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Application Study of Time-frequency Analysis Methods to Offshore Wind Turbines

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Currently, a variety of time-frequency analysis methods have been developed for different applications. However, it is not yet known whether these methods are applicable for offshore wind turbines. Therefore, in this paper, four time-frequency analysis methods—short-time Fourier transform, wavelet transform, Hilbert–Huang transform, and short-time Prony transform (STPT)—are compared by using a nonstationary numerical signal and a set of field test data from an offshore wind turbine. Results from the STPT seem to have better properties for resolving the frequency content of such data.

INTRODUCTION

Because of the stability and availability of wind sources in the marine environment, offshore wind energy has become one of the fastest-growing renewable energies in the world. But because of the impact of the harsh marine operation environment, offshore wind turbines are vulnerable to be destroyed. For example, nearly 1,000 offshore wind turbine safety accidents occurred in 2014 (Seyr and Muskulus, 2016). Therefore, real-time monitoring of offshore wind turbines has become increasingly more important. However, offshore wind turbines have dynamic characteristics that change over time as a result of time-varying environmental loadings such as waves, winds, currents, and operational loadings and even as a result of the changes in soil stiffness over the lifetime; all of these constitute a time-varying system in modal analysis. In other words, measured frequencies of time-varying offshore structures might be discontinuous and changeable over time, which requires suitable time-frequency analysis techniques before implementing a modal analysis of offshore wind turbines in the field. In recent years, the identification of time-varying structures based on measured dynamic responses has been researched thoroughly, and time–frequency analysis has become an effective approach, because signals are presented in a time–frequency–amplitude/energy density three-dimensional space. Hence, both the constituent frequency components and their time variation features can be revealed.

Traditional signal analysis methods are based on the Fourier transform (Champeney, 1982). In the Fourier transform, a signal, as a whole, is decomposed into different frequency components. The whole and localized characteristics cannot be considered in the time and frequency domain simultaneously. By only conducting a pure frequency analysis, information about the occurrence or duration of the dominating frequencies cannot be obtained. To retain time information, many scholars generalized and even revolutionized the Fourier transform. A joint function of time and frequency was used, and a series of new theories to process the signals was developed. Therefore, the energy and magnitude of a signal can be characterized in the time and frequency domain, and characteristic parameters, such as instantaneous frequency and instantaneous bandwidth, can be used to analyse the signal.

To overcome the periodicity requirements of the Fourier transform, Gabor (1946) proposed the short-time Fourier transform (STFT) method. In STFT, the signal is divided into a series of short time periods by a fixed window, and the Fourier transform was used to analyze the local power spectrum of the signal in each time period. To overcome the limitation of the fixed window, French geophysicist Morlet (Morlet et al., 1982) put forward wavelet analysis, which adds a sliding window with variable scale to the segment and thereby analyzes the signal. In essence, it is a Fourier transform method with an adjustable window. This method has good local properties, both in the time domain and in the frequency domain. Additionally, it is a linear transformation, so there will be no cross-term interference for multicomponent signals. The above methods are based on the Fourier transform method and may produce contradictory phenomena, such as false signals and false frequencies. Huang et al. (1998) provided the Hilbert–Huang transform (HHT) method, which is based on the concept of instantaneous frequency. In Huang et al. (1999), some improvements to this method were made. In HHT, the concept of an intrinsic mode function (IMF) was defined, and a decomposed method called empirical mode decomposition (EMD) was proposed. The HHT method is a major breakthrough in linear time-frequency analysis and has been widely used in various fields (Guo et al., 2008; Chen et al., 2019; Lazhari and Sadhu, 2019). However, when the frequencies of each component are close, EMD will lose its function, and the results will be influenced by mode mixing (Dong et al., 2019).

With the development of the time-frequency analysis method, the theories have gradually improved. Time-frequency analysis is being applied increasingly in engineering. For ocean engineering, because of the influence of the complex marine environment, the real response signal is often polluted by various types of noise. The vibration response of offshore platform structures is excited only by irregular environmental excitations, and the true modes

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KEY WORDS: Time-frequency analysis, offshore wind turbines, STFT, wavelet, Hilbert transform, STPT.