THE ANALYSIS OF WIND DATA WITH RAYLEIGH DISTRIBUTION AND OPTIMUM TURBINE AND COST ANALYSIS IN ELMADAĞ,TURKEY

Yağmur ARIKAN[1], Özge Pınar ARSLAN [1], Ertuğrul ÇAM [1]

[1]Kırıkkale University, Faculty of Engineering, Electrical and Electronics Engineering Department

yagmurarikan@gmail.com, pozge.arslan@gmail.com, ertugrul_cam@yahoo.com

Abstract: *In this study, wind energy potential of Elmadağ region is analyzed statistically by using the data of wind speed that is measured hourly between 2012-2013 years, then economic analysis of wind investment in the region has been studied. Wind turbine parameters and wind speed distribution in the region play an important role to get energy. Therefore, firstly, Rayleigh statistical method is used for the research of region's wind energy potential. Wind speed data of region, scale parameters value, energy density quantity, the most common wind speed, speed values that have maximum contribution to energy generation are calculated monthly and annually with this method. In the second part of the study, amount of energy generation and capacity factors are calculated annually by using three different turbines. Finally, cost analysis of investment is made by various calculation methods and economic profitability is calculated. According to results, the most convenient and profitable turbine is determined by comparison.*
Keywords: *Wind energy potential, energy generation, cost analysis.*

1. Introduction

The need of electricity is increasing with every passing day. This problem makes people to use new energy sources and has led to diversify the energy sources. The needed energy must be supplied in a continuous, good quality and secure way to sustain human life and increase the quality of life. The high amount of this energy is supplied from fossil resources. The reduction of fossil fuels and high carbon dioxide emission of power plants that uses these fuels has caused to focus on renewable and alternative energy sources for energy generation.

One of the studies in recent years is energy generation by using wind potential that shows great improvement in the world especially in Europe. Circulation of wind freely in the atmosphere, bringing environmental pollution hardly make the wind one of the indispensable options in using energy generation. According to report prepared in December 2013 by Global Wind Energy Council, installed wind power has been increasing incrementally since 2000. For instance, installed wind power has reached to 17.400 MW in 2000, 73.938 MW in 2006, and 318.105 MW in 2013. [1].

Turkey is a rich country in terms of wind potential. According to General Directorate of Renewable Energy, Turkey's techno-economic wind potential is 48.000 MW. However, it is determined that economic portion of this potential is approximately 20.000 MW [2,3]. Wind speed at hub height must be about 7 m/sn and region's wind power density must be 400 W/m^2 for economic wind power plant [4]. Therefore, various analyses must be performed before making an investment of wind power plant at region.

In this study, Elmadağ which is the county of Ankara is selected for application region for having comprehensive wind data of it and being appropriate for investment. Hence, amount of generated energy, number of turbines that meet the electricity need of region, and capacity factors with three different turbines which have same hub height are calculated by evaluating wind potential of region with Rayleigh statistical method and by using its hourly wind speed data which are got from State Meteorology Affairs General Directorate and belong 2012-2013 years [5].

Then, the most appropriate turbine for region is determined by finding payback period of investments and profil amounts with present value and internal stability methods by using current cost data.

2. Basic Analyses In Wind Energy Fesability Study

Before the installation of wind power plant in a region, various economic, environmental, and technical assesments must be made. The next stage is investment after feasibility investigation. Investors are getting help from various

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companies for these assessments. The subjects that companies help are given respectively below;

a) Examination of the regulations about wind energy.
b) Selection of region that wind power plant will build, taking measurements with placement of measurement stakes in region, and recording them.
c) Comparison of measurements with data taken from the nearest meteorological station.
d) Prediction about future with various statistical methods after determining the reliability of data.
e) Investigation of field's tomographic structure.
f) Selection of appropriate turbines for region, calculation of amount of energy.
g) Calculation of investment cost, payback period of this investment and amount of profit that investor will get with various economic methods [6].

After obtaining reliable data for region, studies are grouped into three main headings. These are potential analysis, energy analysis and feasibility analysis of investment. Analyses and methods are described in detail below.

2.1. Potential Analysis- Weibull and Rayleigh Distribution

Wind speed is not constant in each region and varies depending on surface and weather. Making appropriate and accurate predictions for wind is important in changing energy markets in recent years. There are two solution methods for predictions. These are increasing the number of measurements or getting characteristic of wind speed in the region with statistical methods. Increasing the number of measurements is not preferred generally because it postpones investment and increases cost [7,8].

There are various methods for getting characteristic of wind speed. Weibull and Rayleigh distribution are the most preferred methods. Probability density function and cumulative density function are determined with this distribution methods. These methods are suitable for wind speed distribution, easy in terms of determination of parameters and flexible so they are used enormously [9, 10].

Weibull distribution was found by Swedish physicist Waloddi Weibull in the 1930s. The distribution consists of two parameters. Weibull probability density function that is used in the determination of the most frequent wind speeds is expressed as in equation 1[8]:

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

where $f_w(v)$ is the probability of observing wind speed v, k is the Weibull shape parameter and c is the Weibull scale parameter. While k parameter varies with the frequency of the wind, c parameter varies with mean speed. When Weibull distribution is applied to wind data, shape parameter takes the value of one near the equator, two for temperate latitudes and three for continuous wind zones [8,9,11].

Weibull cumulative distribution gives the probability of occurance of wind speed which is less than or equal to vertain V value and is expressed as in equation 2 [8]:

$$F(v) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

Rayleigh distribution is a special form of Weibull distribution and shape parameter is always equal to two. Mean wind speed is enough to determine wind characteristic in this distribution. It is known that wind distribution is more applicable to Rayleigh distribution when mean wind speed is greater than 4.5 m/s [8].

Rayleigh distribution function is shown in equation 3. Frequency probabilities of wind and blowing time in one year can be established thanks to this distribution. When this distribution is shown graphically, the area under it is equal to 1. Rayleigh cumulative distribution function is also given in equation 4. V_m in the equations represents the mean speed [8].

$$\text{fR (w)} = \frac{\pi v}{2Vm^2}\exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{Vm}\right)^{2}\right] \quad (3)$$

$$\text{FR (w)} = 1 - \exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{Vm}\right)^{2}\right] \quad (4)$$

Rayleigh probability density function can be expressed as in equaiton 5 depending only on scale parameter as scale parameter in distribution is always equal to two. Scale parameter can be found from equation 6 depending on mean speed [8, 9].

$$\text{f R (w)} = \frac{2v}{c^2}\exp\left[-\left(\frac{v}{c}\right)^{2}\right] \quad (5)$$

$$c = \frac{2}{\pi}\text{ Vm} \quad (6)$$

2.2. Energy Generation From Wind

Wind is defined shortly as the movement of air in the atmosphere. Air in the atmosphere has a certain speed as it has a certain mass and moves. Kinetic energy that air has due to its mass and velocity is given in equation 7 [8].

$$E_{kinetic} = \frac{1}{2}mV^2 \quad (7)$$

The vertical component of the wind is neglected because it is very low compared to the horizontal component. The wind power can be expressed as in equation 8 based on the principles of conservation of momentum and kinetic energy. ρ is air density and A represents cross section in the equation. As seen from the equation, wind power is proportional to the cube of wind speed and intensity of wind speed plays an important role in energy and economic dimensions while wind power plants are being established [8].

$$Pr = \frac{1}{2}\, p\, A\, v^3 \quad (8)$$

The amount of energy obtained from wind in any region at a certain time interval t is calculated by integration of wind power in time interval 0-t and it is shown in Equation 9 [8].

$$\mathrm{E} = \int_0^t Pr dt = \int_0^t \frac{1}{2} pA\, V^3\, dt \quad (9)$$

There are many factors that affect the amount of energy. These are:

Height: Wind speed is converted to the desired height with Hellman equation. It is shown in Equation 10. H_o represents height of measurement, H represents height of wind speed to be changed, V_o represents wind speed at H_o height, V represents wind speed at H height, and $\propto$ represents roughness coefficient [12].

$$\left(\frac{v}{v_0}\right) = \left(\frac{H}{H_0}\right)^{\propto} \quad (10)$$

Roughness Coefficient: While rougness coefficient is increasing, wind speed and the amount of energy derived from wind decreaes as can be seen from Equation 10. Roughness coefficient varies with ground shape. For instance, the area which has harsh land has the value of 0.1 while the area with long grass has the value of 0.15. It is 0.25 for rural forest areas and 0.4 for area that has buildings [12].

Temperature and Pressure: The values of temperature and height of area affect the air density. The air density is established as 1.225 kg/m^3 at 15ºC temperature and 1 atm pressure [12].

Turbulence: Turbulence intensity is the ratio of the standard deviation of wind speed to the mean wind speed. If this value is too much, it affects the operation of wind turbines negatively [12].

Wind turbines are the mechanisms that convert kinetic energy of wind speed into mechanical energy and electrical energy respectively. The amount of energy is calculated by using wind turbine power curves. Therefore, it is important to overlap with wind speed of region when wind turbine is selected. According to Betz theory, maximum efficiency that can be obtained from wind turbine is 59%. It is approximately 35-40% for today's wind turbines. Capacity factor is the other term that is related to performance of wind turbine and it can be found from Equation 11 [8].

$$\text{Capacity Factor} = \frac{Total\ generated\ energy}{Pr * 8760} \quad (11)$$

If the capacity factor is 0.30 and more than it, it can be said that this region is suitable for wind energy investment.

2.3. Cost Analysis of Wind Investment

Wind energy systems are high cost systems and it is required to make financial analyses before starting to investment. In wind energy systems, the total cost consist of wind turbines (70-75%), construction and installation (20-25%), project and consultation (3-4%) , maintanence and reparation (2-3%), and other costs that may arise during investment (3%).

After the total cost of investment is determined, it can be decided whether the investment is cost-effective by using these and other data with various analyses. Explanation of this analysis is shown below.

Present Value Method (Pv): Pay-back period of investment can be found and investor can know the amount of profit that will get each year during the life of investment with this analysis. Present value is shown in Equation 12. Pv represents the present value of the investment, N represents interest rate and t represents time in the equation [13].

$$Pv = \sum_{t=0}^{h} At(1+i)^{-t} \quad (12)$$

2.4. Effect of Wind on Clean Environment

Environmental pollution with the use of fosil fuels and global warming are important issues today. Wind is a clean source of energy and it doesn’t raise greenhouse gas emissions. To reduce greenhouse gas emissions, there is punisment if specified limits are exceeded and there is award if emission is less.

3. Features of Studied Region

In this study, Elmadağ region which is district of Ankara is selected. Elmadağ is in the Central Anatolia Region in Turkey, has 39º54’N ve 33º23’E coordinates, and its altitude is 1178 meters. Hourly wind speed data obtained from State Meteorological Station which belongs 2012-2013 years is gotten at 10 meter from the ground surface [5]. According to these measurements, the mean speed data of twelve months are calculated as in Table 1.

Table 1. Monthly mean wind speed data

Months	Mean Wind Speed (m/s)	Months	Mean Wind Speed (m/s)
January	6.78	July	4.95
February	5.86	August	6.08
March	3.71	September	1.89
April	4.67	October	2.14
May	4.98	November	2.65
June	6.41	December	7.29

Mean wind speed of region at 10 meter measurement height is 4.78 m/s. The lowest mean wind speed data is calculated in September and highest mean wind speed data is calculated in December.

4. Analyses and Results

In this study, the potential analysis of Elmadağ region is calculated by using Rayleigh statistical method in order to both make prediction about future and extract wind frequency distribution with the help of hourly wind speed data that belongs 2012-2013 years. The results using only mean wind speed data are given in Table 2 and Table 3. V_m is mean wind speed, c is scale parameter, E_y(W) is energy density, E_t(kW) is total amount of energy, V_{fmax} is the most frequent wind speed, V_{emax} is the value of wind speed that makes significant contribution to energy generation in the table. These values are at the measurement height. If it is desired, they can be converted to the values at different heights by the help of Equation 10.

Table 2. Rayleigh analysis results

Months	V_{mean}	c	E_y(W)
January	6.78	7.65	364.61
February	5.86	6.61	235.41
March	3.71	4.19	59.74
April	4.67	5.27	119.15
May	4.98	5.62	144.49
June	6.41	7.23	308.12
July	4.95	5.59	141.89
August	6.08	6.86	262.94
September	1.89	2.13	7.90
October	2.14	2.42	11.47
November	2.65	2.99	21.77
December	7.29	8.23	453.23
Annual mean	4.78	5.40	127.77

Table 3. Energy analysis results

Months	E_t(kW)	V_{fmax}(m/s)	V_{emax} (m/s)
January	3193.98	5.41	10.82
February	2062.23	4.68	9.35
March	523.32	2.96	5.92
April	1043.74	3.73	7.45
May	1265.70	3.97	7.95
June	2699.09	5.11	10.23
July	1242.97	3.95	7.90
August	2303.32	4.85	9.70
September	69.19	1.51	3.02
October	100.43	1.71	3.42
November	190.71	2.11	4.23
December	3970.33	5.82	11.63
Annual mean	1119.25	3.81	7.63

The obtained results are perfectly suitable for measurement height. Three different turbines that have rated power between 600-800 kW and we have power curve are used for energy generation by means of these results. Some technical specifications of turbines are given in Table 4 [13,14].

Table 4. Technical specifications of turbines

Wind Turbine	Rated Power (kW)	Hub Height (m)	Rotor Diameter (m)
Enercon-48	800	50/60/75/76	52.9
Enercon-53	800	60/73/75	48
Nordex-43	600	40/50/60/78	43

Power curve of turbines is shown in Figure 1:

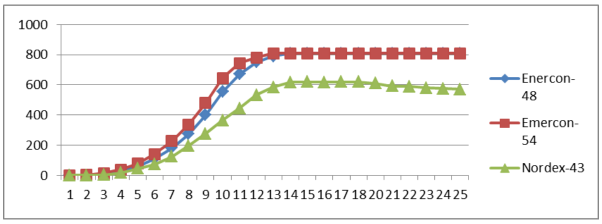

Figure 1. Power curve of turbines

The amount of energy obtained from turbines and capacity factors are calculated by using technical specifications of selected turbines and region's annul data. Firstly, annual and seasonal mean wind speed data of region at 10 meters are converted to the value that is at hub height which turbines will be used by using Hellman equation. Common hub height is taken as 60 meters for three different wind turbines. Hellman roughness coefficient is determined as 0.2 by observing the region's feature. The mean wind speed at 60 meters height is found as 6.84 m/s. According to these values, probabilities of wind speed are calculated by using Rayleigh probability density function. By multiplying these values with total time, blowing time of wind speed during the year is calculated. Rayleigh probability density diagram is shown in Figure 2.a and frequency probability of wind speed during the year is shown in Figure 2.b. The amount of energy obtained from turbine is calculated by multiplying blowing time with power value that corresponds to the wind speed at power curve. The amount of annual energy generation is found with summing them. This is formalized as in equation 13.

$$E_{totalenergy} = \sum_{i=0}^{i=25} B_i * P_{turbin,i} \tag{13}$$

In the equation, the lower limit is 0 and the highest limit is 25 because the power values that corresponds to wind speed beyond these limits in the turbine power curve are zero. B_i represents the blowing time that corresponds to the i. wind speed and $P_{turbin,i}$ represents the amount of power that corresponds to i. wind speed in the power curve.

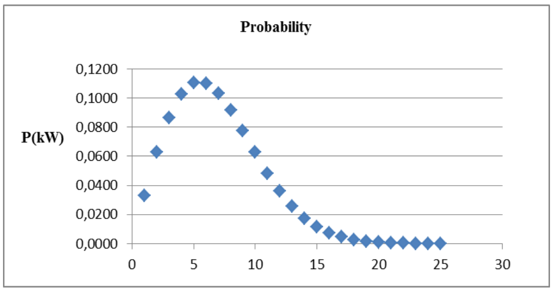

Figure 2.a. Rayleigh probability density function diagram

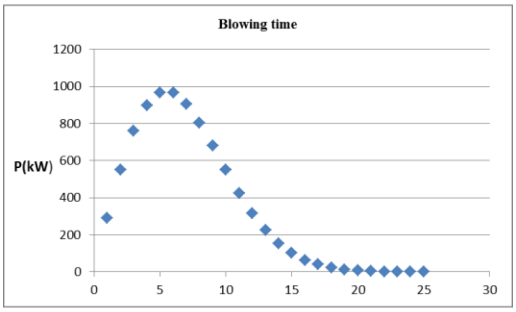

Figure 2.b. Blowing time of wind speed during the year diagram

The amount of annual generated energy is found by means of equation 13 and capacity factor is found by means of equation 11 for three different turbines. The amount of energy and capacity factors for three different turbines are given in Table 5.

Table 5. Amount of generated energy and capacity factors

Turbine	Hub Height (m)	Amount of Energy (MWh)	Capacity Factor (%)
Enercon-48	60	2178.657	31.0881
Enercon-53	60	2485.687	35.4693
Nordex-N43	60	1526.12	29.0358

The market is investigated after getting the results of energy generation. Then total cost is calculated for three turbines with considering rated power and the results obtained from market. According to this, cost of wind energy system that Nordex-43 turbine which has 600 kW rated power is used is approximately 2.500.000,0 TL. It is 3.000.000,0 TL for Enercon-48 and Enercon-53 turbines which have 800 kW rated power.

The present value method is used for feasibility of investment. In these calculations, it is intended to sell energy generated from wind energy systems to the market. Therefore, annual yield of generated energy is calculated by considering that 1 kWh electricity will be sold from 7.8 cents. The dollar is traded as 2.235 TL on 23.09.2014 and interest rate is taken as 7%. The obtained results are shown in Table 6.

Table 6. Cost Analysis Results of Turbines

Turbine	Pay-back period (year)	Profit (TL)
Enercon-48	8-8.5	14.994.621,66
Enercon-53	6.5-7	21.190.345,00
Nordex-N43	9.5-10	7.054.843,00

Finally, emission analysis is made to see the effect of clean energy obtained from wind on environment. The wind emission coefficient is taken as 0.449 tCO_2 for 1 MWh for Turkey. The obtained results are shown in Table 7.

Table 7. Results of emission analysis

Turbine	**Net annual greenhouse gas reduction ($tC0_2$)**
Enercon-48	979.59
Enercon-53	1.117.65
Nordex-N43	686,196

5. Conclusions

In this study, feasibility analysis of wind potential for investment is made with region's Rayleigh statistical method by using 2012-2013 period hourly wind speed data of Elmadağ region received from State Meteorological Station. Region's mean wind speed data for 10 meters height is found as 4.78 m/s. After it is determined that region is suitable for wind investment, amount of annual generated energy, pay-back period, amount of profit, and amount of net annual greenhouse gas reduction are calculated with three different wind turbines which have same hub height and are suitable for region's wind regime.After calculations, it is determined that Enercon-53 is the most suitable turbine for region. It is found that this turbine will generate 2.485.687 MW in a year, investment will pay off itself for 6.5-7 years, investor will bring 21.190.345,00 TL profit and approximately 1 tCO_2 in environment will be reduced.

6. References

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Note:

Ertuğrul Çam, received the B.Sc degree in Electrical and Electronics Engineering from Dokuz Eylul University in 1996, the M.Sc degree in Electrical and Electronics Engineering from Ege University in 1999 and the Ph.D degree in Mechanical Engineering from Kırıkkale University in 2004. He is currently working as a Associate Professor at Kırıkkale University and he is also Associate Dean of Engineering. His research areas consist of Power System Control, Renewable Energy Sources, Fuzzy Logic.

Yağmur Arıkan, received the B.Sc and M.Sc degree in Electrical and Electronics Engineering from Kırıkkale University, Turkey in 2011 and 2014, respectively. She is currently a Research Assistant at Kırıkkale University. Her research interests include Power Systems, Renewable Energy Sources, Wind Power Plants.

Özge Pınar Arslan, received the B.Sc degree in Electrical and Electronics Engineering from Eskişehir Osmangazi University, Turkey in 2012. She is currently a Research Assistant and M.Sc student at Kırıkkale University. Her research interests include Power System Optimization, Optimal Power Flow, Renewable Energy Sources, Economic Load Dispatch.