Power Disturbances Simulation and Analysis in Wavelet Domain

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Abstract – **The paper discusses the wavelet transform as a tool for detection of power disturbances. On contrary of Fourier transform, wavelet transform provides both time and frequency localization. Compared to short-time Fourier transform, wavelets provide better frequency localization.**

Keywords – **Power disturbances, Wavelets, Simulink.**

I. Introduction

Nowadays, technology is largely dependent on the continous availability of electrical energy. In automated processes it is possible entire production lines to fail which would create dangerous situations for employees and large loss of material. In software systems, data damage due to power interruption can create problems, too. Detection of disturbances in electricity supply is an essential step in removing or limiting their harmful impact.

Wavelet transform is a powerful tool for detecting disturbances. It has received significant attention recently from mathematicians, signal analysts and engineers as a promising tool for feature extraction, signal and image compression, edge detection and denoising. Unlike the traditional Fourier techniques, wavelets are localized both in time and frequency domain. This feature makes them suitable for the analysis of nonstationary signals.

This paper considers classification of power disturbances and an analysis and practical implementation of the wavelet transform for their detection. The paper is organized as follows. After the introduction, the wavelet theory 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.

II. Wavelet Transform

The wavelet transform performs an analysis by representing signals in terms of a basis of functions localized in both space and frequency domain. It decomposes the signal into a set of orthogonal components describing the signal variation across the scale [1]. The orthogonal components are generated by dilations and translations of a prototype function ϕ, called mother wavelet.

In analogy with other function expansions, a function f is presented for each discrete coordinate t as a sum of a wavelet expansion up to certain scale J plus a residual term, that is:

$$f(t) = \sum_{j=1}^{J} \sum_{k=1}^{2^{-j}M} d_{jk}\psi_{jk}(t) + \sum_{k=1}^{2^{-J}M} a_{Jk}\phi_{Jk}(t) \qquad (1)$$

where Ψ_{jk} and Φ_{Jk} denote wavelet and scaling function, respectively, the indexes j and k are for dilatation and translation, and a_{Jk} and d_{jk} are approximation and detail coefficients. The approximation coefficients aJk contain the signal identity while the detail coefficients djk can be processed for the purposes of denoising, compression, edge detection, etc.

III. 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 [2].

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. These types of power disturbances are illustrated in Figs. 1a and b.

An interruption as power disturbance is defined as the complete loss of supply voltage or load current (Fig. 1c). Depending on its duration, an interruption is categorized as instantaneous, momentary, temporary, or sustained.

Sag/Undervoltage (Swell/Overvoltage) is reduction (increase) of AC voltage (Fig. 1d).

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 presence of a DC current or voltage in an AC power system (Fig. 1e). 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

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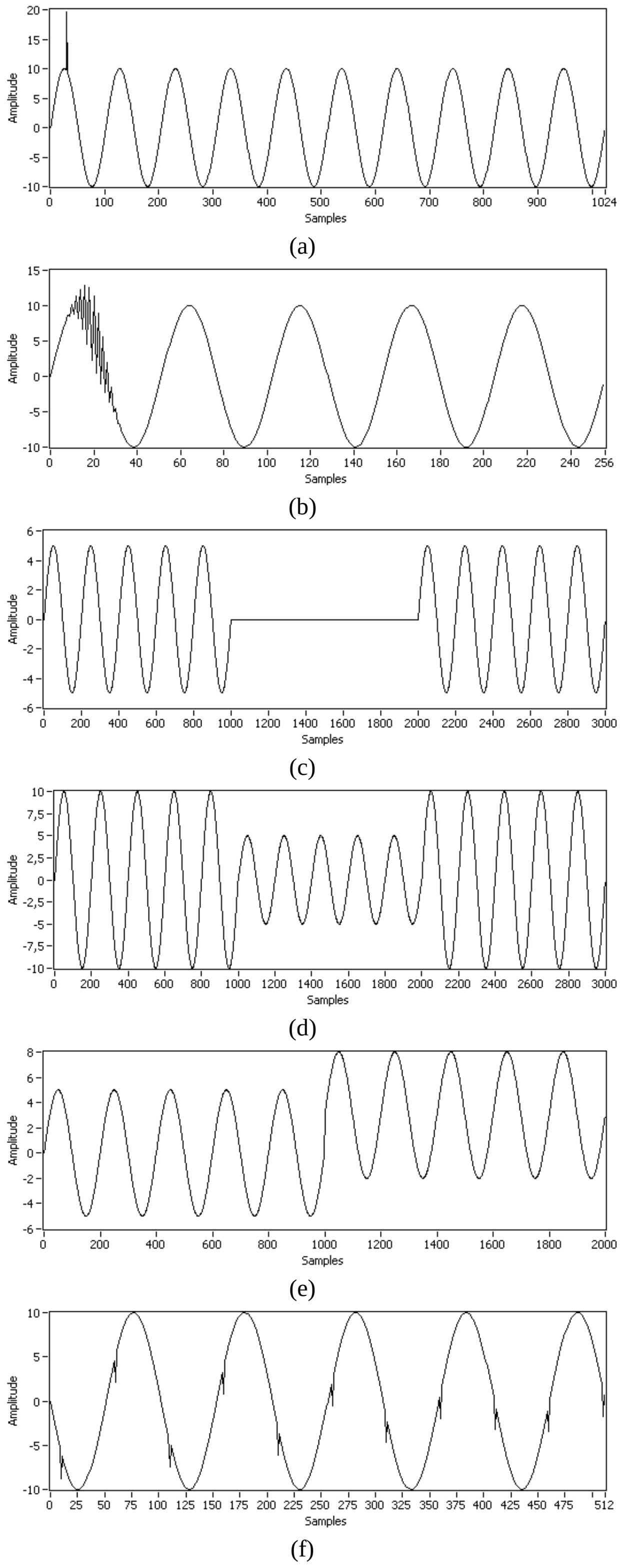


Fig. 1. Power disturbances: (a) Impulsive; (b) Oscillatory; (c) Interruption; (d) Sag; (e) DC offset; (f) Notching.

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 (Fig. 1f). *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.

Some of the above mentioned types of power disturbances are illustrated in Fig. 1.

IV. Simulations and Analysis in Frequency Domain

Basic tool for analysis of the frequency spectrum of a signal is the Fourier transform. But, the Fourier transform is appropriate for stationary signals, while for non-stationary signals time information for the changes is lost.

This drawback is overcomed with the wavelet transform, which enables good localization both in frequency and time. Hence, the power disturbances can be detected on the basis of change of the wavelet coefficients. Further, in this Section, three models that simulate tranzient-oscilatory and interruption power disturbances are shown. Signals are anylized by wavelet decomposition in six levels with db4 wavelet.

A.Simulation model 1

Fig. 2 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. 3.

Both moments of turning the switches P_1 and P_2 on are detected by discrete wavelet transform (DWT) (Fig. 4). At the beginning, the detail coefficients have small values until the moment of turning the switch P_1 on, when the coefficients rapidly increase their values. The moment of turning the switch on can be determined precisely from detail coefficients d_1, because the time precision is highest for this level. Next, the coefficients have small values again because the voltage and current have proper sinusoidal shape. The moment of turning the switch P_2 on implies new change of the values of the detail coefficients. After signals stabilize, the coefficients have small values again, which means there are no power disturbance anymore.

B.Simulation model 2

The second Matlab Simulink model, shown in Fig. 5, 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

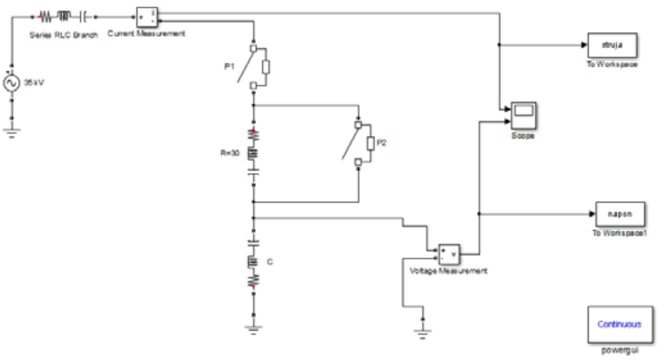
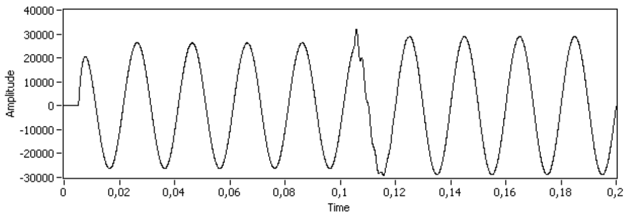
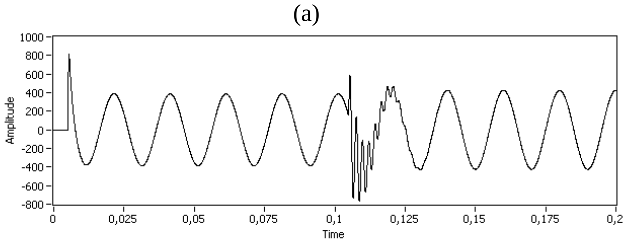


Fig. 2. Simulink model 1.



(a)



(b)

Fig. 3. Voltage and current for the Simulink model 1.

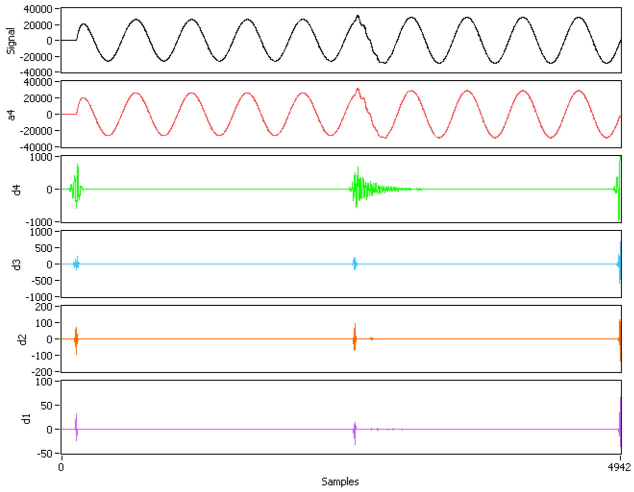
branch is measured. The switch P turns on at the moment $t = 35ms$, hence the second RLC branch is short-circuited and this could corresponds to an interruption in the power supply. The switch turns off at the moment $t = 253ms$. Because of the reactive elements in the system, oscillations appear and then weackens after certain time. The voltage is shown in Fig. 6.

By applying discrete wavelet transform, as it is illustrated in Fig. 7, the moments of turning on and off of the switch can be determined. The rapid changes in the magnitudes of coefficients d_1, d_2 and d_3 determine the moment of turning the switch on. The voltage has proper sinusoidal shape until that moment, and after that its magnitude decreases, and as a result the detail coefficients have big values. After switching P off, the wavelet coefficients have big values again and later decrease as the oscillations weaken.

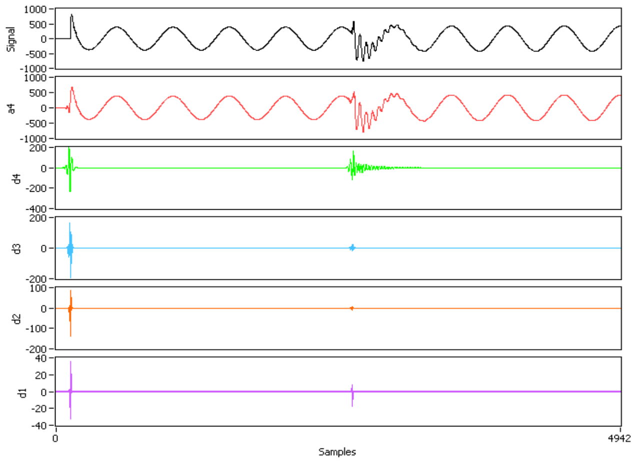
C.Simulation model 3

Fig. 8 illustrates a part of an electrical power transmition system. The simulation duration is 0.1*s*. 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. 9.

Discrete wavelet transforms of the voltages U_a and U_b are given in Fig. 10. The moment when both switches turn on is



(a)



(b)

Fig. 4. DWT of (a) voltage and (b) current from Simulink model 1.

determined from the detail coefficients d_1. After the oscillations are weakened, the detail coefficients again have small values.

V. Conclusion

Detecting power disturbances is a fundamental step in removing or limiting their harmful impact. This contributes to extending the life of electrical devices, improving their work and increasing the safety of persons handling these devices.

Wavelet transform is a powerful tool for detecting disturbances. The improved precision due to the variable resolution for different decomposition levels makes the wavelet transform more suitable for use compared to other types of transformations with fixed resolution, such as short-time Fourier transformation.

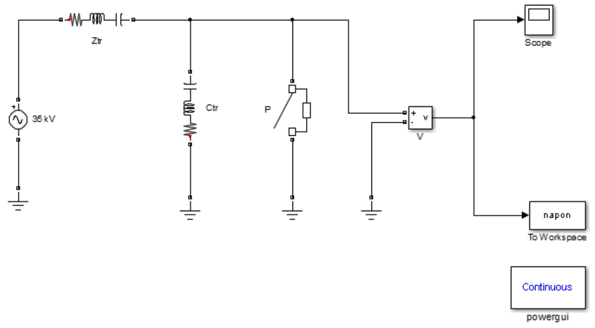


Fig. 5. Simulink model 2.

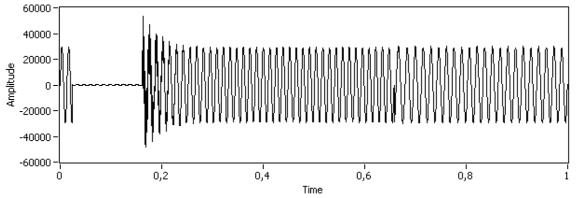


Fig. 6. Voltage for the Simulink model 2.

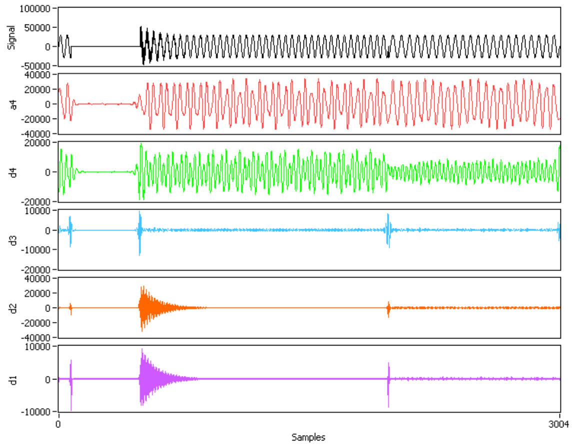


Fig. 7. DWT of the voltage from Simulink model 2.

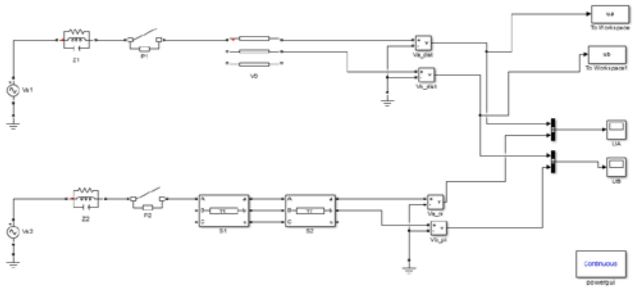
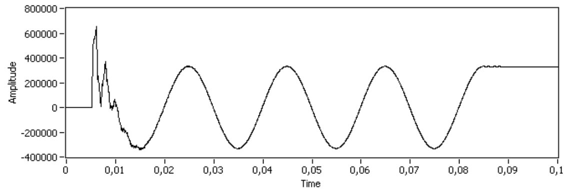
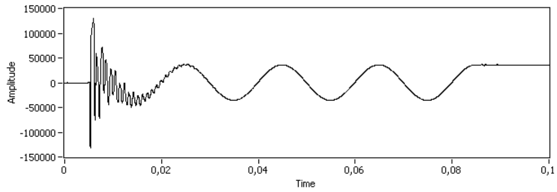


Fig. 8. Simulink model 3.

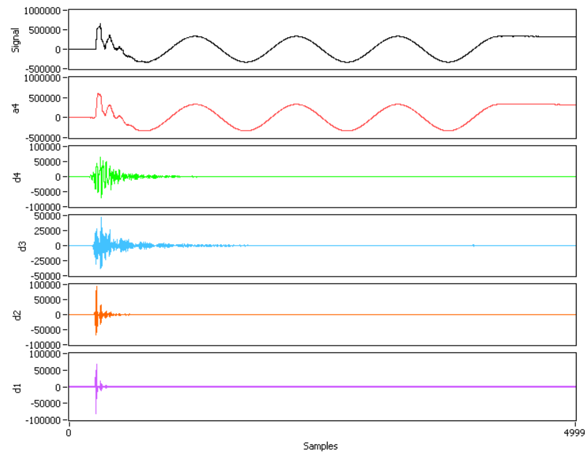


(a)



(b)

Fig. 9. Voltages U_a and U_b for the Simulink model 3



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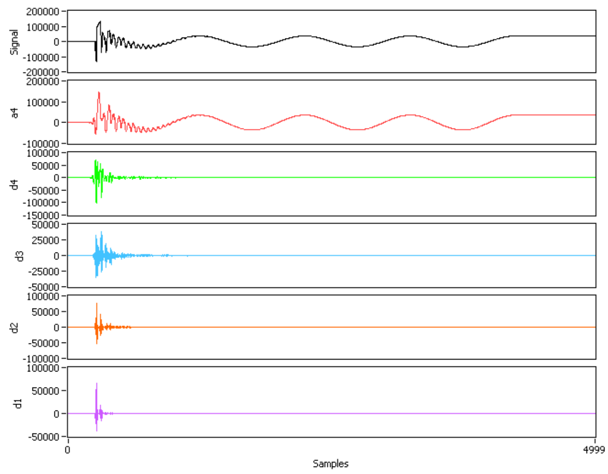

(b)

Fig. 10. DWT of the voltages U_a and U_b from Simulink model 3

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