A Study on the Analysis of Wind Measurement Data and Electrical Energy Production Potential

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Abstract

In recent years, due to the growing problems about fossil fuels such as increasing slopes of reserves reducing and also expanding environmental problems yield countries and also energy companies to increased demand for clean and renewable energy sources all over the world and also over Turkey. Establishing wind energy farms is one of the most rapidly growing businesses among the renewable energy sources installation in terms of the lack of this type of utilization for Turkey and also growing energy supply related to high population growth and rate of economic development and then also due to high rate of imported energy sources. Turkey is one of the rich countries in Europe with respect to wind energy potential, especially for the Marmara and Aegean coastlines of Turkey surrounded with sea sides at its three parts of the boundaries that have regular and continuous wind energy potential. Effective using of this wind energy potential is very crucial for Turkey and it also depends on accurate measurement and careful analysis of that measurements wind energy.

Wind speed values such as velocity, frequency and direction distributions are some of the most important values for the calculation of electrical energy production from the selected wind turbines and also selection of the proper types of wind turbines. For this study, wind measurement mast has been established and annual wind measurements from Sakarya-Esentepe region of Turkey have been used for the statistical analysis of wind measurements by using proper softwares for wind energy such as WindPro and WASP then proper types of wind turbines selected and annual electrical energy production has been predicted as an example for this type of wind plant.

Keywords: Wind energy, wind turbine, electrical energy production, wind energy prediction.

1. INTRODUCTION

Today, electrical energy generation from wind by using modern wind turbines is very widespread in all around the world. As end of 2015, the wind energy installed power capacity in the world was 432.883 GW. Turkey is considered in a good position with respect to wind energy potential, due to the fact that she meets more than half of its energy necessity as imported as a raw source from foreign countries. As end of 2015, installed wind power capacity in Turkey has been pointed out as 4694 MW [1].

In this study, by using the measured data about wind obtained from wind measurement station mast for the study about local wind energy generation purpose, analysis steps and methodology of wind measurements and also determination of electrical energy generation potential from selected proper wind turbines have been studied. In the study, proper wind turbine selection for wind measurement analysis and also how much energy and power can be obtained have been also examined. By using the wind measurements obtained from the wind measurement station mast installed at Sakarya- Esentepe region, the annual electrical energy generation value from a selected proper type of wind turbines and also appropriate installation of this type of turbines at this location have been also predicted.

2. METHODOLOGY CONCEPTS

According to related studies about determining the wind energy potential for a specific location, it has been showed that wind velocity distributions shows Weibull distribution [2-13]. The general expression of the two-parameter Weibull probability density function can be shown as follows [9, 14]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (1)$$

which *f(v)* expresses the Weibull density function for the wind speed with respect to *v* and *k* non-dimensional parameters and the scale parameter of *c* also. To find these non-dimensional and scale parameters, graphical method has been used. The average wind speed of Weibull distribution can be expressed as follows [5]:

$$v_m = c\Gamma(1+\frac{1}{k}) \qquad (2)$$

where Γ() expresses the gamma function and k is non-dimensional parameter. Obtainable wind power per unit area of turbine can be expressed with the following equation;

$$p(v) = \frac{1}{2}\rho v^3 \quad (3)$$

where ρ is the air density at this location. The average wind power density P for Weibull distribution can be expressed with the following equation [5, 7, 15]:

$$P_m = \int_0^\infty p(v) f(v) dv = \frac{1}{2}\rho c^3 \Gamma\left[1 + \frac{3}{k}\right] \quad (4)$$

For a selected wind turbine, C_p is the turbine power coefficient, η_{mec} is the mechanic system efficiency and η_e electric system efficiency and the initial wind power is $p(v)$, the electrical power to be obtained from ideal wind turbine can be expressed as follows [16]:

$$P_e = C_p \eta_{mec} \eta_e p(v) \quad (5)$$

A wind turbine starts power generation with its initial speed of V_1 (cut-in speed) and continues until it reaches to nominal power generation (P_R) in speed of V_R. After the turbine reaches its nominal power generation, it begins to slow down in a controlled manner. This deceleration movement ends in cut-off speed of (V_0). The turbine turns off itself in wind speeds above V_0 cut-off speeds and makes no energy generation [16]. The energy generation amount to be obtained from an ideal wind turbine E_{TW} can be expressed with the following equation [15-17].

$$E_{TW} = T\left[\int_{V_1}^{V_R} P_e f(v) dv + \int_{V_R}^{V_0} P_R f(v) dv\right] \quad (6)$$

Here, T expresses the time. The real value (P_{Te}) of electrical power obtained from wind by means of the wind turbine and generator can be calculated with the turbine performance curve. The real energy amount E_{TA} that may be obtained from a wind turbine can be expressed with the following equation.

$$E_{TA} = T \int_{V_1}^{V_0} P_{Te}(v) f(v) dv \quad (7)$$

Efficiency of a wind turbine η_T is equal to the proportion of the real energy generation amount obtained from turbine to the ideal energy generation amount. The capacity factor C_F of a wind turbine expresses the energy generation performance of a turbine and is the proportion of real energy generation amount to the energy generation amount in nominal power [15, 18].

3. ANALYSIS AND APPLICATION

In this study, 12-month wind data obtained from the wind measurement power station installed in Sakarya-Esentepe region including 2006 and 2007 years were used. The analysis study consists of two phases. In the first phase, statistical analysis of wind data is made. In the analysis, in determination of wind speed distribution, two-parameter Weibull distribution is used. In the second phase, the wind power station (WPS) analysis is made to determine the turbine locations of wind farm planned to install for purpose of energy generation in the region, to select wind turbine types and determine the energy amount to be generated. Besides, in analysis of wind data, establishment of graphics and WPS analysis, the WindPRO and WAsP softwares were used [19].

In this research, statistical analysis of wind data have been used from another study of the authors [20]. By making statistical analysis of wind data, the wind speed frequency distribution was obtained (Figure 1). The annual average wind speed and frequency are given in Figure 2. Figure 2 shows that the maximum wind speed frequency is in the north and annual frequency is greater than 22% in this direction. Also in the North-Eastern and North-Western, it was seen that aspects of the notably-sized wind frequency. Annual mean wind speed values are higher than 4m/s in North, North-Eastern, North-Western, West and South. In Table 1, the monthly and annual average wind speed, Weibull parameters and average power density values are given. According to the table, the highest and the lowest average wind speed values for 30 m hub height occur in January and October respectively. Annual average wind speed and power density values are determined as 4.55m/s and 121.01 W/m2 according to the Weibull distribution. In Table 1, it is showed that Weibull and real values of average wind speed and power density are too close to the each other. As shown in Figure 3, the highest sectoral annual energy density occurs in the north direction and is also above 250 kWh/m^2.

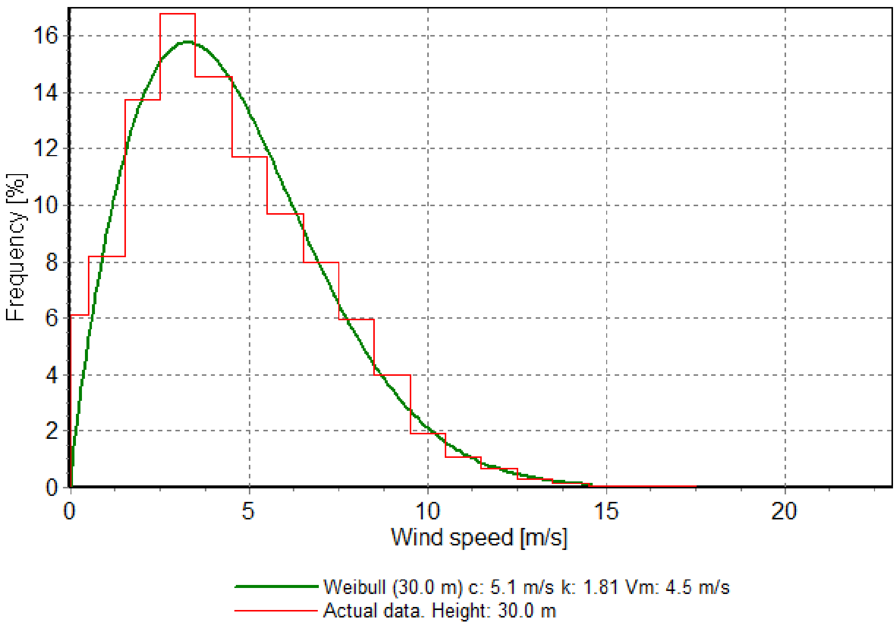

Fig. 1 Frequency Distribution of Annual Wind Speed.

As a result of the WPS analysis, Tahtalık and Çakırlıgeçit Tepe surroundings were selected as the wind farm installation area that is planned for purpose of model application (Figure 4). Besides, for the model wind farm, 3 pieces Fuhrlander FL-2500 type wind turbines of which nominal power is 2500 kW, hub height 160 m, rotor diameter 100 m were deemed appropriate. In Figure 4 and Table 2, placement and coordinates of the wind turbine are given. In Figure 5, calculation used in energy production, power generation curve of the wind turbine is given.

The results of analysis made by using the wind data for the model wind farm are given in Table 3. When the table is examined, it is seen that the annual total energy generation amount of the 7.5 MW wind farm is 13445.3 MWh, capacity factor value is 20.5% and Park efficiency is 98.3%.

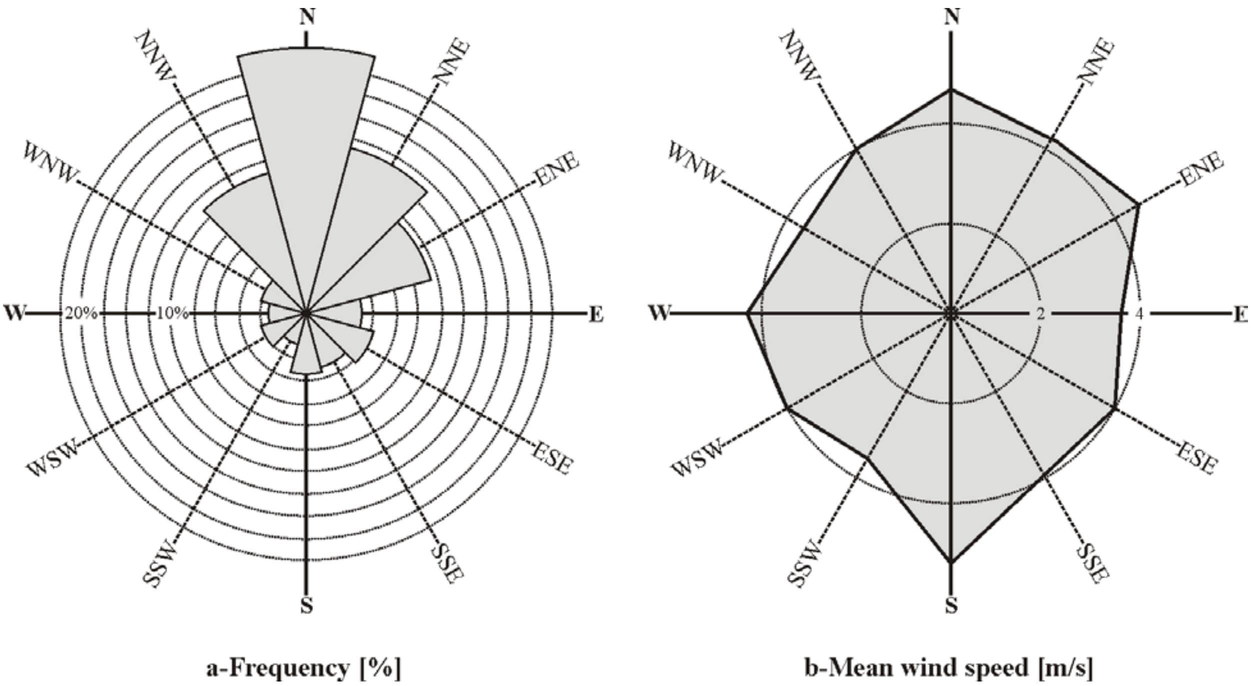

Fig. 2 Local Sectoral Velocity and Frequency Variation for Selected Region

4. CONCLUSIONS

In this study, by using the wind data obtained from wind measurements made for purpose of energy generation in a region, the amount of energy generation was estimated. Analysis of wind data and energy and power connections of wind turbines were examined. For this purpose, the wind data obtained from measurements obtained from the wind measurement station installed at Sakarya-Esentepe Region were used.

Detailed statistical analysis has been made by using WindPRO and MATLAB softwares and after this statistical analysis of wind data, the annual average wind speed value has been obtained as 4.55m/s and also annual average power density value has been obtained as 121.01 W/m^2 and in this region, dominant wind blowing direction has been determined as the north direction.

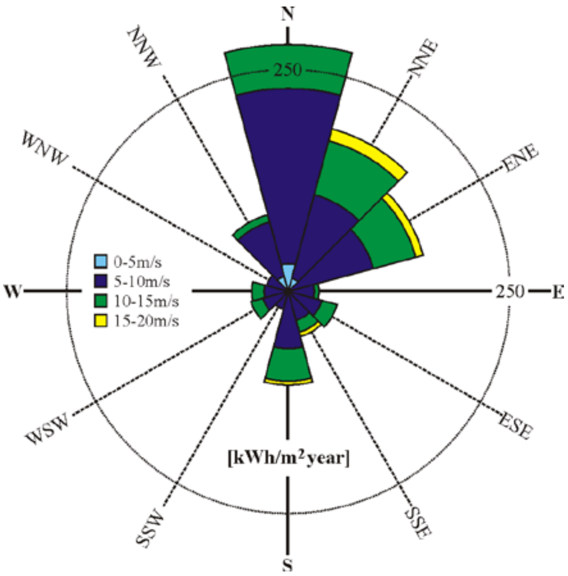

Fig. 3 Local Rose Map of Sectoral Wind Energy Variation for selected region

Table 1 Monthly and Annual Averages of Wind Speed, Weibull Parameters and Power Density

Months	Weibull distribution				Actual data	
	V_m [m/s]	k	c [m/s]	P_m (W/m^2)	V_m [m/s]	P_m (W/m^2)
January	6.22	2.11	7.02	258.00	6.16	261.19
February	5.37	1.99	6.06	177.06	5.23	178.54
March	5.28	1.91	5.95	178.77	5.27	181.05
April	4.24	2.03	4.79	86.53	4.16	87.90
May	3.99	1.94	4.50	76.60	3.91	77.74
June	3.92	1.90	4.41	72.95	3.85	74.43
July	4.33	1.83	4.87	99.89	4.22	101.48
August	4.24	1.88	4.78	92.35	4.20	94.18
September	4.29	1.98	4.84	91.55	4.21	93.15
October	3.62	1.92	4.08	57.88	3.56	58.79
November	4.56	1.89	5.13	114.50	4.47	116.10
December	4.25	1.55	4.73	120.43	4.24	121.12
Annual	4.55	1.81	5.12	121.01	4.49	122.26

Table 2 Coordinates and Locations of Wind Turbines

Turbine number	Coordinates	Altitude (m)	Nearest turbine	Horizontal distance to nearest turbine (m)	Distance as rotor diameter	Park efficiency (%)
T1	274.193 – 4.516.332	330	T2	447	4.5	98.6
T2	274.640 – 4.516.349	335	T1	447	4.5	97.2
T3	275.063 – 4.516.593	290	T2	488	4.9	99.0

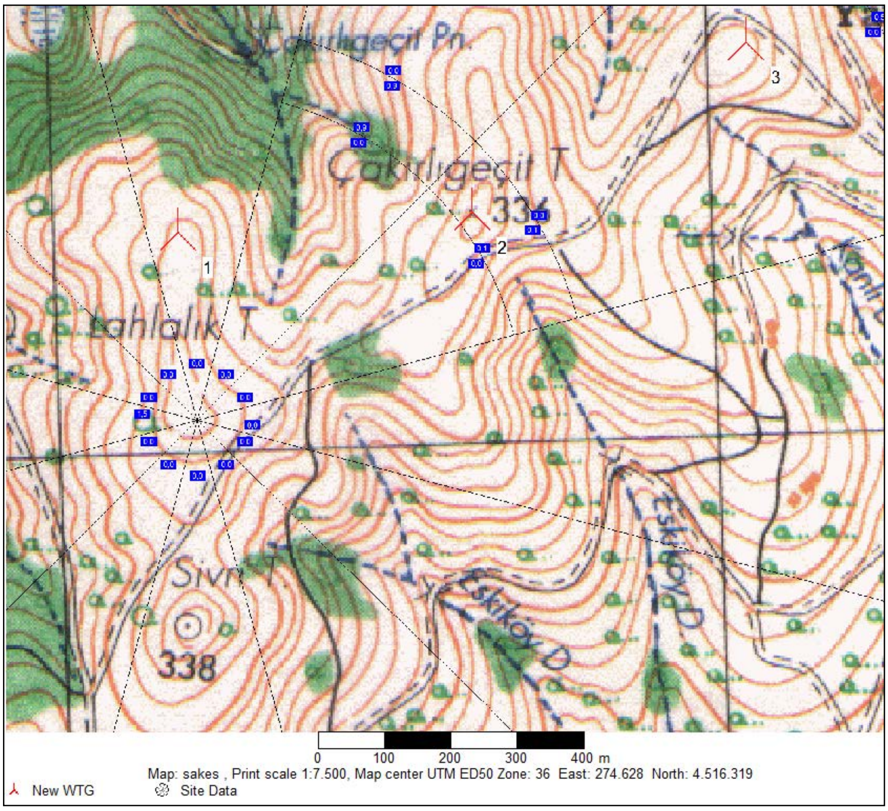

Fig. 4 Locations of Wind Turbines for selected region

Table 3 Analysis results

WTG Manufacturer	Fuhrlander
WTG type	FL 2500-100
Hub height (m)	160
Rotor diamater (m)	100
Installed power (MW)	7.5
WTG number	3
Rated power (kW)	2500
Total energy production (MWh)	13445.3
Capacity factor (%)	20.5
Park efficiency (%)	98.3

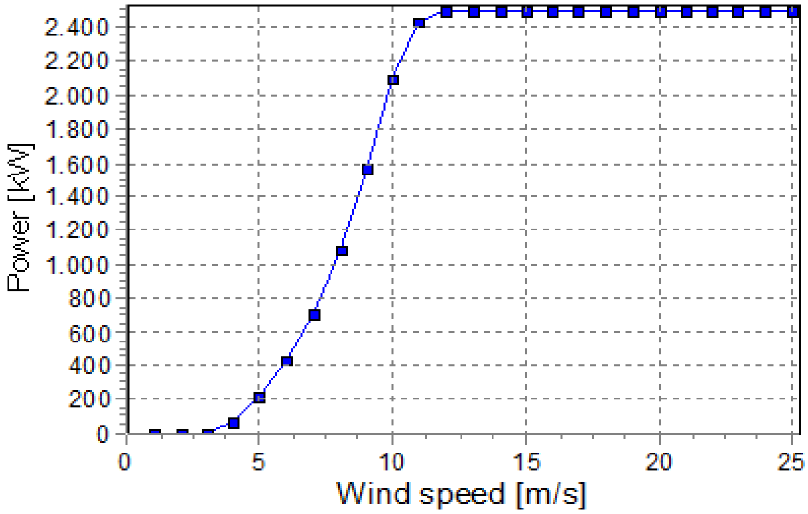

Fig. 5 Power generation curve of the selected wind turbine

As a result of the WPS analysis made for purpose of calculation of electric energy to be generated from wind in the region, a model wind farm was planned. For this wind farm, an appropriate wind turbine types and installation places of turbines were determined. As a result of the analysis made for this purpose, the annual total energy generation amount, capacity factor and part yield values of the model wind farm were determined.

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