

# Comparison of S-transform and Wavelet Transform in Power Quality Analysis

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**Abstract**— In the power quality analysis non-stationary nature of voltage distortions require some precise and powerful analytical techniques. The time-frequency representation (TFR) provides a powerful method for identification of the non-stationary of the signals. This paper investigates a comparative study on two techniques for analysis and visualization of voltage distortions with time-varying amplitudes. The techniques include the Discrete Wavelet Transform (DWT), and the S-Transform. Several power quality problems are analyzed using both the discrete wavelet transform and S-transform, showing clearly the advantage of the S-transform in detecting, localizing, and classifying the power quality problems.

**Keywords**— Power quality, S-Transform, Short Time Fourier Transform, Wavelet Transform, instantaneous sag, swell.

## I. INTRODUCTION

IN modern electrical energy systems, voltages and especially currents have become very irregular due to the large number of non-linear loads and generators on the grid, particularly power electronics-based systems such as adjustable speed drives, power supplies for IT-equipment and high efficiency lighting and inverters in systems generating electricity from renewable energy sources [1]. These voltage fluctuations drastically affect the quality of the energy distributed by electrical companies [2]. Voltage flicker causes annoying variations in the output illumination from lamps, deteriorates the performance of electric drives, leads to malfunction of protective relays, and disturbs other electric and electronic equipments that are sensitive to voltage fluctuations. This may lead to a great reduction in the life span of most equipment. Flicker envelope detection is a crucial task for assessing the flicker level and evaluating the flicker severity. It can be applied to control flicker mitigation devices or voltage regulators. Electric utility companies may have limits for an individual customer, such as a large fluctuating industrial load, due to the impact on the quality of power in the service to other customers [3]. Thus, an accurate method is required to measure the level of the flicker in the signal.

Many techniques have been proposed in the literature to detect the flicker envelope. The discrete Fourier transform

(DFT), which is computed via the fast Fourier transform (FFT), is used to extract the flicker content included in voltage waveforms [4]. However, the accuracy of the DFT algorithm is affected by the “leakage” effect that is a byproduct of the variations of the flicker level. Further pitfalls of the DFT are discussed in [5], which describes the digital filtering of the flicker waveform. The wavelet transform (WT) has been introduced as a powerful tool for voltage flicker signal extraction and harmonic detection [6]. The main disadvantage of the WT is its batch processing, which in turn, results in some delay. The S-transform [7], on the other hand, is an extension to the ideas of wavelet transform, and is based on a moving and scalable localizing Gaussian window and has characteristics superior to either of the transforms. The S-transform is fully convertible from the time domain to two-dimensional frequency translation domain and to then familiar Fourier frequency domain. The amplitude frequency-time spectrum and the phase-frequency-time spectrum are both useful in defining local spectral characteristics. The superior properties of the S-transform are due to the fact that the modulating sinusoids are fixed with respect to the time axis while the localizing scalable Gaussian window dilates and translates. As a result, the phase spectrum is absolute in the sense that it is always referred to the origin of the time axis, the fixed reference point. The real and imaginary spectrum can be localized independently with a resolution in time, corresponding to the basis function in question and the changes in the absolute phase of a constituent frequency can be followed along the time axis and useful information can be extracted. The phase correction of the wavelet transform in the form of S-transform can provide significant improvement in the detection and localization of power quality disturbance transients.

The rest of this paper is organized as follows. Section II gives a background on the wavelet and S-Transform techniques. Section III compares the performance of these two techniques on analyzing and visualizing synthetic data with time-varying waveform distortions. Section IV summarizes the advantages and disadvantages of these techniques.

## II. WAVELET AND S-TRANSFORM FOR POWER QUALITY ANALYSIS

### A. Discrete Wavelet Transform

A discrete wavelet transform (DWT) maps the time-domain

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signal of  $f(t)$  into a real-valued time-frequency domain and the signals are described by the wavelet coefficients. Suppose that a signal  $f(t)$  is already in the approximation space  $V_j$ , that is:

$$f(t) = \sum_{k \in \mathbb{Z}} a_k^j \varphi(2^j t - k) \in V_j \quad (1)$$

Then, the decomposition of this signal to the next level can be written as [7]

$$f(t) = \sum_{k \in \mathbb{Z}} a_k^{j-1} \varphi(2^{j-1} t - k) + \sum_{k \in \mathbb{Z}} d_k^{j-1} \psi(2^{j-1} t - k) \quad (2)$$

where the  $a_k^j$ 's are the approximation coefficients which represent the smoothed part of the signal, and the  $d_k^j$ 's are the detail coefficients.

A five-scale signal decomposition is performed to ensure that all disturbance features in both high and low frequencies are extracted. Thus, the output of the wavelet transform consists of five decomposed scale signals, with different levels of resolutions. The first scale signal has a frequency range of  $f/2 - f/4$ , where  $f$  is the sampling frequency of the time domain disturbance signal. The second, third, fourth, and fifth signals have frequency ranges of  $f/4 - f/8$ ,  $f/8 - f/16$ ,  $f/16 - f/32$  and  $f/32 - f/64$ , respectively. This wavelet transform is useful in detecting and extracting disturbance features of various types of electric power quality disturbances because it is sensitive to signal irregularities but insensitive to the regular signal behavior.

### B. Discrete S- Transform

The discrete S-transform is defined as follows. Let  $h[kT], k = 0, 1, \dots, N-1$  denote a discrete time series corresponding to  $h(t)$  with a time sampling interval of  $T$ . The discrete Fourier transform of  $h[kT]$  is obtained as

$$H\left[\frac{n}{NT}\right] = \frac{1}{N} \sum_{k=0}^{N-1} h[kT] e^{\frac{i2\pi nk}{N}} \quad (3)$$

where  $n = 0, 1, \dots, N-1$ . In the discrete case the S-transform [7,8,9], is the projection of the vector defined by time series  $h[kT]$  onto a spanning set of vectors. Spanning vectors are not orthogonal and elements of S-transform are not independent. Each basis vector is divided into  $N$  localized vectors by an element by element product with  $N$  shifted Gaussian windows. Using (3), S-transform of a discrete time series  $h[kT]$  is obtained by letting  $f$  tending to  $n/(NT)$  and  $\tau$  tending to  $jT$ . Thus discrete S-transform is given by:

$$S\left[jT, \frac{n}{NT}\right] = \sum_{m=0}^{N-1} H\left[\frac{m+n}{NT}\right] G(m, n) e^{\frac{i2\pi mj}{N}} \quad (4)$$

Where  $G(m, n) = e^{\frac{-2\pi^2 m^2 \alpha^2}{n^2}}$  and  $\alpha = 1/b, n \neq 0; n = 1, 2, 3, 4, \dots, N-1; j = m = 0, 1, 2, 3, 4, \dots, N-1; N =$  total number of samples. A typical value of  $b$  varies between 0.333 to 5, giving different resolutions. For low frequencies, a high value of  $b$  is chosen and for high frequencies, lower value of  $b$  is

chosen to provide suitable frequency resolutions. For  $n = 0$ , the S-transform assumes the form represented by :

$$S[jT, 0] = \frac{1}{N} \sum_{m=0}^{N-1} h\left[\frac{m}{NT}\right] \quad (5)$$

The amplitude of S-matrix is obtained from  $|S\left[jT, \frac{n}{NT}\right]|$ .

Eqn. (5) averages zero frequency components. The average of amplitude of S-matrix over time results in Fourier spectrum.

## III. SIMULATION RESULTS

Power quality analysis comprises of various kinds of electrical disturbances such as voltage sags, voltage swells, harmonic distortions, flickers, imbalances, oscillatory transients and momentary interruptions [1]. Using the time frequency localization property of the S-transform, the above power quality problems are analyzed and detected and the results of the S-transform are compared with obtained by using a daubechies 4 (db4) wavelet [3, 4] as mother wavelet performing first level of decomposition. In this section we have considered voltage sag, voltage swell and oscillatory transients based on the computer generated waveforms using MATLAB code. Frequency ( $f$ ) is normalized with respect to a base frequency. S-transform output shows plot of amplitude contours of a given magnitude in time-frequency coordinate system [9]. Wavelet outputs [10] are also shown for comparison with those outputs obtained from S-transform. Three cases studies using both S-transform as well as wavelet transform are presented below for comparison of results obtained from both cases.

### A. Instantaneous Voltage Sag:

In order to investigate the performance of the above mentioned techniques, a wavelet-based technique with parameters given in [10] is considered: Figure 1 shows signal contaminated with instantaneous sag and time-frequency plot of S-transform contours. It can be seen that S-transform contours have a magnitude reduction during the disturbance similar to that in case of a voltage sag in time domain, clearly detecting, localizing and classifying the disturbance. In comparison with results of the fifth level of db4 wavelet decomposition of signal contaminated with instantaneous sag given in [10] it is shown that although this version indicates presence of harmonics at different times, but can't be classified disturbances. S-transform generates contours which are suitable for classification by simple visual inspection, but in wavelet transform it is not possible directly.

### B. Instantaneous Voltage Swell

Figure 2 shows signal contaminated with instantaneous swell and time-frequency plot of S-transform contours. From the Figure 2, it is found that S-transform contours show an increased magnitude during disturbance similar to that in case of a voltage swell in time domain, clearly localizing, detecting and classifying the disturbance. If we apply wavelet technique

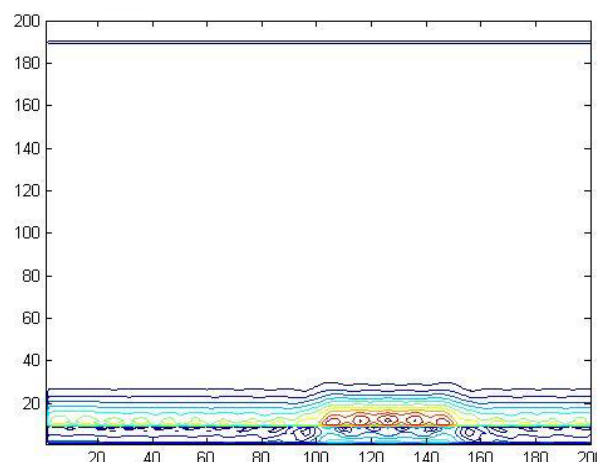
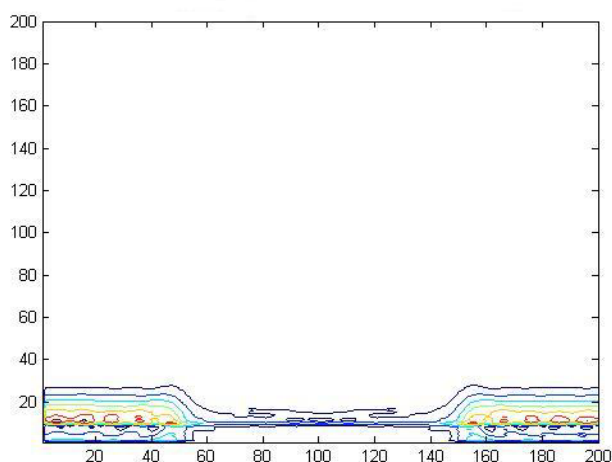
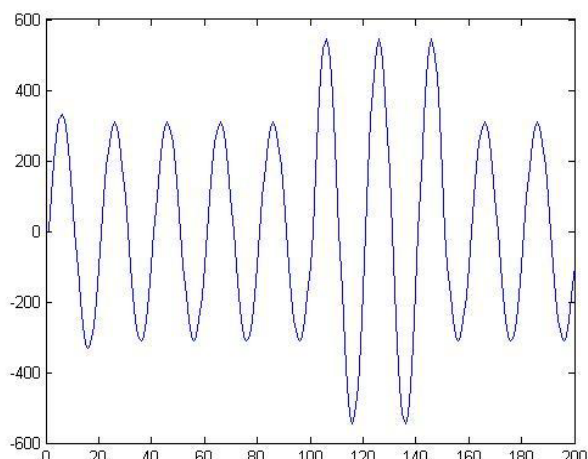
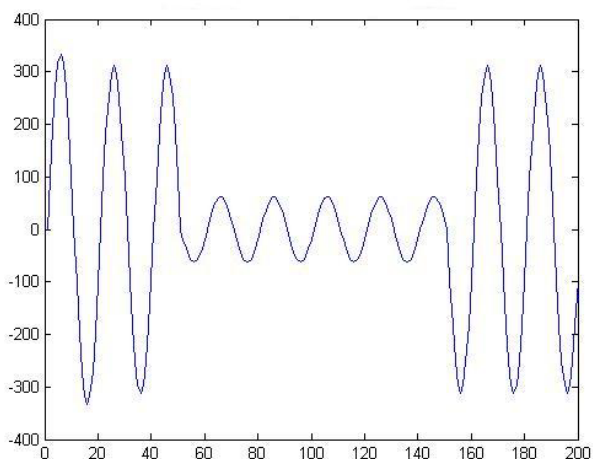


Figure 1: Signal contaminated with Instantaneous Sag and S- transform contours

Figure 2: Signal contaminated with Instantaneous Swell and S- transform contours

for the similar disturbance we will be able to detect swell disturbance as shown in [10]. Although the wavelet technique indicates presence of harmonics at different times, but can't be classified disturbances. S-transform generates contours which are suitable for classification by simple visual inspection.

### C. Frequency Variation

Figure 3 shows signal contaminated with frequency variation and time-frequency plot of S-transform contours. It can be seen from figure 3 that S-transform contours show an increased magnitude during disturbance similar to that in case of a frequency increment in time domain, clearly localizing, detecting and classifying the disturbance. The results of frequency variation distortion detection using wavelet technique is given in Figure 5 [10]. It compares with the Figure 3 it can be seen that although wavelet indicates presence of harmonics at different times, but it can not distinguish and classify this disturbance with sag and swell. S-transform generates contours which are suitable for classification by simple visual inspection

### IV. CONCLUSION

This paper investigates a comparative study on two techniques for analysis and visualization of voltage distortions with time-varying amplitudes. The techniques include the Discrete Wavelet Transform (DWT), and the S-Transform. Several power quality problems are analyzed using both the discrete wavelet transform and S-transform, showing clearly the advantage of the S-transform in detecting, localizing, and classifying the power quality problems.

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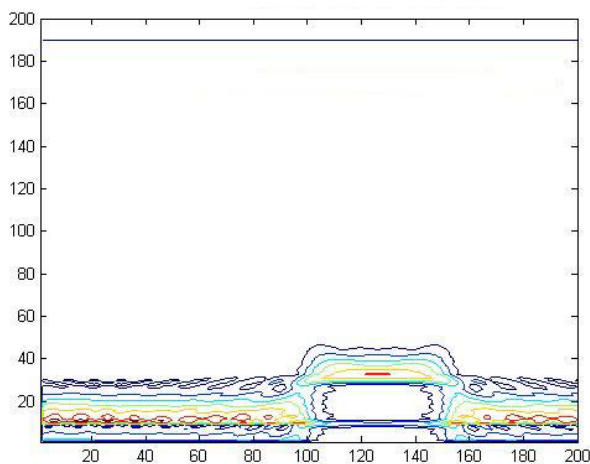
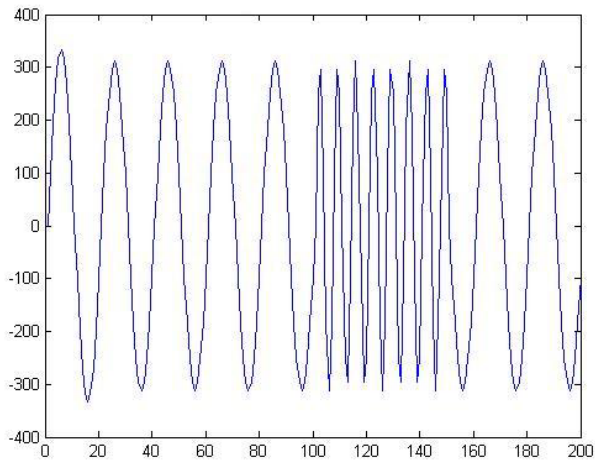


Figure 3: Signal contaminated with frequency Variation and S- transform contours

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