Short Time Fourier Transform for Power Disturbances Analysis

Mitko Kostov[1], Blagoj Gegov, Metodija Atanasovski and Mile Petkovski

Abstract – **The Short-Time Fourier transform is described as a detection method of power supply disturbances. Compared to the standard Fourier transform, it provides time data in frequency domain. The most common power disturbances are listed and three simulation models are analyzed to describe the advantages and drawbacks of the Short-Time Fourier transform.**

Keywords – **Power disturbances, Short-Time Fourier Transform, LabVIEW, Simulink.**

I. Introduction

Power systems are susceptible to numerous disturbances. Appropriate analysis is needed in order to describe when the disturbances appear and what their intensity is. One possibility is to detect them in the frequency domain. Effective detection and removal of such disturbances is essential to the proper functioning of power systems.

Fourier transform is the most commonly used mathematical tool that transforms the signal from time-domain to frequency-domain [1]. The problem arises when time data is needed in the frequency-domain. In time-domain frequency information cannot be obtained and vice-versa, in frequency-domain time data is not available.

One solution to this issue is the Short-Time Fourier transform [2]. The method consists of sliding a window function over the signal and taking its Fourier transform for every half window length. This way the time information is available in frequency-domain with a resolution that depends on the width of the window function.

Other methods include using the discrete wavelet transform (DWT) for detection of power disturbances [3-6]. This offers improved time and frequency resolution with multiple levels of decomposition of the signal.

This paper considers classification of power disturbances and an analysis and practical implementation of the Short-Time Fourier transform for their detection. The paper is organized as follows. After the introduction, the Short-Time Fourier Transform is summarized in Section 2. Section 3 classifies power disturbances. Matlab Simulink models that simulate two types of power disturbances are presented in Section 4. Section 5 concludes the paper.

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II. Fourier transform

The Fourier transform (FT) is the most commonly used tool for analyzing signals in frequency-domain. It is described with the following integral:

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt,\ \omega \in (-\infty, \infty) \quad (1)$$

The result of the Fourier transform of a signal represents its frequency spectrum as illustrated in Fig. 1.

It is easily noticeable that the base frequency of the signal is detected accurately and it is equal to 50Hz. But, if the frequency of the signal is not of the interest, but rather the time when the interruption occurs in the signal, Fourier transform does not provide any time-data in frequency domain; hence it is not possible to know when the interruption occurred.

III. Short-Time Fourier transform

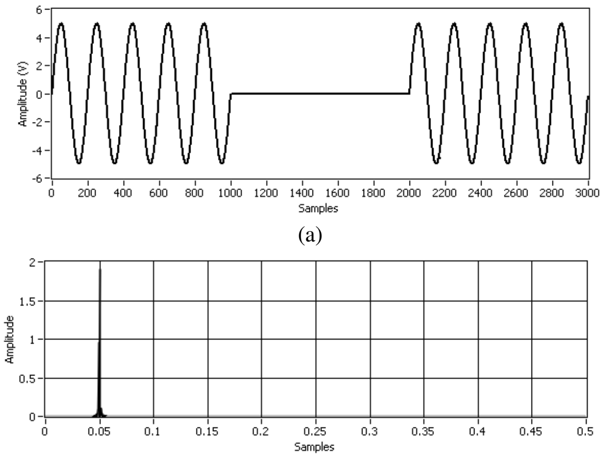
The Short-Time Fourier Transform (STFT) was developed as a solution to the lack of time data in frequency-domain. A signal can be considered stationary in a given time interval. Then the signal can be divided in an n-number of stationary parts. Fourier transform can be performed to each of these stationary parts. Depending on their width; certain phenomena that appear in them can be localized with a certain time or frequency resolution.

The procedure for performing STFT is as follows: the window function is set in *t*=0 and it is multiplied with the signal. Every value outside the window will have a value of 0. The FT of the product of the signal and the window function is calculated. The result is the FT of the part of the signal that is covered by the window. After that the window is moved by *t*' seconds and the procedure is repeated until the end of the signal is reached.

Mathematically, STFT is described with the following expression:

$$STFT_x^{(\omega)}(t,f) = \int [f(t) * \omega_p^*(t-t')e^{-j2\pi ft}dt \quad (2)$$

where $STFT_x^{(\omega)}$ denotes the Short-Time Fourier transform of the signal, $f(t)$ is the analyzed signal, ω_p is the window function (usually a symmetric function that has a non-zero value during a short time interval) and t' denotes the translation along the time axis.



(a)

(b)

Fig. 1. Signal with interruption and its FT.

The resolution of the analysis depends on the width of the window function. A wide window provides good frequency and bad time resolution. A narrow window provides good time and bad frequency resolution.

Fig. 2 illustrates the Short-Time Fourier Transform of the signal in Fig. 1.

Now, it is clearly visible that the interruption occurs around the 1000th sample and stops approximately at the 2000th sample of the signal. The issue now is that the base frequency of the signal is not clearly visible because of the narrow width of the window. Here a compromise is made in order to detect the moment of occurrence of the disturbance more accurately at the expense of the frequency resolution.

IV. Classification of Power Disturbances

Power quality disturbances can be divided into seven categories based on wave shape: Transients, Interruptions, Sag/Undervoltage, Swell/Overvoltage, Waveform distortion, Voltage fluctuations, and Frequency variations [7].

Potentially the most damaging type of power disturbance, transients fall into two subcategories: Impulsive and Oscillatory. Impulsive transients are sudden high peak events that raise the voltage and/or current levels in either a positive or a negative direction. An oscillatory transient is a sudden change in the steady-state condition of a signal's voltage, current, or both, at both the positive and negative signal limits, oscillating at the natural system frequency.

An interruption as power disturbance 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.

Sag/Undervoltage (Swell/Overvoltage) is reduction (increase) of AC voltage.

Waveform distortion is defined as a steady-state deviation from an ideal sine wave of line frequency principally characterized by the spectral content of the deviation. There are generally five types of waveform distortion - DC offset, harmonics, interharmonics, notching and noise. *DC offset* is the

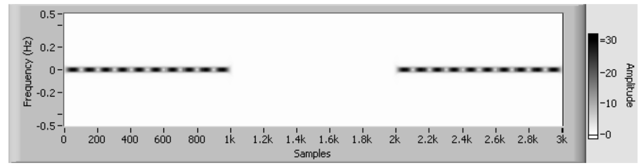


Fig. 2. Short-Time Fourier transform of the signal with an interruption.

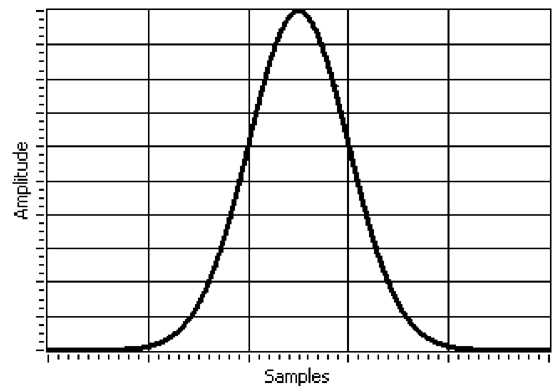


Fig. 3. Gaussian window function.

presence of a DC current or voltage in an AC power system. A *harmonic* is defined as a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. *Interharmonics* are defined as voltages or currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate. *Notching* is a periodic voltage disturbance caused by normal operation of power electronics devices when current is commutated from one phase to another. *Noise* is unwanted distortion of the electrical power signals with high frequency waveform superimposed on the fundamental.

A *voltage fluctuation* is a systematic variation of the voltage waveform or a series of random voltage changes, of small dimensions. *Frequency variation* is extremely rare in stable utility power systems.

V. Simulations and Analysis in Frequency Domain

Power disturbances can be localized using the Short-Time Fourier Transform. The resolution that they can be localized with depends on the width and the type of the window function.

Three Matlab/Simulink models are presented. The Short-Time Fourier Transform of the outputs of the simulations is performed using NI LabVIEW, using a Gauss window function (Fig. 3). The window function is described with the following expression

$$\omega(n) = e^{-\frac{1}{2}\left(\frac{n-(N-1)/2}{\sigma(N-1)/2}\right)^2};\ \sigma \leq 0.5 \qquad (3)$$

where N represents the width of the window in samples and σ is the time step. In the analysis the width of the window is constant and is equal to 100 samples. The time step is set to -1

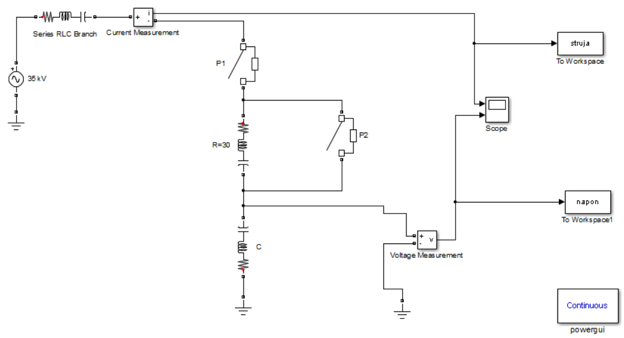
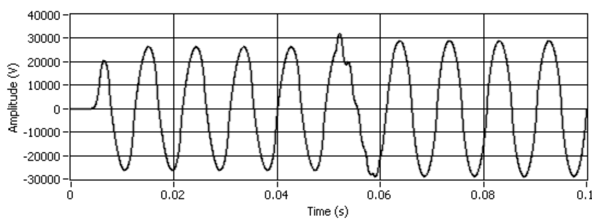


Fig. 4. Simulink model 1.



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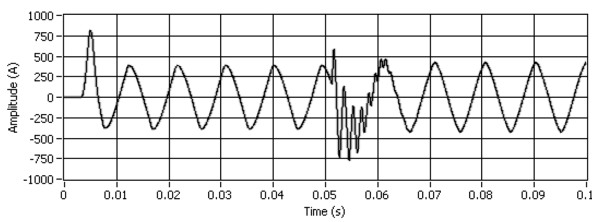


(b)

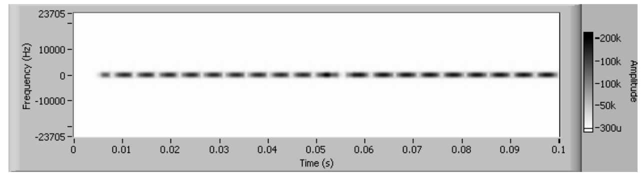
Fig. 5. Voltage and current for the Simulink model 1.

which means that LabVIEW decides which setting is best for the analyzed signal.

A.Simulation model 1

Fig. 4 illustrates a Matlab Simulink model that simulates tranzient-oscilatory power disturbance. It contains three serial connected RLC branches with parameters: 1) $R = 0.808\Omega$, $L = 2.6mH$, 2) $R = 30\Omega$, 3) $C = 46.8mF$. The simulation duration is $0.2s$. The voltage in the third branch and the current in the circuit are measured. The switch P_1 turns on at the moment t=$0.02s$. The voltage and current have proper sinusoidal shape until the moment t=$0.12s$ when the switch P_2 turns on. Switching on of P_2 spoils the proper shape of the voltage and current for certain period, and after that the disturbances are weakened and the signals are stabilized, as it is illustrated in Fig. 5.

The moments when the switches P_1 and P_2 are turned on are not visibly detected by the Short-Time Fourier Transform (Fig. 4). The analysis for the current signal (Fig. 4b) provides better insight about the disturbance. The moments when the switches are closed is better visible. If we reduce the window width, the time resolution will improve, but the basic signal frequency will be indistinguishable.



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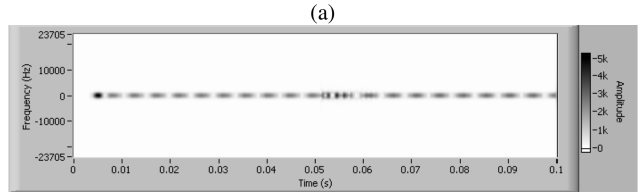


(b)

Fig. 6. STFT of (a) voltage and (b) current for the Simulink model 1.

B.Simulation model 2

The second Matlab Simulink model, shown in Fig. 7, simulates interruption in power supply (interruption power disturbance). It contains two serial connected RLC branches with parameters: 1) $R = 0.25\Omega$, $L = 15.8mH$ и 2) $C = 11mF$. The simulation duration is 1s. The voltage of the second branch is measured. The switch P turns on at the moment $t = 35ms$, hence the second RLC branch is short-circuited and this could corresponds to an interruption in the power supply. The switch turns off at the moment $t = 253ms$. Because of the reactive elements in the system, oscillations appear and then weackens after certain time. The voltage is shown in Fig. 8.

Using the Short-Time Fourier Transform the disturbance can be detected with a satisfactory time resolution (Fig. 9). The moment when the switch is turned on is described by coefficients with a high frequency and low amplitude. After the switch is turned off, the oscillatory transient disturbance that appears is illustrated by the decaying high frequency coefficients.

C.Simulation model 3

Fig. 10 illustrates a part of an electrical power transmition system. The simulation duration is $0.1s$. The voltages of two lines V_a and V_b are measured. The switches P_1 and P_2 turn on at the moment $t = 4ms$. At the beginning the voltages have big oscillations which later weaken, and eventually the voltages obtain proper sinusoidal shape. This condition last until the switches turn off at the moment $t = 80ms$. The waveforms of the voltages U_a and U_b are given in Fig. 11.

The Short-Time Fourier transform of the voltages U_a and U_b in Fig. 12 illustrates that the moment when both switches are turned on. Again, the resolution is not perfect and the moment is illustrated with coefficients with a low amplitude and high friequency (better visible at the analysis of the signal for U_b). The oscillatory transient disturbance then decays over time until it disappears completely.

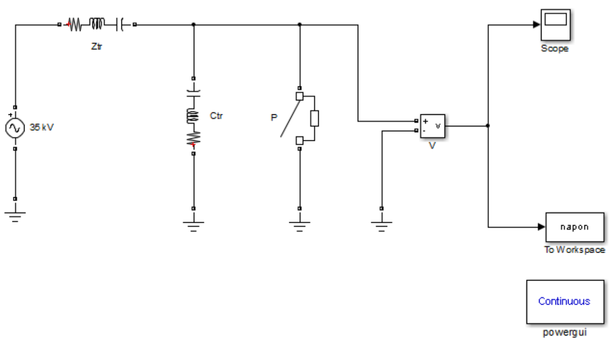


Fig. 7. Simulink model 2.

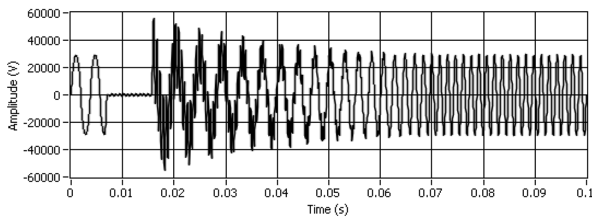


Fig. 8. Voltage for the Simulink model 2.

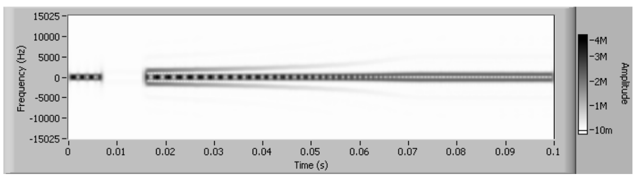


Fig. 9. STFT of the voltage for the Simulink model 2.

VI. Conclusion

The detection of power disturbances is essential towards their efficient removal. This ensures proper functioning of the power system and helps avoid workplace accidents.

STFT can be used to detect power disturbances with a somewhat satisfactory time resolution. We can never obtain a perfect solution, due to the fixed width of the window function. The ideal result would present a compromise between the time and frequency resolution.

An improvement to this method would be the discrete wavelet transform [1]. It possesses an improved resolution, due to the decomposition of the signal in different levels with different wavelet widths. Compared to the discrete wavelet transform, STFT provides better results when analyzing harmonic disturbances.

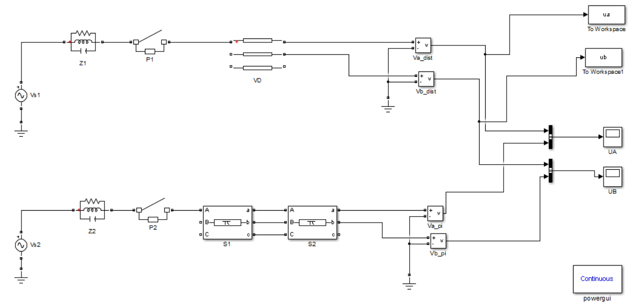
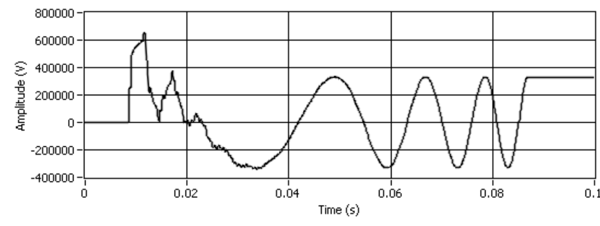


Fig. 10. Simulink model 3.



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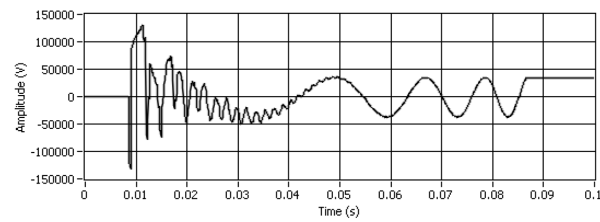

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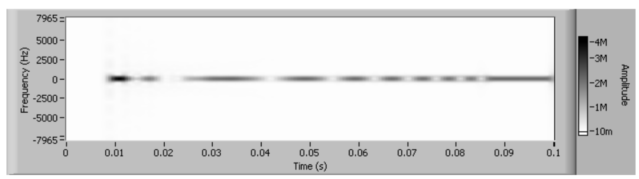
Fig. 11. Voltages U_a and U_b for the Simulink model 3.



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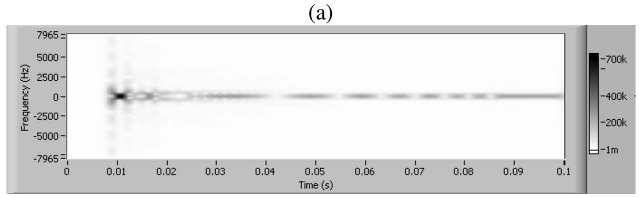

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Fig. 12. STFT of the voltages for the Simulink model 3.

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