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Research Article

WIND SPEED MODELLING USING INVERSE WEIBULL DISTRUBITION: A CASE STUDY FOR BİLECİK, TURKEY

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Abstract

Wind speed modelling plays a critical role in wind related engineering studies. Frequency distribution of wind speed can be displayed different distributions such as Gamma, lognormal, Rayleigh and Weibull. Weibull distribution is used to model of many regions of the world wind speed in recent year. In this paper, wind speed potential analysis realized using Inverse Weibull Distribution (IWD) for Bilecik, Turkey. Maximum likelihood method for parameter estimation used for wind speed modelling analysis. All analysis is carried out by Matrix Laboratory (MATLAB) programming language. Monthly and yearly wind speeds are modeled by Inverse Weibull distribution. Accuracy of the modelling is evaluated in terms of Root Mean Square Error (RMSE).

Keywords*- Wind Speed, Modelling, Weibull Distrubition, Renewable Energy,Inverse Weibull Distrubition..*

1. Introduction

In modern societies, one of the most important indicators of the economic growth is energy. Energy demand increases continuously due to the rapid population growth and industrialization. This demand cannot be satisfied with the available limited resources. Thus, it is gaining much more importance to benefit from the renewable energy resources in a more effective manner.

One of the renewable energy resources is wind energy. Actually wind energy which is the oldest source has been used since BC 2800 by humankind. Until recent year this energy has been used for water pumping and power generation in rural areas. Today it is used as an alternative source of energy production. Wind energy systems operate depend on wind regime, wind shaft position and size of power generation system [12,13]. The potential of wind energy of a certain region can be determined before a wind conversion system is installed. The determination of wind energy potential depends on accurately modeling wind speed. Statistical properties of the wind speed are important to predict the output energy of a wind conversion system [13]. There are several distribution functions for wind speed and power density analysis in literature. The log-normal distribution [4,14.17], the inverse Gaussian distribution [11], the wake by [3,24], three-parameter log normal [6], the gamma distribution [10,19], two-parameter gamma distribution [21], hybrid distributions [8,16,22], the three parameter generalized gamma distribution [4,18], and similar distribution functions were used about energy and other research areas. Two-parameter Weibull density function [22] is commonly used in wind resource assessment to describe wind speed as a stochastic quantity. There are many different methods for estimating the shape (k) and scale (c) parameters of Weibull wind speed distribution function [1,7,15,20].

Alternative distribution which is Inverse Weibull Distribution (IWD) for modelling wind speed data is proposed by [2]. IWD is used for Bursa and Sakarya seasonal wind speed data by them. In this paper, monthly and yearly modeling of wind speed realized using Inverse Weibull distribution and Two Parameter Weibull distribution for Bilecik, Turkey. Maximum likelihood method used for modeling of wind speed. This paper is structured as follows: IWD and Two-parameter Weibull distribution methods are explained

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by Section 2. Section 3 contains parameter estimation method for IWD. Comparative modeling results are presented in Section 4. Finally, conclusion is given in Section 5.

2. Inverse Weibull Distribution

There are different methods for determining the wind speed distributions. In the literature, the two parameters Weibull distribution is often used in the statistical analysis of data. The Weibull distribution function is given by Equation (1).

$$f_W(\mathrm{v}) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

Where $f_w(v)$ is the frequency or probability of occurrence of wind speed v, c is the Weibull scale parameter with unit equals to the wind speed unit and k is the unitless Weibull shape parameter. The higher value of c indicates that the wind speed is higher, while the value of k shows the wind stability. The cumulative Weibull distribution function $F_w(v)$ gives the probability of the wind speed exceeding the value v. It is expressed by Equation (2):

$$\mathrm{F}_W(\mathrm{v}) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \tag{2}$$

The probability density function and cumulative density function of Inverse Weibull Distrubition are given below (Akgül et al. 2016)

$$f_{IW}(\mathrm{v}) = \frac{k}{c}\left(\frac{v}{c}\right)^{-k-1} e^{-\left(\frac{v}{c}\right)^{-k}} \tag{3}$$

and

$$\mathrm{F}_{IW}(\mathrm{v}) = e^{-\left(\frac{v}{c}\right)^{-k}}. \tag{4}$$

Different scale (k) and shape (c) parameter estimation methods which are Maximum Likelihood Method (MLM), Modified Maximum Likelihood Method (MMLM), Moment Method (MM), Power Density Method (PDM), Graphical Method (GM) and empirical methods are used in literature.

3. Maximum Likelihood Method for IWD

The likelihood function for two parameter Weibull distribution is given by

$$\mathrm{L(k,\ c)} = \prod_{i=1}^{n} f(\mathrm{v}_i;\theta) \tag{5}$$

$$\mathrm{L(k,\ c)} = \prod_{i=1}^{n} kc^{-k} v_i^{k-1} \exp(-\mathrm{c}^{-k}\mathrm{v}_i^{k}) \tag{6}$$

Taking the natural logarithm of likelihood function

$$\ln L(\mathrm{c,k}) = \mathrm{nlnk} + \mathrm{nklnc} - (\mathrm{k}+1)\sum_{i=1}^{n} \mathrm{lnx}_i - c^k \sum_{i=1}^{n} x_i^{-k} \tag{7}$$

By taking the derivatives of left side the equation with respect to these parameters and equating them zero, the following likelihood equations are obtained

$$\frac{\partial \ln L(\mathrm{k,c})}{\partial k} = \frac{n}{k} + n\ln c - \sum_{i=1}^{n} \ln \mathrm{v}_i - c^k \ln c \sum_{i=1}^{n} x_i^{-k} + c^k \sum_{i=1}^{n} x_i^{-k} \ln v_i = 0 \tag{8}$$

$$\frac{\partial \ln L(\mathrm{k,c})}{\partial c} = \frac{nk}{c} - kc^{k-1}\sum_{i=1}^{n} \mathrm{v}_i^{-k} = 0 \tag{9}$$

These equations are solved Newton-Raphson iterative method by using Matlab (MATrix LABoratory) software in this paper.

4. Wind Speed Potential Analysis

Future and available wind potential is very important to build of wind energy conversion system. For this reason estimation parameter results of distribution are studied monthly. Optimum model can be chosen according to performance criteria. The actual data sets collected hourly basis in Bilecik, Turkey, are taken from the Turkish State Meteorological Service. The IW and the Weibull distributions are used to model these data sets. Bilecik is located at N 39° 39' and E 30° 40' at the height of 850 m in Turkey as shown in Figure 1.

The maximum likelihood method was used for determining Inverse Weibull and Weibull parameters. Some descriptive statistics including maximum, mean, standard deviation, skewness and kurtosis of the used wind speed data for selected station is presented Table 1. The coefficient of Kurtosis is very high for Bilecik. It gives the degree of width of peak of a distribution.

In this paper, estimation of monthly and annual parameters for Bilecik region are implemented in Table 2 by using hourly wind speed data for 2014 year.

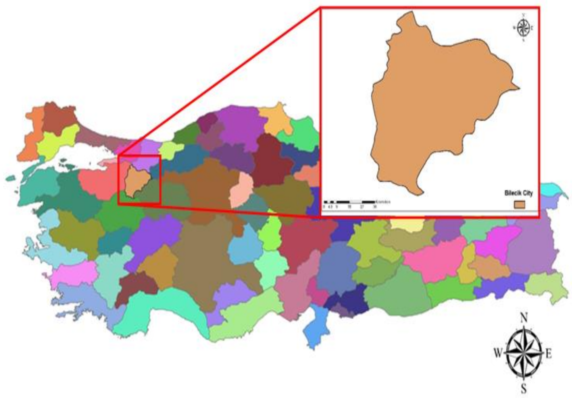

Fig. 1. Location of selected station and Bilecik province on the map of Turkey.

Hourly wind speed recorded by Turkish State Meteorological Service at 10 m height for the period of one years from January 2014 to December 2014.

It can be seen from the Figure 2 that Weibull and Inverse Weibull probability distribution function and cumulative distribution function of sample data, April 2014, are shown;

Table 1. Statistical values of wind speed data for certain region

Region	Bilecik
Maximum	12.00
Minimum	0.2
Mean	2.0318
Std.Dev.	1.1306
Skewness	1.0800
Kurtosis	4.2291

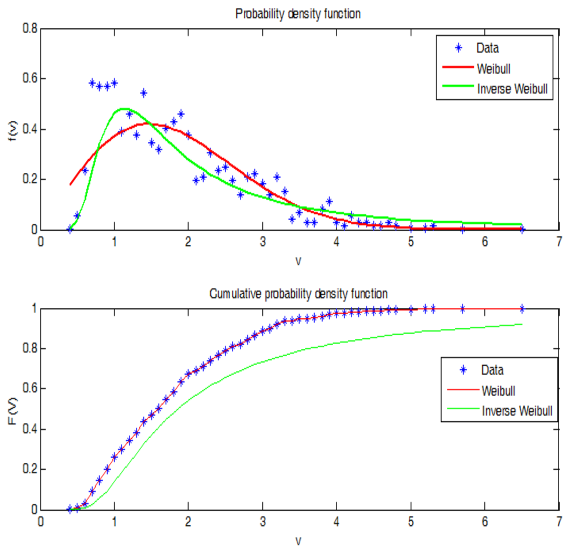

Fig. 2. Probability density and cumulative probability density function for sample month for Weibull and Inverse Weibull distribution.

Performance criteria of analysis is shown Root Mean Square Error (RMSE) by Equation (10).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)^2} \quad (10)$$

Where, y_i is the actual wind speed probability value, x_i is the probability value calculated from Weibull distribution and n is the number of observations.
Table 2 shows monthly wind speed data modeling results which consist of Weibull and Inverse Weibull distributions and error values. Error values presented for probability density functions (pdf).
IWD results for some months are better than Weibull distribution. Especially, left side of the probability density function is good fit to IWD. In other words, good results are observed for low wind speed data in IWD (Figure 3).

5. Conclusions

The potential of wind energy of a certain region can be determined before a wind conversion system is installed. The determination of wind energy potential depends on accurately modelling wind speed. Statistical properties of the wind speed are important to predict the output energy of a wind conversion system. There are several distribution functions for wind speed and power density analysis in literature.

Table 2. Monthly analysis results for weibull and IWD

Months	Methods	2014		
		k	c	RMSE for pdf
January	Weibull	2.1885	2.0545	0.0977
	IWD	1.6473	1.4704	0.0836
February	Weibull	1.9435	1.8455	0.0981
	IWD	1.6627	1.4806	0.1008
March	Weibull	2.2748	2.1660	0.0692
	IWD	2.0288	1.4890	0.0857
April	Weibull	2.0241	2.0614	0.0914
	IWD	1.6926	1.4989	0.0866
May	Weibull	2.0202	2.0965	0.0977
	IWD	1.7354	1.5225	0.0895
June	Weibull	2.1401	2.3132	0.0690
	IWD	2.5904	2.4307	0.0640
July	Weibull	2.2348	2.5420	0.0737
	IWD	2.1376	1.5341	0.0956
August	Weibull	2.0093	2.5030	0.0773
	IWD	2.1966	1.5634	0.0945
September	Weibull	2.1629	2.1439	0.0791
	IWD	2.0498	1.4956	0.0710
October	Weibull	2.2758	1.8371	0.0990
	IWD	1.8458	1.4105	0.0880
November	Weibull	2.1381	1.8864	0.1021
	IWD	1.5017	1.3814	0.0888
December	Weibull	1.9591	1.7732	0.0925
	IWD	1.0575	1.3276	0.1248
Yearly	Weibull	2.0466	2.1061	0.0595
	IWD	1.5048	2.3537	0.0770

In this paper Inverse Weibull Distribution which is proposed for wind speed data by Akgül et al. and Two-parameter Weibull Distribution function are used for actual hourly wind speed data for Bilecik, Turkey. Although Akgül et al. modelled for seasonal wind speed data, monthly analysis are used for IWD in this paper.
IWD results are better than Weibull distribution function for low wind speed data modelling. These analysis are preliminary research for wind speed data. In future studies, we will apply this method for seasonal analysis which has lots of years and different parameter estimation methods.

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We are thankful to Turkish State Meteorological Service, for the support in the accomplishment of the present study.

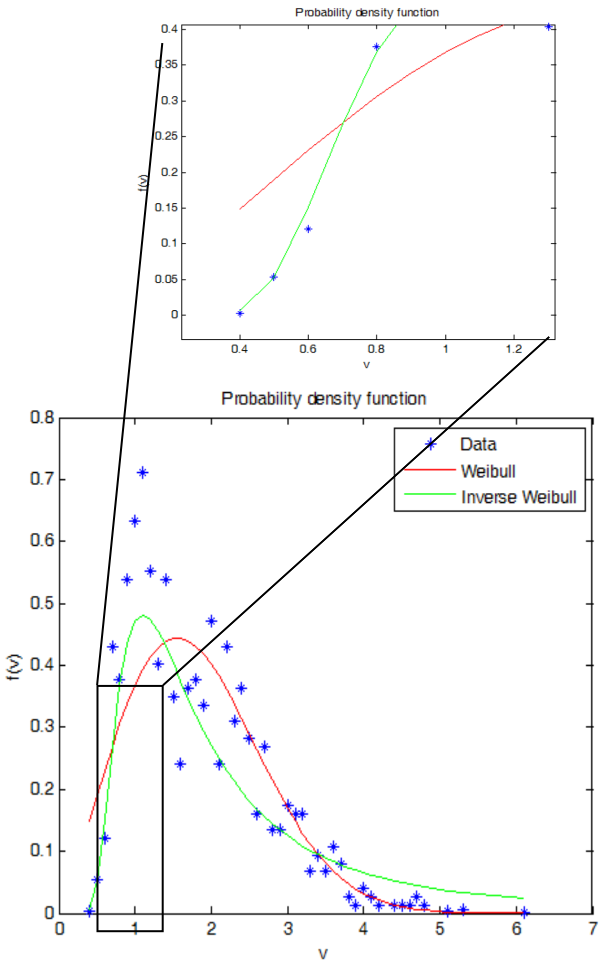

Fig. 3. Comparison of low wind speed data.

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