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Least Error Squares Approach: A Practical Method for Power System Frequency and Amplitude Estimation

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Abstract

Deregulation, competitive electricity market, expansion of transmission and distribution network, increased applications of power electronics make the power system more complex and the determination of accurate power system frequency becomes more difficult. The algorithm based on the Taylors series expansion principle of the least error squares curve fitting technique for measuring the practical frequency at a power system bus is presented in this paper. The algorithm was tested practically in laboratory and results are presented in this paper. The effect of data window size, sampling frequency, time reference selection and Taylor's series expansion on the performance of the algorithm are also discussed in this paper.

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*Keywords:*Phasor; frequency; sampling rate; window size; least error square

1. Introduction

In a power system, frequency and phasor are the most important and fundamental parameters for power system analysis, operation and control because they can reflect the whole power system situation. Phasor can constitute the state of the power system, while frequency can represent the dynamic balance between load and generating power. Hence fast and precise estimation of frequency and phasor is vitally necessary. In last two decades due to power industry deregulation, expansion of the transmission and distribution network, and increased applications of power

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electronic makes the power system more complex and make the estimation of power system frequency and phasor more difficult.

In the past several frequency and phasor estimation algorithms / techniques have been introduced. The zero crossing detection technique and its modifications most commonly used to estimate the frequency of the signal and phasor[1-3]. Leakage effect of the discrete Fourier transform (DFT) is another method to estimate frequency and phasor [4].Another conceptually similar method is based on the phasor angle analysis [5, 6].The concept of Kalman filtering (KF) is also used for power system frequency and phasor estimation [7-9], wavelet approach is another method used for power frequency and phasor estimation [10]. The Adaptive neural network (ANN) is the basis for another set of approaches for power system frequency and phasor estimation in power system [11, 12]. The concept of three phase locked loop (PLL) is also widely used for phase and frequency estimation [13], and so on. However, most of the aforementioned methods have tradeoff between accuracy and speed.

In this paper, we present an algorithm which is based on the Taylors series expansion principle of the least squares error curve fitting technique for estimation of power system frequency and amplitude practically using Matlab as a software tool. The organization of this paper is as follows, we described the basic principle of least error square algorithm in Section 2. Section 3 describes the hardware structure used for algorithm testing. To provide the isolation between the computer and power system supply, the gain control circuit is used. Data acquisition card by Advantech is used to capture the voltage signals. To evaluate the performance of the proposed algorithm, the voltage signal is captured from the mains power supply and recorded at a sampling rate of 1000, 1200, 2500, 5000 samples /second. The factors affecting the performance of the algorithm are described in Section 4. The algorithm was tested for different sampling rate by varying the time duration in Section 5. Finally, section 6 concludes this paper.

2. Background of the frequency estimation algorithm

In this section we present an algorithm for frequency estimation. The Taylors series expansion is the under laying principal of the Least Error Squares (LES) technique. Suppose the power signal (system voltage or current signal) is sampled for measuring frequency expressed as:

$$v(t) = V_m \sin(2\pi ft + \theta) \tag{1}$$

Where V_m is the peak value of the voltage $\omega = 2\pi f$ represents the actual frequency is the time in seconds, and θ is an arbitrary phase angle. Using the trigonometric identity $\sin(2\pi f + \theta)$ of equation (1) can be expanded as follows:

$$v(t) = V_m \cos\theta \sin(2\pi ft) + V_m \sin\theta \cos(2\pi ft) \tag{2}$$

Expanding the Taylor series of $\sin(2\pi ft)$ and $\cos(2\pi ft)$ centred on the nominal frequency f_0, the first three terms are taken, and substituting in equation (2) the following equation is obtained:

$$\begin{aligned} v(t) &= V_m \cos\theta\left[\sin(2\pi f_0 t) + 2\pi(f - f_0)t\cos(2\pi f_0 t) - (f - f_0)^2 \sin(2\pi f_0 t)\right] \\ &+ V_m \sin\theta\left[\cos(2\pi f_0 t) + 2\pi(f - f_0)t\sin(2\pi f_0 t) - \frac{(2\pi t)^2}{2}(f - f_0)^2 \cos(2\pi f_0 t)\right] \end{aligned} \tag{3}$$

Now, putting $(f - f_0)^2 = (f^2 - 2ff_0 + f_0^2)$ in equation (3) and rearranging the terms the resulting equation:

$$\begin{aligned} v(t) &= V_m \cos\theta\left[\sin(2\pi f_0 t)\right] + \left[2\pi t\cos(2\pi f_0 t)\right](f - f_0)V_m \cos\theta + \left[\cos(2\pi f_0 t)\right]V_m \sin\theta + \\ &\left[-2\pi t\sin(2\pi f_0 t)(f - f_0)V_m \sin\theta\right] + \left[t^2 \sin(2\pi f_0 t)\right]\left[\frac{-(2\pi)^2}{2}f^2 + (2\pi)^2 ff_0 - \frac{(2\pi)^2}{2}f_0^2\right]V_m \sin\theta \end{aligned} \tag{4}$$