

# Slantlet Transform: An Efficient Approach for Compression and De-noising of Power Quality Events

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## ABSTRACT

The Slantlet Transform (SLT) is an orthogonal Discrete Wavelet Transform (DWT) having two zero moments with improved time localization. SLT retains usual characteristics of filter bank implementation with a scale dilation factor of two. The basis is not based on iterated filter bank like DWT; instead, different filters are used for each scale. This paper proposes the De-noising method of Power system disturbances through signal decomposition, thresholding of slantlet transform coefficients and signal reconstruction. Slantlet transform coefficients having values below the threshold are discarded and above are retained. The cost for data storing and transmitting is competently reduced when Compared to the energy retained of the compressed Power Quality (PQ) disturbance signals and at no cost De-noising is happening through thresholding.

## Keywords

Power Quality events, Slantlet transform, Thresholding, De-noising, Compression.

## 1. INTRODUCTION

The performance of power system equipments is repeatedly affected by faults. Usual disturbances are signals which are having transients, sudden rise or sudden reduction in signals etc. Power quality faults phenomena spans a broad frequency spectra [1]. For example, impulsive transients owed to lightning strikes could have a frequency spectrum of order of MHz. In order to capture a broad range of disturbance phenomena, including impulsive transient disturbances, dedicated PQ monitoring devices on light/medium stations with MHZ of sampling rates are used. Since transient disturbances take place in order of tens of micro seconds, a single captured event using such monitoring devices can produce megabytes of data [2].As an effect, the volume of the recorded events increases considerably, leads to high cost in storing and transmitting such data. Therefore compression of such recorded events with slightest error in reconstruction is highly needed.

A useful requirement in general for compression is analysis of data initially by a transform to extract the feature information in data and removal of redundancy, before doing thresholding. Transformations have been generally used in this area in recent years are discrete Fourier transform, discrete cosine transform, discrete wavelet transform etc. Here in this paper slantlet transform [3] is used for analysis of recorded events.

The intention of this work is to use SLT in compressing PQ system disturbances and also to compress the PQ events with addition of noise.SLT is an orthogonal DWT having two zero moments and shorter support which are challenging criteria in the construction of wavelet filter banks unlike iterated filter bank in DWT[3].Octave band characteristics remains in the basis and leads to a clean DWT for limited length

signals(boundary issues will not arise as long as data length is power of two)[3].Basis is particularly suited for piecewise linear signals as is supported by compression and denoising examples shown further.

The organization of paper is as follows. In section 2, SLT and its important features is outlined. Data compression using thresholding and reconstruction, performance parameters definitions is presented in section 3.In section 4, simulation of disturbance signals under consideration, test results are obtained and interpreted for all the events related to disturbances in PQ system. Finally conclusions have been made in section 5.

## 2. SLANTLET TRANSFORM THEORY

The class of bases described by Alpert [4] constructed based on Gram-Schmidt orthogonalization is used in SLT. It is based on a structure of filter bank where different filters are used for different scales. Filters are of shorter length satisfies orthogonality and zero moment conditions. The filter bank for two zero moments used in SLT is as shown in Figure 1. Having lengths 8 and 4 [3] [6].This is one of the advantage of filter bank when compared to Daubechies-2 filter bank in terms of filter length. Every filter bank works with scale dilation factor of two and provides a multiresolution decomposition. The filters used are piecewise linear.

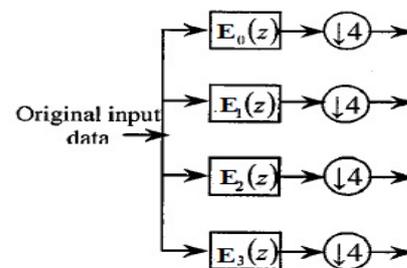


Fig 1: Filter Bank Structure using SLT

The different filters used here are not products like filters in Daubechies-2 and with this extra degree of freedom by giving up product form, filters are intended with shorter length satiating orthogonality and zero moment conditions. The filter coefficients [3] are as follows

$$E_0(z) = \left(-\frac{\sqrt{10}}{20} - \frac{\sqrt{2}}{4}\right) + \left(\frac{3\sqrt{10}}{20} + \frac{\sqrt{2}}{4}\right)z^{-1}$$

$$+ \left(-\frac{3\sqrt{10}}{20} + \frac{\sqrt{2}}{4}\right)z^{-2} + \left(\frac{\sqrt{10}}{20} - \frac{\sqrt{2}}{4}\right)z^{-3}$$

$$E_1(z) = \left(\frac{7\sqrt{5}}{80} - \frac{3\sqrt{55}}{80}\right) + \left(-\frac{\sqrt{5}}{80} - \frac{\sqrt{55}}{80}\right)z^{-1}$$

$$+ \left(-\frac{9\sqrt{5}}{80} + \frac{\sqrt{55}}{80}\right)z^{-2} + \left(-\frac{17\sqrt{5}}{80} + \frac{3\sqrt{55}}{80}\right)z^{-3}$$

$$+ \left(\frac{17\sqrt{5}}{80} + \frac{3\sqrt{55}}{80}\right)z^{-4} + \left(\frac{9\sqrt{5}}{80} + \frac{\sqrt{55}}{80}\right)z^{-5}$$

$$+ \left(\frac{\sqrt{5}}{80} - \frac{\sqrt{55}}{80}\right)z^{-6} + \left(-\frac{7\sqrt{5}}{80} - \frac{3\sqrt{55}}{80}\right)z^{-7}$$

$$E_2(z) = \left(\frac{1}{16} + \frac{\sqrt{11}}{16}\right) + \left(\frac{3}{16} + \frac{\sqrt{11}}{16}\right)z^{-1}$$

$$+ \left(\frac{5}{16} + \frac{\sqrt{11}}{16}\right)z^{-2} + \left(\frac{7}{16} + \frac{\sqrt{11}}{16}\right)z^{-3}$$

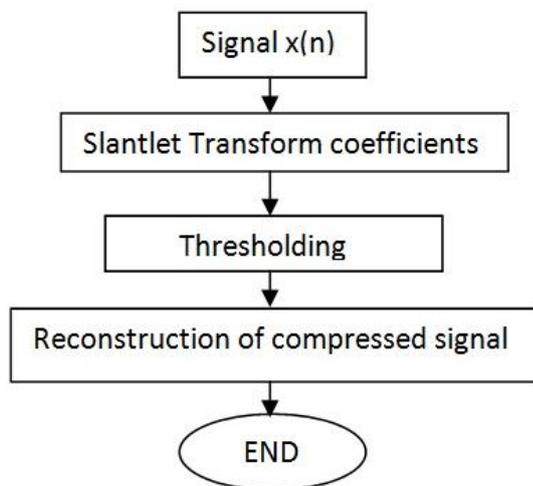
$$+ \left(\frac{7}{16} - \frac{\sqrt{11}}{16}\right)z^{-4} + \left(\frac{5}{16} - \frac{\sqrt{11}}{16}\right)z^{-5}$$

$$+ \left(\frac{3}{16} - \frac{\sqrt{11}}{16}\right)z^{-6} + \left(\frac{1}{16} - \frac{\sqrt{11}}{16}\right)z^{-7}$$

$$E_3(z) = z^{-3}E_2\left(\frac{1}{z}\right).$$

### 3. DATA COMPRESSION AND RECONSTRUCTION USING SLT

The Flowchart for the process of compression and reconstruction of the signal is shown in Figure 2.

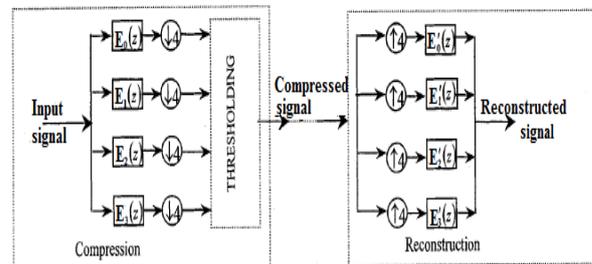


**Fig 2: Flowchart for the process of compression and reconstruction.**

As we can observe in the flowchart, Initially SLT is applied for the transformation. Then suitable threshold is chosen for discarding the SLT coefficients which are not having

significant energy in the second step called thresholding. The above two steps will ensure the compression part and then inverse SLT is applied to get the reconstructed signal.

The block diagram of the entire process of compression and reconstruction is shown in figure 3. The filter coefficients used in analysis part are mentioned in section 2. The PQ system disturbance signal is applied as input to the two scale filter bank and the outputs are then getting down sampled by 4. The transformed coefficients used for the analysis filter bank are  $E_0(z)$ ,  $E_1(z)$ ,  $E_2(z)$ ,  $E_3(z)$  as shown in figure 3. The transformation preserves most of the signal energy in some selective coefficients and remaining coefficients are insignificant. Therefore, suitable threshold is chosen to discard the coefficients. Also keeping reconstruction of signal and quality of the same in sight, the threshold is fixed. The insignificant coefficients are set to zero once we chose the threshold value. The remaining coefficients represent the original input signal in compressed form.



**Fig 3: Block diagram for SLT based compression and reconstruction.**

The coefficients in compressed form are then encoded to binary form used for storing and transmitting purpose. From the thresholded data the original PQ disturbance signal is reconstructed by using the two scale SLT synthesis filterbank as shown in the figure 4. Transformed coefficients used in synthesis filterbank are  $E'_0(z)$ ,  $E'_1(z)$ ,  $E'_2(z)$ ,  $E'_3(z)$  as shown in the Figure 3. These filter coefficients are the time reversal of the corresponding analysis filters. The compressed data are upsampled by four and then convolved with the synthesis filter coefficients of each channel. These data are then added to get the reconstructed PQ disturbance signal for further use. The parameters used to assess the quality of compression are energy retained in percentage and mean square error (MSE) in decibels. The percentage of energy retained (ER) is defined as

$$\left[ \frac{\text{(Vector norm of the retained SLT coefficients after thresholding)}}{\text{Vector norm of the original SLT coefficients}} \right] \times 100.$$

It is used as a performance index for compression. MSE in decibels is defined as

$$\text{MSE (dB)} = 10 \left[ \log_{10} \left( \frac{1}{N} \sum_{i=1}^N \|x(i) - \hat{x}(i)\|^2 \right) \right]$$

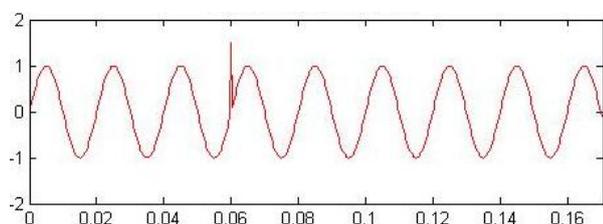
Where  $x(i)$  is the original signal and the other is the reconstructed signal[5].

The process explained above is done for the same PQ disturbance signals with addition of additive white Gaussian noise of SNR 15dB. Again energy retained and MSE is calculated and compared with the other having no noise.

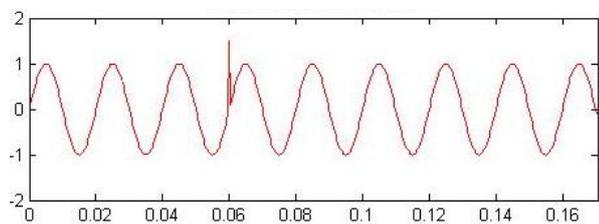
Chosen test signals are PQ disturbance signals which are sine impulse, voltage sag, voltage swell, Harmonics, Momentary interruption, Oscillatory transient and Voltage flicker.

#### 4. SIMULATION AND TEST RESULTS

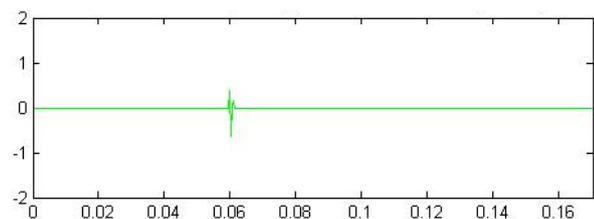
Compression capability of SLT approach is revealed by taking a sine impulse signal containing impulse at certain time as shown in Figure 4. Breakdown of the signal into two levels and the corresponding outputs of the filter are shown in the Figure 5. Information of different frequency components is shown by the outputs of filter and it also shows how precisely it localizes the disturbance point. Once thresholding is done by proper value of threshold, later the reconstruction process is done. Reconstructed signal is as shown in the Figure 6. The ratio between the original signal coefficients to the number of signal coefficients remained after thresholding is compression ratio (CR). Here in present case  $CR = 10$  is considered. It is detected that higher the CR values less data are retained after thresholding and hence accuracy is sacrificed in reconstructing the signal.



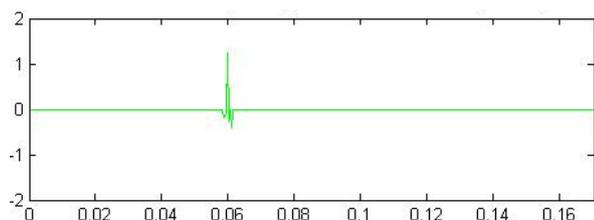
**Fig 4: Original Sine impulse signal of 50 Hz.**



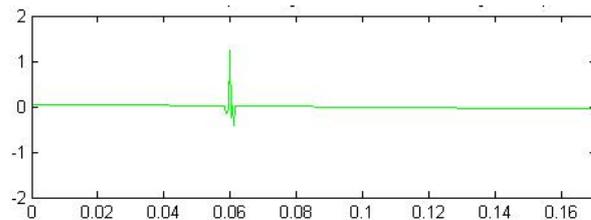
**Fig 5: a) Original sine impulse signal of 50 Hz**



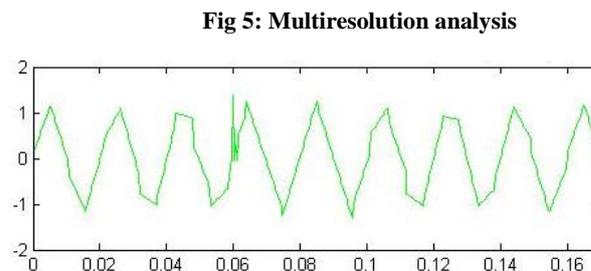
**Fig 5: b) First filter output**



**Fig 5: c) Second filter output**



**Fig 5: c) Third filter output**



**Fig 6: Reconstructed sine impulse signal**

All the PQ signals are generated in the MATLAB at the sampling rate of 3 kHz. Simulation is done with sinusoidal signals of 50Hz and 1 p.u. amplitude. MSE and ER is calculated for all the PQ disturbance signals and listed in the Table 1.

**Table 1. Percentage of Energy retained and MSE in dB obtained using SLT based compression approach for all signals at CR=10**

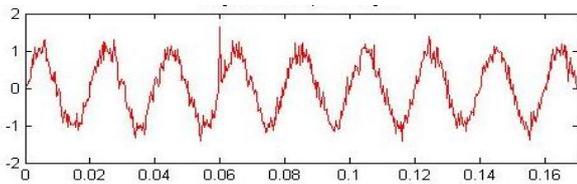
Input Signals without noise	DCT		DWT		SLT	
	ER (%)	MSE (dB)	ER (%)	MSE (dB)	ER (%)	MSE (dB)
Impulse	88.01	-10.67	91.13	-13.56	98.21	-16.98
Sag	87.81	-10.08	90.01	-13.04	98.61	-17.54
Swell	89.46	-11.88	91.01	-13.77	98.61	-17.95
Harmonics	87.69	-11.04	90.89	-13.31	91.90	-17.68
Momentary Interrupts	90.44	-12.27	91.10	-15.89	98.91	-18.79
Oscillatory Transient	91.63	-12.98	90.88	-14.45	98.11	-19.07
Voltage Flicker	90.75	-10.76	91.34	-14.74	98.75	-19.78

In the same way for all the PQ signals a white Gaussian noise of SNR 15dB is added and then compression and reconstruction is done. Again the ER and MSE is calculated for all the PQ signals and listed in Table 2.

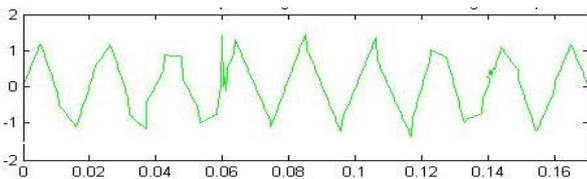
**Table 2. Percentage of energy retained and MSE in dB obtained using SLT based compression approach for all signals with SNR of 15dB at CR=10**

Input Signals with noise	SLT		DWT	
	ER (%)	MSE (dB)	ER (%)	MSE (dB)
Impulse	93.7501	-14.7121	90.8701	11.2921
Sag	92.8994	-15.6653	89.7054	11.1653
Swell	95.4906	-14.3391	89.9594	10.1591
Harmonics	87.1272	-11.1386	85.0872	9.6383
Momentary Interruption	91.1185	-15.1829	88.1085	12.2829
Oscillatory Transient	93.0431	-14.3747	88.8831	9.7547
Voltage Flicker	94.0553	-14.8708	90.2153	9.8308

Figure 7, Shows the original sine impulse signal with SNR 15dB added noise and Figure 8, shows the reconstructed signal from the thresholded data. From figure 8 it can be easily seen that signal which is reconstructed contains much less noise and pattern of reconstructed signal without noise is kept. Therefore good denoising can be done through data compression. It is since the slantlet transform coefficients caused by noise are generally small and mostly concentrated in high frequency bands, i.e., the first several scales. So that any thresholding can reach the denoising to a certain degree.



**Fig 7: Sine impulse signal with AWGN of 15dB SNR.**

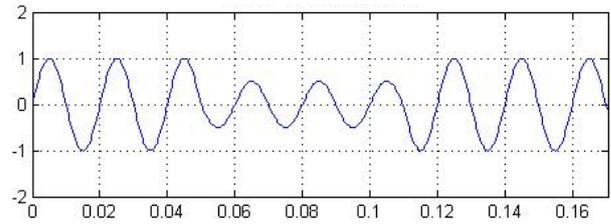


**Fig 8: Reconstructed sine impulse signal.**

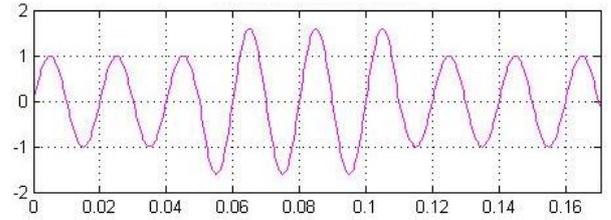
Definitions of all the PQ system disturbance signals used here are described [5] and MATLAB simulated PQ signals are shown in Figures (9,10,11,12,13,14).The reconstructed signals of original disturbance signals with noise are comparable to reconstructed signals of original disturbance signals without noise. For example if we look into the table 1, the energy retained in percentage for the sine impulse signal is 98.2191 and energy retained for the same with noise is 93.7501 as mentioned in Table 2.The difference in percentage between these two values is 4.55 which is acceptable.

Similarly for all the signals the difference in percentage of energy retained of the signals with and without noise is about 5. From this reflection we can say that a decent denoising has happened through compression. As the SLT approach is the efficient method for data compression when compared to

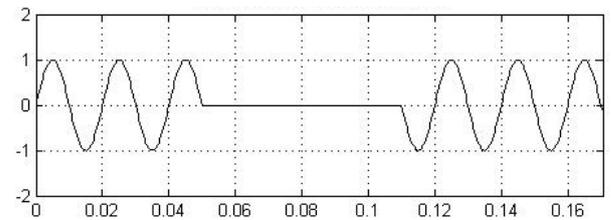
DCT and DWT [5].SLT based compression technique is also the efficient technique for compression as well as denoising through compression.



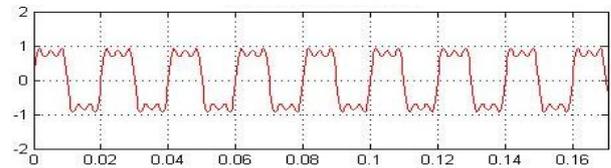
**Fig 9: Voltage Sag signal of 50 Hz.**



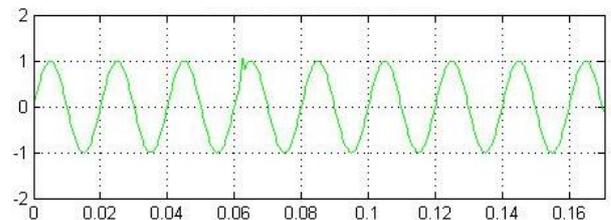
**Fig 10: Voltage Swell signal of 50 Hz.**



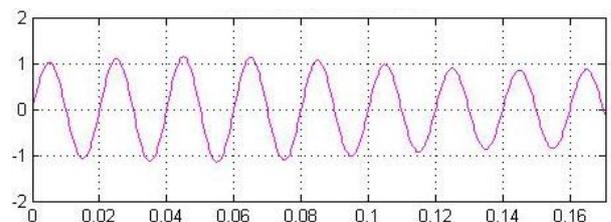
**Fig 11: Momentary interruption signal of 50 Hz.**



**Fig 12: Signal with third and fifth Harmonics of 50 Hz.**



**Fig 13: Oscillatory transient signal of 50 Hz.**



**Fig 14: Voltage Flicker signal of 50 Hz.**

## 5. CONCLUSION

In this paper, SLT is applied for compression of PQ disturbance signals and signals with additive white Gaussian noise of SNR 15dB. The performance is assessed through computer simulation for both the cases. Considering percentage of energy retained and mean square error in dB of different disturbance signals, it is in general witnessed from analysis that accuracy is good for efficient compression, high quality compression and good denoising effect. Thus it is, in general, conclude that SLT based compression technique is efficient for compression of transient signals without noise and with noise upto certain degree when compared to DCT and DWT.

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