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EVALUATION OF WIND CHARACTERISTICS IN BAC LIEU IN 2016 USING THE WEIBULL FUNCTION

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ABSTRACT: In this paper, the characteristics of wind speed at 20 m height at the Bac Lieu atmospheric physic station (Bac Lieu station) in 2016 were evaluated using the Weibull distribution function. The wind speed data set (every minute) from January 7th to December 31st, 2016 was used to calculate the two parameters of Weibull function including Weibull shape factor "k" and Weibull scale factor "c". The results showed that at the Bac Lieu station in 2016, the values of k and c were 1.69 and 3.91, respectively. Some characteristics of wind speed were also estimated such as wind energy density (P_a/A=57.3 W/m^2), wind speed of maximum energy carrier (V_{mec}=6.2 m/s), the most probable wind speed (V_{mp}=2.3 m/s), mean wind speed (V_{mean}=3.5 m/s) and standard deviation of wind speeds (σ = 2.1 m/s).

Keywords: Weibull function, wind speed, Bac Lieu.

INTRODUCTION

Wind power is a green energy source. The wind energy potential at a specific site is controlled by wind speed and its probability distribution. Although there are many types of wind probability density functions (PDF), the Weibull function is one of the most popular PDF because of its two flexible parameters [1-5]. The shape parameter defines the width of data distribution, while scale parameter gives the abscissa scale of data distribution. From the two parameters characteristics of wind speed such as wind energy density, wind speed of maximum energy carrier, the most probable wind speed, mean wind speed and standard deviation of wind speeds can be computed [2].

In Viet Nam, estimation of wind energy potential has been mentioned in several studies [6-8]. In 2001, the World Bank project on the wind energy had constructed the wind energy resource atlas for four countries including Cambodia, Laos, Thailand and Vietnam [9]. The project was extended in 2011 to improve the wind energy map for Vietnam. Le Van Luu et al., (1998) [10] used one month of the wind speed data with one minute temporal resolution in July 1998 to calculate the two parameters of Weibull function for Phuoc Hoa, Binh Dinh site. In 2006, the one-minute wind data from 4/1998 to 4/2000 were used to evaluate the wind energy potential for Binh Dinh [11]. Nguyen, K. Q., (2007) [12] used the Weibull function to estimate the technical potential of wind energy in Vietnam.

The objective of this study is to evaluate the wind characteristics for Bac Lieu observation site. The one-minute wind data at 20 m-height at Bac Lieu wind tower in 2016 are used to calculate the Weibull parameters to investigate the characteristics of wind.

DATA AND METHOD

Wind speed data

The Bac Lieu wind tower with a height of 20 m is located at the Bac Lieu atmospheric physic station, Bac Lieu city. The tower location is at 9.28^{o}N, 105.73^{o}E, about 10 km distance from the sea. The Bac Lieu atmospheric physic station is surrounded by rice fields, orchards and houses. The position and image of the wind tower are shown in fig. 1.

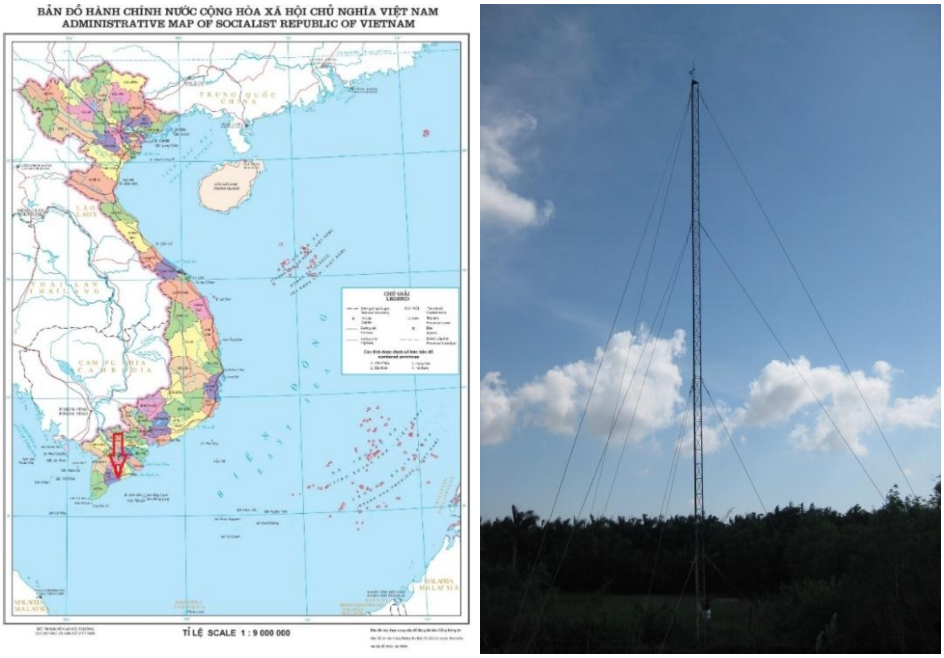

Fig. 1. The location and image of Bac Lieu wind tower

Technical specifications for equipment at the station are specified in table 1. The measurement time starts from January 7th, 2016 to the end of December, 2016 with 1 minute interval. In 2016, the wind tower had recorded 465724 data.

Table 1. Technical specifications of DAVIS equipment

Parameter		Resolution	Range	Accuracy
Barometric pressure		0.01” Hg; 0.1 mmHg; 0.1 hPa; 0.1 mb	16” to 32.5” Hg; 410 to 820 mmHg; 540 to 1100 hPa; 540 to 1100 mb	0.03” Hg; 0.8mmHg; 1.0hPa; 1.0 mb
Humidity	inside	1%	1 to 100%	3% RH; 4% above 90%
	outside	1%	1 to 100%	3% RH; 4% above 90%
Dew point		1^{o}F; 1^{o}C	-105^o to 130^{o}F; -76^o to 54^{o}C	3^{o}F; 1.5^{o}C
Temperature	inside	0.1^{o}F; 0.1^{o}C	32^o to 140^{o}F; 0 to 60^{o}C	1^{o}F; 0.5^{o}C
	outside	0.1^{o}F; 0.1^{o}C	-40^o to 150^{o}F; -40^o to 65^{o}C	1^{o}F; 0.5^{o}C
Wind direction		1^o	0 to 360^o	3^o
Wind speed		1 mph; 1 kts; 0.1 m/s; 1 km/h	2 to 200 mph; 2 to 173 kts; 3 to 322 km/h; 1 to 80 m/s	5%
Wind chill		1^{o}F; 1^{o}C	-110^o to135^{o}F; -79^o to 57^{o}C	2^{o}F; 1^{o}C
Rainfall	daily	0.01”; 0.2 mm	To 99.99”; 999.8 mm	greater 4% or 1 tip
	monthly	0.01”; 0.2 mm	To 199.99”; 6553 mm	greater 4% or 1 tip
Time		1 min	0 to 24 hours	8 sec./mon.
Solar radiation		1 W/m^2	0 to 1800 W/m^2	5% of full scale
UV radiation		0.1	0 to 16	5% of full scale

Method

The Weibull probability density function is given by Eq. 1 [1-3].

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

Where: $p(v)$ is the probability of the measured wind speed, v, k is the Weibull shape parameter, generally ranges from 1.5 to 3 for most wind conditions, and c is the Weibull scale parameter, c has the unit of wind speed (m/s).

The cumulative frequency distribution is the integral of the Weibull probability density function, given by Eq. 2.

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

By transforming into logarithmic form, Eq. 2 could be then expressed by Eq. 3.

$$\ln[-\ln(1 - P(v)] = k\ln(v) - k\ln(c) \qquad (3)$$

Comparing with the linear equation: $y = Ax+B$, yields, y = ln[-ln(1-P(v)], x = ln(v), and B = -kln(c).

RESULTS AND DISCUSSIONS

Annual and diurnal behavior of mean wind speed

Bac Lieu is located in the Southern Vietnam with typical monsoon climate characterized by two distinct seasons: the rainy season from May to October with prevailing southwesterlies and the dry season from November to April with northeasterlies [13]. The annual mean wind speeds normally control the amount of energy at a specific location. In the present case, the annual mean wind at 20 m above ground level (AGL) at the Bac Lieu wind tower in 2016 was 3.5 m/s. The value was calculated from the daily mean wind speed of 345 days (fig. 2). The prevailing wind direction was E and SW during the data collection period. The monthly variation of wind speed provides potential of the availability of energy in different months of the year. Monthly changes in wind speed at 20 m over the entire data collection period are shown in Fig. 3. The monthly variation of wind speed has two maxima, one in February (peak of winter monsoon) and the other in August (peak of summer monsoon). Fig. 3 shows the variation of hourly mean wind speed during data collection period. It is evident from this figure that wind speed in the day time is higher than that in the night time. The wind speed is found mostly above 4.0 m/s for all of the time from 9 h - 17 h, while from 23 h - 5 h, the wind speed is round about 2.5 m/s. This result shows that the wind characteristics at the Bac Lieu station reasonably well reflect the monsoon climate of the region.

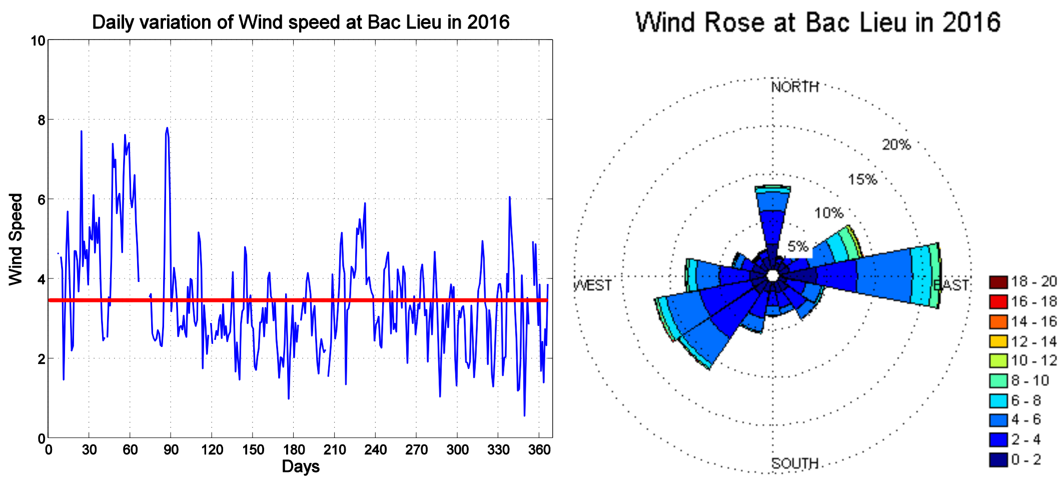

Fig. 2. Daily variation of wind speed and wind rose at 20 m at Bac Lieu in 2016

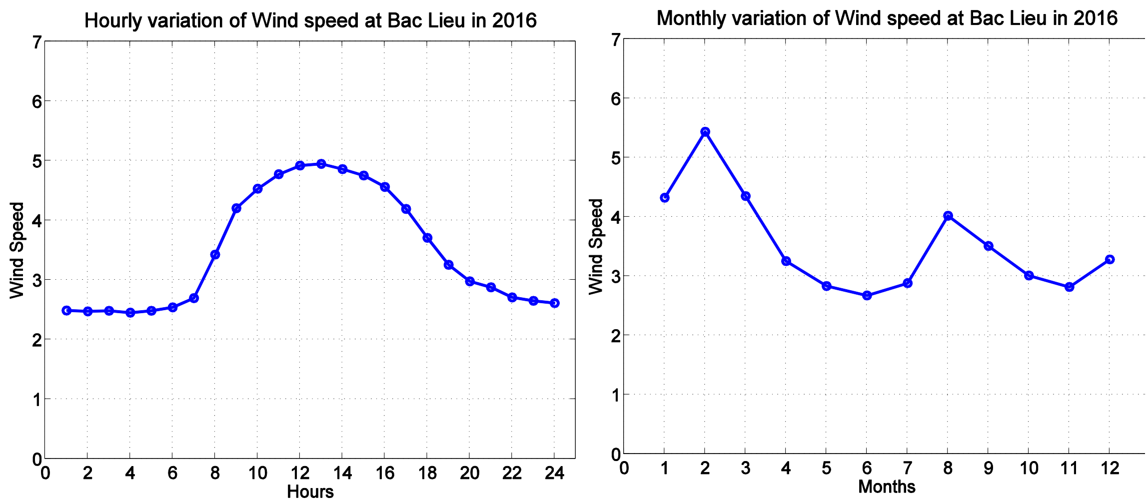

Fig. 3. Hourly and monthly variation of wind speed at 20 m at Bac Lieu in 2016

Weibull parameters

To calculate the parameter c and k, the wind speed data set of n observations (n=645724 in this case) is divided in N classes (N=19) with the probability for each class (the 4th column of table 2). The 5th column of table 2 gives the percentage probability for each wind class according to the relation [2]:

$$p(v_i) = \frac{f_i}{\sum_{i=1}^{N} f_i} = \frac{f_i}{n}, \qquad i = 1, \dots, N \tag{4}$$

The cumulative probability in the 6th column of table 1 is determined from:

$$P(v_j) = \sum_{i=1}^{j} p(v_i) \tag{5}$$

Where $i \leq j$ and $p(v_i)$ is the probability of each velocity v_i for i= 1,2,3…N. The probability of wind speed will be unity.

$$P(v_N) = \sum_{i=1}^{N} p(v_i) = 1 \tag{6}$$

Table 2. Frequency distribution and the probability density distributions calculated from the Weibull function at Bac Lieu in 2016

i	v (m/s)	v_i	f_i	$p(v_i)$	$P(v_i)$	$P_w(v_i)$
1	0.1-1	0.5	54864	11.7804	0.117804	10.0201
2	1.1-2	1.5	54759	11.7578	0.235382	18.2582
3	2.1-3	2.5	94248	20.2369	0.437751	19.8821
4	3.1-4	3.5	84404	18.1232	0.618982	17.5402
5	4.1-5	4.5	90525	19.4375	0.813357	13.4593
6	5.1-6	5.5	35991	7.7280	0.890637	9.2568
7	6.1-7	6.5	20969	4.5025	0.935661	5.7999
8	7.1-8	7.5	12498	2.6836	0.962497	3.3445
9	8.1-9	8.5	10472	2.2485	0.984983	1.7875
10	9.1-10	9.5	3601	0.7732	0.992715	0.8900
11	10.1-11	10.5	1916	0.4114	0.996829	0.4145
12	11.1-12	11.5	875	0.1879	0.998707	0.1811
13	12.1-13	12.5	383	0.0822	0.999530	0.0745
14	13.1-14	13.5	167	0.0359	0.999888	0.0289
15	14.1-15	14.5	30	0.0064	0.999953	0.0106
16	15.1-16	15.5	15	0.0032	0.999985	0.0037
17	16.1-17	16.5	5	0.0011	0.999996	0.0012
18	17.1-18	17.5	1	0.0002	0.999998	0.0004
19	18.1-19	18.5	1	0.0002	1.000000	0.0001

The parameters A and B can be found out by the least squares method [2]:

$$A = \frac{\sum_{i=1}^{N}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{N}(x_i - \overline{x})^2} \quad \text{and} \quad B = y - Ax \qquad (7)$$

Where $\overline{x}$ and $\overline{y}$ are means of x_i and y_i which have to be determined considering the frequency f_i from:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{N} f_i x_i \quad \text{and} \quad \overline{y} = \frac{1}{n}\sum_{i=1}^{N} f_i y_i \qquad (8)$$

For the given data in table 3, the linear relation between x_i and y_i has been calculated $\overline{x}$ = 1.2349 and $\overline{y}$ = -0.2200 and plotted (fig. 4). From Eq. 7 we can thus obtain k=A= 1.697 and c = exp(-B/A)=3.91 m/s.

Table 3. The values of x_i and y_i for data collected from Bac Lieu station

i	f_i	$x_i = \ln(v_i)$	$y_i = \ln(-\ln(1-P(v_i)))$
1	54864	0.000	-2.077
2	54759	0.693	-1.315
3	94248	1.099	-0.552
4	84404	1.386	-0.036
5	90525	1.609	0.518
6	35991	1.792	0.794
7	20969	1.946	1.009
8	12498	2.076	1.189
9	10472	2.197	1.435
10	3601	2.303	1.594
11	1916	2.398	1.750
12	875	2.485	1.895
13	383	2.565	2.036
14	167	2.639	2.208
15	30	2.708	2.299
16	15	2.773	2.407
17	5	2.833	2.514
18	1	2.890	2.569
19	1	2.944	Inf

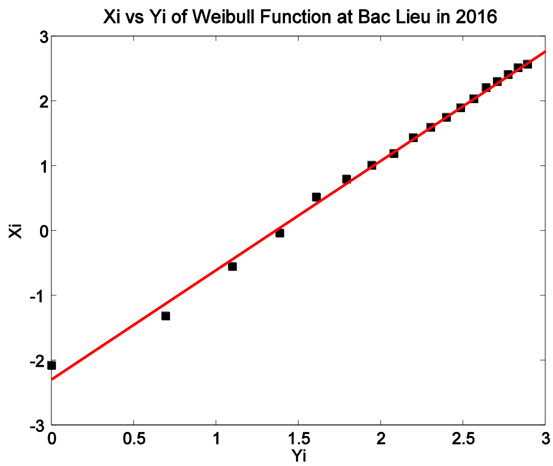

Fig. 4. Least square line through which the parameters K and C are estimated

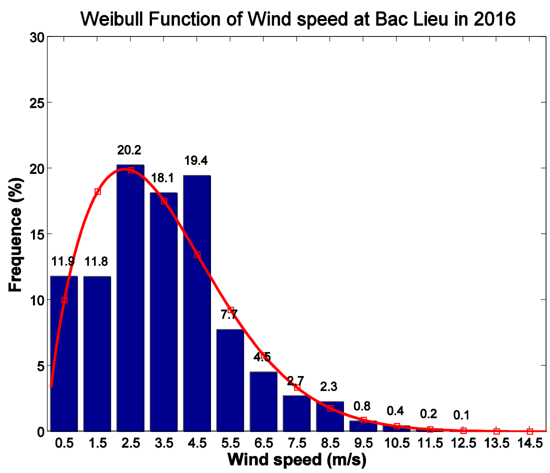

Fig. 5. Wind speed frequency with fitted Weibull distribution for Bac Lieu in 2016

Evaluation of wind power characteristics

From the scale and shape parameters, the most probable wind speed is computed as [2]:

$$V_{mp} = c(1 - \frac{1}{k})^{1/k} = 2.3\ (m/s)$$

The wind speed carrying maximum energy represents is:

$$V_{mp} = c(1 + \frac{2}{k})^{1/k} = 6.2\ (m/s)$$

The average wind speed (V_{mean}) and wind speed standard deviation (σ) can also be calculated:

$$V_{mean} = c\Gamma(1+\frac{1}{k}) = 3.5 \ (m/s)$$

$$\sigma = c[\Gamma(1+\frac{2}{k}) - \Gamma^2(1+\frac{1}{k})]^{1/2} = 2.1 \ m/s$$

Wind power density of a site based on a Weibull probability density function can be calculated.

$$P_a/A = \frac{1}{2}\rho c^3\Gamma(1+\frac{3}{k}) = 57.3 \ \mathrm{w}/m^2$$

Where ρ is calculated from temperature and pressure at Bac Lieu station.

CONCLUSION

The analysis of the measured data showed that the annual average wind speed at Bac Lieu in 2016 was 3.5 m/s. The maximum of wind speed was observed in February and August while the minimum was in June and November. The wind speed during day time was higher than that at night.

The wind speed characteristics and the wind power densities of Bac Lieu have been analyzed using the Weibull function. The results showed that at the Bac Lieu station, in 2016, the values of k and c were 1.69 and 3.91, respectively. The wind energy density, P_a/A = 57.3 W/m^2; wind speed of maximum energy carrier, V_{mec} = 6.2 m/s; the most probable wind speed, V_{mp} = 2.3 m/s; mean wind speed, V_{mean} = 3.5 m/s; and standard deviation of wind speeds, σ = 2.1 m/s.

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