Assessment of Wind Energy Potential in Thailand Based on Using the Multiple-Weibull Distribution

Wikanda Sridech[1*] and Teerawat Klabklay[2]

Abstract

Wind energy potential analysis is a design key to maximize wind turbine efficiency and annual energy output. Typically, the annual wind speed frequency is represented by a Single-Weibull distribution curve in spite of strong and calm wind patterns could occur through a year in many regions in the world, Thailand for instance. For this reason, wind energy potential should be analyzed by Multiple-Weibull distribution curves which are the representative of the meteorological seasons due to the monsoon's effect. Therefore the objective of this study is to compare the accuracy of the Single-Weibull distribution and the Multiple-Weibull distribution in assessment of wind energy potential. The comparison was made between these two statistical distribution functions and the actual wind speed distribution (measured wind speed frequency) in order to determine the level of credibility of these two distribution functions. The wind speed data employed in this study was measured at Lamtakhong dam site in Nakhon Ratchasima province, Thailand. As the results, the error between the Single-Weibull distribution was 16.46% where the error between the Multiple-Weibull distribution was 14.82%, it was revealed that the smaller error, the higher reliability. Two of the most widely used wind turbines (Enercon E-30 and Windspot) were selected to verify the Multiple-Weibull concept. Approximately 40% increase in annual energy yield by using this method. So, the results confirmed that the Multiple-Weibull distribution is valid for the assessment of the annual energy production of wind turbines. Therefore, this will be a practical method for achieving the optimal design of stall-regulated wind turbine in the further work.

Keywords: Monsoon's effect, Maximum AEO, Multiple-Weibull distribution, Stall-regulated wind turbine

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1. Introduction

To optimize the performance of fixed speed or a stall-regulated wind turbine is a complex procedure according to the several trade-off decisions. This type of wind turbine is mostly small and medium-size that is suitable for household utilization in remote areas. The initial capital cost of investment is likely low due to the unnecessary intelligent control system, therefore installing the stall-regulated wind turbine in the low wind sites could be the attractive choice. Merely, by optimizing the aerodynamic efficiency of the rotor, the best wind turbine could produce the maximum annual yield for a given Weibull wind speed distribution. Another significant factor in designing the optimal rotor for the specific wind sites is the quality of the measured wind speeds. There are several parameters that affected the quality of the measured wind speeds namely period of time for collecting wind data (weekly monthly or yearly), frequency of collecting data including the accuracy of the instruments, and so on. An acceptable collected duration should be at least 2 years [1], afterward, the credible wind speed distribution curve will be carried out.

As mentioned above, Thailand located in a monsoon climate zone where there is a seasonal reversing wind correspond to the seasonal changes including windy and calm periods. The monsoon pattern is quite simple as shown in Fig.1; the southwest monsoon blows toward the land crossing the Indian Ocean and brings the moisture over the ocean with it result in rainfall in May. Until the end of June, rainfall has decreased for a while so-called *Rain Drop Range*. The southwest monsoon starts again approximately in July and lasts till October, it brings heavy rain or depression or typhoon depending on strength of high- and low- pressure area. In November, the northeast monsoon brings less rain, rather dry and cool air from China. Winter season in Thailand normally starts in November and ends in February. It would be colder especially in the North and North East of Thailand unless the South, heavy-rain is last long enough to cause flooding, particularly in the Southeast coast. However, the rainy season may start sooner or later in the range of approximately one or two weeks.

As described earlier, evaluation the wind performance at a given site by using the multiple-Weibull (including monsoon's effect) could yield the more accurate annual energy than the single-Weibull (represented a year-round wind statistic). The concept of this study is to separate the measured wind data into 4 ranges and evaluate each of them by the individual Weibull's parameters that will be discussed later. The effect of monsoon season on energy production is illustrated in Fig. 2(b) and 2(d) to ensure that an assessment on annual wind energy by a single statistical model (Fig. 2(a) and 2 (c)) is underestimated than multiple models. The average wind speed pattern is shown in Fig. 2(a) whereas Fig. 2(b) explains the characteristic of average wind speed pattern with the presence of monsoon's effects. Fig. 2(c) and 2(d) showed the values of V^3 that represent the wind power evaluated by Single-Weibull and Multiple-Weibull distribution, respectively. As much as two times of V^3 that provided by the Multiple-Weibull method compare to the Single-Weibull method. This is a derivation of exploring the Multiple-Weibull statistic to achieve the wind potential assessment and optimal wind turbine for a specific area. From meteorological observation over a year for wind characteristic with monsoon's effect divided a year into 4 ranges, the 1st range is over February-April, the 2nd range is over May-July, the 3rd range is over August-October and the 4th rang is over November-January. Nevertheless, two of the most widely used wind turbines were selected to show the credibility of the new concept, namely Enercon E-30 and Windspot. For further work, this concept will be applied to optimize blade shape in enhancing the annual energy output (AEO) [6-7]. The iterative approach is utilized in order to complete the blade pitch optimization by the aerodynamic model based on BEM theory [2-5].

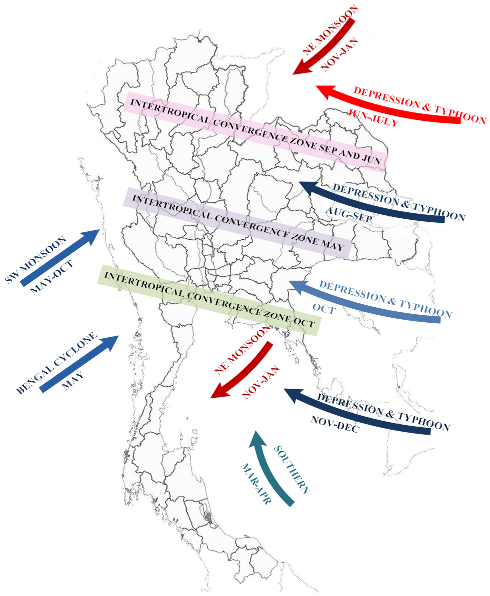

Fig. 1. The monsoon pattern in Thailand (Bureau of Large Scale Water Resources Development)

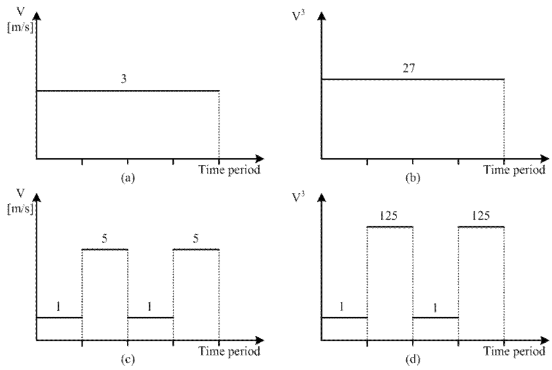

Fig.2. The comparison between a single statistical curve and multiple statistical curves including monsoon's effect 2a) average annual wind speed 2b) average wind speed in monsoon seasons 2c) represented annual wind power 2d) represented wind power in monsoon seasons

2. Study of wind statistic

The measured wind speeds those were used in this study have been acquired from a meteorological station at Lamtakong dam site in Nakhonratchasima located between 14°47’58"N latitude and 101°33'32.2"E longitude. The measured data were collected from 2006 – 2008 at the height of 661 m above sea level and has been supported by the Electricity Generating Authority of Thailand (EGAT).

2.1. The actual distribution

The frequency distribution of the measured wind speeds is mostly presented as a wind speed histogram with a bin width of 1 m/s [2]. It can be theoretically evaluated based on method of bins by using Equation (1).

$$f_H(v) = \frac{\sum_{i=1}^{n} A_{I_k}(V_i)}{n.W}, \quad v \in I_k \tag{1}$$

Where n is a number of the hourly mean wind speed data set, W is bin width and $A_{I_k}(u)$ is the indicator function of the interval I_k, which is 1 provided that $u \in I_k$ and is otherwise 0. Each interval is equal to 1 m/s according to the bin width setting. Fig.2 shows the variable frequency of the individual wind speed calculated using Equation (1).

2.2. Weibull distribution

The actual distribution is mostly fitted with the Weibull distribution which is rather flexible due to its two parameters as shown in Equation (2). Annual wind speed frequency distribution curve and its statistical parameters corresponding to the measured wind speeds are expressed in Fig. 2 and Table 1, respectively.

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^{k}\right] \tag{2}$$

Where V is instantaneous wind speed, k is shape parameter and c is scale parameter [m/s],

$$k = \left(\frac{\sigma_V}{\overline{V}}\right)^{-1.086}, \quad c = \frac{\overline{V}}{\Gamma(1+1/k)}$$

And $\overline{V}$ is mean wind speed can be calculated from the following relation

$$\overline{V} = c\Gamma(1+1/k), \quad \Gamma(x) = \int_0^{\infty} e^{-t} t^{x-1} dt$$

The Annual wind energy was calculated by Equation (3)

$$E_{annual} = 8760 \int_v P_w(V) \times f(V) dV \quad ;$$

$$P_w = \frac{1}{2}\rho V^3 \tag{3}$$

Where P_w is wind power produced at instantaneous wind speed per unit area which can be calculated from the following relation

2.3. Multiple-Weibull distribution

In this approach, wind energy assessment and analysis are focused on the monsoon's effect in Thailand. There are 4 observed periods throughout the year namely Feb-Apr, May-Jul, Aug-Oct and Nov-Jan, respectively. The measured wind data fall in those ranges are statistically evaluated by Weibull probability distribution function (Weibull PDF) as shown in equation (2). The Weibull's parameters are presented in Table 1 whereas the correlation between actual PDF and Weibull PDF are shown in Fig.3 and Fig. 4.

3. The Goodness of fit

Test goodness fit between Weibull distribution curves with respect to the actual values are evaluated based on Regression analysis. The correlation coefficient (R^2) is used to measure the correlation between the calculated values from the Weibull PDF and the actual values or measured data. It is determined by Equation (4).

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(p_i - \hat{p}_i)^2}{\sum_{i=1}^{N}(p_i - \overline{p})^2} \tag{4}$$

Where p_i is the relative frequency of the sample given by Equation (1), $\hat{p}_i$ is the probability obtained from Weibull PDF at each interval I_k, $\overline{p}$ is the mean of the total p_i values and N is the total number of intervals.

In Table 1, R^2 corresponding R^2 to the Single-Weibull and Multiple-Weibull (1st Range – 4th Range) are 0.96, 0.94, 0.87, 0.95 and 0.94, respectively. According to R^2 that represents the credibility of Weibull distribution fitted by Weibull PDF and measured wind speeds, a higher R^2 represents a better fit using Weibull PDF and the highest value it can get is one while the lowest is zero. As a result, it could be concluded that the Weibull PDF is suitable to estimate the wind speed probability because of its high values of R^2.

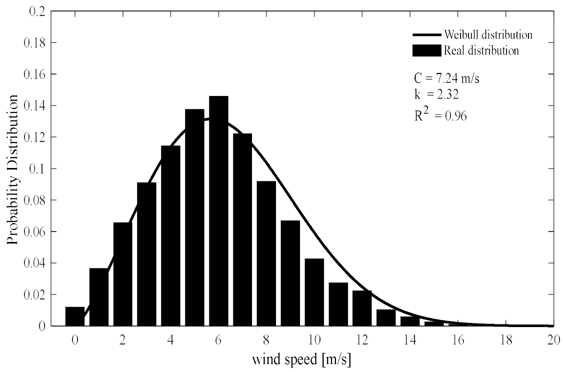

Fig.3. The measured wind speeds frequency histograms and Weibull PDF curve at Lamtakong in Nakhonratchasima

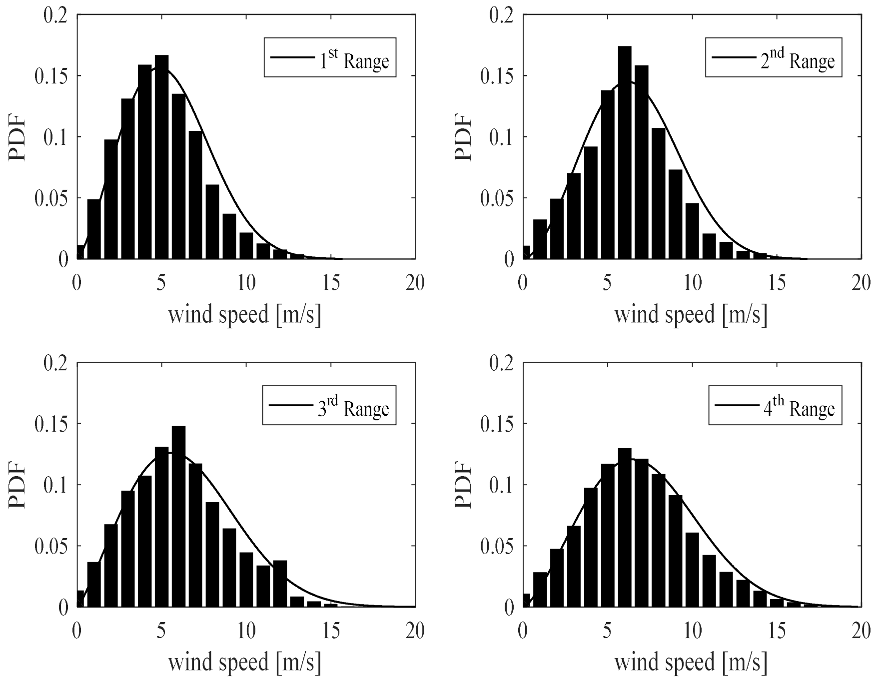

Fig.4. The measured wind speeds frequency histograms and Weibull PDF curves divided into 4 ranges at Lamtakong in Nakhonratchasima

Table 1 The statistical parameters for a Single-Weibull and Multiple-Weibull

	Year-round	**1st Range**	**2nd Range**	**3rd Range**	**4th Range**
c [m/s]	7.24	6.15	7.36	7.30	8.08
k	2.32	2.35	2.68	2.22	2.39
Variance	8.64	6.07	6.94	9.51	10.16
Mean [m/s]	6.42	5.45	6.54	6.47	7.16
$\sqrt[3]{(V^3)}$ [m/s]	9.47	7.99	9.06	9.76	10.42
R^2	0.96	0.94	0.87	0.95	0.94

4. Wind turbine power production

The Annual Energy Production (AEP) calculated by Equation (5). This study proposed the new concept to precisely evaluate the annual yield produced by the selected wind turbines. Therefore the power density curves are separated to four curves in a year corresponding to Energy Productions (EP) for each range as shown in Eq.6 – Eq.9.

$$AEP = 8760 \int_v P_t(V) \times f(V)\, dV \quad (5)$$

Where f and P_t are the Weibull's probability density function and wind turbine power at instantaneous wind speed, respectively.

First Range: $$EP_1 = 2208 \int_v P_t(V) \times f(V)\, dV \quad (6)$$

Second Range: $$EP_2 = 2208 \int_v P_t(V) \times f(V)\, dV \quad (7)$$

Third Range: $$EP_3 = 2184 \int_v P_t(V) \times f(V)\, dV \quad (8)$$

Fourth Range: $$EP_4 = 2160 \int_v P_t(V) \times f(V)\, dV \quad (9)$$

The constant numbers before the integral sign are the number of hours in each range.

4. Result and Discussion

The selected wind turbine, Enercon E-30, and Windspot represent a medium and a small wind turbine, respectively. They are used to verify the statistical function and to evaluate the AEPs corresponding to the medium and the small wind turbine suppose they are running at the specific area, Lamtakong in Nakhonratchasima province. The performance curves are shown in Fig. 5 and Fig. 6.

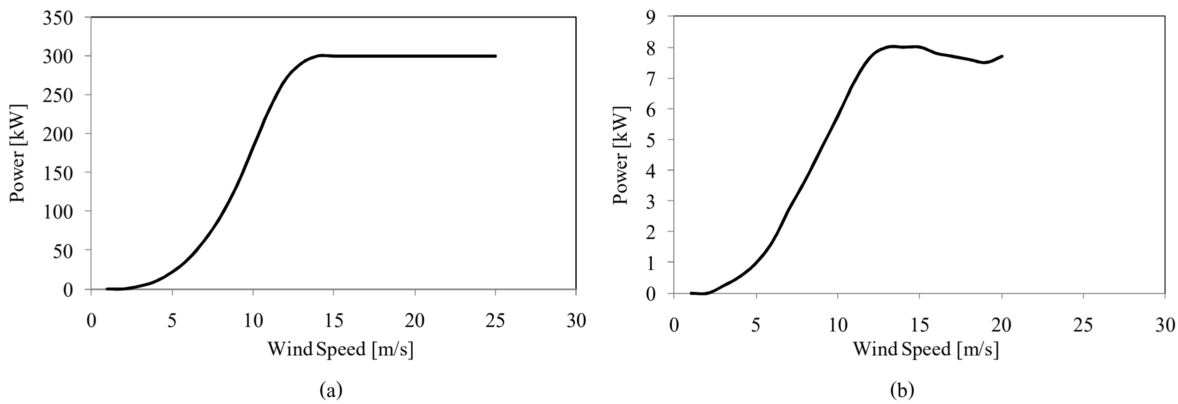

Fig. 5. (a) Power curve of Enercon E-30 wind turbine (300 kW) (b) Power curve of Windspot wind turbine (8kW)

Table 2 The annual energy yield from a Single-Weibull and Multiple-Weibull analysis

	Wind energy	**Enercon E-30**	**Windspot**
AEP from single Weibull [Wh/year]	7,447,600	633,403.39	22,566.88
AEP from multiple Weibull [Wh/year]	10,236,300	868,173.79	30,892.96
% increase	44.54	37.06	36.90

As the results, the error between the Single-Weibull PDF was 16.46% where the error between the Multiple-Weibull PDF was 14.82%. So, the results indicated that the Multiple-Weibull PDF is more accurate in statistical analysis of wind speed than the Single-Weibull PDF.

The different size of wind turbines operated under the high potential site contributed to the different annual yield which depended on the machine rating. What if the machine rating is increased, the higher the electricity produced, the higher the profitable revenue would be gained accordingly; likewise, the higher credibility of the statistical model, the higher reliable annual yield and economic assessment. From Table 2, the AEPs calculated by Multiple-Weibull PDF compared to the conventional one could be increased by 44.54%, 37.06%, and 36.90% for evaluating wind energy, Enercon E-30, and Windspot, respectively. The increasing percentage is not only affected by the profitable revenue that would be gained but concerns with a minimum COE as well. This issue will be carried out in further work.

5. Conclusions

The merit of this research is the novel reliable statistical model, Multiple-Weibull PDF, which is able to identify the suitable wind turbines for installing at specific areas. The wind data from Lamtakong dam site in Nakhonratchasima were utilized for wind potential energy analysis. As a result, the AEPs were increased approximately 40% by using the Multiple-Weibull PDF instead of using the Single-Weibull PDF. Therefore, further work is to analyze the Multiple-Weibull concept together with economic principles that will turn out the maximum profitable revenue from electricity selling and optimal wind turbine blade shape as well.

6. Acknowledgement

The authors would like to thank for the data used in this work that has been supported by the Electricity Generating Authority of Thailand.

7. Reference

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