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# Short-term wind speed forecasting based on fast ensemble empirical mode decomposition, phase space reconstruction, sample entropy and improved back-propagation neural network

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ABSTRACT

With the sharp consumption of fossil energy and deterioration of ecological environment, wind power, as a clean and renewable energy resource, gains more and more attention from all over the world. However, due to the intermittency and stochastic nature of wind speed, an accurate wind power/speed forecasting is not only crucial for availably dispatching the wind power resource but also has a direct relationship with the State Grid operation safely and steadily. In this paper, an innovative hybrid wind speed forecasting model, including fast ensemble empirical mode decomposition, sample entropy, phase space reconstruction and back-propagation neural network with two hidden layers, is proposed to enhance the accuracy of wind speed prediction. The data is firstly preprocessed by fast ensemble empirical mode decomposition and sample entropy. Subsequently, the prediction model called improved back-propagation neural network is built to forecast the sub-series, whose inputs and outputs are obtained in accordance to phase space reconstruction. To verify the effectiveness and advancement of the proposed model, the paper chooses the real data from two wind farms located in different site in China for experiments. Comparing with the benchmark models, the proposed model shows a better performance in short-term wind speed forecasting.

## 1. Introduction

With the prosperous development of the global economy, accompanied by the rapid growth of GDP, there are also some serious issues about the rapid depletion of fossil fuels and the worsening environmental pollution. China government put the attention on the renewable energy resources such as wind power, solar energy and nuclear power, which can be regarded as an alternative to the power industry energy and can support for sustainable economic development and environmental protection forcefully, so that the country can adhere to the strategy of sustainable development and low-carbon green development all along and take the road of sustainable development of socialism with Chinese characteristics. Among the new energies, wind power has a sustained and increasingly grow trend around the world owing to short construction period, low environmental requirements, abundant reserves, etc. However, there are also several inherent defects in wind power itself, the characteristics of instability and intermittent may constrain the wind power from integrating into the power grid system on a large scale. An effect solution overcoming these difficulties is to improve the wind speed forecasting precise to reduce the uncertainty of wind power.

At present, there are mainly two representative theories in the wind speed or power forecasting: the physical method and the statistical approaches which reveal the relationship between the wind speed and other variables through the analysis of historical data.

The physical methods, which are mainly based on the numerical weather prediction system (NWP), have a better performance in the longer horizons. According to a series of meteorological data (wind direction, temperature, humidity, atmospheric pressure, air density, etc.) and wind farm surrounding environment (contour lines, roughness, obstacle, etc.), the models conduct a comprehensive analysis and obtain the result. Pan et al. [1] put up with a new reginal NWP model called the weather research and forecasting numerical weather prediction (WRFNWP) for probabilistic short-term wind power forecasting. The NWP can improve the resolution to accurately predict a certain point of weather parameters. Nevertheless, there are also some limitations during the practical application process, such as diverse physical properties which demands researchers to know and huge computation time it consumes.

Time series models, which are mainly based on the statistical

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method, include autoregressive model (AR), moving-average (MA), auto-regressive integrated moving average (ARIMA), etc. Qin et al. [2] developed a combination model with smooth transition periodic autoregressive model (STPAR) and the Elman artificial neural network (EANN) to predict the six-hourly wind speeds. In [3], linear and nonlinear ARMAX models for 10-min ahead forecasting for wind speed had been built and the performance of the models were tested for multi-step ahead prediction. Comparing with other prediction models, the proposed model showed a better performance. A hybrid model based on autoregressive (AR) model and Gaussian process regression (GPR) was proposed for probabilistic wind speed forecasting by Zhang et al. [4]. The overall structure of wind speed series was captured by AR model and the GPR was adopted to extract the local structure. Aiming at improving the accuracy of the wind speed forecasting, Cadenas and Rivera [5] put forward a method, in which the autoregressive integrated moving average (ARIMA) was utilized to forecasting the wind speed time series and then the artificial neural network (ANN) is exploited to take the nonlinear tendencies into account. It is worth noticing that the statistic models which simply use the historical data are only effective for the short-term wind speed forecasting (about 1–4 h ahead), and the models based on the statistical methodology cannot solve the non-linear problem well.

Machine Learning (ML) and Artificial Neural Networks (ANNs), with the characteristic of strong generalization, fast calculation speed and nonlinearity, have emerged increasingly in recent decades. Wang et al. [6] used the support vector machine (SVM) based on structure risk minimization principle to predict the short-term wind power. Meanwhile an improved pattern search algorithm, which took use of Lagrange interpolation to obtain the initial points, was availed to optimize the parameters of SVM. Yuan et al. [7] regarded the least squares support vector machine (LSSVM) as prediction model to forecast the wind power. Considering the kernel function and parameters influence, the paper established LSSVM model based on different kernel functions to conduct and then chose the best one. Also, an optimal algorithm called gravitational search algorithm (GSA) was used to optimize the parameters in the LSSVM model. Back Propagation Neural Network (BPNN), as a typical neural network, has an abundant application in prediction field. Gao et al. [8] investigated a BPNN-based model to forecast the short-term wind speed. In order to improve the accuracy, singular spectrum analysis and firefly algorithm were employed for the data preprocessing and parameter optimization, respectively. Chang [9] compared three different methods in short-term wind speed forecasting, namely persistence method, back propagation neural network method (BPNN), and radial basis function (RBF) neural network method. Jia et al. [10] successfully introduced the historical moment of wind speed, current moment of air pressure and temperature into the prediction model. The result showed that the improved artificial bee colony algorithm (ABC-BP) has the characteristics of a high precision and fast convergence rate.

Based on the aforementioned discussion, it can be seen that most of the model were only optimized by other algorithms, such as the improved pattern search algorithm (IMPS), gravitational search algorithm (GSA), firefly algorithm (FA) and improved artificial bee colony algorithm (ABC) so on. Considering the original wind speed time series characteristics of stochastic and instability, signal decomposing technique was introduced into the wind speed or power forecasting, and the simulation experiments demonstrate that it is effective.

At present, researchers generally use wavelet transform (WT) or empirical mode decomposition (EMD) to analysis the time series so that to achieve the goal of eliminating the wind stochastic volatility. Shao et al. [11] executed the wavelet transform to decrease the complex and stochastic of original wind speed data and enhanced the robustness of the prediction model. Tascikaraoglu et al. [12] carried out the WT work to boost the prediction performance considerably and the proposed method provided a significant improvement of in terms of forecasting, comparing with the various benchmark models. Hu et al. [13] presented an improved wavelet transform called empirical wavelet transform (EWT) to preprocess the original time series and the computational results showed that the suggested hybrid model favorably improves point wind speed forecasts in comparison with other models and provides satisfactory interval wind speed prediction.

However, there is a crucial problem that the scale level of WT usually set by researchers when using, which may cause fluctuations for the prediction results. Different from the WT, Empirical Mode Decomposition (EMD), a data-driven algorithm which plays a role in dealing with non-linear and non-stationary signals, can decompose the original signal into several sub-series. Generally speaking, the procedure of experiments based on the EMD and prediction models conducted as follows: (1) decompose the original wind speed series into several sub-series to reduce the random fluctuation; (2) the diverse prediction models were implemented to forecast the sub-series; (3) add all the results together and get the final prediction outcome.

Wang et al. [14] designed a novel hybrid model including EMD and Elman neural network for the wind speed forecasting. Hong et al. [15] invented one hour-ahead wind speed and power forecasting using empirical mode decomposition (EMD). The simulation data derived from a wind-turbine generator in Taiwan and they conducted the experiments for four seasons, respectively. Zhang et al. [16] came up with a novel combination including empirical mode decomposition (EMD), feature selection with artificial neural network (ANN) and support vector machine (SVM) for short-term wind speed forecasting. In that paper, EMD was tapped to decompose the original non-stationary wind speed series into several sub-layers and then a feature selection process was introduced to constitute the relevant and informative features which were used in the predictive model (ANN or SVM). The case analysis told that EMD can heighten the prediction precise and the hybrid model is suitable for the wind speed forecasting.

The mode mixing phenomenon hinders EMD from decomposing the original data into constituents with real physical meaning. With regard to this shortcoming, ensemble empirical mode decomposition (EEMD), restrained the mode mixing problem by adding the white-noise signal, was proposed by Huang in 2009 [17]. Wang et al. [18] put the EEMD and GA-BP neural network together to predict the on-line ultra-short term (10 min) and short-term (1h) wind speed forecasting, respectively. Comparing with the EMD-GA-BP and WT-GA-BP model, the GA-BP with EEMD performed the best accuracy. To further enhance the capacity of EEMD in the computational aspect, Wang [19] proposed a new decomposing algorithm called as fast ensemble empirical mode decomposition (FEEMD). Some studies have demonstrated that FEEMD algorithm can handle the jumping wind speed data successfully. Sun and Liu [20] decomposed the wind speed time series using the FEEMD and then predicted the subseries by the RELM separately. Three wind farms located in different sites in China were conducted to validate the efficient and practicable of built model.

Wind speed time series is a typical dynamic and nonlinear dataset and only relying on the signal decomposition techniques restricts the improvement of precision in wind speed or power prediction filed. Thanks to the chaos theory, some problems can be well solved by reconstructing the chaotic phase space. Chaos theory has a wide application in multifarious fields especially in the forecasting aspect. Kang et al. [21] utilized the chaotic phase space reconstruction for the displacement forecasting of surrounding rocks in Tongyu tunnel. Zhang et al. [22] applied chaotic theory into urban traffic flow prediction, by taking Ji'nan city traffic flow as example, the author presented a detailed illustration on defining the parameters of urban traffic flow time series phase space. Shang et al. [23] indicated that the chaotic characteristics obviously exist in the traffic system and chaotic local prediction method is implemented to analysis and forecast the traffic speed on the Beijing Xizhimen highway. Considering the strong nonlinear and the complex seeming stochastic dynamics behavior of the traffic time series in the globe system for mobile communication network, Hu and Wu [24] reconstructed the phase space and then conducted chaotic