**Comparison of Two Methods for Determining the Weibull Wind Distribution Parameters and Evaluation of the Seasonal Changes in Wind Speed Distribution**

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Abstract

The Weibull distribution function is the most popular means of determining the wind speed distribution, which is used by wind engineers to determine the design of the wind turbine and to evaluate and compare the economic viability of different sites. In order to determine the Weibull distribution curve of a set of wind data, the scale and shape parameters of the Weibull function must be calculated. The purpose of this experiment is to use the inbuilt Matlab functions and a set of equations to calculate the parameters and compare the results for a given set of data. The set of wind data is for one year. The data was then divided into seasons to compare the differences in wind speed distribution and power generation. The results showed that there was variability between each season, and there were differences in the confidence interval for each season. It is recommended further data from previous years will need to be collected and analyzed to determine whether the unusual wind pattern in the winter is due to an unusual weather event or if this is the standard climate for the site. Further data could determine if there are seasonal variations or annual changes in the wind speed distribution.

Introduction

In order for the wind energy industry to design efficient wind turbines and to perform an accurate economic analysis to determine whether a specific location is economically viable, wind data is analyzed using probability distribution functions (PDF). The most popular PDF is the Weibull distribution due to its ability to accurately fit historical data, and to predict wind speed distributions in the future. The Weibull distribution has two parameters that are calculated from annual data from different locations. The two parameters are c (scale parameter) and k (shape parameter). This experiment will calculate the shape and scale parameters of the Weibull distribution from wind data for an entire year from a particular location. Two different methods will be used to calculate the parameters and then will be compared using graphs. The wind for the entire year will also be divided into the four seasons, and the Weibull distribution parameters and confidence intervals will be calculated for each season and compared.

Theory

In order for a wind turbine company to determine the optimal turbine design for a specific location, engineers will need to predict the wind speed distribution and power generated for an entire year (Azad, Golam & Yusaf, 2014). This can be performed using PDFs, and the most popular wind speed distribution curve is the Weibull distribution due to its relative simplicity and accuracy. Figure 1 compares different PDFs for a given set of wind data. As can be clearly shown, the Weibull distribution function fits the data the most accurately, therefore the Weibull distribution will be used in this experiment.



*Figure 1: Comparison of four different distributions to fit wind data.*

The equation for the Weibull distribution function is shown below in equation 1.

(1)

Parameter v is the wind speed, k is a shape parameter and c is a scale parameter. The parameters c and k are calculated from a set of wind data and then used to plot the distribution function. By using measured data from a given location, a distribution function can be calculated that describes the likelihood a particular wind speed will occur in the future. A factor to consider is whether the shape of the wind distribution curve will change over time due to differences in weather from year to year, as well as changes in climate over longer periods of time. This will be discussed later in the theory section.

Another factor to consider is the sample size of the wind data. If the sample size is too small, the data will produce a curve that does not accurately reflect the wind distribution for that particular location, leading to an incorrectly designed turbine and eliminating potential power production and revenue from the wind farm. In order to ensure the sample size is sufficient for applying a Weibull distribution in the design of a wind turbine, a confidence interval for the scale and shape parameters can be used to determine whether the curve can be used, or if more data is needed.



*Figure 2: Comparison of different scale and shape parameters for Weibull distribution.*

Experimental Method

This experiment will use two different methods to obtain c and k for the Weibull distribution. One method will use a set of equations, and the other method will use an inbuilt function from Matlab. The equations have no particular name or method. The Matlab function will also be used to calculate and compare the Weibull distributions for the four seasons. Matlab can calculate the confidence interval of each Weibull distribution, which will be used to compare how well the distribution curve fits to the data for each season.

Two equations will be used to calculate for c (scale parameter) and k (shape parameter), and are shown below in equations 2 and 3 (Baidu.com, 2014).

(2)

(3)

is the standard deviation of the data, v is the average wind speed, and is the gamma function.

A function in Matlab called ‘fitdist’ (fit distribution) will be used to calculate the Weibull distribution parameters. This function outputs the scale and shape parameters, and can then be used to plot the Weibull function. Another function called ‘histfit’ (histogram fit) will be used to graphically compare how well the Matlab function ‘fitdist’ fits the Weibull distribution curve to the data. The hisfit function uses a histogram of the data to visually see how well the Weibull distribution curve fits the data. The histogram fit function can be seen in figures 2, 3, and 5. The results from the PD method and the Matlab function fitdist will be compared in the results.

The parameters of the Weibull distribution for each season will be calculated using the fit distribution function in Matlab. The histogram fit function will be used to visually see how well the wind data fits each Weibull distribution curve. A confidence interval of 99% will be produced for each curve using a function called ‘paraci’ (parameter confidence interval). This will determine how well each curve fits the data for each season.

(4)

Equation 4 is the wind power equation, with the air density (equal to 1.225 kg/m3, A equal to the wind-swept area of the blades, and V equal to the wind speed. This will used to calculate and compare the potential energy generation for each season.

Results

Table 1 summarizes the calculated parameters for the inbuilt Matlab function fit distribution, and the equation method. Figure 3 shows the Weibull distribution of the wind data for the entire year using the histogram fit function in Matlab. Figure 4 are the Weibull distribution curves for the Matlab function method and the equations.

*Table 1: Shape and scale parameters for the Matlab method and the equations.*

|  |  |  |
| --- | --- | --- |
| Method | Shape Parameter - k | Scale Parameter - c |
| Matlab | 5.38 | 1.41 |
| Equations | 5.34 | 1.38 |



*Figure 3: Weibull distribution using the histogram fit function in Matlab.*



*Figure 4: Comparison of the Weibull distribution using the Matlab function and equations.*

Figure 5 used the histogram fit function in Matlab to visually show how well the Weibull distribution curve fits to the wind data for each season.



*Figure 5: Comparison of Weibull distribution by season using the Matlab function.*

Figure 6 shows the Weibull distribution curves for each season and the year. The Weibull parameters were first calculated from the distribution fit function in Matlab, and then were graphed in Matlab. Table 2 summarizes the parameters calculated from the distribution fit function.



*Figure 6: Comparison of Weibull distribution by season with year as a reference.*

*Table 2: Summary of the Weibull distribution parameters c and k calculated using the distribution fit function in Matlab.*

|  |  |  |
| --- | --- | --- |
| Season | Matlab Method | |
| Scale Parameter - c | Shape Parameter - k |
| Spring | 5.20 | 1.48 |
| Summer | 4.23 | 1.53 |
| Fall | 6.12 | 1.52 |
| Winter | 6.03 | 1.31 |
| Year | 5.38 | 1.41 |

Table 3 summarizes the 99% confidence interval of c and k for each Weibull distribution curve for each season and the year. These values were calculated using the parameter confidence interval function in Matlab.

*Table 3: Comparison of the average power output for each season.*

|  |  |
| --- | --- |
| Season | Average Power Output (MW)  Diameter of Swept Area = 100 m  Air Density = 1.225 kg/m3  Efficiency = 100% |
| Spring | 1.43 |
| Summer | 0.73 |
| Fall | 2.24 |
| Winter | 2.70 |

*Table 4: Comparison of the Weibull distribution’s 99% confidence interval for each season and the year calculated using the parameter confidence interval function in Matlab.*

|  |  |  |
| --- | --- | --- |
| Season | Range of 99% Confidence Interval | |
| Scale Parameter - c | Shape Parameter - k |
| Spring | 0.409 | 0.125 |
| Summer | 0.321 | 0.129 |
| Fall | 0.469 | 0.128 |
| Winter | 0.535 | 0.113 |
| Year | 0.222 | 0.059 |

Discussion

The two methods to determine the Weibull parameters are nearly identical, as can be seen in Figure 4. This shows that either method is suitable for determining the Weibull parameters. Both methods are simple to implement and quick to determine the values. Based on the user’s familiarity with Matlab or Excel will determine which method is the more viable option.

The Weibull histogram fit for the different seasons in Figure 5 can visually provide an indication as to how well the curve fits the data. From the figure, it shows that the data for Winter does not fit the data as well as the other curves. This is readily apparent in the graph, as there are large differences in the wind data and the Weibull distribution curve. This can be confirmed using the differences in the confidence interval.

There are two things that affect the confidence interval, the size of the sample and the variability in the data. The size of the sample for all four seasons is the same, so any difference in confidence intervals between two seasons will indicate the variability of the wind data between each season. In table 4, the 99% confidence interval for the scale parameter is largest in the winter data set. This matches the observation in figure 5 that shows the wind data for the winter has the most variability. There could be two explanations as for why the data in the wind is unusual and cannot be accurately described by the Weibull distribution. The unusual wind pattern could be because of abnormal weather during the winter season. The other reason could be because the winter wind pattern could be a result of the local climate.

In order to determine which explanation is correct, historical data from previous winters would need to be evaluated to determine whether the unusual winter wind pattern is due to a weather event, or simply local climate. Further experiments could be carried out to determine whether the annual and seasonal wind speed distribution varies or remains constant. These experiments would confirm whether the weather varies substantially from year to year, or whether even the climate is changing due to increases in the temperature of the Earth’s surface.

The potential power generation for each season was evaluated and the results are shown in table 3. The data shows that the winter has the largest power generation potential. The fall season’s potential power generation is 17% less than the winter season. This is mainly due to the high frequency of wind speeds between 10 and 15 m/s. Even though the frequency of wind speeds between 5 and 10 m/s in the winter is much less than in the fall, the winter is able to generate more power. This can be explained through the wind power equation as shown in equation 4. A doubling of the wind speed will increase the power by six times. This shows that a high frequency of winds at high speeds will have a larger effect on the output than a high frequency of lower wind speeds. The summer season has the lowest power generation, which is 73% less than the winter season. This can be shown in figure 6, where the high wind speed frequency for summer is much lower than for winter.

Conclusion

Two methods were used to determine the Weibull distribution parameters for wind speed. Both of these methods were simple to use and can be applied by wind engineers to determine the parameters. These techniques can be used to quickly and easily determine the wind speed distribution and the potential power generation for a particular site. They can also be used to determine the design specifications of the wind turbine in order to maximize the efficiency, and to also determine which site have the highest potential for power generation. This experiment combined the Weibull distribution curve with findings from the power generation and confidence intervals of the data for each season to determine the reliability of the data, and evaluate the power production for each season. The winter season appears to have the highest potential for power production, but the confidence interval of the data is much higher for the winter than for other seasons. Further data may need to be collected to determine whether the unusual wind pattern in the winter is due to an unusual weather event or if this is the standard climate for the site. Further data could determine if there are seasonal variations or annual changes in the wind speed distribution.

References

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