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WIND ENERGY POTENTIAL: A CASE STUDY OF MERSING, MALAYSIA

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ABSTRACT

The findings regarding the wind velocity and its contribution to the power of wind energy are discussed in this paper. It involves a statistical analysis of its wind regime, the probability distribution of wind speed and power analysis. A rigorous selection of the probability distribution leads to an unambiguous power analysis. The main distribution selected is Weibull and Gama probability distribution. The wind power equation is derived through transformation method and the outcome of wind power analysis demonstrates the feasibility for the efficient extraction of wind energy in Malaysia. This paper suggests the potential of Mersing area for generating wind power.

Keywords: weibull, gama, wind power density.

INTRODUCTION

Dependence on fossil fuel sources so far have given an adverse impact on the availability of resources and the environment. The decline is similar to the use of resources has been urged to alternative sources of fuel or, more specifically renewable energy sources. Among these sources are solar, biomass, wind, tidal and hydropower. Besides of their cleanliness, they also promise of free cost and unlimited natural sources.

The existing renewable energy sources such as solar, wind and biomass should be explored and fully utilized at the heart of sustainable development. Wind is the one of the most common sources that being studied and has produce tremendous technology and performance around the world. The implementation of wind as a source of energy might be much beneficial to those in rural area and remote island as there are out of the national grid electricity (Borhanazad *et al.*, 2013).

As for Malaysia, studies on wind speed and it energy potential has been done since 1980s and it was undertaken in Universiti Kebangsaan Malaysia. (Sopian, 1995) is among the pioneer researcher that focused on the wind speed in Malaysia. As Malaysia is located at equator, land and sea breezes may influence the wind regime. The wind does not blow uniformly and varies according to the month and region. Therefore, studies on wind speed behavior and characteristic has dominated windstudies in Malaysia (Siti Noratiqah *et al.*, 2010; Siti *et al.*, 2011; Masseran, Razali & Ibrahim, 2012; Islam *et al.*, 2011). Southern and east coast of Peninsular Malaysia show higher potential in terms of wind velocity compared to other part on peninsula (Zaharim *et al.*, 2009; Najid *et al.*, 2009; Zaharim, 2009; Masseran, Razali, Ibrahim, *et al.*, 2012). It may due to monsoon seasons that effect such area which exposed to the South China Sea.

Although the average flow of wind is light in Malaysia, it can generate a high amount of energy, especially on remote islands which experiences higher wind speed. Innovation of wind research by hybrid system of solar and wind has led to another promising way of generating wind energy (Sopian *et al.*, 2009). On the other hand, the use of small size wind turbine may overcome the light wind speed condition in Malaysia. (Rosly *et al.*, 2012) has suggested the use of surrounded WTG with wind-lense technology in capturing the light wind speed and optimizing energy production.

This research paper focuses on the trend of wind speed and estimated wind power density in Mersing, Malaysia. Since the data used in this study are quite up-to-date, the findings of this paper will be beneficial in order to expand the wind studies in Malaysia.

Figure-1. Location of Mersing, Johor(MDM 2013).

STUDY AREA AND DATA

Mersing is located at the southern part of Peninsular Malaysia, having a geographic coordinate 2.4333° in the north latitude and 103.8333° in the east longitude. Throughout the year, Mersing experiences a wet and humid condition with mean daily temperature is 31°C and nearly 70 percent humidity (Razali *et al.*, 2012). The wind blows in Malaysia is influenced by the monsoon seasons, namely southwest monsoon, northeast monsoon with two short inter-monsoon. The northeast monsoon which occur from November till March brings about heavier rainfall in the peninsula, with the worst affected areas are in the east and south including Mersing. As shown in Figure-1, Mersing is located near to the sea that caused influenced by the effect of sea breezes and land breezes.

Hourly wind speed (m/s) at 10 meter height data of Mersing is provided by the Malaysian Meteorological Department. The data records is from January 2007 to December 2013.

METHODS

Basically, this paper will discuss the potential of generating wind energy in Mersing. In order to gain results, analysis method will be divided into three sections which are descriptive analysis, parameter estimation of probability distribution and wind power analysis.

On top of that, the hourly wind speed data were analysed by MATLAB R2014a as the main software used in this research.

Descriptive analysis

For descriptive analysis, it will involvethe mean, variance and skewness of wind speed. This analysis is meant to present the characteristic of wind speed in Mersing. Table-1 shows the formula related for descriptive analysis

Table-1. Formula for descriptive analysis.

Mean wind speed	$\boldsymbol{\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}}$
Variance	$s^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})}{n-1}$
Skewness	$g_1 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^3}{(n-1)s^3}$

Parameter estimation

This paper suggests two types of probability distribution which are Weibull and Gama distribution in explaining the shape of wind speed distribution in this area.

The selection of these two probability distribution is basically based on the Goodness of Fit test such as Akaike's Information Criterion (AIC) (Akaike 1974) and R^2 Correlation Coefficient.

(i) $AIC = -2\log(\mathrm{L}) + 2\mathrm{K}$

Where L is the likelihood function model and k is the number of parameters to model.

(ii) $$R^2 = \frac{\sum_{i=1}^{n}(\hat{F}_i - \bar{\mathrm{F}})^2}{\sum_{i=1}^{n}(\hat{F}_i - \bar{\mathrm{F}})^2 + \sum_{i=1}^{n}(F_i - \hat{\mathrm{F}})^2}$$

where F_i is the cumulative function, $\hat{F}_i$ is the estimated cumulative distribution function and $\overline{F}$ is the average of $\hat{F}_i$.

a) Weibull distribution

The probability density function (pdf) for Weibull is presented in equation (1):

$$h(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} e^{-\left(\frac{v}{c}\right)^k} \quad for\ 0 < v < \infty \tag{1}$$

where:
k = shape parameter, c= scale parameter, v = wind speed

The Weibull shape and scale parameters are estimated using Maximum Likelihood method which is given by:

$$k = \left[\frac{\sum_{i=1}^{n} v_i{}^k ln(v_i)}{\sum_{i=1}^{n} v_i{}^k} - \frac{\sum_{i=1}^{n} ln(v_i)}{n}\right]^{-1} \tag{2}$$

where:
v_i= wind speed in time step, *I,* n= number of data points

The value of *k* is evaluates by using an iterative technique. In this study the Newton Raphson method (Schworer and Hovey, 2004) has been used. The scale parameter, *c* is obtained by:

$$c = \left[\frac{1}{n}\sum_{i=1}^{n} v_i{}^k\right]^{1/k} \tag{3}$$

b) Gama distribution

$$f(x;\alpha,\beta) = \frac{1}{\Gamma(\alpha)} x^{\alpha-1} exp\left(-\frac{x}{\beta}\right) \tag{4}$$

Equation (4) represents the probability density function (pdf) for Gama distribution.

Where:
α= shape parameter, β = scale parameter; $\Gamma(x)$= Gama function
As for α and β, the value can be estimated by using:

$$\hat{\beta} = \frac{\bar{x}}{\alpha} \tag{5}$$

$$\ln(\hat{\alpha}) - \Psi(\hat{\alpha}) = ln\left(\frac{1}{n}\sum_{i=1}^{n} x_i\right) - \frac{1}{n}\sum_{i=1}^{n}\ln x_i \tag{6}$$

Equation (5) and (6) can be solved using iteration technique (Carta *et al.*, 2009).

Wind power analysis

The wind power density is the number of watts of electrical energy produced per square meter of air space (W/m²).
The general formula for wind power is:

$$P = \frac{1}{2}\rho_k V^3 \tag{7}$$

As mention earlier, this paper discusses the wind power analysis from two distributions which are Weibull and Gamma.It reflected that the wind power analysis has to consider the role of Weibull and Gama. In order to solve it, this study use transformation method (Wackerly *et al.*, 2008) as a tool converting their probability density function into wind power. The details method would not be discussed in this paper due to limited space.

$$wind\ power\ density = \rho_k u c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{8}$$

$$wind\ power\ density = \frac{\rho_k \beta^3 \Gamma(\alpha+3)}{2\Gamma(\alpha)} \quad (9)$$

where:

$$u = \frac{1}{2}\rho_k A;\ \Gamma(x) = \int_0^\infty e^{-t} t^{x-1} dt$$

Equation (8) and (9) represent the wind power density for Weibull and Gama respectively (Safari & Gasore, 2010). These two formula are derived from equation (7) together with equation (1) and (4) by using transformation method. For Malaysia case, the value of air density, $\rho_k = 1.16 kg/m^3$ (Sopian, 1995).

RESULT AND DISCUSSIONS

Descriptive analysis is a must initial analysis that should be done before any advance analysis. It gives idea how the overall data is. Basically, this analysis consists of mean, variance and skewness of the data. For this study, the details on wind speed descriptive analysis is shown in Table-2 below.

Table-2. Descriptive analysis.

Year	Mean	Variance	Skewness
2007	**2.7063**	**1.5215**	**1.0941**
2008	2.9201	2.1176	0.7435
2009	2.8270	1.8835	0.9423
2010	2.6051	1.5953	0.7158
2011	2.8723	2.1013	0.9896
2012	2.5776	1.7215	1.0149
2013	2.7432	1.9314	0.8221

From Table-2, mean wind speed for Mersing is within (2.58-2.10) m/s or (7.56-9.288) km/h for that respective year. In general, minimum 2 m/s of wind speed is required to start rotating most small wind turbines [6].

While for variance, the values for all years are considered moderate which is between (1.5-2.2) m/s or (5.4 - 7.9) km/h. Variance is the indicator that all the data recorded are not much different from its mean value. Skewness coefficient is between 0.74 - 1.09 shows that the data is following its distribution quite well, in this case is Weibull distribution. For all years, the values of mean, variance and skewness share a very close value without any outliers. It shows that the raw wind speed data is well distributed without any extreme values.

For this study, an appropriate distribution has been determined by fitting two types of statistical distribution to the data, namely Weibull and Gama. It is validated by the Akaike's Information Criterion (AIC) and R^2 Correlation Coefficient value. The model provides the lowest AIC value will be selected as the best model for data, while the higher value of the coefficient R^2 indicates the goodness of fit of the model to the data better. Among other tested distribution, AIC gives 147932 and 145873 for the Weibull and Gama respectively. Whereas R^2 shows 0.9716 and 0.9854 respectively.

Parameter estimations for each model is verified by using maximum likelihood method. The maximum likelihood estimator (MLE) for the parameters of each can be determined numerically by using Newton Raphson method. Table-3 below shows the result of parameter estimation for the Weibull and Gama distribution. These parameter estimation values are then being used in the respective probability distribution function.

Table-3. Estimation parameter.

Year	Weibull distribution		Gama distribution	
	Shape parameter k	Scale parameter c	Shape parameter α	Scale parameter β
2007	2.10758	3.05830	0.9765	2.6543
2008	2.09565	3.29368	0.9937	2.9386
2009	2.16443	3.19343	1.4894	1.8981
2010	2.14770	2.95556	0.9410	2.7685
2011	2.08609	3.24657	1.6434	1.7478
2012	2.06077	2.91111	1.1984	2.1516
2013	2.08768	3.10305	1.8319	1.4975

It is then being converted into the wind power density function by using transformation techniques. This new form of the function is then being used in calculating the mean wind power or the wind power density per unit area (W/m^2).

Evaluation of wind power and energy per unit area is an important information in the assessment of wind powerproject. The yearly estimate wind power density at 10 metre height is shown in Table 4. This result indicates that the estimate wind power density varies from 10.6952 W/m^2 to 26.3734 W/m^2. Based on the result, Mersing can be a promising station in generating wind energy. Eventhough the energy production is not very high, but with some innovation may help for a better energy harvesting.

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Some innovation steps need to be taken in order to make the quite constantly high wind speed in Mersing.With the correct size and scale of wind turbine may capture more energetic wind and convert to electricity. Or else, the use of hybrid solar/wind system may be more beneficial to fully utilizethe solar radiation and wind (together with land and sea breezes).

Table-4. Estimate wind power density (W/m^2).

Year	Weibull	Gama
2007	23.3346	20.8981
2008	10.9553	12.8680
2009	21.7809	19.0981
2010	10.6952	13.4147
2011	23.0414	21.0489
2012	15.7058	11.0419
2013	26.3734	20.8285

CONCLUSIONS

The wind speed analysis may not be a new approach in studying wind energy. But, methods and analysis techniques involved may vary from one researcher to another. Weibull and Gama probability distributions has been used throughout the paper because of the statistically proven (AIC and R^2 test) that it fits data into the distribution. Transformation method has converted the probability distribution function to wind power.

The assessment of wind power density or wind power per unit area in Mersing, reveals that Mersing is a promising location in generating wind power. With power density values varies between (10-26) W/m^2 ignite a more comprehensive research in Mersing. It is may be some innovation step such as solar/wind hybrid system or the small size of wind turbine may interpret the wind potential in Mersing. Solar/wind hybrid system might be more constructive which it can use solar during the day and reserve wind for the night use.

Further studies should be carried out at Mersing to locate the exact location that can trigger the highest wind energy power. With that exact location, an accurate investigation may lead to a bigger discovery. The potential will be useless without any beneficial steps by all parties, including researchers, government and private sectors.

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