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Wind Speed Potential Analysis Based on Weibull Distribution

E. Dokur, and M. Kurban

***Abstract*— Weibull probability density function used to determine the wind energy potential commonly. In this paper, wind energy potential of Bilecik region is analyzed statistically by using the Turkish State Meteorological Service's hourly wind speed data between 2010-2014 measured in Bilecik meteorological station. It is used the two- parameter Weibull to determine wind energy potential of the region. The parameters of the Weibull distributions used for finding the estimation of average speed, standard deviation, and power density is found by using the Maximum likelihood method. All analysis is carried out by Matrix Laboratory (MATLAB) programming language. Monthly and yearly wind speeds are modeled by Weibull distribution statistically. Accuracy of the modeling is evaluated in terms of Root Mean Square Error (RMSE).**

***Index Terms*— Weibull Distribution, Wind Speed, Energy.**

I. Introduction

GLOBALLY fossil resources have very wide application area. The reason that fossil fuels used for meeting the energy need shall run short together with the fact that they are harmful for the environment leaded the path for a search of new energy sources worldwide and renewable energy sources have gained importance in this respect.

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 [1,2].

Wind energy conversion systems are chosen based on wind speed potential analysis of a region. Frequency distribution of wind speed can be displayed different distributions such as Gamma, lognormal, Rayleigh and Weibull. Two parameter Weibull distribution is used to model of many regions of the world wind speed in recent year. The reason of using this method is very good fit wind distribution [3].

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Two Weibull parameters are estimated using both the graphical and maximum likelihood methods. Genc et al [4]. Wind energy potential of Nigde region is studied statistically by using the Turkish State Meteorological Service's hourly wind speed data between 2008 and 2009 measured in Nigde meteorological station by Yıldırım et al [5]. On the side, there is novel method about Weibull distribution in literature [6].

In this paper, wind energy potential is modelled based on two parameter Weibull distribution statistically for Bilecik ,city in Turkey, by using the Turkish State Meteorological Service's hourly wind speed data between 2010 and 2014 measured. Scale and shape parameters are determined by maximum likelihood method. Matlab © (Matrix Laboratory) software is used for all analyses. Performance criteria of model is shown that RMSE (Root Mean Square Error).

II. 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 formula (1) :

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

Where $f(v)$ 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. k shape parameters are between 1.2 and 2.75 in the literature. The cumulative Weibull distribution function F(V) gives the probability of the wind speed exceeding the value V. It is expressed by formula (2):

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

Maximum frequency of wind speed is determined by formula (3):

$$v_{\mathrm{mod}} = c\left(1-\frac{1}{k}\right)^{1/k} \quad (3)$$

Maximum wind speed can be calculated formula (4) [7] :

$$v_{maks} = c\left(\frac{k+2}{k}\right)^{1/k} \quad (4)$$

Wind power is found commonly by formula (5) :

$$P = \frac{1}{2}\rho A v^3 \quad (5)$$

Where ρ (kg/m^3) is air density, A (m^2) is swept area. Mean power density for Weibull distribution is given by formula (6):

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \quad (6)$$

Where Γ is gamma function. Here, taking into account, the density of the air at sea level, 1 atmosphere pressure and 16.6. Celsius degree ρ_0 =1.225 kg/m^3 value; the corrected air density in reference to the height of the sea level (H_m) and other location information can be found according to formula (7) [8].

$$\rho = \rho_0 - 1.194.10^{-4} H_m \quad (7)$$

As is seen that the most important input is wind speed data for determining of power potential. Wind direction is important for position of installation wind energy conversion systems.

III. MAXIMUM LIKELIHOOD METHOD

Several methods are available in order to determine the two parameters of Weibull distribution. One of these methods is maximum likelihood method that is proposed by Steven and Smulders [9]. Maximum likelihood method requires large scale numerical iterations. Shape parameter and scale parameter are calculated by formula (8) and formula (9):

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right)^{-1} \quad (8)$$

$$c = \left(\frac{\sum_{i=1}^{n} (v_i)^k}{\sum_{i=1}^{n} v_i^k}\right)^{\frac{1}{k}} \quad (9)$$

Where v_i is wind speed and n is number of wind speeds.

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

IV. 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. In this paper, estimation of monthly and annual parameters for Bilecik region are implemented in table 1 by using hourly wind speed data between 2010 and 2014. The maximum likelihood method was used for determining Weibull parameters.

It can be seen from the Figure 1 that Weibull distribution function and cumulative distribution function of sample data, April 2010, was shown.

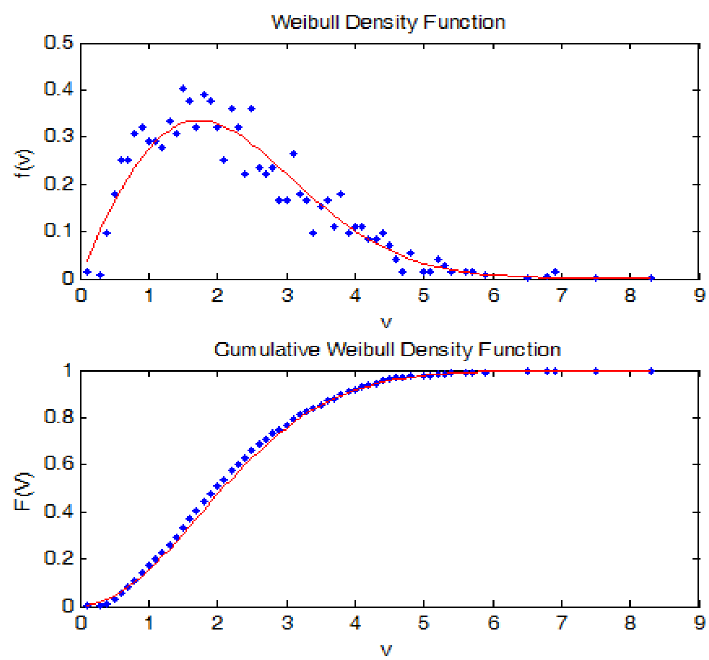

Fig.1. Probability density and cumulative probability density function for sample months

TABLE 1
WEIBULL PARAMETERS AND ERROR VALUES

	2010			2011			2012			2013			2014		
Months	**k**	**c**	**RMSE**	**k**	**c**	**RMSE**	**k**	**c**	**RMSE**	**k**	**c**	**RMSE**	**k**	**c**	**RMSE**
January	1.8139	2.4980	0.0254	2.0186	2.1777	0.0232	1.8901	2.4506	0.0367	2.2400	2.4860	0.0284	2.1885	2.0545	0.0328
February	1.8435	2.4785	0.0250	2.0939	2.0817	0.0281	1.9126	3.1130	0.0338	2.1236	2.2914	0.0387	1.9435	1.8455	0.0406
March	1.8592	2.4059	0.0228	1.8042	2.4342	0.0311	1.8626	2.2839	0.0304	2.0730	1.2524	0.0364	2.2748	2.1660	0.0261
April	1.9416	2.5110	0.0172	1.7541	2.4472	0.0301	1.7668	2.6074	0.0318	2.3111	2.3331	0.0267	2.0241	2.0614	0.0320
May	1.7574	2.3265	0.0292	2.0714	2.2945	0.0197	1.9938	2.1983	0.0317	1.9387	2.3502	0.0322	2.0202	2.0965	0.0258
June	1.9759	2.5162	0.0267	2.1847	2.3154	0.0177	1.9064	2.4906	0.0287	1.9435	2.6441	0.0322	2.1401	2.3132	0.0294
July	2.2358	2.9342	0.0158	2.1570	2.6608	0.0220	2.1363	2.9130	0.0231	2.3567	3.1580	0.0247	2.2348	2.5420	0.0301
August	1.9625	2.7771	0.0177	2.2373	2.9908	0.0246	2.0782	2.8532	0.0287	2.1287	2.8553	0.0362	2.0093	2.5030	0.0324
September	2.0343	2.4339	0.0204	2.2018	2.4763	0.0186	1.9479	2.3917	0.0280	2.0093	2.3163	0.0291	2.1629	2.1439	0.0353
October	1.7729	2.0780	0.0393	2.1314	2.1950	0.0222	2.1143	2.0224	0.0353	1.8692	2.0347	0.0367	2.2758	1.8371	0.0390
November	1.7828	2.1033	0.0341	2.2821	1.9283	0.0297	2.3329	2.1829	0.0259	2.2285	1.7290	0.0391	2.1381	1.8864	0.0371
December	1.9091	2.4441	0.0339	1.8086	2.2769	0.0437	1.8765	2.2167	0.0413	2.1275	2.2904	0.0321	1.9591	1.7732	0.0347
Yearly	1.8535	2.4775	0.0204	2.0053	2.3580	0.0203	1.8976	2.4743	0.0263	1.9156	2.3089	0.0268	2.0466	2.1061	0.0284

Wind data, consisting of hourly wind speed records over a 5-year period, 2010-2014, were measured in the Turkish State Meteorological Service in Bilecik. In Bilecik region by using wind speed measured for 4 years between 2010 and 2014, the conformity of wind speed blowing hours with Weibull function has been examined. Distribution of Wind speed is shown by Weibull functions. Scale and shape parameters are calculated 1.8535,2.0053,1.8976,1.9156,2.0466 and 2.4775, 2.3580, 2.4743, 2.3089, 2.1061 (m/s) for years, respectively.

Table 1 shows scale and shape parameters for each months of five years and error values.

Other values of 2013 and 2014 years are illustrated in Table 2. σ is standard deviation of wind speed in formula (11). Other formulas of wind speed parameters were given in section 2.

$$\sigma = \sqrt{c^2[\Gamma(1+\frac{2}{k}) - \Gamma^2(1+\frac{2}{k})]} \qquad (11)$$

Probability density and cumulative probability density functions of wind speed are illustrated in Figure 2 and 3, respectively for 2010-2014 years.

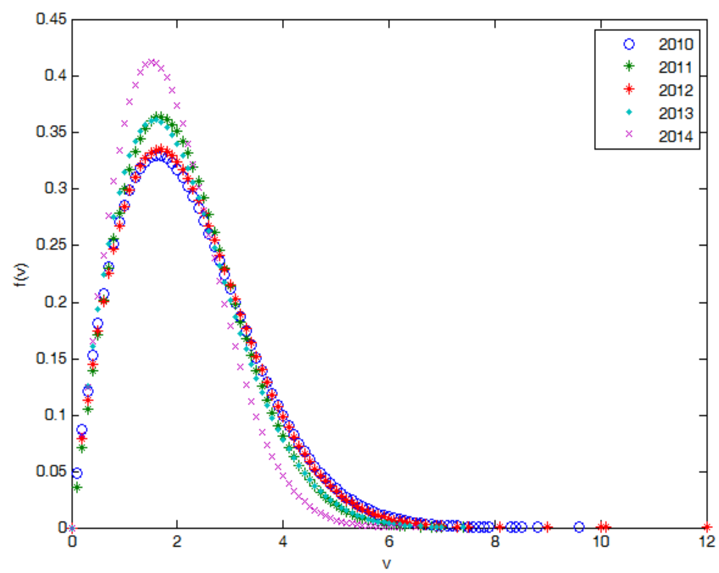

Fig.2. Probability density functions of Weibull distributions

TABLE II
WIND VALUES AND POWER DENSITY

Months	2013					2014				
	v_m	σ	v_{mod}	v_{maks}	P_w	v_m	σ	v_{mod}	v_{maks}	P_w
January	2.2018	1.0396	1.9091	3.3053	10.31	1.8195	0.8772	1.5544	2.7639	5.93
February	2.0294	1.0051	1.6980	3.1320	8.46	1.6365	0.8778	1.2724	2.6559	4.84
March	1.1094	0.5615	0.9115	1.7348	1.41	1.9186	0.8934	1.6791	2.8582	6.73
April	2.0671	0.9490	1.8256	3.0557	8.31	1.8265	0.9445	1.4723	2.8948	6.46
May	2.0842	1.1225	1.6167	3.3876	10.02	1.9368	1.0050	1.8425	3.1246	8.50
June	2.3448	1.2577	1.8230	3.8054	14.24	2.0486	1.0076	1.7236	3.1487	8.64
July	2.7986	1.2625	2.4983	4.0986	20.31	2.2514	1.0652	1.9494	3.3837	11.04
August	2.5287	1.2497	2.1194	3.8976	16.34	2.2180	1.1546	1.7768	3.5300	11.65
September	2.0526	1.0685	1.6443	3.2668	9.23	1.8987	0.9250	1.6092	2.9019	6.81
October	1.8065	1.0037	1.3508	3.0029	6.79	1.6273	0.7575	1.4246	2.4237	4.10
November	1.5313	0.7263	1.3235	2.3047	3.48	1.6706	0.8224	1.4046	2.5690	4.69
December	2.0285	1.0030	1.6994	3.1275	8.43	1.5722	0.8373	1.2315	2.5394	4.25
Yearly	2.0483	1.1131	1.5705	3.3535	9.63	1.8658	0.9553	1.5177	2.9396	6.81

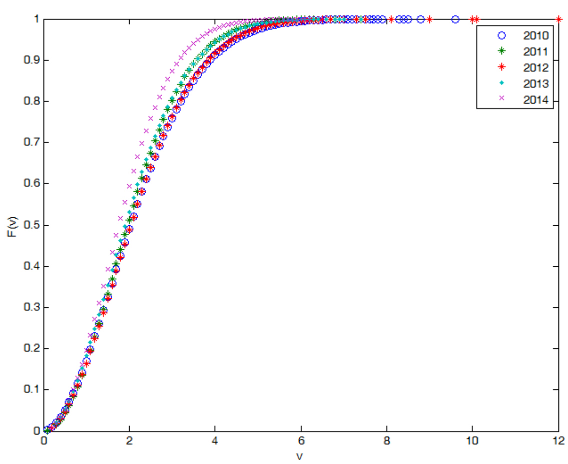

Fig.3. Cumulative probability density function

V. CONCLUSIONS

It is necessary to establish determine wind speed distribution for establishing a region of wind energy potential. Wind power density distribution is determined according to the definition of wind speed.

The wind energy potential in Bilecik is statistically analyzed based on wind speed data which measured hourly in 2010-2014.

It is used the Weibull distribution to determine wind energy potential of the region. Determination of Weibull parameters was used maximum likelihood method. Weibul shape parameter, k and scale parameter, c are found yearly, 1.8535,2.0053,1.8976,1.9156, 2.0466 and 2.4775, 2.3580, 2.4743, 2.3089, 2.1061 (m/s) , respectively.

The lowest power density is observed in winter and autumn for Bilecik region in 2010-2014. Generally, average wind speed and power density values are high in summer. However average wind speed and power density is not only important but also data distribution is significant for energy production.

The studies should continue and the measurements should be done in different regions and at different heights and for long periods of time. The whole region should be examined thoroughly, the characteristics of the region should be identified and cost analysis should be carried out. As a result it is possible to make more accurate and true assessments. Our work about identification and evaluation of renewable energy potential of this region will be continued.

Such studies which are determined to speed up the use of these energy sources and its production in our country is very important for our future.

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BIOGRAPHIES

Emrah DOKUR was born in Istanbul, Turkey in 1987. He received the B.Sc. in Electrical and Electronics Engineering from Faculty of Engineering, Istanbul University, Turkey in 2010 and M.Sc. degrees in Electrical Engineering, Istanbul Technical University, Turkey in 2013. He is a Ph.D. student Department of Energy System Engineering in Bilecik S.E. University. Since 2011, he has been research assistance in the same university. His research areas include high voltage engineering, renewable energy systems, power system analysis.

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