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D.4.1. Summary of the developed algorithm for determining the frequency and phase of measured signals

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Sažetak

Razvijen je novi algoritam ikoji doprinosi boljoj razlučivosti i točnosti mjerenje frekvencije i faze te je otporan na smetnje. Algoritam se koristi unutar mjeriteljskog ispitnog i umjernog okvira za PMU i MU i razvijen je nakon dinamičkog ispitivanja te doprinosi boljoj razlučivosti i točnosti mjerenja što je neophodno za ispitivanje PMU-a.

Abstract

A new algorithm has been developed that contributes to better resolution and accuracy of frequency and phase measurements and is resistant to interference. The algorithm is used within the metrological test and calibration framework for PMU and MU and was developed after dynamic testing and contributes to better resolution and measurement accuracy that is necessary for PMU testing.

Introduction

To detect the frequency and phase of the signal, it is first necessary to filter the signal. The noise is ubiquitous, it cannot be avoided but it can be reduced. The problem of noise was addressed in many analyses and in many different topics. From the side of power quality measurement, noise is unwanted and often it is consequence of non-compliance of measurement equipment characteristics. Measurements are based on separated measurements of voltages and currents. The characterization of measured data needs to be in real time and results are depending on noise level. Today's modern instruments need to be able to handle the signal variations and disturbance [1]. Also, the noise and disturbance are mostly reactive component of power, and not taking the information of noise into consideration might mislead to the wrong measurement result. New signal processing algorithm can be used to improve the quality of measurement data. Today, even very complex algorithm can be calculated in real time, without data buffering, and this feature can drastically improve the quality of measurements results. Real time data analysis results in better controlling of system process, and drastically improving stability of systems. Noise is not a steady process added to the signal, it is nonlinear time variant process, so the noise reduction algorithm has to be robust but not aggressive on the signal. It has to be "smart". Classical approach with static filters is not able to answer to all new needs in data analysis of measurement data. With this summary/abstract we present a solution for noise remove and reduce, but without changing the amplitude, the harmonic component nor phase of measured signal.

Algorithm

If the measured signal is $x(k)$, signal with reduced noise is $x_{nr}(k)$, the wavelet vanishing moment db_{level}, the depth of decomposition is *depth*, then the main problem can be formulated:

$$max\{PSNR(x(k), x_{nr}(k)) : inf(db_{level}, depth)\} \quad (1)$$

The resulting parameters will result with maximal PSNR for infima, minimal, depth of decomposition and wavelet vanishing moment.

In this section the influence of wavelet decomposition parameters on quality of noise reduction will be analyzed. Input signal is simulated with corresponding amplitude, frequency, phase and other parameters. During the analysis the parameters of ideal 24 bit ADC, with full scale range equal to NI 9225 card are used.

Effective number of bits (ENOB) can be defined with Full Scale Range (FSR) and Noise and Distortion (NAD) parameters of ADC [2]:

$$ENOB = \log_2\left(\frac{\frac{FSR}{G}}{NAD\sqrt{12}}\right), \tag{2}$$

where G stands for ADC's gain. The parameter NAD can be defined in frequency domain [3]:

$$NAD = \frac{1}{\sqrt{N(N-3)}}\sqrt{\sum_{n\in S} X_{\mathrm{av\,m}}(f_n)^2}. \tag{3}$$

In (3), $X_{\mathrm{av\,m}}(f_n)$ is the value of n_{th} spectral component on frequency *n*, averaged *m* times, and N is the number of elements of set *S*.

Sampling frequency is set to 50 kS/s (10^3 samples per second). Time length of sample is set to 1 s. The discretized data are analyzed with different number of wavelet tap (vanishing moments) and depth of signal decomposition. Algorithm is also tested with different noise levels which are added to signal. Analysis chain is shown in Fig. 1.

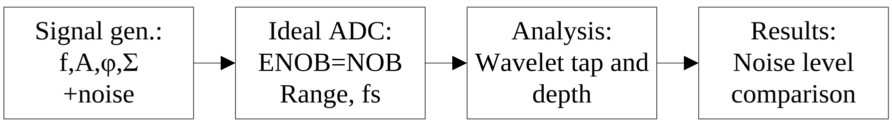

Figure 1. Block diagram of simulation system.

This analysis generates huge amount of data, consequently the results will be presented in 3D graphs. In each analysis two parameters are variable, and others are fixed. The parameters of efficient WT noise reduction are defined in the minimum number of analysis steps.

Conclusion

The analysis made in this paper defines the wavelet transformation setup for noise reduction in power quality measurement. Main aim of this paper was to define depth of decomposition and number of wavelet's vanishing moments for efficient noise reduction. The process of defining the parameters of WT is very complex due to high number of parameters and huge number of simulations. Main contribution of this algorithm is in efficient noise reduction without prior knowledge of signal amplitude or SNR. The noise removal method remains sensitive to signal harmonics, interharmonics and amplitude deviation. The influence on the signal phase is negligible compared to the classic approach with filters so there is no need for phase correction. Wavelet noise reduction is powerful tool for dynamically changing signals in unknown environments in which the events are very important and need not to be defined as outliers. Presented noise reduction setup is usable for both voltage and current measured data. Influence of WT noise reduction on power and energy measurement will be investigated in future work, due to large number of analysis and resulting data. This algorithm, with parameters described according to this paper has been used for filtering data acquired with older equipment (lower precision and ENOB) in substations.

Literature

[1] M. Florkowski, B. Florkowska, Wavelet-based partial discharge image denoising, IET Generation Transmission and Distribution, Vol. 1, Issue 2, pp. 340-347, 2007.

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[3] D. Belega, D. Dallet, D. Petri, A High-Performance Procedure for Effective Number of Bits Estimation in Analog-to-Digital Converters, IEEE Trans. on Instr. and Meas. Vol. 60., No. 5., p. 1522. -1532., May 2011.