Applied Mathematics and Computation 000 (2017) 1–11

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Optimal base frequency estimation of an electrical signal based on Prony's estimator and a FIR filter

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Power system
Frequency estimation
Optimization
Prony's estimator
FIR filters

ABSTRACT

In the frequency domain modeling of power supplying networks, it is usually necessary to determine the frequency spectrum of the currents flowing through the nonlinear devices (Arrillaga and Watson, 2003; Das, 2015; Lewandowski and Walczak, 2014). The spectrum estimation can be done in many different ways (Lewandowski and Walczak, 2014; Łobos and Rezmer, 1997; Ray et al., 2016). In work (Lewandowski and Walczak, 2014) a spectrum estimation method has been proposed, which has better accuracy in comparison with other competitive methods like WIFTA (Window Interpolated Fourier Transform) or TDQS (Time Domain Quasi-Synchronous Sampling), while maintaining a low demand for computing power. The accuracy of this method depends on two main factors: the accuracy of the fundamental frequency estimation and the accuracy of the signal interpolation in the resampling process. For the estimation of the fundamental frequency, the method uses a first order Prony's estimator (Łobos and Rezmer, 1997) and a band-pass FIR (Finite Impulse Response) filter.

In the paper, an attempt was made to find the optimal parameters for both: the Prony's estimator and the FIR filter. First, an analysis of the measurement window size of the Prony's estimator and the number of the FIR filter coefficients was performed. Then, the optimization problem was defined, which is not trivial, since the Prony's estimator is highly nonlinear and some of the parameters (the window size and the number of filter coefficients) are integers. The research allowed to determine the optimal values of the considered parameters of the frequency estimation method. Along with the results presented in Lewandowski and Walczak (2015) it is now possible to implement the spectrum estimation method from Lewandowski and Walczak (2014) using the optimal set of parameters.

1. Introduction

Determination of a frequency domain spectrum of currents flowing through the nonlinear devices is becoming an important part of the design and analysis of modern power networks [1,2]. The number of nonlinear devices is rapidly increasing, and this must be taken into account on the designing stage of the network as well as during its maintenance. Modern software dedicated to simulate the power flow of the network usually contains harmonic flow analysis and the modern measuring equipment can calculate many parameters of the measured signal using its frequency spectrum. In fact the determination

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http://dx.doi.org/10.1016/j.amc.2017.06.004
0096-3003/

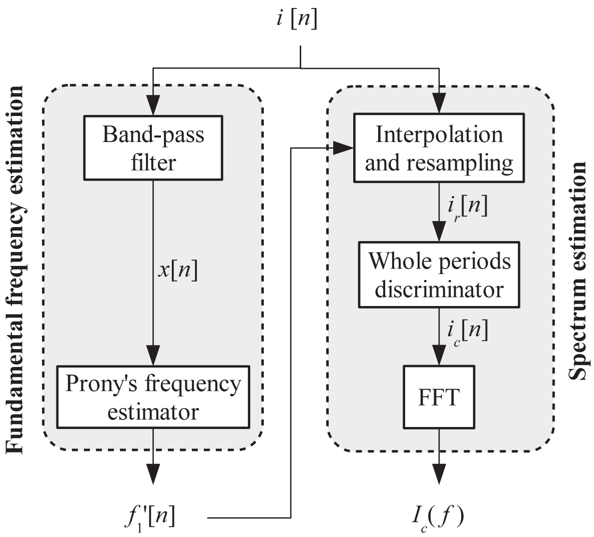

Fig. 1. Current spectrum estimation method.

of the frequency spectrum of currents and voltages in the network is one of the essential steps in modern power system analysis [1–3]. There are many available methods dedicated to spectrum estimation of electrical signals [3,5,7]. This is not a trivial task, since there are many problems to overcome. For example, when the sampling frequency in not synchronized with the base frequency of the signal, the FFT (Fast Fourier Transform) leads to spectrum containing some characteristic and well-known artifacts [1]. In work [3] a spectrum estimation method has been proposed, which has proven to achieve better accuracy in comparison to other competitive methods like WIFTA (Window Interpolated Fourier Transform) or TDQS (Time Domain Quasi-Synchronous Sampling) [8], while still maintaining a low demand for computing power. The main idea of the method is to restore the synchronous sampling of the signal, which solves the artifacts problem mentioned before. The diagram of the proposed method is shown in Fig. 1. It can be noticed in Fig. 1, that a discrete current signal $i[n]$ (where n is the sample index) is processed by a semi-parallel algorithm containing two paths: a fundamental frequency estimation path and a spectrum estimation path with interpolation and coherent resampling. On the first path, the input current $i[n]$ is filtered by a band-pass filter to extract the fundamental frequency component of the signal. The band-pass filter passes only the signal components which are located in between the cut-off frequencies, while damping the components outside this range. The filter cut-off frequencies are set to 47.5 Hz and 51.5 Hz, so they are around the fundamental frequency of the signal equals 50 Hz. Next, using filtered signal $x[n]$, the fundamental frequency $f_1'[n]$ is estimated using the Prony's estimator [4]. The fundamental frequency estimation is performed, because the real frequency of the signal is usually not exactly equal 50 Hz due to the frequency swing present in the power system [9]. The estimated frequency f_1' is then used on the second path of the algorithm for the coherent resampling (the new sampling frequency is an integer multiplication of f_1'). After the resampling, the signal is cut to whole periods in the discriminator and the FFT (Fast Fourier Transform) is performed to obtain the signal spectrum. More details about the method can be found in [3]. It is worth to mention here, that the coherent resampling leads to a spectrum which is free of the negative FFT side effects such as the spectrum leakage [1]. In other words, the coherent resampling allows the FFT algorithm to work in its optimal conditions, as long as the signal is considered to be periodic.

The accuracy of the presented method depends on two main factors: the accuracy of the fundamental frequency estimation and the accuracy of the signal interpolation in the resampling process. The influence of the interpolation has been examined in work [6]. In this paper, the fundamental frequency estimation path with FIR filter and Prony's estimator will be examined and optimized to achieve best performance for a typical power system signals.

2. Fundamental frequency estimation

The frequency estimation problem is not new and a broad range of solutions is available in the literature [4,10–12]. Starting from simple and straightforward algorithms like the zero-crossing detection [8] or the Prony's estimator [4], by more complex methods like least-square data fitting [12] or those based on the Fourier transform [10], to even more sophisticated solutions like the Kalman filter [11] or algorithms which are using the hidden Markov's model [12].

The first order Prony's estimator proposed in [4] was used along with a FIR (Finite Impulse Response) filter in [3] to estimate the base frequency of an electrical current flowing through a nonlinear load. It has been shown in [3] that the method, in spite of its simplicity, performs well even when the signal is distorted and noisy. The fundamental frequency estimation used in [3] is shown in Fig. 2. It is assumed, that the band-pass filter is a FIR filter, which can be described in