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Interharmonics analysis of power signals with fundamental frequency deviation using Kalman filtering☆

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ABSTRACT

In this paper a spectral decomposition-based method for interharmonic computation is proposed for power systems where the fundamental frequency fluctuates significantly. In the proposed method, the frequency domain components of the voltage waveform are obtained by Kalman filtering. Both the system fundamental frequency and the correct spectrum of the voltage waveform, and hence the exact interharmonics are obtained. The proposed method is tested with both simulated and field data obtained from different electric arc furnace (EAF) plants, where the system frequency deviates continuously due to the fluctuating load demands. Since the interharmonic frequencies are obtained by using Kalman filtering, no leakage effect of the DFT-based methods is involved in case of frequency deviations, which is an important advantage of the proposed method.

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1. Introduction

The frequencies, which are not an integer multiples of the fundamental frequency are called *interharmonics*, whereas harmonics are the frequencies at the integer multiples of the fundamental frequency [1]. Spectral analysis of harmonics and interharmonics of the power signals are usually obtained by using the fast Fourier transform (FFT) algorithm due to its computational efficiency. However, FFT may suffer from aliasing, spectral leakage, and picket-fence effect associated with the nature of the discrete Fourier transform (DFT) algorithm on which FFT is based on [2].

In power systems, fundamental frequency is expected to be exactly 50 or 60 Hz. However, the fundamental frequency may deviate from the nominal value due to various reasons such as disturbances, subsequent transients and or the dramatic real power fluctuations of arc furnace plants as stated in [3–5]. In [3], it is reported that the most preferable frequency deviation is ± 0.02 Hz, however, for case studies with a large steel mill or an arc furnace plant, the standard change in transient frequency lies between ± 0.50 Hz. In [6], it is reported that US-wide power system frequency usually varies between 59.99 and 60.02 Hz; however, in case of an event the frequency may drop down to 59.55 Hz. It is observed that during safe operation, the power system frequency deviates due to various reasons; however, in interconnected systems such as the US-power network [6], this deviation is much less than that of the power systems without such an interconnection [3,7].

In FFT-based algorithms, frequency deviation causes leakage effect, which is one of the major problems associated with FFT applications. It has been shown that leakage effect can cause really big problems in spectral decomposition-based methods unless correction procedure is applied to prevent these effects. To solve the FFT leakage problem, various approaches have been proposed [9–23], which are explained in [8] briefly. The proposed approaches for obtaining a correct spectrum are generally based on windowing and interpolation in the frequency domain or utilization of an adjustable spectrum which varies frequency scale by means of adjusting the frequency resolution and the frequency shift to overcome the FFT leakage effect. For spectral estimation of the power signals, wavelet algorithms [14] and high-resolution spectrum estimation methods such as Prony, minimum norm (min-norm), estimation of signal parameters by rotational invariance techniques (ESPIRIT) and multiple signal classification (MUSIC) are also used. Some different usage of these high-resolution spectrum estimation methods for interharmonic and harmonic analysis are explained in [20–22]. Adaptive Prony, adaptive ESPIRIT and adaptive MUSIC methods are employed in [20] for spectral estimation of power

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