Comparative Study of Three Methods for Determining Weibull Parameters in Pauh Putra, Perlis

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Abstract. This paper studied about analysis characteristics of wind speed at Pauh Putra, Perlis, where nearest to Chuping station, Perlis, Malaysia. The wind speed characteristics consist of monthly and annual wind speed in Perlis, Malaysia. By using Weibull distribution, three different methods to calculate the potential of wind power generation and analysis the characteristics of wind speed at Pauh Putra, Perlis. The results present the means wind speed is 1.0790 m/s and 1.1321 m/s for 2018 and 2019, respectively. The highest monthly mean wind speed occurred in February for both years, 2018 and 2019. Besides, the lowest monthly wind speed for 2018 in May and for 2019 in October. The Weibull distribution summarized the highest probability density is 120\% in the wind speed, 1.1 m/s using the Maximum Likelihood Method (MLM) method for these two years. Furthermore, this research found that the Energy Pattern Factor (EPF) Method is stretched to the right, and its height decreased from other methods for both years based on the graph of the wind speed of probability density function. The Maximum Likelihood Method (MLM) for these two years is higher because its shape parameters are relatively higher based on the graph of the wind speed of probability density function.

1. Introduction

In physics, energy is a total capacity doing work exists in many forms [1]. There are different types of energy resources, such as wind, nuclear, coal, water, biomass, oil, natural gas, and solar. Furthermore, each type of energy can be categorized into renewable energy (solar, biomass, wind, and hydro) and non-renewable energy (natural gas, coal, fossil fuel, and nuclear) [2-3]. However, there are many forms of energy, such as electrical energy, kinetic energy, thermal energy, light energy, and others [2]. Wind energy is categorized as renewable energy and in the form of kinetic energy. It is continuous energy and can use the wind turbine to capture and transform kinetic energy into mechanical energy and then convert to electrical energy [4-5].

Today, some country in the World has strong wind speed; it can generate electricity and wind power are growing faster technologies in global. China (221 GW capacity), United State (96.4 GW capacity), Germany (59.3 GW capacity), India (35 GW capacity), Spain (23 GW capacity), United Kingdom (20.7
GW capacity), France (15.3 GW capacity), Brazil (14.5 GW capacity), Canada (12.8 GW capacity), and Italy (10.1 GW capacity) are top ten countries using wind power [6].

The wind power potential depends on the collected data from the selected location. Also, the random variable of wind speed and variation of wind speed used in the potential by the probability density function of wind energy [4]. A lot of researchers justified the suitable method to estimate the wind energy potential is Weibull distribution. Several methods can use to determine the two parameters of Weibull distribution [7-8]. For instance, which widely applied Moment of Method (MoM), Maximum Likelihood Method (MLM), Modified Maximum Likelihood Method (MMLM), Empirical Method (EM), Graphical Method (GM), Energy Pattern Factor Method (EPF) and Power Density Method (PDM) [9].

Most of the researchers studied the potential of wind power generation and wind speed characteristics in the World. Tian Pau Chang [10] verified by simulation test using a small number of variables that the MLM shows good performance than other methods, followed by MoM and MMLM. It affords a more precise estimate of Weibull parameters in the simulation test. P. Chaurasiya, S. Ahmed and V. Warudkar [8] compared nine numerical methods such as MoM, GM, MLM, MMLM, PDM, Alternative Maximum Likelihood Method (AMLM), Least Square Method (LSM), Empirical Method of Justus (EMJ), and Empirical Method of Lysen (EML) and to estimate the two parameters of Weibull distribution in India. MLM and MMLM present the better performance. In contrast, GM and AMLM present a weak performance. Therefore, MLM more accurate in analyzing the wind power potential by using Weibull distribution.

Next, Yusuf Alper Kaplan [11] concluded that PDM is applied to identifying the wind energy potential by using the monthly and annual wind speed data based on three different locations in Southern Turkey. It is appropriate when wind speed suitable with Weibull distribution for all selected locations. A. K. Azad et al. [12] reviewed three methods to analyze wind power generation, such as PDM, LSM, and MMLM. They stated that LSM is more accurate with minimum error value in wind data analysis. P. A. C. Rocha et al. [9] used the GM, MLM, EPF method, MoM, MMLM, and Equivalent Energy Method (EEM) to analyze the wind power potential. According to the results, EEM is the efficient method to calculate the k and c parameters.

Furthermore, the GM and EPF method less efficient methods to fit the curves of Weibull distribution. Besides, Y. M. Kantar et al. [13] analyzed the wind data by using MLM, MoM, MMLM, LSM, Tiku’s Maximum Likelihood Method (TMMLM), and Generalized Spacings Method was adopted to estimate the two parameters of Weibull distribution. Therefore, they are selected TMMLM as the best estimator.

This paper shows the three different methods to calculate the wind power potential by using Weibull distribution, that including Moment of Method (MoM), Maximum Likelihood Method (MLM), and Energy Pattern Factor Method (EPF). The characteristics of wind speed have been analyzed at Pauh Putra, Perlis, where nearest to Chuping station, Perlis. The wind speed characteristics consist of monthly and annual wind speed in Malaysia.

2. Different Methods for Evaluating Weibull Parameters

Weibull distribution is a beneficial statistical method to determine the potential of wind power based on measured data and analyze the data in frequency distribution [4,8]. There are two main Weibull parameters: dimensionless shape parameter, k and scale parameter, c to describe the Weibull probability function \( f(v) \) and the cumulative distribution function \( F(v) \) as given in Equation (1) and (2).
where $v$ is wind speed (m/s), $k$ is shape parameter (dimensionless) and $c$ is scale parameter (m/s). The Weibull distribution divided into two categorized, which is exponential distribution ($k=1$) and Rayleigh distribution ($k=2$) [14-15]. For the Rayleigh distribution, the shape parameter $k$ is equal to 2 and used to find the scale parameter, $c$ [10,16]. There are several methods to determine the parameters of Weibull distribution that are briefly discussed next subsection.

2.1. Maximum Likelihood Method (MLM)
The maximum likelihood method is a complicated mathematical expression method because it uses the numerical iteration to solve the Weibull parameters [8-10]. The mathematical expression contains the assumption of unknown parameters, such as the shape parameter value, $k$ [9-10]. In this method, the shape parameter’s initial value equal to 2 because of using Rayleigh distribution to find another parameter [15]. The Weibull parameters are calculated by using Equation below [7-10]:

$$k = \left[ \frac{\sum_{i=1}^{n} v_i^k \ln(v_i) - \sum_{i=1}^{n} \ln(v_i)}{\sum_{i=1}^{n} v_i^k} \right]$$

(3)

$$c = \left( \frac{1}{n} \sum_{i=1}^{n} v_i^k \right)$$

(4)

where $n$ is the number of data points and $v_i$ is the wind speed measured at the interval $i$.

2.2. Moment of Method (MoM)
Moment of method is a simple method of calculating the population of parameters by using the mean (\(\bar{v}\)), standard deviation (\(\sigma\)), and a gamma function (\(\Gamma\)) to calculate the shape and scale parameter according to numerical iteration by the following Equation:

\[
\bar{v} = c \Gamma\left(1 + \frac{1}{k}\right)
\]

(5)

\[
\sigma = c \left[ \Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right) \right]^{1/2}
\]

(6)
where
\[
\text{Mean } (\bar{V}) = \frac{1}{n} \sum_{i=1}^{n} V_i
\]  

(7)

\[
\text{Standard deviation } (\sigma) = \left[ \frac{1}{n-1} \sum_{i=1}^{n} (V_i - \bar{V})^2 \right]^{\frac{1}{2}}
\]  

(8)

where \( \Gamma(x) \) is the Gamma function defined by

\[
\Gamma(x) = \int_{0}^{\infty} t^{x-1} \exp(-t)dt
\]  

(9)

2.3. Energy Pattern Factor Method (EPF)

The energy pattern factor method is associated with the mean of wind speed (measured data). Before calculating the \( k \) and \( c \) parameters, this method using the ratio between the mean of wind speed cubic and cubic of mean wind speed is expressed by the Equation below [8-10]:

\[
E_{pf} = \frac{\bar{V}^3}{\bar{V}}
\]  

(10)

\[
k = 1 + \frac{3.69}{E_{pf}^2}
\]  

(11)

\[
c = \frac{\bar{V}}{\Gamma\left(1 + \frac{1}{k}\right)}
\]  

(12)

Where \( E_{pf} \) is the Energy Pattern Factor, and \( \Gamma \) is the gamma function.

3. Results and Discussion

In this research, wind speed data have been collected from Chuping meteorological stations located in Perlis. The mean wind speed data has been sorted out based on monthly and yearly in Malaysia. The variation of monthly wind speed in Chuping, Perlis, is presented in Figure 1. Malaysia is located between Thailand, Singapore, and Indonesia; these four countries facing more or less the same climate. However, Malaysia is close to the equator where this country has unique climate characteristics, namely heat, humidity, and rain throughout the year. There are four monsoons in Malaysia, such as Northeast Monsoon, Southwest Monsoon, and two Inter-Monsoon. According to Figure 1, the wind speed value is starting to increase from October to March (Northeast Monsoon) and the constant value of wind speed from May to early October (Southwest Monsoon). However, the wind speed starts to decrease from March to May and early October to Mid-October, called Inter Monsoon.

The monthly variation of wind speed is determined from the hourly data recorded from Chuping station. In 2018, the maximum mean wind speed was found in February (1.7673 m/s), the minimum mean wind speed in May (0.7599 m/s), and the average value is 1.0790 m/s. In 2019, the maximum
mean wind speed was found in February (1.7528 m/s), the minimum mean wind speed in June (0.8135 m/s), and the average value is 1.1321 m/s. The wind speed was higher in February due to Northeast Monsoon. During Northeast Monsoon or winter monsoon, the average wind speed is higher than the other monsoons in Malaysia, and the total rainfall also higher in this period [17]. Furthermore, the wind speeds constant lower from May until early October because that period is Southwest Monsoon.

Figures 2 and 3 show the yearly probability density function of wind speed for 2018 and 2019 using two parameters data of Weibull distribution, respectively. Based on these results, the largest scale parameter, c, is 1.2147 m/s (2018) and 1.2716 m/s (2019) by using the EPF method. On the other hand, the smallest scale, c parameter is 1.0896 m/s (2018) and 1.1179 m/s (2019) using the MLM method. It can be found that the highest probability density of 120% in the wind speed, 1.1 m/s by using the MLM method for these two years. The MoM and EPF are the same trends, but MLM is different than other methods. To determine the yearly probability density function of wind speed for these years using the annual shape parameter shown in Figure 4(a) and scale parameters shown in Figure 4(b).

![Figure 1](image1.png)

*Figure 1. Variation of Monthly Wind Speed in Chuping Station.*

![Figure 2](image2.png)

*Figure 2. Wind speed of probability density function for 2018.*
Figure 3. Wind speed of probability density function for 2019.
Figures 5 and 6 show the monthly variation of shape parameter (Figures 5a and 6a) and scale parameters (Figures 5b and 6b) of Weibull distribution for Pauh Putra, Perlis. An analysis of Weibull distribution has been done by three different statistical methods, such as MLM, MoM, EPF method. Each method using the MATLAB software to simulate the two parameters. After that, the monthly variation of shape parameter in the EPF method closer to the shape of Rayleigh distribution value (k=2) is shown in Figures 5(a) and 6(a). The maximum shape parameter in February (21.9417) for MLM and the minimum shape parameter in December (2.9309) for MoM. Furthermore, Figures 5(b) and 6(b) present the wind energy potential with the EPF method`s scale parameter higher than other methods.
Figure 5. Monthly Variation of (a) Shape Parameter and (b) Scale Parameter (2018).
4. Conclusion
The wind energy potential in Pauh Putra nearest to Chuping meteorological stations has been studied using Weibull distribution. The two parameters of Weibull distribution have been calculated by using three methods, which are Moment of Method (MoM), Maximum Likelihood Method (MLM), and Energy Pattern Factor Method (EPF) and simulate with MATLAB software. According to the yearly probability density function of wind speed, the scale parameter of MLM is smallest than other methods. However, the MLM contains the highest probability distribution function at the wind speed of 1.1 m/s. According to Figures 5a and 6a, it can conclude that the MLM and MoM have largely differed from the Rayleigh distribution. It can explain that the shape parameter, \( k \), is determined as 2 in the Rayleigh distribution. Besides, the analysis found that the graph trend of wind speed of probability density function indicates the EPF method stretched to the right, and its height decreased from other methods for both years. It is because the value of the scale parameter is larger than other methods. Furthermore,
the EPF method results have been justified by Weibull distribution, where the shape parameter is closer to the shape of Rayleigh (k=2). Based on Figures 2 and 3, the MLM method for two years is higher than other methods because its shape parameters are relatively higher than other methods, and it is referred to as the Weibull slope [18].

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