Slantlet Transform based Data Compression and Reconstruction Technique Applied to Power Quality Signals

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Abstract: Wavelets are used to analyze the frequency components of a signal according to a scale. Now-a-days, wavelet transforms have been studied and applied effectively in science and technology fields. One such area of applications of digital signal processing tools is 'Power Quality'. Of late, Slantlet transform (SLT) can be developed by considering the lengths of the discrete time basis function and their moments to achieve both time localization and smoothness properties. It is an orthogonal DWT with two zero moments and possesses improved time localization properties. Present paper describes SLT used for compression of different power quality disturbance data. The performance of proposed novel technique called slantlet transform (SLT) can be assessed by in terms of compression ratio, mean square error and percentage of energy retained in the reconstructed signal is assessed. Simulated data related to varieties of power quality events which include sine impulse, voltage sag, voltage swell, harmonics, momentary interruption, voltage flicker and transient oscillation are used to test the performance of SLT based approach for data compression and signal reconstruction. MATLAB based simulation results shows that the SLT offers superior compression performance results compared to the conventional discrete wavelet transform and discrete cosine transform based approaches reported in the literature.

Keywords: Data compressions, Power quality, Slantlet transform, Wavlet transform, Percentage of Energy.

Introduction

The progress of utility deregulation and competition requires greater demand of power quality, increasing the need of more accurate study of power quality events. As a consequence, the events should be recorded at higher sample rates, thereby increasing the amount of data considerably. The volume of recorded data increases significantly, which leads to a high cost both in storing such data and the communication time from the field instruments to a central location for further study. Therefore, the capability of compressing the data volume is highly desirable. Hence, data compression operation for such data becomes an essential tool. For example, consider at least eight different signals to be recorded. If each signal is acquired at a rate of 200 samples per cycle, storing 5 cycles per minute are accounting for 14,40,000 samples per day and per variable which represents about 30 Mbytes per day for all the signals. In fact, at this rate of data storage requirement, a hard disk of 25 Giga bytes will be full of its capacity, after few months. Moreover, if a modem of 56kbps rate is used, it will take hours to communicate the information to the central location per day and per each substation.

In order to overcome these problems, several data compression methods have been used in different areas such as digital communication or image processing. A useful prerequisite for compression is that the data is analyzed by transform to extract feature information contained in the data and logic for removal of redundancy present in the extracted features before compression. In recent past, discrete wavelet transform are used for compression. Discrete wavelet transform application is usually carried out by filter bank iteration. However, for a fixed number of zero moments, DWT does not yield a discrete-time basis that is optimal with respect to time localization. The fundamental trade off exists between time localization and smoothness characteristics.

In the present work, new transform called slantlet transform (SLT) has been applied for compression of data pertaining to the power quality events. The slantlet transform is an orthogonal discrete wavelet transform and provides improved time localization than discrete cosine transform and discrete wavelet transform. In the application of wavelet bases to image compression, the time localization and the number of zero moments of the basis are both important. Good time localization properties lead to good representation of edges.

SLT Based Data Compression and Reconstruction

Transform methods have played an important role in signal and image processing applications. Recently, Selesnick [10] has constructed the new orthogonal discrete wavelet transform called Slantlet wavelet with two zero moments and with improved time localization.

The data compressions of power quality event signals are carried out in the present work using slantlet transform. To obtain a reasonably high compression ratio with low energy loss, a new integrated scheme of data compression using slantlet transform is adopted. A scheme of data compression and reconstruction using a two-scale slantlet transform filter bank is shown in Fig. 1. It involves three distinct steps, viz.

- Transformation of input signal using the slantlet transform.
- Thresholding of transformed coefficients.
- Reconstruction of the signal from the threshold coefficients.

The first two steps constitute compression operation, whereas the last step performs the reconstruction operation. The power quality disturbance signal is fed to the two-scale slantlet transform filter bank, where the outputs are down sampled by a factor of four. The transformed coefficients of the slantlet transform are H1(z), H2(z), H3(z) and H4(z) respectively. The slantlet transform retains most of its input signal energy in some selective coefficients and the magnitudes of the remaining coefficients are insignificant. Thus, by judiciously fixing the threshold level, a number of slantlet transform coefficients are discarded by setting them to zero. Keeping the quality of signal reconstruction in view, the threshold level is fixed.

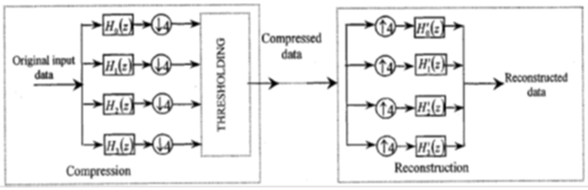

Fig. 1: Two-scale slantlet transform based scheme for data compression and reconstruction adopted in the present work

The remaining threshold coefficients represent the power quality disturbance signal in the compressed form. The retained coefficients are encoded to binary form, for storing and transmission purposes. From the compressed data the original power quality disturbance signal can be reconstructed using the two-scale slantlet transform synthesis filter bank whose transformed coefficients are H'1(z), H'2(z), H'3(z) and H'4(z) respectively. The synthesis filter coefficients are obtained by time reversal of the corresponding analysis filters.

In the reconstruction process, the compressed data are first up sampled by a factor four and then convolued with the synthesis filter coefficients of each channel. These synthesized data are then added together to reconstruct the original power quality signal for the purpose of further analysis and interpretation. Fig. 4 represents the computer procedure adopted in the present work for compressing data pertaining to a power quality event using slantlet transform method and subsequent reconstruction of the power quality signal. To assess the quality of compression, the energy retained in the reconstructed signal and mean square error (MSE) in decibels is used as the performance index. The compression ratio depends on the threshold value selected i.e., the total samples which are retained decides the compression ratio.

The energy retained by the reconstructed signal is defined as the ratio of vector norm of the compressed signal to the vector norm of original signal.

$$\text{Percentage of Energy Retained} = \frac{\textbf{vector norm of compressed data}}{\textbf{vector norm of original data}} \times \mathbf{100} \ldots\ldots(1)$$

The Mean Square Error (MSE) in decibels is defined as

$$\text{Mean Square Error (dB)} = \frac{1}{N}\mathbf{log_{10}} \sum_{i=1}^{N} ||x(i) - \hat{x}(\mathbf{i})||\mathbf{2} \ldots\ldots \ldots (2)$$

Where, x(i) and $\hat{x}$(i) are the original signal and the reconstructed signal. In the present work, a two-level slantlet transform filter bank is chosen considering both the complexity of computation and the quality of compression expected.

Compression ratio is defined as the ratio of original file size to the compressed file size and given by equation

$$\text{Compression Ratio} = \frac{\textbf{Original file size}}{\textbf{Compressed file size}} \ldots\ldots (3)$$

By choosing a different threshold value, a different compression ratio can be obtained. As the compression ratio increases the quality of signal i.e., the total energy retained in the signal get reduced. Similarly, as the compression ratio decreases, energy retained in the signal x ̃(i) increases.

Power Quality Events

Power quality (PQ) events can be referred to as any electrical disturbance, which adversely affect customer load or power system equipment. In the present work, power quality issues that are taken into account are Sine impulse, Voltage sag, Voltage swell, Momentary interruption, harmonically distorted signal, Oscillatory transient and Voltage flicker. Detailed discussions of these PQ events are elaborated in the sub-sections to follow:

Sine impulse

Sine impulse is impulsive transients that are due to lightning strikes. The sine impulse signal proposed in the literature [3] and obtained through simulation is shown in Fig. 2 and Fig. 3. Similarly in the next section other six power quality events signals are simulated in MATLAB as described in the literature [3].

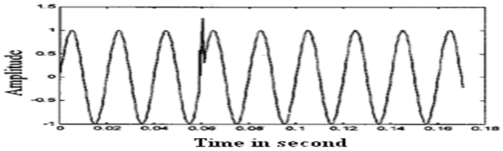

Fig. 2: A 50 Hz fundamental signal with an impulse presented in the literature [3]

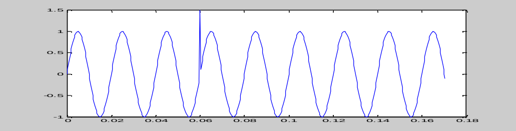

Fig. 3: A 50 Hz fundamental signal with an impulse obtained by MATLAB simulation in the present work

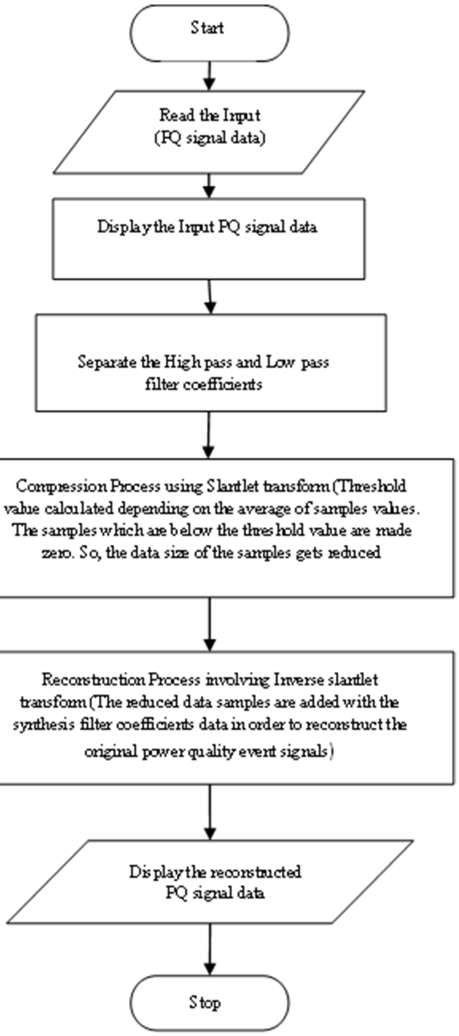

Fig. 4: Flowchart explaining computer procedure adopted for compressing data pertaining to a power quality event using slantlet transform method and subsequent reconstruction of the power quality signal

Voltage sag

Voltage sag is a sudden reduction (10–90%) in the voltage magnitude, lasting for 0.5 cycles to several seconds. Sag may be caused by switching operation associated with temporary disconnection of supply, flow of heavy current associated with the starting of large motor load or the flow of fault currents. The voltage sag signal obtained through simulation is shown in Fig. 5.

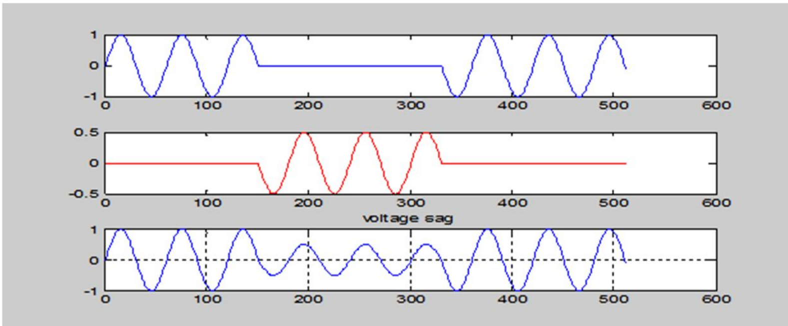

Fig. 5: A voltage sag signal (third signal) obtained by superposition of the first two signals upon MATLAB simulation

Voltage swell

When the voltage signal increases by 10%–90%, it is known as Voltage swell. They often appear on the sound phases of a power system where a phase-to-ground fault occurs or when heavy motor loads are switched off. The voltage swell signal obtained through *MATLAB* simulation is shown in Fig. 6.

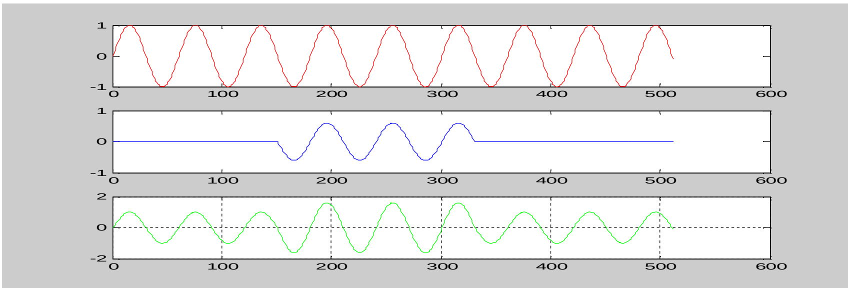

Fig. 6: A 50 Hz signal with voltage swell (third signal) obtained by superposition of the first two signals upon MATLAB simulation

Harmonically distorted signal

With the introduction of more power electronic equipment in distribution system, the power quality is further degraded, as they produce significant amount of different harmonics. The harmonic signal obtained through *MATLAB* simulation is shown in Fig. 7.

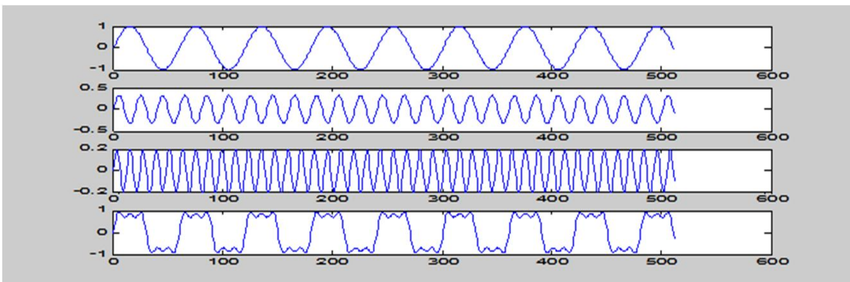

Fig. 7: A 50 Hz signal with harmonics (fourth signal) obtained by superposition of first three signals in MATLAB

Momentary interruption

Interruptions can be considered as voltage sags with 100% amplitude and are mainly due to short circuit faults being cleared by the protection. The momentary interruption signal obtained through *MATLAB* simulation is shown in Fig. 8.

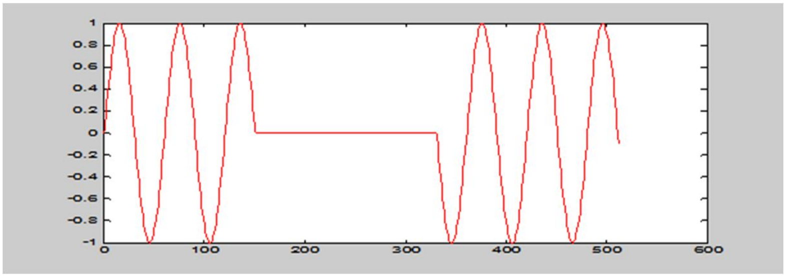

Fig. 8: A 50 Hz signal with momentary interruption obtained upon MATLAB simulation

Oscillatory transient

A transient disturbance waveform may have oscillatory characteristic and such signals are found during capacitor bank switching. The oscillatory transient signal obtained through *MATLAB* simulation is shown in Fig. 9.

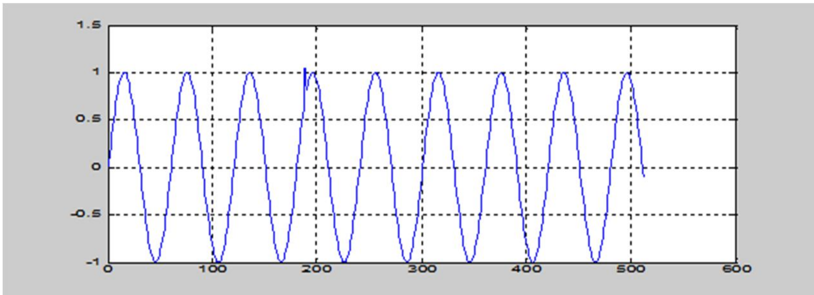

Fig. 9: A 50 Hz signal with oscillatory transient obtained by MATLAB simulation

Voltage flicker

Voltage flicker refers to slow (0.5 – 30Hz) modulation of the voltage magnitude. Cyclic and acyclic loads with temporal variation can cause voltage flicker. The harmonic signal obtained through *MATLAB* simulation is shown in Fig. 10.

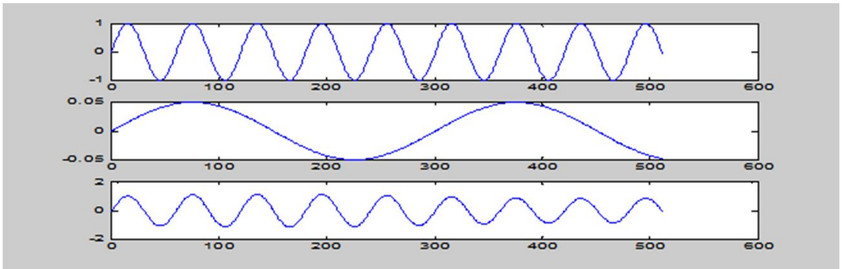

Fig. 10: A 50 Hz signal with voltage flicker (third signal) derived from the first two signals obtained by *MATLAB* simulation

Results and Discussions

In the present work, simulation experiments are performed on power quality data collected for events like Sine impulse, Voltage sag, Voltage swell, Oscillatory transient, Momentary interruption, Harmonically distorted signal and Voltage flicker. Compression ratio of 10 is considered for all power quality events from data communication and storage point of view [3]. The decomposed and reconstructed signal wave shapes arrived at for various PQ event cases. However, the results obtained in one such PQ event case i.e., Voltage swell case is stated and discussed in the sub-sections to follow:

Data analysis of 'Voltage swell' power quality event

Fig. 11 depicts the waveform of a voltage swell (80%) lasting for three cycles. The corresponding data are used for the decomposition and reconstruction using slantlet transform approach. From the *MATLAB* simulation results, it can be concluded that slantlet transform approach shows higher accuracy both in terms of energy retained and mean square error as compared to that of discrete cosine transform and discrete wavelet transform.

For example, at compression ratio equal to 10, the percentage of energy retained as obtained by the discrete cosine transform and discrete wavelet transform approaches quoted in the literature [3] are 89.46% and 91.01%, respectively. But, the slantlet transform approach based on *MATLAB* simulation of the present work gave 98.61% energy retainment. The mean square error for discrete cosine transform and discrete wavelet transform are -11.88 dB and -13.77 dB respectively [3]. The mean square error data for slantlet transform is as low as -19.69 dB (in the present work) as compared with the discrete cosine transform and discrete wavelet transform. From the discussions made on voltage swell data analysis, it can be concluded that slantlet transform offers superior data compression and reconstruction. Slantlet transform based approach of data compression technique is applied to power quality data related to Sine impulse, voltage sag, voltage swell, harmonics, interruption, oscillatory transient and flicker events. Input data are generated using *MATLAB* code.

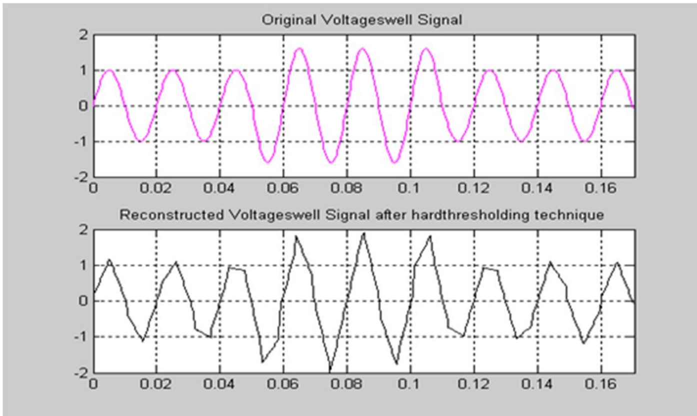

Fig. 11: Original voltage swell signal and reconstructed swell signal with compression ratio equal to10

For all simulation studies taken up, a pure sinusoidal signal of 50 Hz and 1 p.u. amplitude is considered, as adopted in the literature [3] to compare the performance of the Slantlet transform approach with the standard discrete cosine transform and the discrete wavelet transform based approaches reported in the literature. The energy retained and mean square error data are taken into consideration in reference to the literature [3] as performance indices. Percentage of energy retained and the mean square error in decibels are calculated for different type of power quality signals based on slantlet transform approach. With compression ratio equal to 10, the disturbance signals are reconstructed. The percentage of energy retained and mean square error values obtained (results of the present work) are listed in Table 1.

Table 1. Percentage Of Energy Retained And The Mean Square Error In Db Obtained Using The Discrete Cosine Transform, Discrete Wavelet Transform And Slantlet Transform Based Compression/Expansion Techniques For All The Signals At Cr = 10

Power quality events	Energy Retained (%)			MSE (dB)		
	DCT	DWT	SLT	DCT	DWT	SLT
Impulse	88.01	91.13	98.21	-10.67	-13.56	-20.48
Sag	87.81	90.01	98.78	-10.08	-13.04	-23.52
Swell	89.46	91.01	98.61	-11.88	-13.77	-19.69
Harmonics	87.69	90.89	98.03	-11.04	-13.31	-22.56
Momentary Interruption	90.44	91.10	98.70	-12.27	-15.89	-23.78
Oscillatory transient	91.63	90.88	98.11	-12.98	-14.45	-20.24
Voltage Flicker	90.75	91.34	98.75	-10.76	-14.74	-21.91

The values mentioned for discrete cosine transform and discrete wavelet transform cases are as available in the work reported in the literature [3], whereas the one quoted against slantlet transform approach is upon the present work using *MATLAB* simulation of slantlet transform based approach. Clearly the slantlet transform based approach is seen to be more effective.

Conclusion

In the present work, the slantlet transform has been successfully applied for compression of data pertaining to the power quality events. The slantlet transform is an orthogonal discrete wavelet transform and provides improved time localization than the discrete cosine transform and discrete wavelet transform. The performance of slantlet transform based approach is assessed through computer simulation and the results of the present work are compared with those of the discrete cosine transform and the discrete wavelet transforms approaches reported in the literature [3].

Important conclusions that are drawn out of the investigations in the present work are:

- Slantlet transform based compression of data results in better accuracy of the reconstructed signal in comparison to discrete cosine transform and the discrete wavelet transform methods of data compression and reconstruction.
- Better performance of the slantlet transform approach compared to the results presented in the literature [3], is analyzed to be because of the fact that the number of channels used for signal processing get altered with respect to signal length, in comparison to otherwise fixed number of channels.
- It is observed that by changing the threshold value, the compression ratio of the power quality data can be altered. From this, the amount of energy retained in the power quality signal can be altered with respect to consumer needs.
- It is shown that performance parameters such as the percentage of energy retained and the mean square error in decibels for different power quality signals can be used as parameters to successfully assess the accuracy of the reconstructed signal.
- Studies repeated for signals of different power quality events suggests that the slantlet transform based approach can be conveniently applied for signature signal patterns of any type of power quality event, as a novel technique for data compression and reconstruction.

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