Real-time detection of transient disturbances in electric power network

Krzysztof Duda, Andrzej Bień

Department of Measurement and Instrumentation, AGH University of Science and Technology
al. Mickiewicza 30, 30-059 Kraków (Poland) (Europe)
phone: +48 12 6173972, fax: +48 12 6338565, email: [kduda, abien]@uci.agh.edu.pl

Abstract- In this paper we present real-time application for detecting, extracting and automatic classification of transient disturbances in electric power network. Proposed method was implemented on Texas Instruments C6713 DSK toolkit and tested with both laboratory-generated and real-world power network signals with good results. For each detected transient a set of parameters is evaluated including the time of occurrence, duration time, energy and frequency spectrum. Classification of disturbance can relay on arbitrary combination of those parameters (e.g. one can be interested in finding disturbances with sufficiently high energy and specified duration time). The presented implementation was design to be a part of complex system for Power Quality (PQ) monitoring.

I. Introduction

Transient disturbances in power network can be the cause of electric insulation breakdowns and electrical equipment malfunctioning, they can also shorten expected lifetime of electrical equipment. Thus transients are important factor of the PQ for both energy producers and consumers. Duration time of transients is significantly shorter then the main frequency time period in electric power network (20 ms in Europe). Transient disturbances can be impulsive or oscillatory with frequency content typically higher than 500 Hz.

Monitoring and analysis of transients is the topic for many researchers (e.g. [1-9] and others). The solutions for transient detection presented in literature relays both on analog and digital algorithms. Many signal processing techniques including time and frequency domain analysis are applied for detection of transients (e.g. wavelet analysis, artificial intelligence, fractal geometry and others). For real-time implementation low-complexity algorithms are strongly preferable among others. Examples of such solutions are presented in [8-9]. In [8] algorithm for detection of transients that works in time domain is proposed. The main idea is dividing signal into segments (snapshots) and checking the regularity index for each segment. The regularity index is computed for multiple of the signal period and thus demands additional estimation of signal frequency (which may wader). Another algorithm based on processing in time domain is described in [9]. It relays on comparing corresponding samples in present and previous cycle of fundamental frequency. If the difference exceeds proper threshold the transient is detected. Synchronization with fundamental frequency is the main factor of reliability of this method.

Our algorithm presented in this paper works in frequency domain. It takes advantage from the fact that frequency content of the disturbance can be distinguished from 50 Hz component with highpass filter. Such processing is similar to so popular wavelet decomposition where highpass half-band filter is used for decomposing signal to detail coefficients. Wavelet filters are FIR and the selectivity of theirs frequency characteristic is limited. The proposed algorithm relays on highpass, low order IIR filtering and thresholding of chosen parameters of the detected disturbance (such as duration time, energy or frequency content). Proposed system can also be used for long-time (continuous) monitoring of electric power network as only detected disturbance is stored in memory, which significantly reduces required storage capacity. Designing and implementation issues are described in section II, section III gives results of preliminary tests with laboratory-generated and real-world and signals.

II. Implementation

For real-time hardware implementation Texas Instruments C6713 DSK toolkit with floating-point DSP was chosen. Software development for this platform is supported by CCS (Code Composer Studio - assembly and C environment) and Matlab 7.0 with Simulink. For early stage development (especially signal processing algorithms) and designing the core of the system Matlab 7.0 simulation tools were used whereas some final modifications of the algorithm (as logical control) were written in CCS in C language.

Sampling frequency f_s=32 [kHz] was chosen. The data from 16-bit ADC were processed in frames consisted of 32 samples, thus acquisition frequency for frames was equal to f_{frame}=1 [kHz].

A. Matlab Simulink programming

Matlab environment supports the chosen C6713 DSK hardware platform and offers toolboxes with broad range of signal processing procedures. As a result reconfiguration of software being designed is easy and fast.
Simulink model of the algorithm for real time detection of transient disturbances in electric power network is depicted in fig.1. Proposed algorithm was designed for detecting disturbances with frequency content significantly higher than 50 Hz. The disturbances are separated from 50 Hz base frequency with highpass Chebyshev type II filter. Frequency responses of this 14-th order IIR filter are shown in fig.2. Magnitude response is rippled in the stop band and flat in the pass band. Edge frequencies were set to f_{stop}=150 [Hz] (the 3-rd 50 Hz harmonic is eliminated) and f_{pass}=200 [Hz]. Group delay is negligible small for frequencies higher than about 2 kHz, for those frequencies the shape of the disturbances is practically not affected by the filter.

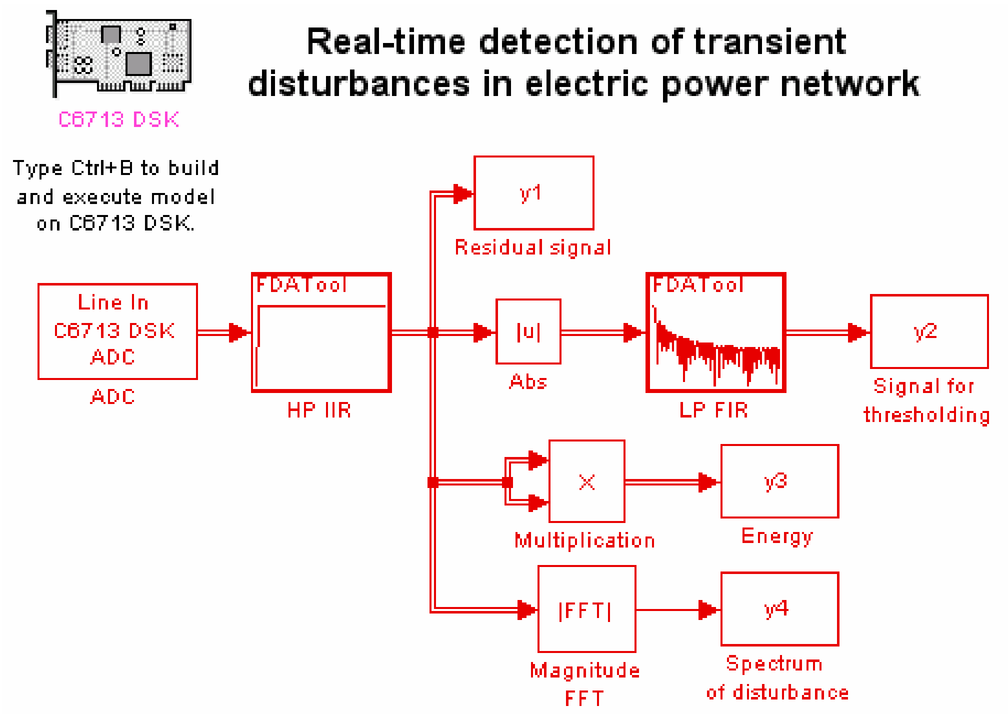

Figure 1. Simulink model of the algorithm for real time detection of transient disturbances in electric power network (denotations: HP IIR - highpass, infinitive impulse response filter, LP FIR - lowpass, finite impulse response filter).

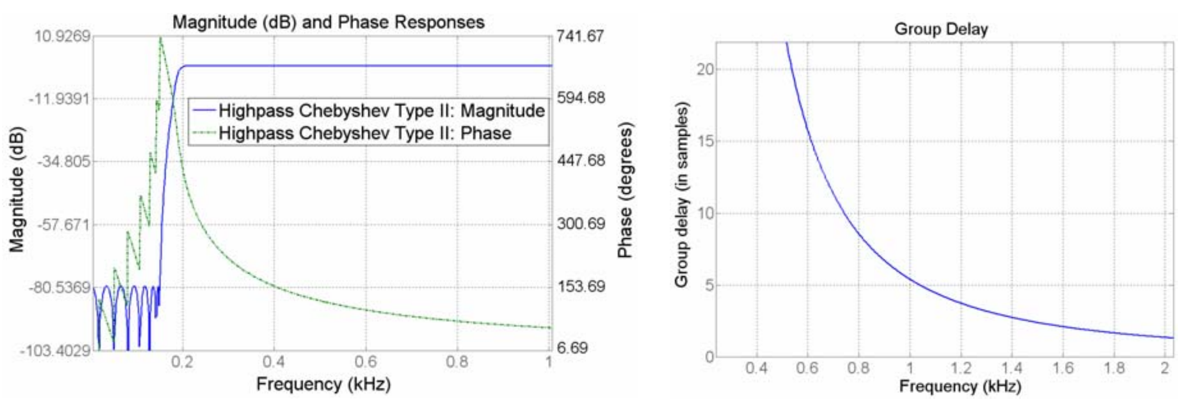

Figure 2. Frequency responses of used 14-th order highpass Chebyshev type II filter (denoted as HP IIR on fig.1).

Residual signal y_1 obtained from highpass filtration is further processed to compute a set of parameters describing the disturbance. Using the residual signal y_1 three additional signals y_2, y_3 and y_4 are computed for

detection and classification of the disturbance. The performance of the algorithm is illustrated in the fig.3. Fig. 3a shows exemplary generated in Matlab, 50 Hz signal with three transient oscillatory disturbances. Duration time of those transients was set to 2 [ms] and base frequencies were equal to 1 [kHz], 4 [kHz] and 6 [kHz] respectively. The envelope of every transient decreased exponentially and the maximum value was about 10% of 50 Hz signal. Fig.3b presents residual signal y_1 and signal for thresholding y_2. The y_2 is computed by averaging the modulus of y_1 with 64-coefficient lowpass FIR filter. It is clear from fig.3b that comparing y_2 with previously user-defined threshold can result in detection of disturbances.
For each 32 samples frame of residual signal y_1 magnitude of FFT is computed with the frequency step d_f=1 [kHz]. The spectra of disturbances are depicted in fig.3c, energy concentration along frequency axis is well correlated with base frequencies of analyzed transients.

a) b) c)

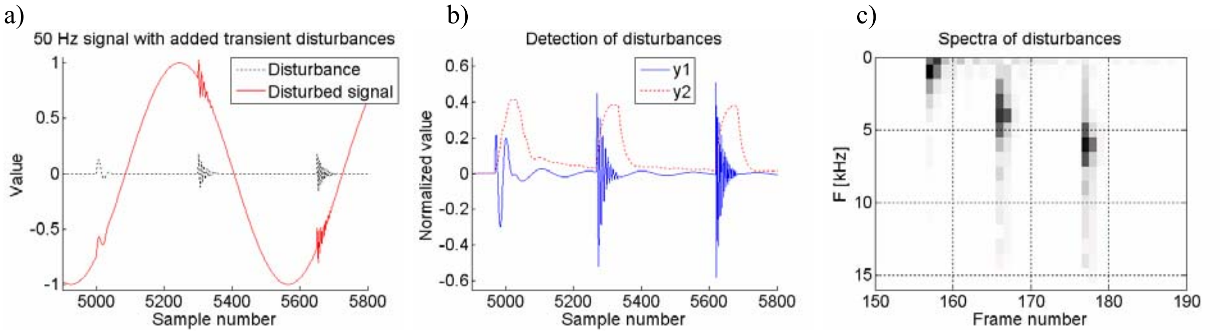

Figure 3. Performance of the algorithm for generated in Matlab testing signal: a) testing signal, b) detection of transients, c) spectra of detected transients.

B. Code Composer Studio programming

Algorithm described in previous subsection was exported to *C* language using Matlab support [10-12]. The system was configured to compute real-time parameters of the disturbance and also to store residual signal in case of detected disturbance. For triggering signal the value of y_2 was chosen. All data presented in the following section were taken from C6713 DSK RAM via debugger function for this presentation.

III. Results and conclusions

Fig.4 shows residual signal y_1 for real time detection of transients. In experiments laboratory-generated signal with disturbances similar to those depicted in fig. 3a and field signal were analyzed. In the first case sound card in PC computer was used as a wave generator. C6713 DSK board was fed from the sound card line output. Detected disturbances were extracted from 50 Hz component and stored in memory. The extracted disturbances are depicted in fig. 4a. In case of field experiment recorded disturbances shown in fig. 4b were intentionally generated by switching capacitors and C6713 DSK board was fed from separating transformer. It is worth to notice that results depicted in fig.4b were obtained in the power network with the strong presence of harmonic distortions (the shape of voltage wave observed on the oscilloscope during measurement was far from pure sinusoid).
Upon fig.4 the following conclusions may be drown: **1)** good detection results were obtained in case of tested oscillatory transients, although for 1 kHz frequency disturbance group delay of Chebyshev type II filter was the reason of shape distortion (compare fig.3a and fig.4a). More reliable results were obtained for transients with frequency content higher then 2 kHz; **2)** The method is very sensitive to disturbance. The transients with amplitude smaller then about 10 % of main frequency amplitude was correctly detected (see fig.3b, fig.4a). The sensitivity of the detection can be adjust by selection of the value of the threshold. During experiments we were able to find small disturbances received from electricity net. **3)** Field results (fig.4a,b) showed that the method can be used for real-time, long-term PQ monitoring.
Compare to solutions of other authors, the implementation of proposed algorithm does not require any pre-processing stage (like fundamental frequency estimation) it is also robust against 50 Hz fluctuations and harmonic distortions (especially the 3-rd one).

a) b)

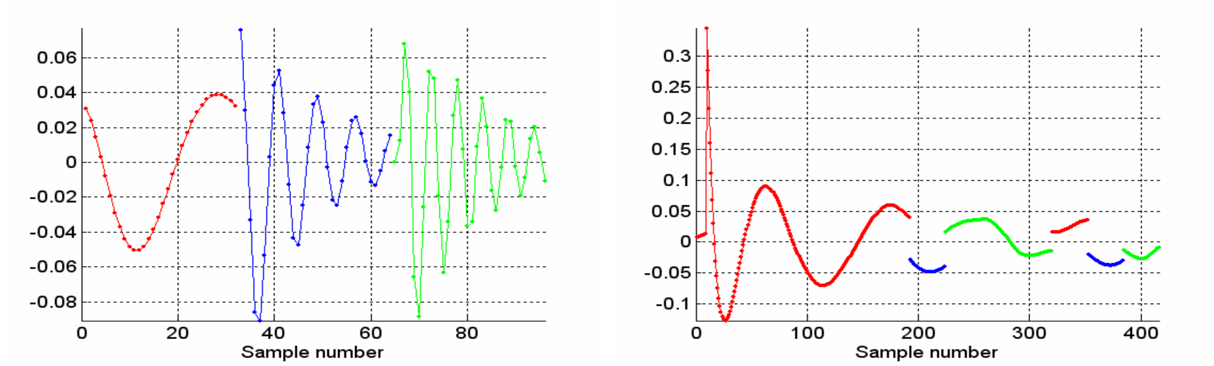

Figure 4. Results of real time detection and extraction of high frequency disturbances on real-world voltage signals: a) disturbances extracted from 50 Hz laboratory-generated testing voltage signal; b) an example of disturbances detected in field experiment in working power network on *AGH University of Science and Technology* on low voltage side.

References

[1]. H.W. Furst, M. Pigl, J. Baier, "An analog method for detecting super-imposed power line voltage disturbances", *IEEE Trans. on Instrumentation and Measurement*, vol.44, December 1994, pp.889-893.

[2]. A. McEachern, "A system for capturing and presenting short duration voltage surges on ac power lines", *IEEE Trans. on Instrumentation and Measurement*, vol.39, February 1989, pp.38-41

[3]. S.J. Huang, C.T. Hsieh, "Feasibility of fractal-based methods for visualization of power system disturbances", *Int. Power Energy Syst.,* no.1, pp.31-36, 2001

[4]. L. Angrisani, P. Daponte, M.D'Apuzzo, "Wavelet network-based detection and classification of transients", *IEEE Trans. on Instrumentation and Measurement*, vol.50, October 2001, pp.1425-1435.

[5]. S. Santoso, E.J. Powers, P. Hofmann, "Power quality assessment via wavelet transform analysis", *IEEE Trans. on Power Delivery*, vol.11, April 1996, pp.924-930.

[6]. P. Daponte, M. Di Penta, G. Mercurio, "TransientMeter: A Distributed Measurment System for Power Quality Monitoring", *IEEE Trans. on Power Delivery*, vol.19, no.2, April 2004, pp.456-463.

[7]. G. Bucci, E. Fiorucci, C. Landi, "Digital Measurement Station for Power Quality Analysis in Distributed Environments", *IEEE Trans. on Instrumentation and Measurement*, vol.52, no.1, February 2003.

[8]. M. Artioli, G. Pasini, L. Peretto, R. Sasdelli, F. Filippetii, "Low-Cost DSP-Based Equipment for the Real-Time Detection of Transients in Power Systems", *IEEE Trans. on Instrumentation and Measurement*, vol.53, no.4, August 2004, pp.993-939.

[9]. D. Castalado, D. Gallo, C. Landi, A. Testa, "A Digital Instrument for Nonstationary Disturbances Analysis in Power Lines", *IEEE Trans. on Instrumentation and Measurement*, vol.53, no.5, October 2004, pp.1353-1361.

[10]. *Simulink Simulation and Model-Based Design®*, Using Simulink® Version 6, www.mathworks.com

[11]. *Real-Time Workshop® For Use with Simulink ®*, User's Guide, Version 6, www.mathworks.com

[12]. *Embedded Target for the TI TMS320C6000™ DSP Platform For Use with Real-Time Workshop®*, User's Guide Version 2, www.mathworks.com