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Wind power potential and characteristic analysis of Chiang Mai, Thailand †

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Abstract

An investigation of wind characteristics and wind energy potential at Chiang Mai Province, Thailand was studied. Wind data taken from the weather station at Chiang Mai International Airport between 2001-2006 was analyzed in order to obtain the potential energy generated by a Vertical Axis Wind Turbine (VAWT). It was found that the yearly average wind velocity was 5.7 meters per second with a standard deviation value of 2.2 meters per second. The analysis assumed that wind blew in the S.W. to N.E. direction. Two parameters for the local wind, the shape parameter (k) and scale parameter (c) were obtained at 2.928 and 6.381 meters per second, respectively. The estimated power that could be generated by a Vertical Axis Wind Turbine was 183.09 W/m^2 at 30 meters above ground level. This particular site corresponds to class 1 wind power. This level of power density may be adequate for non-connected electrical and mechanical applications, such as battery charging and water pumping.

Keywords: Wind characteristic; Vertical Axis Wind Turbine (VAWT); Wind data in Chiang Mai

1. Introduction

The demand for energy is increasing steadily in Thailand. According to the Energy Policy and Planning Office, Ministry of Energy, and the Royal Thai Government, the energy consumption of Thailand as of 2006 was 1,547.7 Toe/day. In 2006, Thailand spent 919 thousand million baht for the import of energy in the forms of oil, natural gas, coal and electricity. The ratio of energy consumption in 2006 is shown in Fig. 1. The Royal Thai Government has created a nation-wide campaign to save energy and encourage use of all types of energies: e.g. biomass, biogas, solar, small hydro power plant and wind.

Wind is an existing source of energy which is clean, renewable and abundant. In principle, wind is freely accessible to be utilized. Forces exerted by wind are readily apparent, and thus, efforts to harness wind energy appeared very early in the history of mankind. Recent increases in the cost of fossil fuels has revived the interest in modern exploitation of this form of energy, i.e. wind power.

Wind power is proportional to the cube of the wind speed. Therefore, the knowledge of the wind and its characteristics are important requirements in order for the wind turbine to be designed accurately for higher efficiency. The analysis of wind's energy potential requires proper statistical assessment of wind characteristics such as mean wind speed, direction of wind and its frequency distribution. The wind speed gradient can help predict the potential wind energy at higher elevations with respect to the ground. However, it requires wind data from at least two elevators of the same site so that the power law exponent can be calculated. Vertical variations in wind velocities depend on the season, time of the day and topographical features of the region. To find the most efficient location to set up a wind turbine of any particular size, long-term accumulation of wind data is required.

A Vertical Axis Wind Turbine (VAWT) is suitable for a location with an unidentified wind direction due to the fact that a VAWT accepts wind from any direction. The turbine may be built at locations where high structures are prohibited, such as a city or locations near an airport. Chiang Mai province is located in the north of Thailand and consists of flatlands and mountains. This rolling topography causes high local wind shear. There are two types of seasonal or monsoon wind [2]: the northeast and the southwest monsoon winds, active during November-February and May–August, respectively. So, the objectives of this work are to study the wind characteristics and quantify the wind energy potential at Chiang Mai Province, Thailand, and estimate the power potential that may be

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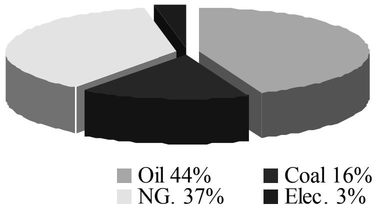


Fig. 1. Thailand's energy consumption in 2006 [1].

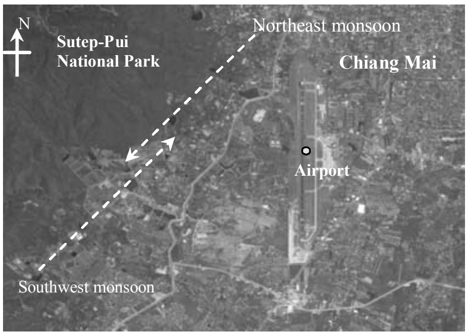


Fig. 2. Chiang Mai International Airport and topography around the airport [4].

generated by a Vertical Axis Wind Turbine (VAWT).

2. Wind data and limitation in this study

This analysis used the wind data collected by the weather station at Chiang Mai International Airport from 2001 to 2006. The station is located at 18º 46' 35.57'' N and 98º 57' 57.07''E. The wind speed data were measured in kilometers per hourwas measured at a height of 2.5 meters above ground level, while the wind direction was measured at 14.0 meters above ground level. The data were converted to meters per second and values were converted to a standard measuring height of 10.0 meters above ground level. Weibull distributions were consequently analyzed. Wind power potential was calculated at 10.0-30.0 meters above the ground level. Finally, the power output of a Vertical Axis Wind Turbine (VAWT) at 30.0 meters was estimated based on the turbine efficiency at 40% with transmission and generator efficiency at 85%.

3. Wind data analysis

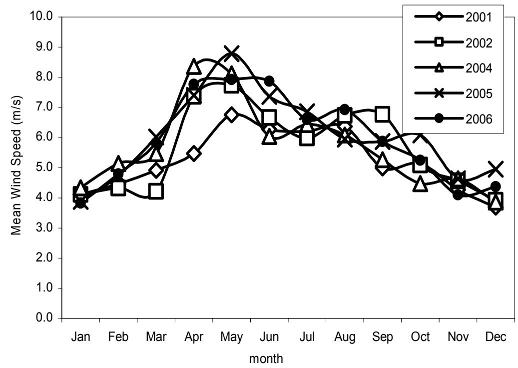
3.1 Wind speed

The monthly mean wind speed ($\overline{V}$) and the standard deviations (SD) were calculated by Eqs. (1) and (2), respectively.

$$\overline{V} = \frac{1}{N}\sum_{i=1}^{N_B} m_i f_i \tag{1}$$

$$\sigma_V = \sqrt{\frac{1}{N-1}\left\{\sum_{i=1}^{N_B} m_i^2 f_i - N(\overline{V})^2\right\}} \tag{2}$$

The method of bins [5] was used to prove the average wind speed and standard deviation, as shown in Eqs. (1) and (2). The data must be separated into the wind speed intervals, or bins, in which it occurs. It is most convenient to use the same-sized bins. Suppose that the data are separated into N_B bins. Each bin has the width w_i, with midpoint m_i, with the number of occurrences in each bins of frequency f_i.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AV
$\overline{V}$ (m/s)	4.1	4.7	5.3	7.3	7.9	6.8	6.4	6.4	5.8	5.2	4.4	4.2	5.7
SD (m/s)	1.4	1.4	2.1	3.5	3.1	2.5	2.1	2.1	2.1	2.1	1.8	1.8	2.2

Fig. 3. Distributional parameters on a monthly basis, calculated from the measured daily time-series maximum wind speed data of Chiang Mai International Airport at 2001-2006.

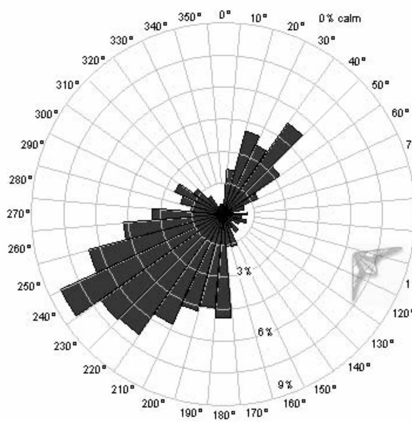


Fig. 4. Wind frequency rose for 2001-2006 at Chiang Mai International Airport.

Fig. 3 shows that the high wind speeds occurred in the summer months, April to August, and diminished in the rainy season from September to December. However, in the cold season, January to March, mean wind speed slightly increased. The annual average wind speed was 5.7 m/s with a standard deviation of 2.2 m/s.

3.2 Wind direction

Wind direction is shown by the wind frequency rose (Fig. 4). Increasing wind frequency was used as an indicator of a main direction. The airport is quite an inappropriate location to setup the wind turbine because this site has a high value of surface roughness, and the turbine will be dangerous to airplanes. However, this data shows the general trend of the values and directions of the wind. The data from the present location indicates that the expected potential wind power should be greater for a site where the surface condition is characterized by a flat open area with low surface roughness.

Most of the wind blows in the South-West to North-East direction or 180-270^o when 0^o is North. The frequency of wind in the 180-270^o direction was 57%. Comparison of Figs. 2 and 4 reveals that the wind is blowing parallel to the mountain range of Sutep-Pui National Park.

4. Vertical wind speed gradient

The wind speed at the surface is zero due to the shear friction between the air and the surface of the ground. The wind speed increases with height most rapidly near the ground, but at a progressively diminished rate at greater heights. At a height of about 2 kilometers above the ground, the changes in the wind speed become zero. The vertical variation of wind speed, or the wind speed profile, can be expressed by different functions. In this study, the power exponential function (Eq. 3) was used to analyze the vertical variation of wind speed at a standard height (10 meters above ground level) and to estimate the wind speed at 20-30 meters above ground level [5].

$$\frac{V_Z}{V_{Z_r}} = \left(\frac{z}{z_r}\right)^{\alpha} \tag{3}$$

Where V_Z, the actual wind speed, is recorded at height z, V_{Z_r} is the wind speed at the required or extrapolated height z_r and α is the power law exponent. The power law exponent can be determined as a function of speed and height with following equation [6],

$$\alpha = \frac{0.37 - 0.088\ln(V_{ref})}{1 - 0.088\ln(\frac{z_{ref}}{10})} \tag{4}$$

where the unit of V_{ref} is in meters per second and z_{ref} is in meters.

The data in Table 1 shows that the predicted wind speed will increase with elevation above ground level. Wind speed at 10 meters above the ground was predicted to be about 30% greater than wind speed at 2.5 meters, and wind speed at 40 meters above the ground was predicted to be 70% greater than wind speed at 2.5 meters. The results show that the wind turbine can capture more energy from wind at higher elevations above ground.

Table 1. The power law exponent and wind speed at 2.5-40 meters above ground level from 2001-2006 at Chiang Mai International Airport.

Month	Power law exponent (α)	Wind speed (m/s) at elevation above ground level			
		2.5 m	10 m	20 m	30 m
Jan	0.25	4.8	5.8	6.9	7.6
Feb	0.24	5.5	6.5	7.7	8.5
Mar	0.23	6.2	7.3	8.5	9.3
Apr	0.20	8.4	9.6	11.0	11.9
May	0.19	9.0	10.3	11.7	12.7
Jun	0.21	7.9	9.1	10.5	11.4
Jul	0.21	7.4	8.6	10.0	10.8
Aug	0.21	7.4	8.6	9.9	10.8
Sep	0.22	6.7	7.8	9.1	10.0
Oct	0.23	6.1	7.2	8.4	9.2
Nov	0.24	5.3	6.2	7.4	8.1
Dec	0.25	4.9	5.9	7.0	7.7
AV	0.22	6.6	7.7	9.0	9.9

5. Statistical analysis of wind data

Statistical analysis can be used to determine the wind energy potential of any site. The wind speed probability distributions and the functions representing them mathematically are the main way to analyze data. Their use includes a wide range of applications, from the techniques used to identify the parameters of the distribution functions [7] to the use of such functions for analyzing the wind speed data and wind energy economics [8]. In general, there are two popular probability distributions to use for wind data analysis, i.e. Rayleigh and Weibull.

The Weibull distribution is based on two parameters:the shape parameter (k) and scale parameter (c). The probability density, $p(V)$ and the cumulative distribution functions, $F(V)$ of the Weibull distribution are given by Eq. 5 and 6 respectively.

Weibull probability density functions, $p(V)$

$$p(V) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1} \exp\left[\left(\frac{V}{c}\right)^{k}\right] \tag{5}$$

Weibull cumulative distribution functions, $F(V)$

$$F(V) = 1 - \exp\left[\left(\frac{V}{c}\right)^{k}\right] \tag{6}$$

It is not a straightforward process to find the shape parameter (k) and scale parameter (c) in terms of $\overline{V}$ and σ_V. There are several methods that can be used. Eqs. 7 and 8 are empirical equations [6]. They are commonly used to calculate the shape and scale parameters.

$$k = \left(\frac{\sigma_V}{\overline{V}}\right)^{-1.086} \quad 1 \le k < 10 \tag{7}$$

$$c = \frac{\overline{V}}{\Gamma(1+1/k)} \tag{8}$$

where $\Gamma(x)$ is gamma function

$$\Gamma(x) = \int_0^{\alpha} e^{-t} t^{x-1} dt \,. \tag{9}$$

The gamma function can be approximated by [9]

Table 2. Weibull parameter and gamma function of (1+(1/k)) at Chiang Mai International Airport.

Month	$\overline{V}$ * (m/s)	SD (m/s)	k	c (m/s)	$\Gamma(1+(1/k))$
Jan	4.1	1.4	3.13	4.53	0.895
Feb	4.7	1.4	3.68	5.20	0.903
Mar	5.3	2.1	2.80	5.93	0.891
Apr	7.3	3.5	2.23	8.20	0.886
May	7.9	3.1	2.76	8.83	0.891
Jun	6.8	2.5	3.04	7.65	0.894
Jul	6.4	2.1	3.38	7.14	0.899
Aug	6.4	2.1	3.36	7.13	0.899
Sep	5.8	2.1	2.94	6.44	0.893
Oct	5.2	2.1	2.63	5.85	0.889
Nov	4.4	1.8	2.70	4.99	0.890
Dec	4.2	1.8	2.50	4.68	0.888
AV	5.7	2.2	2.93	6.38	0.893

* Mean wind speed at 2.5 m above ground level

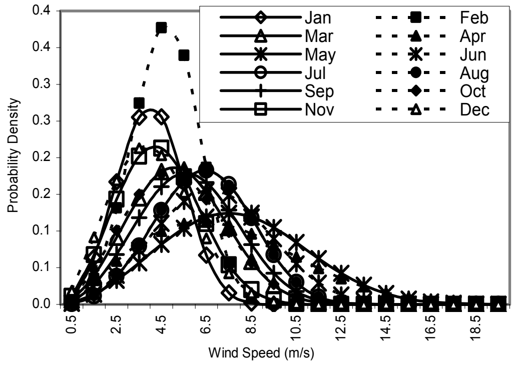


Fig. 5. Weibull probability density distributions at Chiang Mai International Airport.

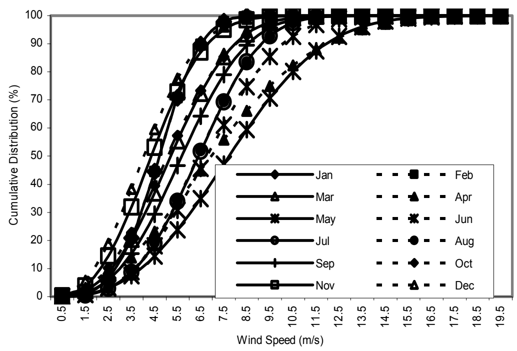


Fig. 6. Weibull cumulative distribution at Chiang Mai International Airport.

$$\Gamma(x)=\left(\sqrt{2\pi x}\right)\left(x^{x-1}\right)\left(e^{-x}\right)\left(1+\frac{1}{12x}+\frac{1}{288x^2}-\frac{139}{51840x^3}+...\right) \quad (10)$$

The Weibull parameter and gamma function of (1+(1/k)) at Chiang Mai International Airport was analyzed by using the wind speed at 2.5 meters above ground level and is listed in Table 2. The Weibull probability density distributions and Weibull cumulative distribution are shown in Figs. 5 and 6, respectively.

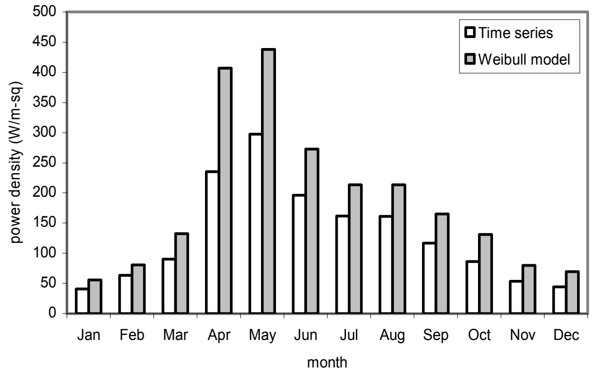


Fig. 7. Wind power densities obtained from the measured data and Weibull models.

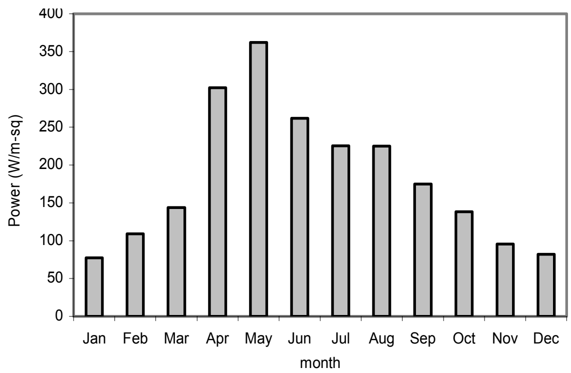


Fig. 8. Potential power generation by VAWT at 30 meters above ground level.

The shape parameter (k) varied between 2.225 and 3.681 and the scale parameter (c) varied between 4.528 and 8.826. The gamma function of (1+(1/k)) varied between 0.886 and 0.903 and is in direct variation with shape parameter (k).

6. Wind turbine power production

The average wind power density, $\overline{P}/A$, represents average available wind power per unit area. This is given by:

$$\frac{\overline{P}}{A}=(\frac{1}{2})\rho\overline{V}^3 \quad (11)$$

whereas the mean power density for the Weibull function (P_W) is given by:

$$P_W=\frac{1}{2}\rho c^3\Gamma\left[1+\frac{3}{k}\right] \quad (12)$$

The power densities calculated from the measured probability density distributions and those obtained from the Weibull models are shown in Fig. 7. The minimum power densities occur in January with 40.8 W/m^2. It is interesting to note that the highest power density values occur in the summer months of April, May, June, July and August, with a maximum value of 297.6 W/m^2 in May. The power densities in the remaining months fall between these minimum and maximum groups.

Fig. 8 shows the potential power density generated by VAWT at 30m above ground level. The specific values used to calculate this is composed of 40% of performance efficiency, C_p , 85% of efficiencies of the drive train, η_m , and the generator, η_e . The power generated is calculated by Eq. 13. The highest power values occur in the summer months with a maximum value of 361.95 W/m^2 in May.

$$P_{VAWT} = \frac{1}{2}\rho C_p \eta_m \eta_e V^3 \tag{13}$$

7. Conclusions

In the present study, daily measured time-series maximum wind speed data from 2001-2006 at Chiang Mai have been statistically analyzed. The probability density distributions have been derived from the time-series data and the distributional parameters were identified. Probability density functions have been fitted to the measured probability distributions on a monthly basis. The wind energy potential of the location has been studied based on the Weibull models. The most important outcomes of the study can be summarized as followed:

(1) The yearly average wind speed and standard deviation values were 5.7 and 2.2 m/s, respectively. The wind primarily blew from the southwest direction.

(2) The average shape parameter (k) was 2.928 and the average scale parameter (c) was 6.381

(3) The yearly average wind power density value was 128.95 W/m^2 at 2.5 m above ground level. The estimated power potential generated by VAWT was 183.09 W/m^2 at 30m above ground level; this particular site corresponds to the wind power class of 1. This level of power density may be adequate for non-connected electrical and mechanical applications, such as battery charging and water pumping.

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