Wind energy potentiality assessment of Chengshantou using the Weibull model

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Abstract. The potential of wind energy is valued in recent years. The wind resource and information for details of the wind characteristics at a place is required for planning a wind energy project. Chengshantou (37.4°N, 122.68°E) located in Shandong province of China is a windy region. This work analyzed 10 years (1995-2004) measured daily mean wind speed data of Chengshantou. The Weibull model is used to study the wind energy potential of Chengshantou. It is concluded that Chengshantou is promising for the establishment of large wind farms.

1. Introduction

In recent years, changing energy structure, reducing pollution discharge and helping the environment need the wind power development in China. Before planning a wind energy development at a special place, it is significant to predict the resources.

Chengshantou (37.4°N, 122.68°E), also known as the “end of heaven”, is located in the east of Shandong province of China. Chengshantou is surrounded by the sea on three sides and connected to the land on one side, facing South Korea across the sea, only 94 miles from the sea. Chengshantou is the easternmost end of China’s land-sea junction, the first place to see the sunrise.

There are few studies on the wind speed distributions of some special sites in China [1-3]. This paper analyzes a windy coastal area (Chengshantou).

2. Wind power Simulation

Monthly-mean wind speed \( v_m \) (m/s) can be calculated by:

\[
v_m = \frac{1}{N} \sum_{i=1}^{N} v_i
\]  \hspace{1cm} (1)

While the standard deviation \( \sigma \) (m/s) can be calculated by:

\[
\sigma = \left[ \frac{1}{N-1} \sum_{i=1}^{N} (v_i - v_m)^2 \right]^{1/2}
\]  \hspace{1cm} (2)

Where \( N \) is the number of measurements.

The following equation gives the wind speed probability density function \( f(v) \) of Weibull model which is usually used to analyze wind data [4,5]:

\[
f(v) = \frac{k}{\beta} \left( \frac{v}{\beta} \right)^{k-1} e^{-\left( \frac{v}{\beta} \right)^k}
\]
The following equation can be used to obtain the corresponding cumulative distribution function:

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

(4)

In this paper, due to the simplicity of the graphical method and its acceptable and good results [6,7], the parameters of \( c \) and \( k \) is calculated by the graphical method [8]:

\[ \ln(-\ln(1 - F(v))) = k \ln v - k \ln c \]  

(5)

The measured average wind power density \( P_m \) (W/m²) is:

\[ P_m = \sum_{i=1}^{n} \left[ \frac{1}{2} \rho v_i^3 f(v_i) \right] \]  

(6)

The average power density of \( P_m \) (W/m²) of Weibull function can be calculated by [9]:

\[ P_m = \frac{\rho v_m^3 \Gamma(1+3/k)}{2[\Gamma(1+1/k)]^3} \]  

(7)

3. Wind power potential of Chengshantou

Chengshantou (37.4°N, 122.68°E) is located in Shandong province of China. Chengshantou is a warm temperate monsoon-type humid climate zone. The four seasons are clear, sunlight is sufficient, the rain and heat are in the same season, winter is not cold and summer is not hot. The annual average temperature is 11.4°C and the annual precipitation is about 660mm.

This work used the data of measured daily mean wind speed of 1995 to 2004. The long-term average wind speed is 6.02m/s.

\( v_m \) and \( \sigma \) calculated by Eqs.(1) and Eqs.(2) from the ten years measured data are listed in Table 1. These average values change from 4.442 m/s in August to 7.358 m/s in December. It is windy all the year. It is generally the most windy during the cold winter months. Winter months all have the mean speeds of nearly 7m/s. July and August (the summer months) have the smallest values (4.836m/s and 4.442m/s, respectively). The minimum wind speed for the pump to be used is limited to 2.2 to 3.1m/s [10]. And the minimum speed needed for effective wind turbines is 6.0 m/s [10]. Except for the months from May to September, all the monthly means of Chengshantou are higher than this limit of 6.0 m/s. And although the values of summer months are below the minimum speed required for an effective wind turbine of 6.0 m/s, but it is sufficient for water pumping applications.

**Table 1.** Monthly average wind speed and Weibull parameters of Chengshantou.

| Month | \( v_m \) (m/s) | \( \sigma \) (m/s) | \( c \) (m/s) | \( k \) | \( R^2 \) |
|-------|-----------------|-----------------|--------------|-------|--------|
| Jan.  | 6.949           | 3.207           | 7.953        | 2.690 | 0.962  |
| Feb.  | 6.668           | 2.970           | 7.486        | 2.680 | 0.982  |
| Mar.  | 6.388           | 2.771           | 7.415        | 2.883 | 0.964  |
| Apr.  | 6.459           | 2.113           | 7.169        | 3.444 | 0.995  |
| May   | 5.499           | 1.815           | 6.166        | 3.637 | 0.980  |
| Jun.  | 4.854           | 1.678           | 5.462        | 3.477 | 0.967  |
| Jul.  | 4.836           | 1.665           | 5.340        | 3.390 | 0.993  |
| Aug.  | 4.442           | 1.895           | 4.961        | 2.440 | 0.989  |
| Sept. | 5.532           | 2.660           | 6.427        | 2.651 | 0.965  |
| Oct.  | 6.296           | 2.879           | 7.162        | 2.561 | 0.967  |
| Nov.  | 6.992           | 3.136           | 8.017        | 2.733 | 0.974  |
| Dec.  | 7.358           | 3.453           | 8.420        | 2.587 | 0.969  |
From Table 1, December has the greatest daily wind speed variation for its largest standard deviation ($\sigma = 3.453\text{m/s}$). The smallest standard deviation ($\sigma = 1.665\text{m/s}$) occurred in July.

Table 1 also shows the estimated values for the parameters of $c$ and $k$ of Chengshantou. August has the minimum scale parameter (4.961 m/s). December has the maximum (8.420 m/s). In addition, August has the minimum shape parameter $k$ (2.440). May has the maximum (3.637).

The fitness of Weibull model with the measured data is contrasted by $R^2$ in the sixth column of Table 1. $R^2$ vary from 0.962 to 0.995. The monthly average value is 0.976, indicating the Weibull model can be used to estimate the measured data well.

The monthly probability density $f(v_j)$ is shown in Fig.1.

**Figure 1.** $f(v_j)$ of Chengshantou.

Fig.2 shows $f(v)$ and $F(v)$ of Chengshantou calculated by ten years (1995-2004) measured wind speed data. The maximum probability density (4.5%) appears at the speed of 5 m/s.

**Figure 2.** $f(v)$ and $F(v)$ of wind speed of Chengshantou.
Fig. 3 shows the comparison of $P_p$ calculated by the Weibull model and $P_m$ of the measured data. The power density changes a lot every month. The maximum power density is 416.703 W/m$^2$ in December for its maximum wind speed. August has the minimum value of 83.939 W/m$^2$. The annual average value is 226.148 W/m$^2$.

**Figure 3.** Wind power density comparison calculated by the Weibull model and the measured data.

The errors in estimating the power densities by the Weibull model using the following equation are shown in Fig. 4:

$$\text{Error}(\%) = \frac{P_W - P_m}{P_m} \times 100\%$$ \hspace{1cm} (8)

Then the yearly average error:

$$\text{Error}(\%) = \frac{1}{12} \sum_{i=1}^{12} \left| \frac{P_W - P_m}{P_m} \right| \times 100\%$$ \hspace{1cm} (9)

All the calculated values are below the measured values so the errors are all negative in Fig. 4. February has the maximum error of power density of -10.05%. The best fitness appears in May. May has a very small error of -2.03%. The annual average error is -5.11%. As a whole the errors are acceptable.

**Figure 4.** Monthly error of the Weibull model.

4. Conclusion

This work analyzed the measured wind speed data at Chengshantou station in Shandong Province. The average wind speed is 6.02 m/s, which is larger than the minimum wind speed of 6.0 m/s required by the effective wind turbine. Chengshantou is a very promising wind power plant. The calculation reveals that Weibull model provides wind good power density estimation for Chengshantou.
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