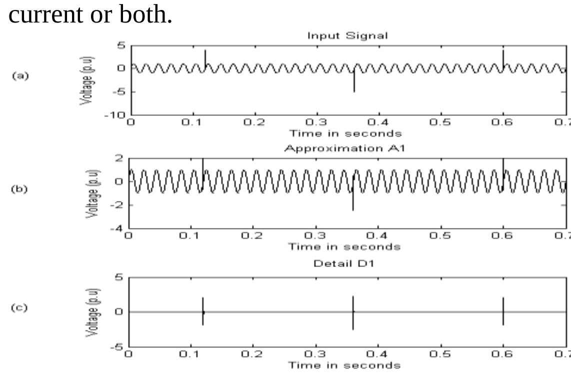

Figure 13. Detection of Impulsive transient

9. Testing of Algorithm on Real Data

Real data was acquired to verify the functioning of the algorithm when subject to work conditions with noise, harmonics and frequency variations. Real sag and swell situations captured during start of an induction motor; intermittent operation of an arc welding machine; dynamic loading of diesel generator set. These waveforms were acquired using a digital storage oscilloscope and the algorithm was tested on them in Matlab-Simulink environment.

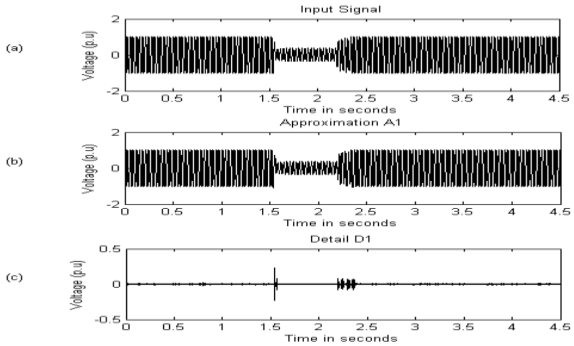

Figure 14. Detection of sag in welding data

10. Conclusion

Based on the above studies done on the detection of disturbance in single phase power supply systems (sags, interruptions, swells and transients) using Haar and Daubechies, the following observations are made.

The Haar wavelet is memory efficient; it is exactly reversible without the edge effects that are a problem with other Wavelet transforms. The Haar window is only two elements wide. If a big change takes place from an even value to an odd value, the change will not be reflected in the high frequency coefficients i.e. (detail)

The Daubechies4 gives accurate results in terms of detection of both, instant of occurrence as well as magnitude and type of disturbance for all disturbance types. Hence it is recommended as the best wavelet algorithm for the detection of above mentioned disturbance types in single phase power supply systems.

11. References

[1]Surya Santoso, Edward J. Powers, W. Mack Grady and Antony C. Parsons, "Power Quality Disturbance Waveform Recognition Using Wavelet-Based Neural Classifier—Part 1: Theoretical Foundation" *IEEE Trans on Power Delivery*, Vol. 15, No. 1, January 2000.

[2] Roger C. Durgan / Mark F. McGranaghan, Surya Santoso / H.Wayne Beaty, "*Electrical Power Systems Quality*", Second Edition, The McGraw-Hill Companies.

[3] Amara Graps, "An Introduction to Wavelets"