Energy for Sustainable Development 22 (2014) 34–47

Contents lists available at ScienceDirect

Energy for Sustainable Development

Extraction of the inherent nature of wind speed using wavelets and FFT

Md. Mahbub Alam [a,*], S. Rehman [b], L.M. Al-Hadhrami [b], J.P. Meyer [c]

[a] Institute for Turbulence-Noise-Vibration Interaction and Control, Harbin Institute of Technology, Shenzhen Graduate School, Shenzhen, China
[b] Center for Engineering Research, Research Institute, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[c] Mechanical and Aeronautical Engineering Department, University of Pretoria, Pretoria, South Africa

ARTICLE INFO

Article history:
Received 22 September 2013
Revised 21 February 2014
Accepted 22 February 2014
Available online 18 March 2014

Keywords:
Wind energy
Wind speed
Wavelet
Fast Fourier transform
Power spectrum

ABSTRACT

Due to technological advancement, availability of multi-megawatt wind turbines, ease of installation and maintenance, economic compatibility and commercial acceptance, wind power is being used globally for both grid-connected and off-grid applications. The wind power is intermittently available due to the fluctuating nature of the wind and hence needs to be understood well. Its variability was studied in this paper both in time and spatial domain. The present work utilized daily mean values of wind speed from different meteorological stations spread over the Kingdom of Saudi Arabia in conjunction with wavelet transform and fast Fourier transform power spectrum techniques to understand the dynamic nature of the wind at nine stations. The study found that wind speed changed by ± 0.6 to ± 1.6 knots over a long period of about 10 years depending on the locations. The long-term mean wind speed of 5.6, 8.9, 6.25, 8.1, 6.0, 7.1, 6.0, 8.6 and 7.3 knots was obtained at Abha, Dhahran, Gizan, Guriat, Hail, Jeddah, Riyadh, Turaif and Yanbu, respectively.

Introduction

When thinking of installing a wind firm at a site, an indispensable task is to conduct an on-site wind speed measurement campaign for a few years (the longer the better) and analyze the measured data to extract information on the variability of the wind (Jaramillo and Borja, 2004). The variability covers a wide spectrum of time-scales from seconds to several years, say, random variation at very short interval (turbulence scale), synoptic scale, seasonal variation, annual cycle variation, etc. This statistical information is required not only for a feasibility study of the wind farm to be installed but also for wind power prediction at different years/seasons/months/days as well as wind turbine control. This article provides statistical information about wind speed nature for a long time in the past which is direly needed for long-term wind speed predictions. Furthermore, without analytical prediction, the statistical information on variations of past wind at different time-scales can give us a rough idea about how the wind will behave in the near future (Garcia-Marin et al., 2013).

The wind power has become a commercially available and financially acceptable technology. For proper and optimal utilization of wind power, understanding of its characteristics in time and spatial domains has become essential. Time series modeling of wind speeds is based on the valid assumption that all the causative factors are implicitly accounted for in the sequence of occurrence of the process itself. Wind speed characteristics have been reported worldwide by using statistical, mathematical, empirical and physical time series analysis (Fourier transform, wavelet transform, detrended fluctuation analysis, artificial neural networks (ANN), Hurst exponent, autoregressive moving averages, etc.). In recent times, power spectral density and wavelet transforms have been employed as useful tools to analyze measured wind speed data in particular and meteorological data in general.

Usually, most of the signals contain numerous non-stationary or transitory characteristics such as drift, trends, abrupt changes, and beginnings and ends of events. These characteristics are often the most important part of the signal and are needed to be analyzed to understand physical phenomena hidden behind the signal. To study these characteristics, wavelets have been developed since the early eighties. Wavelet analysis methods allow the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information. One major advantage afforded by wavelets is the ability to perform local analysis, that is, to analyze a localized area of a larger signal.

Kitagawa and Nomura (2003) used the inverse wavelet transform method to generate wind velocity fluctuations. To investigate the time-scale structure of natural wind, the wavelet transform was applied to the time history of measured wind velocity data. Yamada and Ohkitani (1991) applied the wavelet transform on historical time series of wind data and estimated the probability density functions (PDFs) of the wavelet coefficients. Their results showed that PDFs of the wavelet coefficients for small-scale fluctuations deviated from the Gaussian distribution, though the power spectrum agreed with Kolmogorov's $-5/3$ law. The inverse Fourier transform is a traditional method to generate time histories (Shinozuka and Deodatis, 1991) but it fails to reflect

* Corresponding author:
E-mail address: alamm28@yahoo.com (M.M. Alam).

http://dx.doi.org/10.1016/j.esd.2014.02.004
0973-0826/

Table 1
Site specific information of meteorological stations considered in this study.

Location	From	To	Latitude (°N)	Longitude (°E)	Altitude (m)	Anemometer height (m)*
Abha	01/09/1983	31/12/2006	18.20	42.70	2084	10
Dhahran	01/01/1970	31/12/2006	26.30	50.20	17	10
Gizan	01/01/1970	31/12/2006	16.90	42.60	3	8
Guriat	01/01/1984	31/12/2006	31.40	37.30	499	12
Hail	01/01/1990	30/11/2006	27.40	41.70	1013	9
Jeddah	01/01/1970	31/12/2006	21.70	39.20	12	10
Riyadh	01/04/1984	31/12/2006	24.70	46.70	612	10
Turaif	03/08/1970	31/12/2006	31.70	38.70	813	10
Yanbu	22/02/1977	31/12/2006	24.20	38.10	14	10

*Above ground level.

time-dependent characteristics of the data. Pettit et al. (2002) applied the wavelet transform to the time data of roof-corner pressures with extreme local loads and obtained the PDFs on the time-dependent characteristics of the pressure transients. Based on these PDFs, a method to generate synthetic signals was developed, and time histories similar to the original roof-corner pressure data were composed. Aksoy et al. (2004) introduced a new wind speed data generation scheme based on wavelet transformation and compared this scheme with existing wind speed generation methods. Their results indicated that the proposed wavelet-based method was the best for wind speed data generation compared with existing methods such as statistical.

Turbelin et al. (2009) estimated wavelet cross-coherence, wavelet cross-correlation and spectral wavelet cross-correlation coefficients and displayed these as functions of the equivalent Fourier period. The study found that the ANN models were effective in computing the large-scale fluctuations of large amplitude. Chellali et al. (2010) applied wavelet transform as a time–frequency analysis to meteorological data for the region of Adrar, Algeria. They conducted this analysis to investigate the power spectra behaviors of wind speed and its variations with time. The results showed significant synoptic oscillations for periods of 2 to 16 days in the cold weather. The wavelet power spectrum also revealed the presence of intra-seasonal oscillations for periods of 30 to 60 days. Giorgi et al. (2011) proposed a wind speed prediction system based on the wavelet decomposition technique and forecasted the wind speed in two time horizons (1 and 24 h) with acceptable accuracy compared with other techniques. Chellali et al. (2011) reported a stochastic and cyclic study of wind speed behavior at Hassi-R'mel meteorological data collection site in Adrar, Algeria by fitting the wind speed data to Weibull distribution and the usage of time–frequency analysis. The results showed that the spectrum wind process was able to enfold many limited interval oscillations which is not possible with other methods. In the recent years, wavelets have been extensively employed as a tool to analyze measured data in general and wind data in particular to study the wind effects on structures (Rossi et al., 2004), feature extraction for wind turbine vibration signals (Jiang et al., 2011; Karegar and Sobhani, 2012; Liu et al., 2010; Tang et al., 2010) and to evaluate the quality of synthetic wind speed signals (Kareem and Kijewski, 2002).

Fig. 1. Physical locations of the meteorological stations used in the study.