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Wind Characterization for Renewable Energy Applications

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KEYWORDS

Wind characteristics
Wind energy density
Weibull function
Rayleigh function

ABSTRACT

This project aimed to study and estimate wind characteristics and energy potential of Kuala Terengganu. Data used in this study were collected on site from 2004 to 2007. Wind speed distribution curves were developed using the Weibull and Rayleigh probability density functions. Average Weibull shape parameter and scale parameter were found to be 1.76 and 3.21 m/s, respectively. Yearly mean wind speed in Kuala Terengganu is 2.9 m/s and monsoon season (November to March) mean wind speed is 3.9 m/s. Wind power density is lowest in southwest monsoon season, while it is highest in northeast monsoon season as 84.55 W/m^2. Monthly average power density and probability of wind were found as 40.52 W/m^2 and 0.50, respectively which exceed cut-in wind speed of 2.5 m/s. Normally more than 10 years of wind data is required to capture climatic variability. Further, in order to get more precise spatial wind map, there must be more presenting points. Therefore, this research may be considered as first step of renewable energy study in the research area.

1. INTRODUCTION

The environmental issues span a continuously growing range of pollutants, hazards and eco-system degradation factors that affect areas ranging from local through regional to global scales. Many environmental issues are caused by or relate to the production, transformation and use of energy [1]. Global concerns over above facts linked to fossil fuel consumption have increased the pressure to generate power from renewable sources [1].

The human population growth and development activities, growing at a rapid pace today, have increased the energy demands. Owing to the present day's energy crisis, growing environmental concern and escalating cost of fossil fuels, we ought to take every effort to supplement our energy base with renewable sources. As environmental and sustainability issues arise with our current energy system (fossil fuel based), pressure is being applied on policy makers, governments and the energy sector, to provide for our typical energy requirements, in sustainable manner. In response, a variety of 'road maps' for the future of our energy systems have been tabled which boldly state that energy from renewable sources (wind, solar, wave, biomass, etc.) will become a major contributor to the energy mix in the next few decades.

Global energy consumption is increasing, and this is particularly noticeable in the developing nations as they move towards industrialization. It is therefore important that, where new energy demands are created, these are met, where possible, by sustainable and non-polluting means, in order to stop the escalation of the already visible environmental effects of fossil fuel use. This alone, however, will not be enough to meet emissions targets and reduce the environmental threat posed by the production of carbon dioxide and other pollutants. To achieve this, the current reliance on fossil fuels for all energy uses must be reduced and eventually eliminated.

Consequently, it will be necessary to re-evaluate the way in which energy is produced, distributed and used in Malaysia and worldwide. This, however, will not happen until less expensive, easily implemented and equally reliable alternatives become available.

Malaysia, as a country, faces a high rate of population growth. The Malaysia economy has witnessed active growth in the last decades and consequently, the demand for energy has also increased [2]. The demand for energy and particularly for electricity is growing rapidly, because of social and economic development of the country. The **Fig**. **1** shows the final use for the overall energy consumed in Malaysia between 1980 and 2001 [3]. From this it can be seen that the energy use in all sectors, has increased during this period. Importantly, the energy use for transport and industry has almost four times increased in this 20-year period, and continues to grow, representing around 80% of the overall primary energy use in 2001. Similar patterns can be seen in other industrialized and developing nations, showing energy use for transport and industry to be a significant and increasing problem. Despite

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this, there has been a 10% increase in the overall annual energy use in Malaysia since 1980.

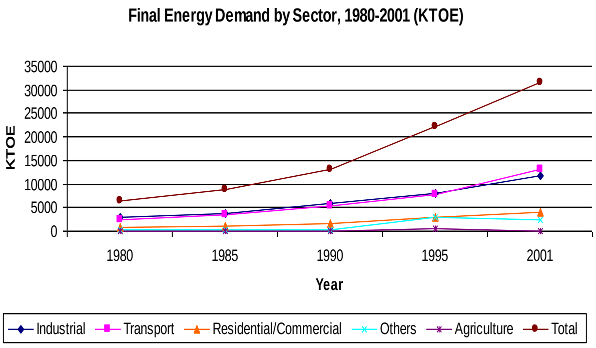

Fig.1. Final energy consumption 1980 to 2001 [3]

The government of Malaysia is encouraging the use of renewable energy sources in her ninth Malaysian Plan [4]. The increased use of energy raised serious concern by the government of Malaysia to introduce renewable energy in the energy matrix. Furthermore, with the increase in energy demand, the issue of energy shortage becomes significant. Since there is more and more concern on energy conservation and environmental protection, interest has been increasingly focused on the use of renewable energy. Renewable energy, as a clean energy source is abundant in Malaysia.

Wind energy is considered one of the economic alternatives that meet the needs of modern societies by protecting the atmosphere from the adverse consequences of global warming. Wind is the fastest growing energy source in the world today. Over the past decade, annual worldwide growth in installed wind capacity is nearly 30% [1]. However, the development of new wind projects continues to be hampered by the lack of reliable and accurate wind data in many parts of the world. Such data are needed to enable governments, private developers and others to determine the priority that should be given to wind energy utilization and to identify potential areas that might be suitable for development [1]. The distribution of wind speeds is important for the design of wind farms, power generators and other applications. A continuous record of wind data over a year cycle would be sufficient to realize its potential.

Annual average wind speeds of 3 to 4 m/s may be adequate for electrical or mechanical applications for water pumping, residential or small commercial loads [5]. Annual average wind speeds of about 5 m/s are generally needed for grid-connected wind generating systems to be an economical resource [5]. These systems may be interconnected to the grid or they may be operated independently from the grid using battery storage to provide electrical supply during times of low or no wind.

Wind resources vary with the time of day, season, height above ground and type of terrain. The distribution of wind speeds is important for the design of wind farms, power generators and other applications such as the irrigation. Proper sitting in windy locations away from large obstructions enhances a wind turbines performance. In order for the wind energy systems to be competitive, they have to be adapted to the local wind energy climate and demand. If one has more detailed knowledge of the wind energy climate of a particular site, the easier it is for designers of wind energy systems to optimize the technology and make it competitive. Wind energy production is closely related with the wind energy climate in the concerned region. However, the development of new wind energy projects continues to be hampered by the lack of reliable and accurate wind energy data in many parts of the world including Malaysia.

Several studies had published substantial results regarding the wind energy in Malaysia where it had identified the wind regimes in some areas with estimates of its energy potential. Lee [6] analyzed the wind characteristics and the power potential of West Malaysia based on the wind data supplied by the Meteorological Department of Malaysia. The study is of interest in the utilization of wind power in West Malaysia and the surrounding islands.

Sopian et al. [7] assessed the wind energy potential of 10 weather stations (Mersing, Melaka, Kuala Terengganu, Alor Seta, Petaling Jaya, Cameron Highlands, Kota Kinabalu, Tawair and Labuan and Kuching) owned by the Malaysian Meteorological Department. In this analysis they used Weibull distribution function to characterize the wind with around 10 years of wind speed data (1982-1991) at 10m height. This study recommended Mersing and Kuala Terengganu stations for further study with actual wind speed measurements.

Abas et al. [8] analyzed the wind energy in three metering stations (Mersing, Batu Berendam and Senai) located at southern peninsula of Malaysia. They also recommend the Mersing station than the other stations for further study. Further, this study concludes that Malaysia experiences low wind speed resource and suitable for small scale electricity production.

Abas et al. [9] also studied the wind energy potential of all Peninsular Malaysia sites and they found that the yearly average wind speed is 4-5 m/s and is not suitable for large scale wind turbine application. Small wind turbines could be installed for electricity generation on the whole length of the east coast of Peninsular Malaysia (the states of Malacca and Kedah and the islands of Penang and Langkawi). Further, Cameron Highlands, coastal areas near Kuantan and Pulau Tioman also exhibit relatively high wind power density of 100-600 W/m^2.

Abas et al. [10] performed a similar study in 10 stations (Kuching, Sri Aman, Sibu, Bintulu, Miri, Labuan, Kota Kinabalu, Kudat, Sandakan and Tawau) in Sabah and Sarawak. In this work 5 years (1998-2002) of wind data (wind speed, wind direction, roughness and obstruction) were used in the analysis. In general, more than 70% of wind speed is in the range of 1.5-5 m/s.

Azmi [11] analyzed the wind energy in Mersing, Pulau Tioman, Pulau Redang and Pulau Perhentian of Malaysia. The wind data used in this study also were obtained from the Meteorological Department of Malaysia. Based on his study Pulau Tioman has the highest wind energy potential compared with the other places. Ibrahim et al. [12] analyzed the hybrid wind and solar energy potential at Kuala Terengganu using measured data (2004-2006) at Universiti Malaysia Terengganu in Kuala Terengganu. They used the simple method to analyze the renewable energy possibility.

In general, based on the literature reviewed, Malaysia is located in low wind speed region. Mersing and Kuala Terengganu would be promising wind energy potential sites. However, all the studies cited above were conducted utilizing the Meteorological Department of Malaysia weather stations data. These locations may not be the ideal sites for wind energy power generation. Hence, actual wind data measurements are required in order to get a good wind energy assessment and characterization at pre-identified sites. Further, no study was conducted on the wind energy potential of offshore sites, since, Malaysia having several offshore islands.

In this respect, the importance of wind energy data for design and efficient operation of wind energy systems has been acknowledged. Therefore, it is important to map the available wind energy to optimize the benefits from prospective developments. Although wind energy potential has been reported for few cities around Malaysia, reliable and yearlong data is still needed for the research area. The main objective of the research is to investigate and evaluate the characteristics of wind energy source for a possible renewable energy application. The objective was realized through standard resource assessment methods using available past and present data collected from the research area.

2. STUDY AREA AND MEASUREMENT

The Universiti Malaysia Terengganu Renewable Energy Research Center wind station is located at 4°13.6′ N and 103°26.1′ E. **Fig**. **2** shows the location of the chosen site. In this research, the wind speed and direction data were measured using NRG Symphonic Data Retriever for 4 years (2004-2007) .All measurements were recorded at a height of 23m at mean sea level (18 m above the ground level). The integrated hourly time-series data from multiple months (2004-2007), excluding incomplete data were combined for validation. Data were manually validated to remove outlier events due to failure of instruments, etc. and statistically analyzed. MATLAB was used to process raw data to generate useful wind characteristics.

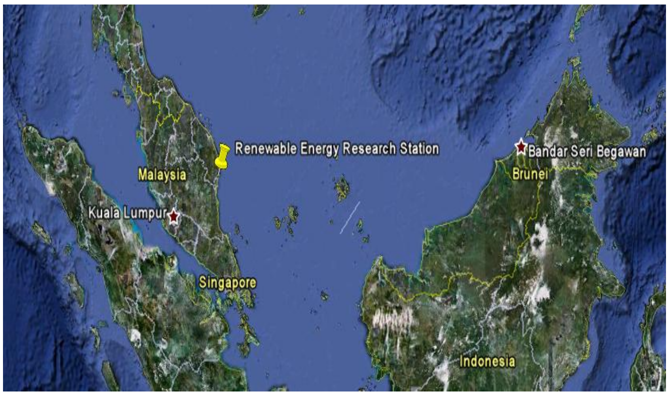

Fig. 2. Location of the research area

3. METHOD OF WIND ENERGY ESTIMATION AND WIND MAPPING

In the wind energy analysis, it is necessary to have only a few key parameters that can explain the behaviour of a wide range of wind speed data. The simplest and most practical method for the procedure is to use a distribution function. There are several density functions, which can be used to describe the wind speed frequency curve. The most common two are the Weibull and Rayleigh functions [13]. Knowledge of the wind speed frequency distribution is a very important factor to evaluate the wind potential in the windy areas.

The Weibull distribution function [13] which is a two-parameter distribution can be expressed as

$$f(v) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(V/c\right)^k} \quad (1)$$

where V is the wind speed, c is a Weibull scale parameter and k is a dimensionless Weibull shape parameter. In this study, the two parameters of Weibull are determined by using maximum likelihood method. The cumulative probability function of the Weibull distribution [13] is given as follow;

$$F(V) = 1 - e^{-\left(V/c\right)^k} \quad (2)$$

Another distribution function used to the wind speed frequency is Rayleigh distribution. This distribution is a special case of the Weibull distribution in which the shape parameter k is 2.0. Probability density and cumulative function of Rayleigh distribution [13] are given bellow;

$$f(V) = \frac{\pi}{2}\frac{V}{V_m^2} e^{-\left[\pi/4\left(V/V_m\right)^2\right]} \quad (3)$$

and

$$F(V) = 1 - e^{-\left[\pi/4\left(V/V_m\right)^2\right]} \quad (4)$$

where V is the wind speed and V_m is the mean wind speed.

The power of wind can be estimated by using the following equation (5),

$$P = \frac{1}{2}\rho V^3 \quad (5)$$

where ρ is mean air density, V is mean value of the wind speed. The average wind energy density of a site can be expressed based on Weibull probability density function [14 and 15] as

$$E_D = \frac{\rho . c^3}{2}\frac{3}{k}\Gamma\left(\frac{3}{k}\right) \quad (6)$$

where ρ is mean air density, c is a Weibull scale parameter, k is a dimensionless Weibull shape parameter and Γ is a gamma function. The probability of wind to exceed a velocity of V_x is given by equation (7).

$$P(V > V_x) = e^{-\left(V_x/c\right)^k} \quad (7)$$

Spatial wind mapping are interpolated by the approach of Inverse Distance Weighted (IDW) method. The IDW method estimates an unknown value as the weighted average of its surrounding points, in which the weighted is the inverse of distance raised to a power [16 and 17]. The expression of IDW is show by Equation 1.

$$Z_u = \frac{\sum_{i=1}^{S} Z_i {d_{iu}}^{-k}}{\sum_{i=1}^{S} {d_{iu}}^{-k}} \quad (8)$$

where, z_u-unknown value of estimated at u, z_i-attribute value at control point i, d_{iu}-distance between point i and u, s-number of control point used in estimation and k-a factor.

Measured wind speeds at study station and Kuala Terengganu air port (from Malaysian Meteorological Department) were used to calculate the unknown wind speed values for the surrounding spatial wind energy mapping.

4. Results and Discussion

The **Table 1** shows the monthly average wind speeds for the period of 4 years at Kuala Terengganu study area. The highest monthly mean wind speed is determined as 5.20 m/s in January 2007 while the lowest mean wind speed 2.00 m/s was occurred in June 2005. Annual mean wind speed for the 4 years period is obtained as 2.89 m/s.

The monthly variation of Weibull parameters for Kuala Terengganu during the years 2004–2007 is given in **Table 2**. As seen from **Table 2**, the Weibull shape parameter k varies between 1.27 and 2.68, while scale parameter c varies between 2.25 m/s and 5.83 m/s. The average values of the Weibull parameters k and c are 1.76 and 3.22 m/s for the study period, respectively. The monthly average value of the Weibull shape parameter k is between 1.47 and 2.15, while the monthly average value of c is between 2.45 m/s and 5.02 m/s. The lowest k value is in the month of December 2005 and the highest value is in the month of January 2004. It can be seen that the highest c value is found in the month of January 2007 as 5.83 m/s.

The frequency histogram of hourly average wind speed for a complete year 2004 is presented in **Fig**. **3**. The frequency is highly peaked in the range 1-6 m/s. This indicates that most of the wind energy at Kuala Terengganu lies in this range. This distribution of wind speed is important in determining the percentage of time during a year, the power that could be generated from a wind machine. Moreover, this information can be used to determine the amount of power which can be generated in a given speed band. Hence it indicates the wind power potential of Kuala Terengganu for wind power applications.

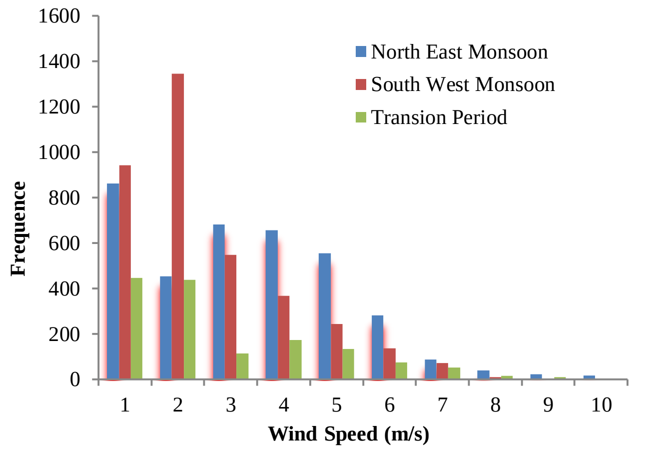

Fig. 3. Frequency distribution of hourly average wind speed for a year

Table 1. Monthly Average Wind Speed (m/s) at Kuala Terengganu

Month/Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual Average
2004	4.82	3.55	3.63	2.66	2.31	2.19	2.29	2.10	2.15	2.80	2.64	4.81	3.00
2005	3.78	2.94	3.51	2.58	2.10	2.00	2.25	2.16	2.31	2.36	3.13	3.52	2.72
2006	4.05	4.72	2.69	2.45	2.25	2.33	2.16	2.24	2.17	2.13	2.12	4.43	2.81
2007	5.20	3.49	2.65	2.60	2.27	2.25	2.17	2.18	2.17	2.85	3.6	4.9	3.03
Annual Average	4.46	3.68	3.12	2.57	2.23	2.19	2.22	2.17	2.20	2.54	2.87	4.42	2.89

Table 2. The Weibull Scale and Shape Parameters Monthly Variations for Kuala Terengganu

Year/ Month	Weibull scale parameter, c (m/s)				Weibull shape parameter, k				Monthly Average	
	2004	2005	2006	2007	2004	2005	2006	2007	c	k
January	5.41	4.27	4.57	5.83	2.68	1.91	1.87	2.13	5.02	2.15
February	4.01	3.32	5.31	3.93	2.16	2.01	2.12	1.94	4.14	2.06
March	4.00	3.93	3.04	2.98	1.46	1.64	1.85	1.61	3.49	1.64
April	2.99	2.90	2.77	2.93	1.68	1.61	1.74	1.72	2.90	1.69
May	2.61	2.35	2.55	2.57	1.78	1.55	1.96	1.76	2.52	1.76
June	2.47	2.25	2.64	2.52	1.78	1.67	1.82	1.55	2.47	1.70
July	2.59	2.55	2.44	2.45	1.80	1.83	1.66	1.87	2.51	1.79
August	2.35	2.44	2.54	2.88	1.57	1.80	1.86	2.44	2.45	1.74
September	2.43	2.61	2.45	2.91	1.80	1.79	1.86	2.51	2.50	1.82
October	3.11	2.67	2.42	2.73	1.44	1.71	1.86	2.15	2.73	1.67
November	2.94	3.44	2.38	2.83	1.49	1.34	1.57	1.91	2.92	1.47
December	5.40	3.80	4.83	3.95	1.81	1.27	1.35	2.10	4.68	1.48
Annual Average	3.36	3.04	3.16	3.21	1.79	1.68	1.79	1.99	3.22	1.76

The seasonal wind characteristics in Terengganu were also studied in this research. The highest mean wind speed value at 3.90 m/s occurred during the northeast monsoon season while the lowest was recorded during the southwest monsoon season at 2.22 m/s. The Weibull shape parameter k varies between 1.54 and 1.74, while the scale parameter c varies between 2.49 and 4.37 m/s. The highest c value was during the northeast monsoon season and lowest during the southwest monsoon season. The lowest standard deviation at 1.32 m/s was calculated during the southwest monsoon season. The wind power density is lowest during southwest monsoon season, while it is highest during the northeast monsoon season estimated at 84.55 W/m^2. The probability of wind to exceed a velocity of 2.5 m/s estimated at 0.68 and 0.37 during northeast and southwest monsoon seasons, respectively.

Comparison of probability density distributions for January 2004 according to measured data with Weibull and Rayleigh functions for study site is illustrated in **Fig. 4**. It is seen from **Fig**. **4**, that the peak probability value for Rayleigh probability distribution is found as 0.1640 on the wind speed of 4 m/s, while the peak value for Weibull probability distribution is determined as 0.1932 on the wind speed of 5 m/s and the peak value for field data probability distribution is determined as 0.1962 on the wind speed of 5 m/s.

The **Fig**. **5** shows the annual variation of measured field data with Weibull and Rayleigh distribution for year 2004 at study area. It clearly shows that the Weibull and Rayleigh distributions are almost identical shape.

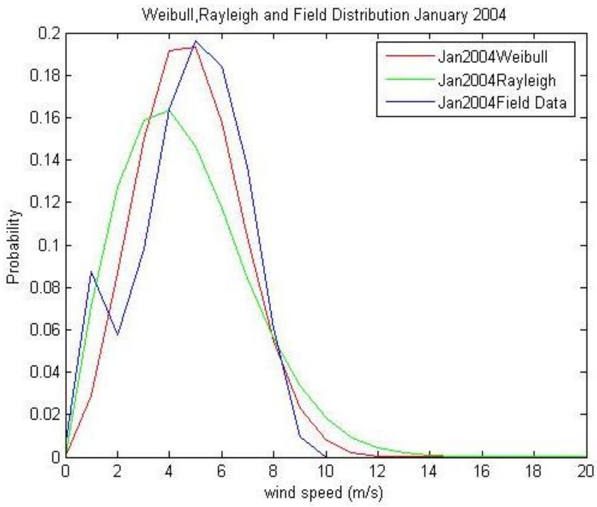

Fig. 5. Comparison of probability density distributions of January 2004 according to measured data with Weibull and Rayleigh functions

A comparison of the seasonal Weibull probability density distributions at the research site is shown in **Fig**. **6**. It is seen from **Fig**. **6**, that the highest peak probability value is obtained in the south west monsoon season as 0.30 on the wind speed of 2.0 m/s. The lowest peak probability value is found in the north east monsoon season as 0.176 on the wind speed of 3.0 m/s for the investigated site.

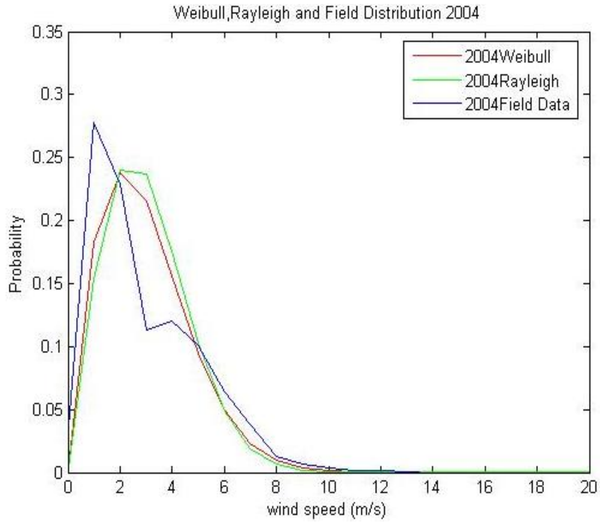

Fig. 6. Comparison of observed and calculated probability density distributions for year 2004

In **Fig**. **7**, comparison of probability density distributions for entire study period based on measured data with Weibull, Rayleigh functions and Weibull seasonal distribution for study site is illustrated. The peak probability value for Rayleigh probability distribution is 0.2301 at wind speed of 3 m/s, while the peak value for Weibull probability distribution is 0.2282 at wind speed of 2 m/s. And the peak value for field data probability distribution is 0.2947 at wind speed of 1 m/s and the peak value for northeast monsoon seasonal Weibull probability distribution is 0.1853 at wind speed of 2 m/s.

The wind speed cumulative probability distributions obtained from Weibull and Rayleigh probability density functions for the study site and it is seen that wind speeds on the cumulative probability distributions have a similar effect for Weibull and Rayleigh functions.

The wind speed of Kuala Terengganu were estimated using Inverse Distance Weighted method base on the mesured data. The evaluated resultes show that the wind speeds of Kuala Terengganu are same as mesured values with in the range of $\pm$ 6%.

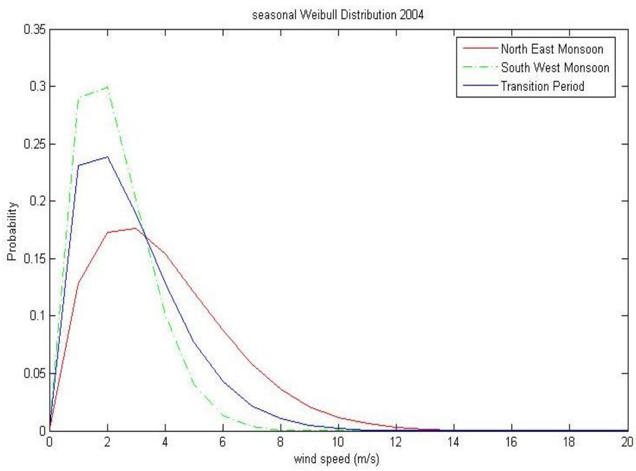

Fig. 7. Comparison of seasonal wind speed frequency distributions in the investigated site

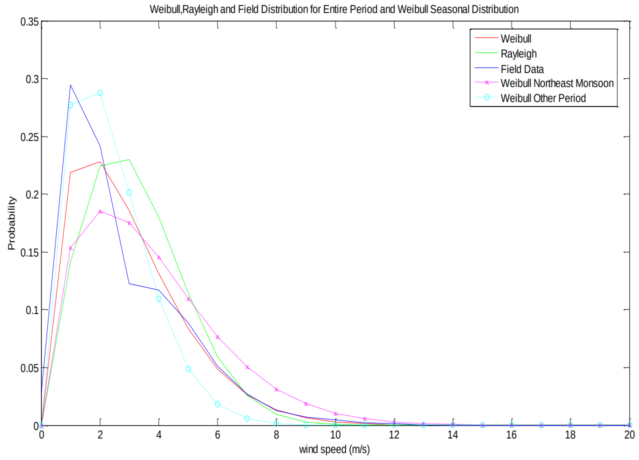

Fig. 8. Comparison of probability density distributions of entire period according to measured data with Weibull and Rayleigh functions and Weibull seasonal distribution

5. CONCLUSIONS

Monthly and yearly wind speed distribution and wind power density during the study period of four years in Terengganu were evaluated. The wind speed frequency distribution was found by using Weibull and Rayleigh distribution functions. The research reveals that the highest monthly mean wind speed is determined as 5.20 m/s in January while the lowest monthly mean wind speed 2.00 m/s is occurred in June. Annual mean wind speed for the study period is obtained as 2.85 m/s. The wind power is ranged between 11.33 W/m ^{2} and 154.02 W/m ^{2}. The wind power is lowest in the southwest monsoon season, while it is highest in the northeast monsoon season as 84.55 W/m^2. The highest time factor (wind power availability) value with 0.68 is determined in the northeast monsoon season while the lowest value is in the southwest monsoon season as 0.37. The highest Weibull factors were found in the northeast monsoon season and lowest values were in the southwest monsoon season. The average values of Weibull shape parameter and scale parameter were found as 1.76 and 3.22 m/s, respectively. The highest mean wind speed value with 3.90 m/s is determined in the northeast monsoon season while the lowest value is in the southwest monsoon season with 2.22 m/s. As a conclusion, small or medium wind machines could be used to provide power as a part of hybrid renewable energy system.

The wind energy may be used for pumping water or other mechanical applications in addition to generate electricity. Wind energy can be used as stand-alone applications or they can be connected to a utility power grid or even combined with a photovoltaic (solar energy) system. Wind turbines are mounted on a tower at 30 m or more above ground to capture the most energy; they can take advantage of the faster and less turbulent win. Most of the wind energy is available at high altitude and cannot manufacture low wind speed turbines of that height. So researchers have to think of new ways to trap that wind power blowing at a significant height. To ensure the efficiency of wind energy system under various wind conditions, a new kind of air-flow technology must be adapted, so that the low wind speed system is usable at research area. Further, we may think about the portable wind generator for domestic application in this area.

The terrain in which a wind energy system is located has a significant effect on the local wind speeds as well as the wind system and turbine design. Normally, more than 10 years of wind data is required to capture climatic variability. Further, in order to get more precise IDW spatial wind mapping, there must be more presenting points. Therefore, this study may be considered as first step of renewable energy study in the research area.

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