Identifying, Classifying Of Power Quality Disturbances Using Short Time Fourier Transform And S-Transform

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Abstract: Power Quality has become an important issue for electric utilities and the customers. Electronic devices are sensitive and can be easily disturbed by distortion like voltage sag, voltage swell, Interruptions etc. in the electrical power supply. Power quality analysis has been of utmost importance to experts which helps in determining any disturbances in the network and proposes if any fault is present in the system. Through effective power monitoring, system errors can be classified at an earlier stage and thus the safety and reliability can be improved. The most widely used Techniques are FFT, STFT. Due to some of disadvantages and for the sake of quick power quality monitoring advanced DSP technique Techniques (S-transform) are used and the analysis provide accurate and fast detection of power quality disturbances. This paper presents comparing the simulation results of STFT and S-transform and results that S-transform provides faster detection and is very flexible compared to STFT using IEEE data of 230kv substation [12].

Keywords: Power Quality, disturbance detection, Short Time Fourier Transform (STFT), S-transform (ST).

1. INTRODUCTION

POWER QUALITY PHENOMENON

An electrical power system is expected to deliver undistorted sinusoidal rated voltage and current continuously at rated frequency to the end users. Large penetration of power electronics based controllers and devices along with restructuring of the electric power industry and small-scale distributed generation have put more stringent demand on the quality of electric power supplied to the customers. Utilities treat PQ from the system reliability point of view. Equipment manufacturers, consider PQ as being that level of power supply allowing for proper operation of their equipment, whereas customers consider good PQ that ensures the continuous running of processes, operations, and business.

Today Power Quality has captured increasing concern in recent years and has led to the development of various types of Digital Signal Processing Techniques to perform fast and accurate detection of power quality disturbances. “Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment”[8].

Reliable and real-time monitoring of quality of electric power has become an important task in recent years and a major concern for
consumers, manufacturers and distributors of the electric power. Several methods for detection and classification of power quality (PQ) disturbances that occur in a power system. As far as the detection of transients and similar disturbances is concerned these methods usually rely on some time-frequency representation of the power system’s voltage signal such as the Fast Fourier Transform or the short time Fourier transform. The S-transform which is more flexible and has gained the reputation of being very effective and efficient signal analysis techniques.

2. POWER QUALITY DISTURBANCES
Types of power quality disturbances are

Voltage sag is a reduction of AC voltage at a given frequency for the duration of 0.5 cycles to 1 minute of time. Sag are usually caused by system faults, and result of switching on loads with heavy start-up currents.

Voltage swell is the reverse form of a sag, having an increase in AC voltage for a duration of 0.5 cycles to 1 minute of time. Swell are usually caused by high impedance neutral, sudden load.

 Interruption is defined as the complete loss of supply voltage or load current. Depending on its duration, an interruption is categorized as instantaneous, momentary, temporary or sustained.

Harmonics is defined as a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency usually 50Hz.

DC offset is the change in input voltage required to produce a zero output voltage when no signal is applied to an amplifier.

2.1 Drawbacks of Signal Processing (Transform) techniques used in PQ disturbances:
Various signal processing techniques used in power quality disturbances field are briefly discussed in following subsections.

1. There are number of transformations, among which the Fourier transforms are probably by far the most popular. If the FT of a signal in time domain is taken, the frequency-amplitude representation of that signal is obtained [1],[4]. This plot tells how much of each frequency exists in the signal. FT is a reversible transform. No frequency information is available in time-domain signal and no time information is available in Fourier transformed signal.

\[
X(f) = \int_{-\infty}^{\infty} x(t) \cdot e^{-j2\pi ft} dt --- (1)
\]

\[
x(t) = \int_{-\infty}^{\infty} X(f) \cdot e^{j2\pi ft} df --- (2)
\]

FT gives the spectral content of the signal, but it gives no information regarding where in time those spectral components appear. Fourier transform is not suitable if the signal has time varying frequency (Non-Stationary signals) because it just tells whether a certain frequency component exists or not.

2. A primary tool for the estimation of fundamental amplitude of a signal is the DFT (Discrete Fourier Transform) or its computationally efficient implementation called FFT (Fast Fourier Transform). FFT transforms the signal from time domain to the frequency domain. With this tool, it is possible to have an estimation of the fundamental amplitude and its harmonics with a reasonable approximation.

However, window dependency resolution is a disadvantage e.g. longer the sampling window better the frequency resolution. FFT performs well for estimation of periodic signals in stationary state; however it doesn’t perform well for detection of suddenly or fast changes in waveform e.g. transients, voltages dips or inter-harmonics [3]. In some cases, results of the estimation can be improved with windowing or filtering, e.g. hanning window, hamming window, low pass filter or high pass filter.

3. Finally, the STFT (Short Time Fourier Transform) is commonly known as a sliding window version of the FFT, which has shown
better results in terms of resolution and frequency selectivity.

3. SHORT TIME FOURIER TRANSFORM

The revised version of Fourier transform is short time Fourier transform. In STFT, the signal is divided into small enough segments, where these segments (portions) of the signal can be assumed to be stationary. For this purpose, a window function "w" is chosen. The width of this window must be equal to the segment of the signal where its stationary is valid.

This window function is first located to the very beginning of the signal. That is, the window function is located at t=0. Let's suppose that the width of the window is "T" s. At this time instant (t=0), the window function will overlap with the first T/2 seconds (I will assume that all time units are in seconds). The window function and the signal are then multiplied. By doing this, only the first T/2 seconds of the signal is being chosen, with the appropriate weighting of the window (if the window is a rectangle, with amplitude "1", then the product will be equal to the signal). Then this product is assumed to be just another signal, whose FT is to be taken.

The result of this transformation is the FT of the first T/2 seconds of the signal. If this portion of the signal is stationary, as it is assumed, then there will be no problem and the obtained result will be a true frequency representation of the first T/2 seconds of the signal.

The next step, would be shifting this window (for some t1 seconds) to a new location, multiplying with the signal, and taking the FT of the product. This procedure is followed, until the end of the signal is reached by shifting the window with "t1"(say) seconds intervals. The STFT defined as

$$STFT_{x}^{(w)}(t,f) = \int_{-\infty}^{\infty} [x(t) \cdot w(t - \tau)] \cdot e^{-2j\pi ft} \cdot dt$$

(3)

The width of this window must be equal to the segment of the signal where its stationary is valid. The disadvantage with STFT is width of window function is of finite length it covers only a few portion of the signal and it has no longer perfect frequency resolution(it has fixed resolution at all the time). S-transform overcomes the disadvantage of short time Fourier transform.

4. S-TRANSFORMS

The extension of Fourier transform and short time Fourier transform is the S-transform (ST) introduced by Stockwell and other scholars. A Key feature of the S-transform is that it uniquely combines a frequency dependent resolution of the time-frequency space and absolutely referenced local phase information [6]. It allows to define the meaning of phase in a local spectrum setting, and results in many desirable characteristics.

ST has been applied in classification of power quality disturbances and the results of ST of signals are analyzed by different time frequency analysis method to realize the classification and recognition of power quality disturbances.

Why S-transform?

S-transform uniquely combines progressive resolution with absolutely referenced phase information, which means that the phase information given by the S-transform is always referenced to time t=0, which is also true for the phase given by the Fourier transform. This is in contrast to a wavelet approach, where the phase of the wavelet transform is relative to the centre of analyzing wavelet. The unique feature of S-transform is it uniquely combines frequency resolution with absolutely reference phase, and therefore the time average the S-transform equals the Fourier spectrum [2]. The S-transform expression becomes

$$S(\tau,f) = \int_{-\infty}^{\infty} x(t) \cdot \frac{f}{\sqrt{2\pi}} \cdot e^{-j \cdot \frac{(t-\tau)^2}{2}} \cdot e^{-j2\pi ft} \cdot dt.$$  

(4)

where f is the frequency, t and \tau, are both time. The normalizing factor of f / 2\pi in (1) ensures that, when integrated over all \tau, S (\tau, f)
converges to $X(f)$, the Fourier transform of $x(t)$.

$$\tilde{S}(\tau, f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt = X(f)$$

(5)

Therefore, S-transform is invertible. In this improved ST scheme the window function has been considered as the same Gaussian window but, an additional parameter $\delta$ is introduced into the Gaussian window where its width varies with frequency as follows

$$\sigma(t) = \frac{\delta}{|t|}$$

(6)

The generalized ST becomes

$$S(\tau, f, \delta) = \int_{-\infty}^{\infty} x(t) \frac{|t|}{\sqrt{2\pi\delta}} e^{-\frac{(t-\tau)^2}{2\delta^2}} e^{-j2\pi ft} dt$$

(7)

The adjustable parameter $\delta$ represents the number of periods of Fourier sinusoid that are contained within one standard deviation of the Gaussian window. If $\delta$ is too small the Gaussian window retains very few cycles of the sinusoid. Hence the frequency resolution degrades at higher frequencies. If $\delta$ is too high the window retains more sinusoids within it. As a result the time resolution degrades at lower frequencies. It indicates that the $\delta$ value should be varied judiciously so that it would give better energy distribution in the time-frequency plane.

A spectrogram, or sonogram, is a visual representation of the spectrum of frequencies. Spectrograms are usually created in one of two ways: approximated as a filter bank that results from a series of band pass filters, or calculated from the time signal using the short-time Fourier transform (STFT). These two methods actually form two different Time-Frequency Distributions, but are equivalent under some conditions. S-transform using spectrogram analysis provides better visual analyzation of the signal.

5. SIMULATION RESULTS

The power quality disturbances like Voltage sag, voltage swell, Momentary interruption, harmonics, and DC offset has been analyzed with the IEEE data of 230kv substation[12] using two techniques i.e., short time Fourier transform and S-transform. The Comparison simulation results are as shown in below Fig:1, 2, 3, 4, 5.
The simulation results of power quality disturbances like Voltage sag, voltage swell, Momentary interruption, harmonics, and DC offset using S-Transform is as shown in below Fig: 6, 7, 8, 9, 10.
6. CONCLUSION

In this paper the comparison of short time Fourier transform and S-transform is done. The power quality disturbances like voltage sag, voltage swell, momentary interruption, harmonics and Dc offset are identified and classified. Short time Fourier transform is better of analyzing power quality signals for fixed window lengths. S-transform uniquely provides frequency resolution while maintaining a direct relationship with the Fourier spectrum and provides accurate results of analyzing power quality signals for variable window lengths.

It can be extended to classify the disturbances Using Adaptive neuro fuzzy inference system (ANFIS), provides faster results than with DSP techniques and is very easier.

7. REFERENCES

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