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AN ANALYSIS OF CURRENT AND FUTURE WIND ENERGY GAIN POTENTIAL FOR CENTRAL IOWA

Farrokh Sharifi
Department of Mechanical Engineering
Ames, Iowa, USA

***Nastaran Hashemi**
Department of Mechanical Engineering
Ames, Iowa, USA

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** Corresponding author: Nastaran Hashemi Phone: 515-294-2877, Fax: 515-294-3261*
E-mail address: nastaran@iastate.edu

ABSTRACT

Using a significant quantity of fossil fuels has adverse impacts on our lives and will affect future generations. Additionally, there are limited and decreasing numbers of non-renewable resources around the world. In contrast, renewable resources are not depleted and provide energy with negligible pollution. Wind energy is one of the more common renewable energy resources. This project aims to evaluate Iowa's wind energy potential and to provide suggestions to improve the future well-being of this state. A preliminary analysis shows that Iowa has great potential for wind energy. Based on the preliminary analysis, Ames, Iowa, is selected as a case study of its potential in terms of wind energy. Some important characteristics of wind energy, such as mean wind speed, wind distribution, and wind direction are evaluated for Ames. It is observed that although Iowa has the greatest wind power capacity density in the U.S., there are some untapped places in Iowa that can be utilized to harvest wind power. Results indicate that the city of Ames is one of the places that have strong wind speeds. According to the results, if a wind farm is installed in the city of Ames, reliance on non-renewable energy resources will be considerably decreased.

1. INTRODUCTION

Although there is much activity in the area of improving energy efficiency and finding new energy sources, global energy demand is expected to double by 2050. This demand originates from global population growth, global economic growth, continued urbanization, etc. Also, global warming stemming from greenhouse gases (GHG) is a global issue. Some scientists have concluded that it is necessary to reduce GHG emission by half to keep the global temperature increase below two degrees Celsius. Additionally, many people do not have any access to electricity. These issues have led scientists to identify an energy demand rate which increases continually and creates significant production and environmental challenges. To better understand these issues, it is necessary to consider the advantages and disadvantages of various energy alternatives, as addressed next.

Fossil fuels are a finite non-renewable resource. Energy is produced via burning fossil fuels. The non-renewable fossil fuels include crude oil, natural gas, coal, oil shales, and tar sands. The procedure in which the non-renewable resources were produced started from the sun's light energy. Plants converted this energy into chemical energy millions of years ago. Plants provide energy for living organisms to grow and live. When the living organisms die, the energy was trapped in their body. Over millions of years, after burying and bearing pressure and heating, the organisms were converted to fossil fuels like coal, oil, and natural gas. Electricity is generated by burning coal in a boiler of a power plant. The produced heat increases the water temperature and converts the water to superheat steam. This steam has abundant energy to drive a steam turbine. Finally, the power is converted to generator from the steam turbine and electricity is generated.

Renewable energy is obtained from sources which are renewable and can be easily and quickly replenished [1-4]. The renewable resources are in many forms such as solar thermal, photovoltaics, wind, hydro, tidal/wave and bioenergy (including biomass, biogas, and biofuels). At the present time, renewable resources have only a small contribution in comparison to non-renewable energy resources. The present project aims to focus on wind energy, which is one of the renewable energy resources. The current state of the resource is assessed and present issues are studied. Wind energy is applied in many places around the world. This report is directed towards the state of Iowa with the purpose of gathering data from this state. After, the future potential of wind technology is analyzed for this state.

2. WIND ENERGY

Wind energy is the kinetic energy associated with the movement of atmospheric air. Wind is one of the most significant and rapidly developing renewable energy sources around the world. In fact, wind power has a remarkable rate increase to 283 GW power [5]. Large-scale or small-scale wind turbines can generate electricity for an entire community or a single residence.

2.1 MERITS AND DEMERITS OF WIND POWER

There are some benefits and disadvantages which are specific for wind energy. Wind turbines need little maintenance when installed and can operate for a long time. They also produce no carbon dioxide emissions. Wind resources like other renewable resources will never be run out and the prices of wind turbine equipment and installation have dropped considerably over recent years. However, since wind forces can vary from calm to hurricane-forces, it cannot be predicted exactly. So, generating a steady supply of electricity is very difficult. The capital cost needed for installing dozens of individual wind turbines can be quite high. Although, wind turbine produce no chemical pollution, a wind farm running 24 hours a day can produce sound pollution, like a beehive. In addition, the energy output of a wind turbine is quite small, and dozens of wind turbines are needed to provide electricity for a small city. When a wind farm is installed, there should not be any obstruction along wind streamline. Otherwise, the large wind turbines will operate in a situation which is far from its design point.

3. CURRENT STATE OF WIND ENERGY

The wind energy potential varies in different parts of the world. It is estimated that more than 40 percent of the world's land mass has wind speed of more than 6 m/s [6]. Consequently, wind energy can be utilized in around 40 percent of the world. Since, it is difficult to evaluate all of the places in terms of present and future state of wind energy, this report focuses on Iowa, to find more details and suggest a policy to improve renewable energy in this state for the future. In this regard, the present and previous status of the whole country is reported as well.

In this section, wind energy status in the United States is studied. Due to the country’s large area, it seems reasonable that the potential of wind energy is not the same around the United States. There is some statistical information that provides wind resources around the United States at a 100-m height for all 50 states—the 48 contiguous states, Alaska, and Hawaii—as well as offshore resources up to 50 nautical miles from shore. The results reveal that in the middle, very east, and very west part of United States from North to South, the average wind speed is suitable for installing wind farm [7].

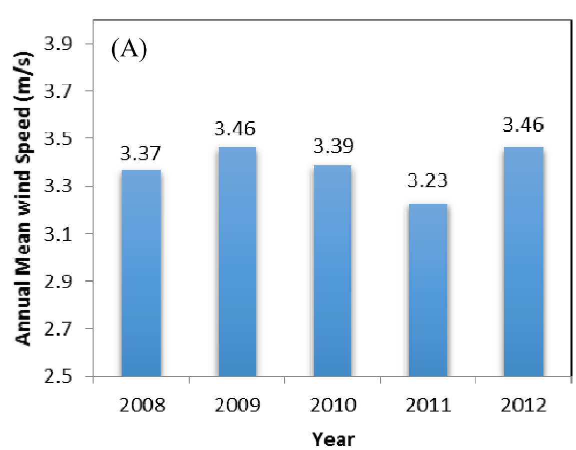
Iowa is one of the most active states and has become a leading U.S. state in wind power generation with 24.5% of the state's electricity generation coming from wind in 2012 [8]. This paper aims to obtain more details about wind energy from the state of Iowa. Iowa has become the third most active U.S. state, after Texas and California, in wind power generation. This state provided 24.5% of its electricity generation from wind power in 2012 [8]. Capacity factor compares the actual power to the maximum power produced by a generator during a period of time. In a project, the wind potential of Iowa was estimated. The optimized net average capacity factor for this state was obtained at 33.49% (pure average, value not weighted with the land area [9]

4. FUTURE STATE OF WIND ENERGY IN LOWA

Although Iowa has become a national leader in wind energy installations and manufacturing, this state can use its potential in wind energy better. According to maps that illustrate the wind speed in Iowa, it can be claimed that there are many unused fields suitable for generating electricity from wind energy. One of these places is the city of Ames, with an area of 62.86 km2 and population of 60,634. Ames is the largest city in Story County. Iowa State University of Science and Technology is located in Ames; so, many students are living in this city. In this condition, it seems to be a good idea for this city to have a wind farm and become independent from non-renewable resources. In this project, the wind speed and wind direction data are used to obtain a general picture of Ames in terms of wind potential.

4.1 ANALYSIS OF WIND DATA FOR THE CITY OF AMES

The hourly wind data was collected from one of the meteorological sites for 5 years from the beginning of 2008 to the end of 2012 [10]. The annual mean wind speed (m/s) is shown in FIG. 1(A). According to this figure, the annual mean wind speed is about 3.4 (m/s) and does not change considerably over time.



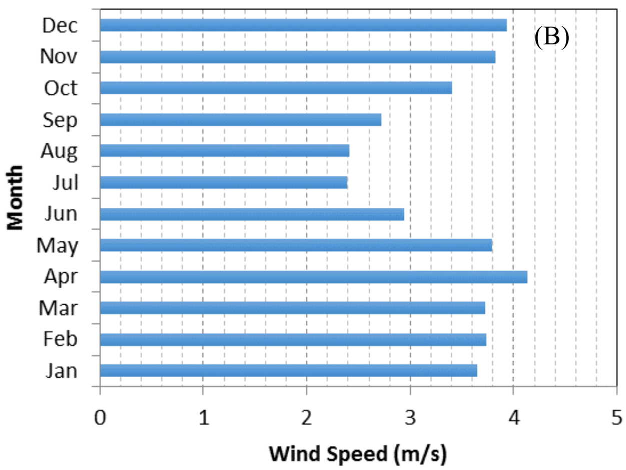


FIG. 1 ANNUAL MEAN WIND SPEED (M/S) (A) AND FIVE-YEAR MONTHLY MEAN WIND SPEED (B) AT 10 FT

Moreover, the monthly mean wind speed is illustrated in FIG. 1 (B). The numbers in this figure are the wind speeds in a specific month that have been averaged over five years.

In wind energy calculations, the velocity available at the rotor height is of concern. The data obtained at any height can be found using the Power Law profile.

4.2 POWER LAW PROFILE

A simple model for the vertical wind speed profile is provided by the power law [11] as

$$\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^{\alpha} \tag{1}$$

where $U(z)$ is the wind speed at height z, $U(z_r)$ is the reference wind speed at height z_r and α is the power law exponent. Von Karman showed that under certain situations, α is equal to 1/7. However, due to the fact that this parameter plays a significant role in the results, it is not a proper assumption to use this number for α in Eq. 1. Instead, there is a correlation for the power law exponent which provide α as a function of velocity and height [11].

$$\alpha = \frac{0.37 - 0.088\ln(U_{ref})}{1 - 0.088\ln\left(\frac{z_{ref}}{10}\right)} \tag{2}$$

Using Eq. (1) and Eq. (2), the wind velocity can be approximated in each height. The wind data is calculated at two different heights: 30 m and 50 m. The annual mean wind speed at 30 m and 50 m are illustrated in FIG. 2. The average wind speed is 5.7(m/s) and 6.4(m/s) at 30 m and 50 m, respectively which reflects this city has a suitable potential in terms of wind energy.

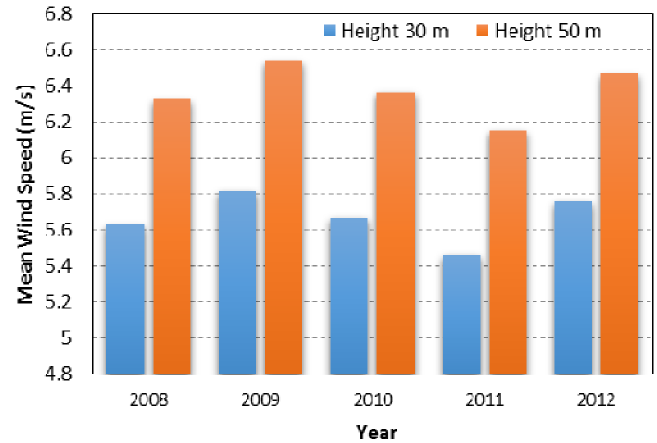


FIG. 2 ANNUAL MEAN WIND SPEED (M/S) AT 30M AND 50M

4.3 DISTRIBUTION OF WIND SPEED

Statistical analysis can be considered as a method through which the wind energy potential of a specific site is evaluated. This type of analysis is based on the use of the probability density function, *P(U)*, of wind speed. Generally, two probability density functions, (1) Rayleigh and (2) Weibull, are applied in wind data analysis. The Rayleigh distribution is based on one parameter while the Weibull distribution uses two parameters and, consequently, can represent a wider variety of wind regimes [11]. Thus, in this project, the Weibull distribution is used.

4.4 WEIBULL DISTRIBUTION

Weibull distribution is a proper density function for wind data. This function has two parameters: k, a shape factor and c, a scale factor. The Weibull probability density function and the cumulative distribution function are given by,

$$P(U) = \left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1} \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \tag{3}$$

$$F(U) = 1 - \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \tag{4}$$

These factors are obtained via curve fitting. The results are shown in Table 1 and FIG. 3 (A) and (B) at height of 30 m and 50 m respectively.

As illustrated in FIG. 3 (A) and (B), the Weibull function gives a proper fit to the experimental data. Moreover, probability density is higher than 10% in the wind range of 3-7.5 (m/s) and 4-8 (m/s) at 30m and 50m, respectively. This behavior reflects suitable conditions for this city in terms of wind energy potential. FIG. 4 shows the cumulative density for city of Ames at two different heights: 30m and 50m. This figure provides that, for example, the wind speed at 30m and 50m height is higher than 4m/s for 79.2% and 71.9% of the time in a year, respectively. It is worth mentioning that the 4m/s is the cut-in speed for many commercial turbines.

TABLE 1 WEIBULL PARAMETERS, C (M/S) AND K (DIMENSIONLESS), AT 30 M AND 50 M

Height (m)	30 m	50 m
c (m/s)	6.534	7.274
k (dimensionless)	2.262	2.434

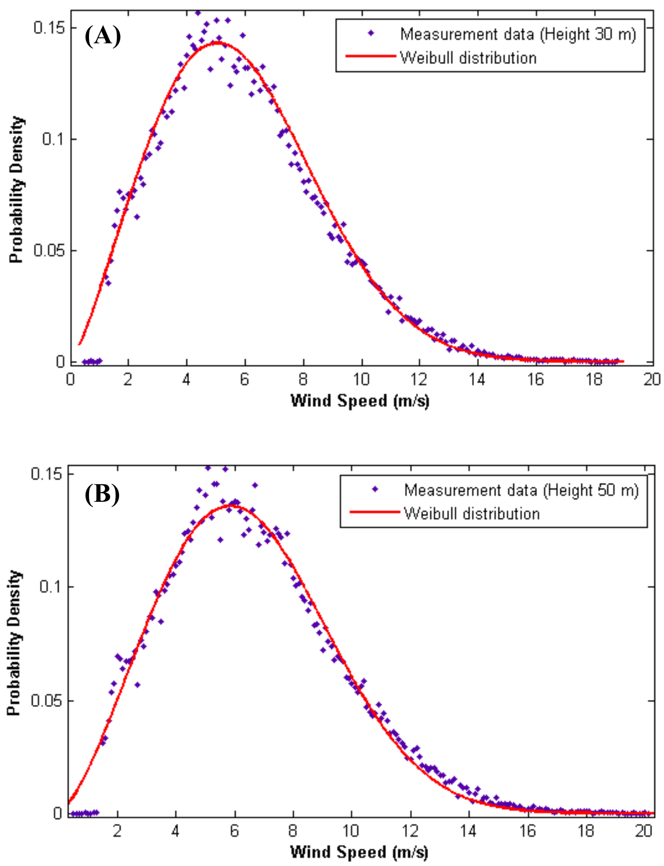


FIG. 3 WIND SPEED DISTRIBUTION AT (A) 30 M AND (B) 50 M

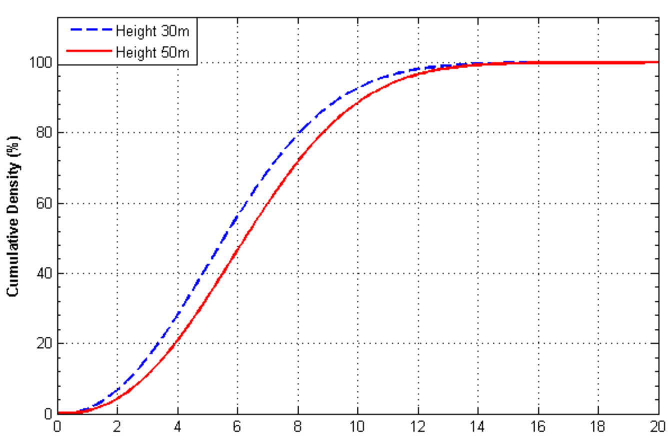


FIG. 4 CUMULATIVE DENSITY (%) AT TWO HEIGHTS

4.5 WIND DIRECTION AND WIND ROSE

Direction of wind is a significant factor in wind energy conversion systems. If a major share of energy available from the wind is received from a certain direction, it is important to avoid any obstructions to the wind flow from that direction.

Combination of the velocity and direction information of wind for a particular place can be shown in wind rose diagrams. A wind rose diagram is a chart which illustrates the distribution of wind in different directions. Additionally, it can help in identifying the energy available from different directions. Regarding the previously stated comments, the wind direction is important in assessing the possibility of using wind energy and has a significant role to play in the optimal positioning of a wind farm in a given area. Fig. 5 provides a wind rose diagram for city of Ames at 10 m height.

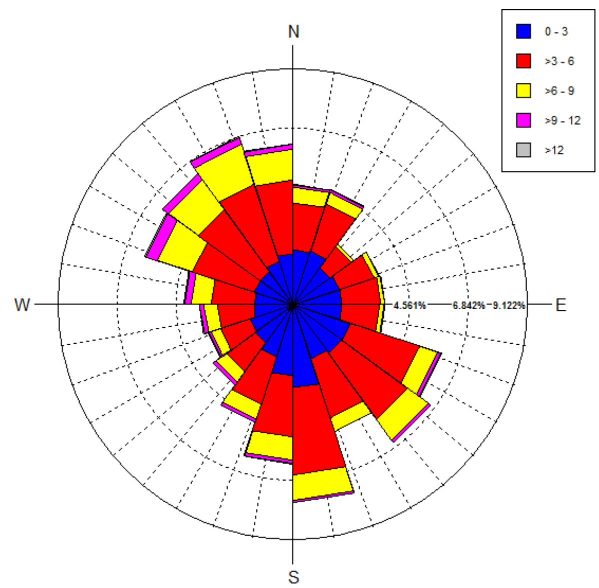


FIG. 5 WIND ROSE DIAGRAM AT 10 M

In this figure, the circular line length is proportional to the frequency of the wind. As illustrated in this figure, the longest lines, which are related to the prevailing wind directions, face south east (130-180 °) and North West (310-340 °). In this condition, although there are two prevailing wind directions, the North West winds are preferred due to their higher wind speed in comparison to south east. So, it can be claimed that the position of the wind turbine should utilize the northwest (290-360 °) winds. These winds have higher speed and frequency (~24%) compared to other directions.

4.6 WIND TURBINE ENERGY PRODUCTION

For a given wind regime, the average wind machine power, p_w is given by [11]:

$$\overline{P_w} = \int_0^\infty p_w(U)p(U)\,dU \qquad (5)$$

where *p(U)* is the probability distribution and $p_w(U)$ is a known machine power curve.

TABLE 2 TECHNICAL DATA FOR TWO DIFFERENT WIND TURBINES

Model	Power (kW)	Rotor Diameter (m)	Hub Height (m)
Vestas (V27)	225	27	33
Enercon (E44)	900	44	45-55

Table 2 shows some technical data for two different wind turbines used in calculations. Their power curves are illustrated in FIG. 6 (a). An approximation for Eq. 6 can be applied. Therefore, with a summation over N bins, the following expression can be used to find the average wind machine power [12]:

$$\overline{P_w} = \sum_{i=0}^{N} \frac{1}{2}\left(U_{i+1} - U_i\right)\left(p\left(U_{i+1}\right) p_w\left(U_{i+1}\right) + p\left(U_i\right) p_w\left(U_i\right)\right) \quad (6)$$

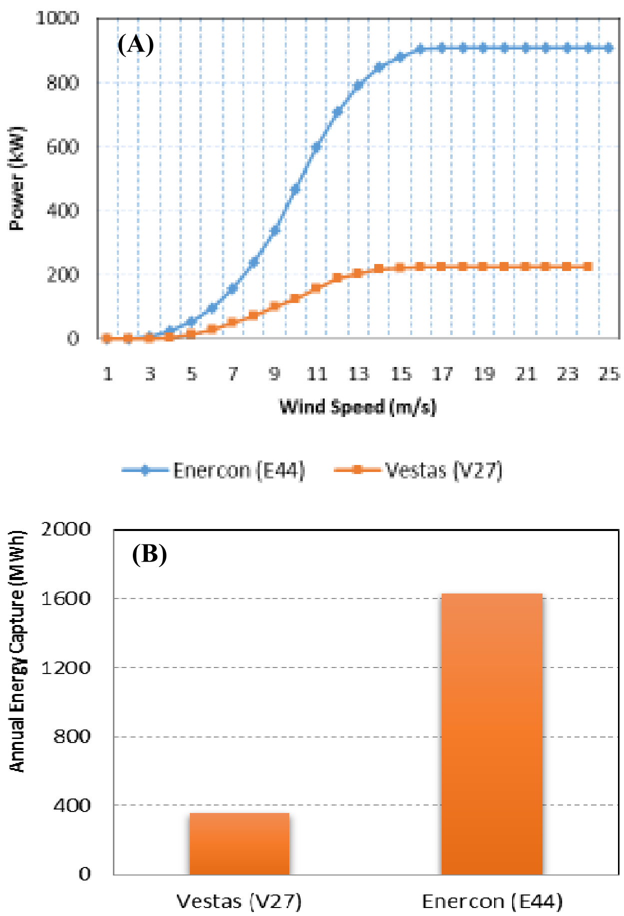


FIG. 6 POWER CURVE (KW) FOR TWO DIFFERENT WIND TURBINE (A) AND THE ANNUAL ENERGY CAPTURE (MWH) FROM THE EACH OF THE TURBINES (B)

As illustrated in FIG. 6 (B) the annual wind energy of Vestas (V27) and Enercon (E44), two different wind turbines, are 360 and 1630 (MWh), respectively. The results reflect that using wind power in this city is promising. It is worth mentioning that FIG. 6 (B) shows the energy captured from one wind turbine; it means that a wind farm in this city can provide electricity at a large scale.

5. CONCLUSION

In this project, we studied the present conditions of Iowa in terms of wind energy potential. It was found that Iowa has great conditions for generating electricity from wind power. This state has the most wind power capacity density of any state due mainly to the fact that in the midsection of the US the wind speed is strong. Additionally, it seems that there are some untapped places in this state that can be utilized to harvest wind power. In this report, the city of Ames was selected to be studied in terms of wind energy potential. The results indicated that it would be less dependent on non-renewable energy resources if a wind farm were installed in this city. Finally, it should be claimed that both of the renewable and non-renewable energy resources have some advantages and disadvantages. Nonetheless, sustainability will play a significant role in the future.

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REFERENCES

[1] Boyle, Godfrey. Renewable energy. OXFORD University press (2004)

[2] Wagner LT, Hashemi N, Hashemi N, "A Compact Versatile Microbial Fuel Cell from Paper", ASME International Conference on Energy Sustainability & Fuel Cell Science, Engineering and Technology Conference, Minneapolis, MN, July 14-19 (2013)

[3] Wagner LT, Yang J, Ghobadian S, Montazami R, Hashemi N, "A Microfluidic Reactor for Energy Applications", Journal of Applied Biosensor, 1, 21-25 (2012)

[4] Yang J, Ghobadian S, Goodrich PJ, Montazami R, Hashemi N, "Miniaturized Biological and Electrochemical Fuel Cells: Challenges and Applications", Physical Chemistry Chemical Physics, 15, 14147-14161 (2013)

[5] Renewable 2014 Global Status Report, Renewable Energy Policy Network for the 21st Centry http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf

[6] 3Tier Company Website http://www.3tier.com/en/support/resource-maps/, Date: 10/07/2014

[7] http://www1.eere.energy.gov/wind/resource_assessment_characterization.html Date: 10/07/2014

[8] Report. U.S. Department of Energy, Energy Information Administration, 26 February 2013
[9] Grassi S, Chokani N, Abhari R, Large scale technical and economical assessment of wind energy potential with a GIS tool: Case study Iowa, Energy Policy 45, 73–85 (2012)
[10] http://mesonet.agron.iastate.edu/agclimate/hist/hourlyRequest.php Date: 10/07/2014
[11] Manwell JF, McGowan JG, Rogers AL. Wind energy explained: theory, design and application. Amherst, USA: John Wiley & Sons (2002)
[12] Burton T, Sharpe D, Jenkins N, Bossanyi E. Wind energy handbook. England: John Wiley & Sons (2001)