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Generalized adaptive neuro-fuzzy based method for wind speed distribution prediction

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ABSTRACT

The probabilistic distribution of wind speed is one of the important wind characteristics for the assessment of wind energy potential and for the performance of wind energy conversion systems. When the wind speed probability distribution is known, the wind energy distribution can easily be obtained. Therefore, the probability distribution of wind speed is a very important piece of information needed in the assessment of wind energy potential. For this reason, a large number of studies have been published concerning the use of a variety of probability density functions to describe wind speed frequency distributions. Two parameter Weibull distribution is widely used and accepted method. Artificial neural networks (ANN) can be used as an alternative to analytical approach as ANN offers advantages such as no required knowledge of internal system parameters, compact solution for multi-variable problems. In this investigation adaptive neuro-fuzzy inference system (ANFIS), which is a specific type of the ANN family, was used to predict the annual probability density distribution of wind speed. The simulation results presented in this paper show the effectiveness of the developed method.

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1. Introduction

Wind plays a main role in many applications such as exploration of wind energy and bridge construction. Hence, the knowledge of wind characteristics is of great importance. When the probability density of the wind speed is known, their characteristics such as mean, variance and power density can be easily determined. In recent years, Weibull distribution has been commonly used, accepted and recommended distribution in literature to evaluate wind energy potential.

The Weibull distribution [1] is a two-parameter function used to fit the wind speed frequency distribution. This family of curves has been shown to give a good fit to measured wind speed data. The Weibull function provides a convenient representation of the wind speed data for wind energy calculation purposes. There are many methods for estimating the parameters of the Weibull wind speed distribution like maximum likelihood method and graphical method. The article in Ref. [2] gives an extensive review of some discrete and continuous versions of the modifications of the Weibull distribution. In paper [3], six kinds of numerical methods commonly used for estimating Weibull parameters are reviewed; i.e. the moment, empirical, graphical, maximum likelihood, modified maximum likelihood and energy pattern factor method. The results show that, in simulation test of random variables, the graphical method's performance in estimating Weibull parameters is the worst one, followed by the empirical and energy pattern factor methods, if data number is smaller. The performance for all the six methods is improved while data number becomes larger. Two mathematical models were proposed in Ref. [4] that respectively utilize Gaussian statistics and the Weibull distribution to accurately model the consequences on turbine productivity within turbulent environments. The main purpose of the study [5] was to investigate the possibility of developing wind speed probability density functions that might have better accuracy than the maximum entropy principle (MEP) and Weibull distribution. The statistical analysis based on the wind power density shows the MEP-type distributions describe the wind power density more accurately than the Weibull distribution. The aim of study [6] was to present the minimum cross entropy (MinxEnt) principle as an alternative method of determination of the wind speed distribution in the wind energy field. It was shown that the MinxEnt principle can be used as an alternative method to estimate both wind distribution and wind power accurately. In Ref. [7], a generalized feed-forward type of neural network (GFNN), was used to predict the annual wind speed probability density distribution. It was observed that ANN based wind

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speed distribution estimation gives better results for calculating the energy output from some commercial wind turbine generators. In Ref. [8] the use of a methodology to estimate the parameters of the Weibull wind speed probability density distribution and its standard errors was proposed. Three of the most commonly used methods to estimate the parameters of the Weibull distribution are revised and compared in Ref. [9]. In study [10], a new method was developed to estimate Weibull distribution parameters for wind energy applications. This new method is called power density (PD) method. Results of this study indicate that PD method is an adequate method to estimate Weibull parameters and it might have better suitability than other methods. Estimation of energy output for small-scale wind power generators is the subject in Ref. [11]. It was shown that the Weibull-representative data estimate the wind energy output very accurately. The overall error in estimation of monthly energy outputs for the total 96 months is 2.79%. The article in Ref. [12] presented the development of compressed wind speed data to be used in wind energy and performance calculations of standalone or hybrid wind energy systems. The overall errors in estimation of the wind energy yield using the Weibull representative compressed wind speed data are 3.67% and 3.21% for the three- and four-day months, respectively.

Even though a number of new mathematical functions have been proposed for modeling wind speed probability density distributions, still the Weibull function continues to be the most commonly used model in the literature. Artificial neural networks (ANN) can be used as an alternative to analytical approach as ANN offers advantages such as no required knowledge of internal system parameters, compact solution for multi-variable problems.

In this investigation adaptive neuro-fuzzy inference system (ANFIS) [13–16], which is a specific type of the ANN family, was used to predict the distribution of annual wind speed density. For the presently developed neural network, the same parameters as those required by the Weibull function are used as inputs for predicting the density distributions. The ANFIS model is designed based on three methods of estimating the parameters of the Weibull wind speed distribution: two variations of the maximum likelihood method as well as the popular graphical method. In other words the ANFIS model should estimates average two-parameter function of Weibull distribution based on the exciting methods.

ANFIS shows very good learning and prediction capabilities, which makes it an efficient tool to deal with encountered uncertainties in any system. ANFIS, as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers in various engineering systems [17–23]. So far, there are many studies of the application of ANFIS for estimation and real-time identification of many different systems [24–31].

2. Materials and methods

2.1. The Weibull function

This family of curves is widely used in statistical analysis. In wind energy analysis it is used to represent the wind speed probability density function, commonly referred to as the wind speed distribution. The Weibull distribution function is given by

$$P(v < v_i < v + dv) = P(v > 0)\left(\frac{k}{c}\right)\left(\frac{v_i}{c}\right)^{k-1}\exp\left[-\left(\frac{v_i}{c}\right)^k\right]dv, \quad (1)$$

where c is the Weibull scale parameter, with units equal to the wind speed units, k is the unitless Weibull shape parameter, v is the wind speed, v_i is the particular wind speed, dv is an incremental wind speed, $P(v < v_i < v + dv)$ is the probability that the wind speed is between v and $v + dv$ and, $P(v > 0)$ is the probability that the wind speed exceeds zero.

Eq. (1) and the other equations in this paper that refer to probability can be applied equally well whether probability is interpreted as relative (fractional or percent) or absolute (number of data points). For example, $P(v > 0)$ in Eq. (1) can be interpreted as the fractional probability that the wind speed exceeds zero or the number of hours per year that the wind speed exceeds zero.

The cumulative distribution function is given by

$$P(v < v_i) = P(v \geq 0)\left\{1 - \exp\left[-\left(\frac{v_i}{c}\right)^k\right]\right\}, \quad (2)$$

where $P(v < v_i)$ is the probability that the wind speed is less than v_i, and $P(v \geq 0)$ is the probability that the wind speed equals or exceeds zero.

The two Weibull parameters and the average wind speed are related by

$$\bar{v} = c \cdot \Gamma\left(1 + \frac{1}{k}\right), \quad (3)$$

where $\bar{v}$ is the average wind speed and Γ is the gamma function.

2.2. Wind speed dataset

Measured wind speed data are commonly available in time-series format, in which each data point represents either an instantaneous sample wind speed or an average wind speed over some time period. An example of such data (giving hourly averages over a 24 h period) is shown in Fig. 1. In some instances, wind speed data may instead be available in frequency distribution format. In this format, the frequency with which the wind speed falls within various ranges (bins) is given. An example of such data is shown in Fig. 2. The methods described in the following section can be used to estimate the Weibull parameters given wind speed in either time-series or frequency distribution format.

2.3. Estimation of Weibull parameters

Three methods of estimating the parameters of the Weibull wind speed distribution are used in this study: two variations of the maximum likelihood method as well as the popular graphical method.

2.3.1. The maximum likelihood method

The Weibull distribution can be fitted to time-series wind data using the maximum likelihood method [1]. The shape factor k and the scale factor c are estimated using the following two equations:

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right), \quad (4)$$

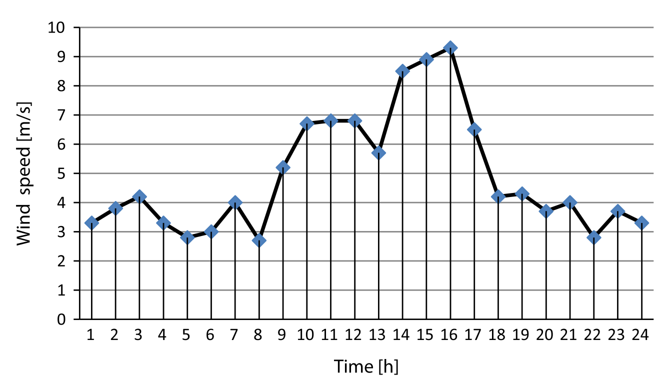

Fig. 1. Wind speed data in time-series format.

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