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AN ANALYSIS OF WIND ENERGY POTENTIAL OF SILCHAR (ASSAM, INDIA) BY USING DIFFERENT MODELS

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ABSTRACT
A proper analysis of wind speed data is an important requirement to estimate wind energy potential for a particular site, and the analysis of wind data is a prerequisite for modelling power curve of a standalone wind energy system in a given terrain. The main objective of this study is to determine wind energy potential of Silchar (Assam, India) by using different models over a period of four years from 2008-2011. For doing this, wind data at 10 m height has been obtained and from that at 25 m height the same has been calculated. The peak average wind speed of Silchar is found to be 1.48 m/s at 10 m height and 1.69 m/s at 25 m height for which this place falls in a low wind speed region. The average power densities is found highest during the month of March, which are 2.1 W/m^2 and 3.2 W/m^2 at 10 m and 25 m heights respectively. Further, the wind rose model of this place is also analysed, and wind speed probability distributions are modelled by using Weibull and Rayleigh's distribution functions. It is found out that Weibull distribution fits the monthly probability density distribution better than the Rayleigh's distribution for all four years wind velocity data. After that autoregressive integrated moving average (ARIMA) model has been fitted to the time series data, which shows that single ARIMA model is useful for prediction of such low wind speed data. The work is finally culminated with a discussion on the possible turbine designs that could be installed in such low wind speed terrain.

KEYWORDS: Wind speed data, Weibull distribution, Rayleigh distribution, Wind rose, ARIMA model, VAWT for low wind speed.

INTRODUCTION

Wind energy is a non-polluting, inexpensive and never-ending renewable energy source which can satisfy the increasing energy needs of the people around the world. It can reduce the carbon dioxide emission in the environment. For all these reasons recently wind energy is receiving a lot of attention as an alternative to conventional fuel sources. With the rising need for power generation, if wind energy is effectively utilized, then it can provide sustainable growth in the global renewable energy market. Statistics provided by Global Wind Energy Council [1] reveals that globally wind power capacity at the end of 2013 is 318,105 MW and they predicted that total wind energy production will be 600 GW by the end of 2018. For proper utilization of wind power in a specific site, availability of wind resources is very important which is controlled by the climatic status of that particular region. Analysis of wind data is a prerequisite for modelling power curve of any wind energy system of a given terrain To estimate wind energy potential of a site, different wind characteristics such as mean wind speed, wind power density, wind velocity probability distribution functions, wind power spectrum etc. need to be studied properly. To design wind farms, generate wind power and for agricultural applications also wind speed distribution is necessary and Weibull and Rayleigh probability distributions are the most commonly used statistical functions to fit a measured wind speed data in a given location over a particular time period. Various researchers from all over the world studied potential of wind energy for various regions based on Weibull and Rayleigh probability distributions (a special form of Weibull distribution) and almost all of them observed that better curve fitting can be achieved by Weibull model compared to Rayleigh model [2-9]. Several researchers studied the wind speed forecasting techniques for different locations in this world based on ARIMA model, ANN model, hybrid ARIMA-ANN model, ARIMA-Kalman model etc. and found that single ARIMA model is capable of predicting the wind speed with good accuracy [10-12]. The main objective of this study is to determine wind energy potential of Silchar (Assam, India) by using different models over a period of four years from 2008-2011. To achieve this, wind speed data at 10 m height has been obtained and at 25 m height this data has been computed. Further, the wind rose model of this place is also drawn and wind speed probability distributions are modelled by using Weibull and Rayleigh's distribution functions. Moreover autoregressive integrated moving average (ARIMA) model has been fitted for predicting the time series data of the present place. The work is finally culminated with a discussion on the possible turbine designs that could be installed in such low wind speed terrain.

DESCRIPTION OF LOCATION

This paper analyzes the wind speed probability distribution and wind energy potential of Silchar, the southern part of Assam, North-east, India. For doing this, the wind data was obtained for the time period 2008-2011 from National Renewable Energy Laboratory website [13] at 10 m height. Coordinates of Silchar are: longitude: 92.51 degrees east, latitude: 24.5 degrees north and height: 114.68 m above sea level [14]. The location of this city in India has been shown in fig.1. In this state weather becomes dry from October to March season which is known as dry season. At the end of March or in the beginning of April rain starts here and stays till September ends which is generally known as rainy season. Winter season generally starts towards the end of November and continues till February and summer is dominant during the rainy season. During winter temperature range is 10-21°C and during summer it lies in the range of 21-36°C. During rainy season it is flooded frequently due to extravagant rainfall and flooding by the Barak River and the annual average rainfall is around 110-130 mm [9].

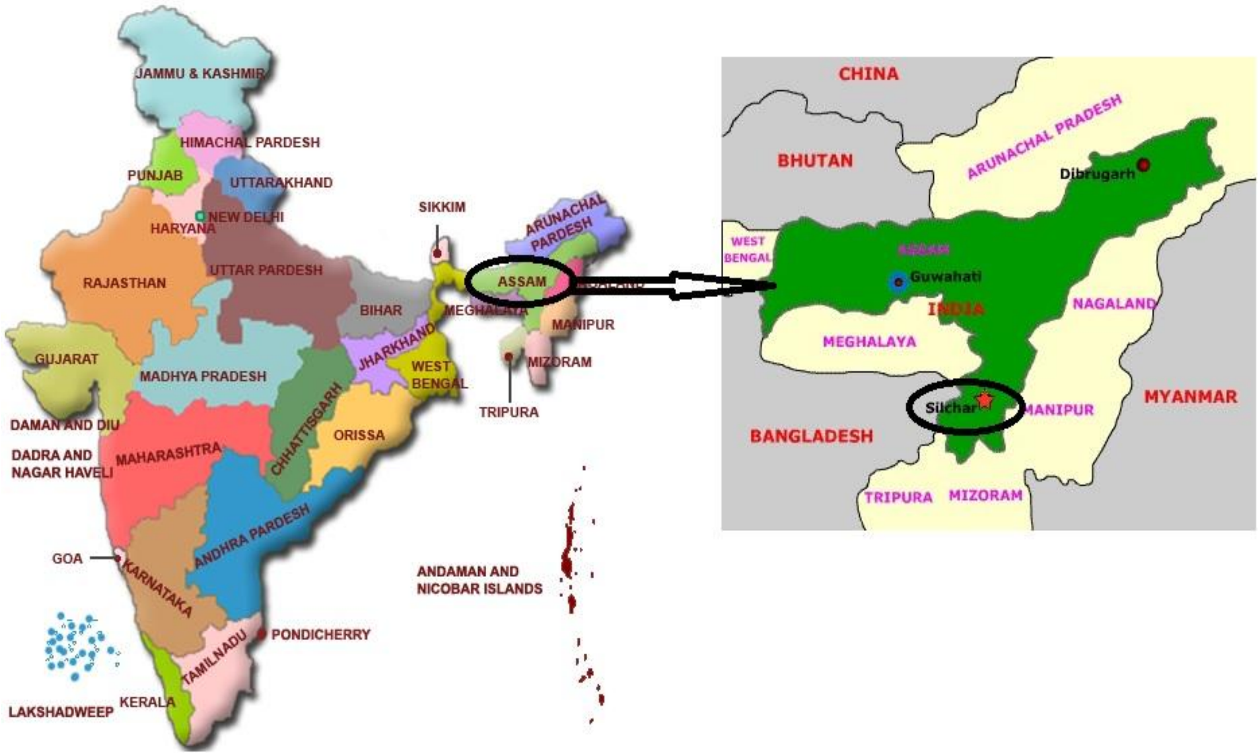


Figure-1 Location of Silchar city in India

WIND DATA ANALYSIS AND MEASUREMENT

In reality, wind velocity has a tendency to change with height in maximum site and the equation is based on power law. The power law used to estimate the wind speed data at 25 m height is:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^m \qquad (1)$$

where v_2 and v_1 are mean wind velocity at heights h_2 and h_1 respectively. The value of power law exponent m is dependent on mainly terrain roughness and atmospheric stability. It generally ranges between 0.05-0.5 and most commonly used value is 0.14 which has been taken in this paper to determine the wind speed at 25 m height [2, 5, 7, 8].

Figure 2 depicts the plot of monthly variation of wind velocity of the four years 2008-2011 at 10 m and 25 m height respectively. These figures show that during February to July month there are higher wind speeds than the rest 6 months. From these figures it is also seen that the highest wind velocity occurs in the month of March which is 1.48 m/s and 1.69 m/s for 10 m and 25 m respectively. Figures 3(a) and 3(b) show the plot of monthly variation of power density for the time period 2008-2011 at 10 m and 25 m height respectively. From these figures the highest average power density is found around 2.1 W/m^2 and 3.2 W/m^2 during the month of March for two selected heights respectively. The average wind power density, P/A is the average available wind power per unit area which is expressed as:

$$\frac{p}{A} = \frac{1}{2} \circ \frac{1}{n} \sum_{i=1}^{n} v_i^3 \qquad (2)$$

where n is the total period of wind data collection over a month, ρ is the air density (1.225 kg/m^3) and v_i is the record of diurnal wind velocity in a day [9].

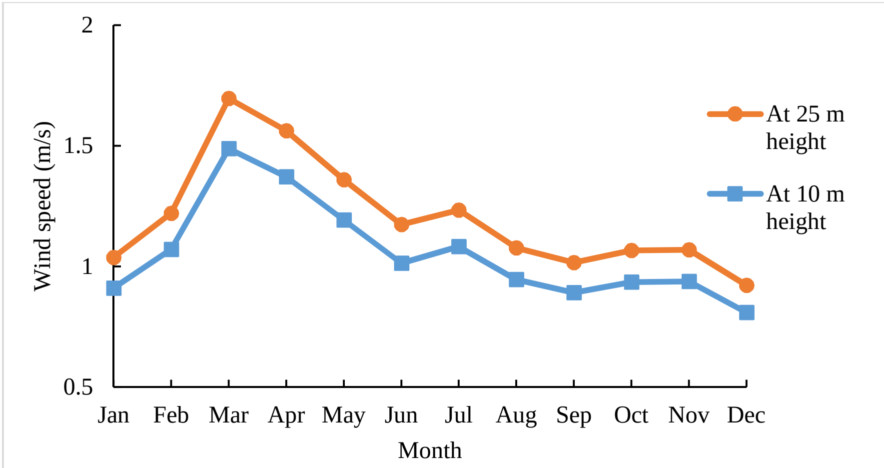
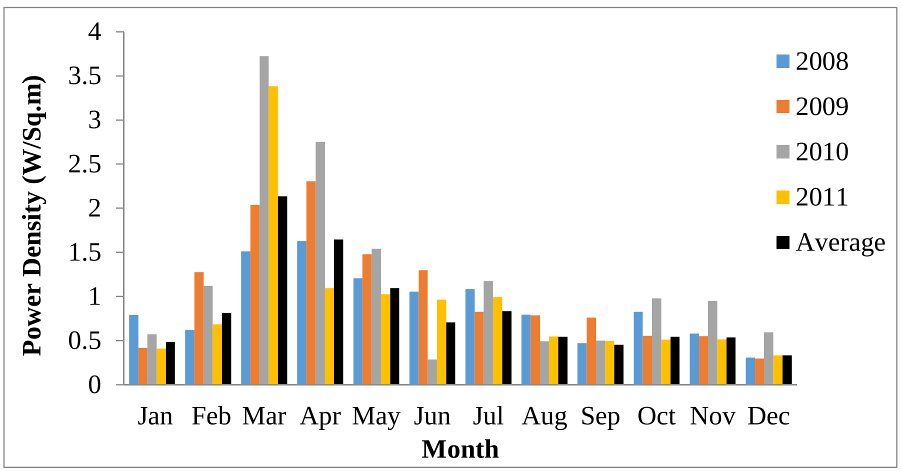


Figure-2 Average of all the monthly mean wind speeds for the time period 2008-2011 at 10 m and 25 m



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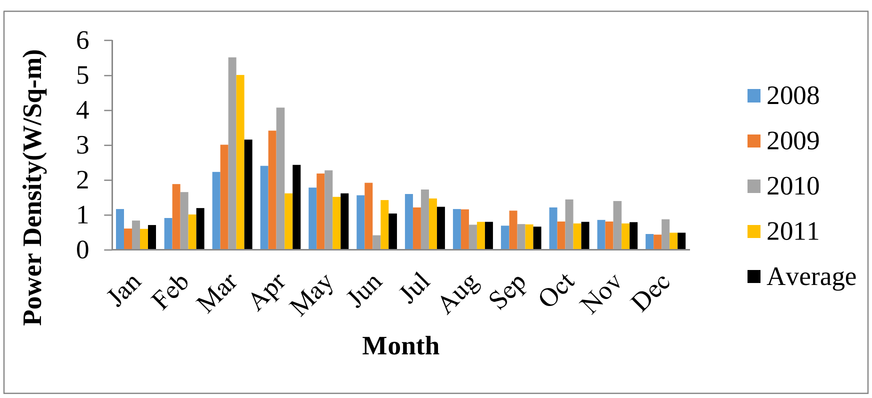


(b)

Figure-3 Monthly variation of power density for the time period 2008-2011 at (a) 10 m and (b) 25 m

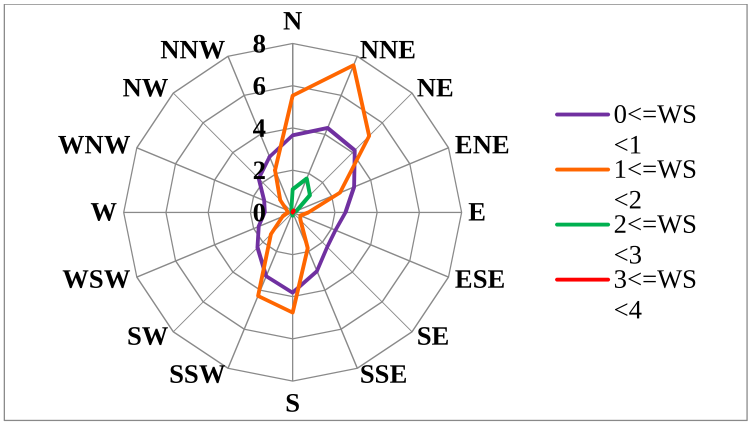


Figure 4: Annual wind rose based on the time period 2008-2011 at 10 m

The annual wind rose for the time period 2008-2011 has been shown in Figure 4 at 10 m height which shows that wind speed ranging from 1-2 m/s occurred most frequently in Silchar city for this reported time and the prevalent wind blows from North to North-East and South to South-South western direction.

WIND SPEED PROBABILITY DISTRIBUTION FUNCTION EVALUATION

Two types of probability distribution functions have been computationally evaluated here using different equations that have been found in the literatures [2, 3, 4, 5, 6, 7, 8, 9, 15]. Firstly, the Weibull two-parameter probability density function which is given by:

$$f(v) = \frac{k}{c}\left(\frac{v_i}{c}\right)^{k-1} \exp\left(-\left(\frac{v_i}{c}\right)^{k}\right) \quad (3)$$

where f(v) is the probability of observing the particular wind speed v_i, c (m/s) is the scale factor which is closely related to the wind speed of the location, and k is the dimensionless shape factor which describes the form and width of the distribution. Higher value of c indicates that wind speed is higher, where k shows wind stability. The monthly mean ($\bar{v}$) of wind velocities and their variance (σ^2) are calculated from the time series data by applying the following equations.

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \quad (4)$$

$$\pm^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(v_i - \bar{v}\right)^2 \quad (5)$$

where n is the number of hours in the considered period of time and v_i is the recorded wind velocities.

Now, to calculate Weibull parameters k and c, the equations that can be used are

$$k = \left(\frac{\pm}{\bar{v}}\right)^{-1.086}, \ (1 \le k \le 10) \quad (6)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (7)$$

where Γ is the gamma function defined mathematically in general x-variable as:

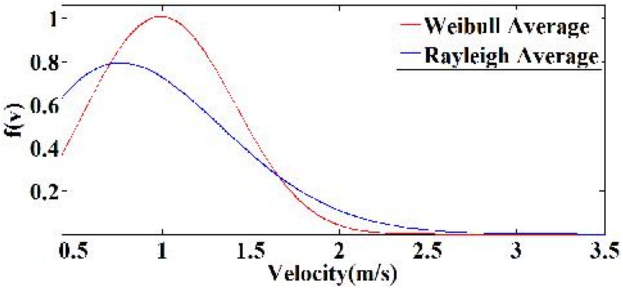
$$\Gamma(x) = \int_0^{\infty} e^{-u} u^{x-1} du \quad (8)$$

The values of the Weibull parameters k and c on monthly basis have been found out by MATLAB 2013a software at two different heights (10 m and 25 m). Secondly, when the Weibull shape parameter k is equal to 2, then that special case is known as Rayleigh distribution [15]. For positive valued random variables Rayleigh distribution characterizes the overall wind speed assuming the magnitude of wind speed as uncorrelated and normally distributed. This distribution function is expressed as:

$$f(v) = \frac{\circledR v_i}{2\bar{v}^2} \exp\left(-\frac{\circledR}{4}\left(\frac{v_i}{\bar{v}}\right)^2\right) \quad (9)$$

where f(v) is the probability of observing the specific wind velocity v_i.

COMPARISON BETWEEN WEIBULL AND RAYLEIGH'S PROBABILITY DISTRIBUTION FUNCTIONS



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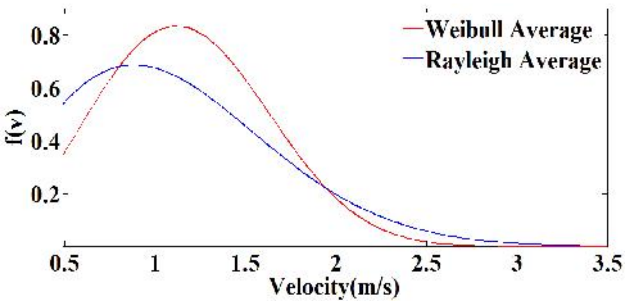

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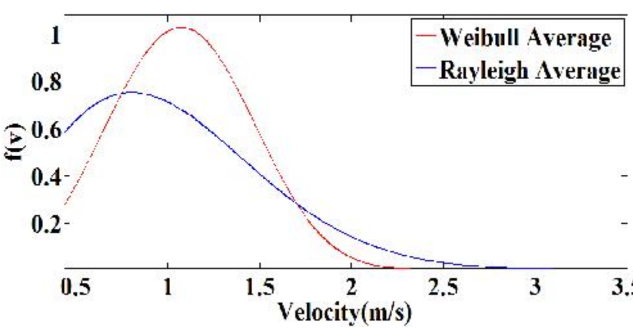
Figure 5. Comparison between average probability distributions of wind speed using Weibull and Rayleigh's method in dry season at (a) 10 m and (b) 25 m



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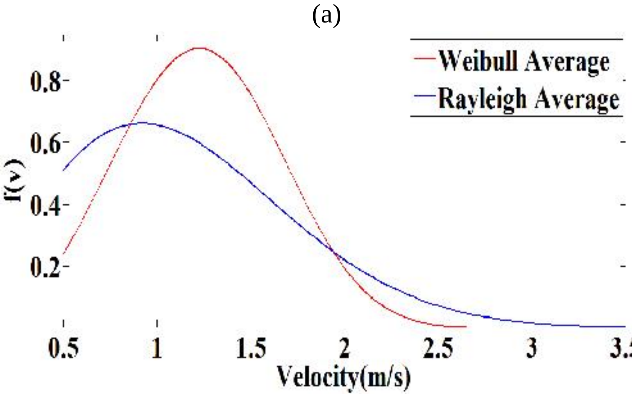
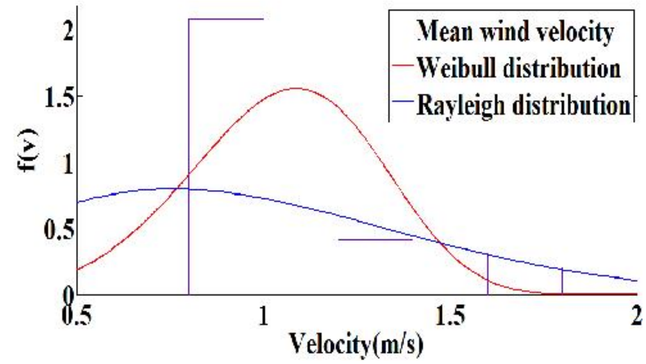


(b)

Figure 6. Comparison between average probability distributions of wind speed using Weibull and Rayleigh's method in rainy season at (a) 10 m and (b) 25 m

Figures 5 and 6 are showing the comparison between Weibull and Rayleigh's distribution functions for wind velocities in the dry season and in the rainy season at 10 m and 25 m heights respectively. Both the figures show that Rayleigh's distribution gives higher occurrence of probability for higher wind velocities (around 2 m/s) and for very low wind velocities (0.6 m/s). It has been noticed that Weibull distribution is showing the probability of occurrence of around 0.8-1.4 m/s wind speed as the highest of the considered four years time period.



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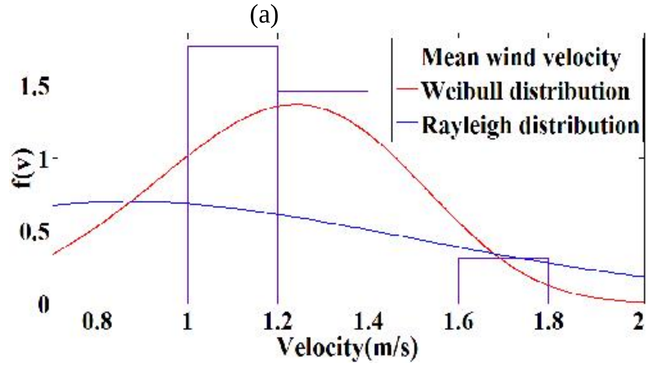


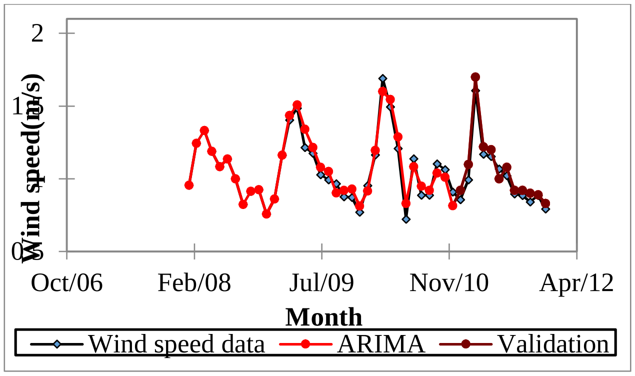
(b)

Figure 7. Weibull and Rayleigh's comparison for the average wind speed of all months for 4 years (2008-2011) at (a) 10 m and (b) 25 m

In Figure 7 all the monthly average wind speeds of the time period 2008-2011 have been considered. So, from these figures, it is clear that Weibull model fits the recorded wind speed data better than Rayleigh's model to measure the probability density distribution.

ARIMA PROCESS FOR FORECASTING WIND SPEED DATA

Autoregressive integrated moving average (ARIMA) models are fitted to time series data either for better understanding of the data or for prediction of future points in the series. This model is widely used for its prediction accuracy and simple computation [11]. The model is generally referred to as an ARIMA(p,d,q) model where parameters p, d, and q are non-negative integers that refer to the order of the autoregressive, integrated, and moving average parts of the model respectively. ARIMA model can analyse both seasonal and non-seasonal data.



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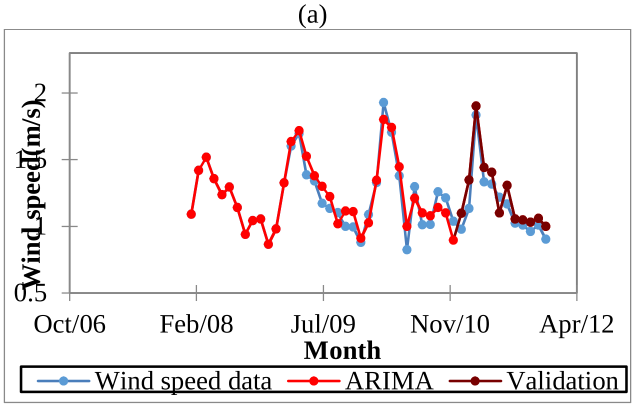

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Figure 8. ARIMA model for validating wind speed data at (a) 10 m and (b) 25 m

ARIMA (0,1,1) (0,1,1) is a well applicable and accepted form of this model which has been applied here for calculation purpose in statistical software [16]. We are having four years (2008-2011) wind speed data which have been averaged here per month basis. ARIMA model has been plotted for all the 4 years and the data of 2011 has been chosen for validation or prediction purpose as shown in Figure 8. From the diagrams it can be seen that the predictions (validations) are very close to the actual wind speed data for the year 2011 for both 10 m and 25 m heights.

SOME POSSIBLE VERTICAL AXIS WIND TURBINE DESIGNS FOR LOW WIND SPEED TERRAIN

Nowadays vertical axis wind turbines (VAWTs) are getting popularity for their various suitable advantages in the built conditions, and therefore vertical axis wind turbines which are having low cut-in wind speed could be installed for power production in low wind speed terrain like the present place. It is required that the policy makers, technocrats and entrepreneurs are provided with detailed data and an insight for selecting tailor-made wind turbine designs suitable for a particular wind terrain. One of the available wind rotor such as Ropatec rotor which is nothing but a hybrid Savonius and Darrieus rotor having airfoil blade design, had the start-up wind speed of around 1.9 m/s and a low cut-in wind velocity 2 m/s at every position. Here, the rotor design and its power curve have been reproduced in Figure 9 which shows a low cut-in wind speed of around 2 m/s [17]. This power curve, a relation between power output and wind speed, is often utilized by wind turbine industries to estimate the technical specifications of wind turbines and its operation surety [18]. A specially designed four rotor Darrieus wind turbine by Solwind in New Zealand had the capability to start at 1.5 m/s wind speed [17]. Another hybrid system made of Darrieus and two stage Savonius wind turbine showed that it is able to start at 1 m/s wind speed [19]. One more hybrid Savonius-Darrieus rotor is there (three blades each) having the capability to start at a low wind speed of 2 m/s [20].

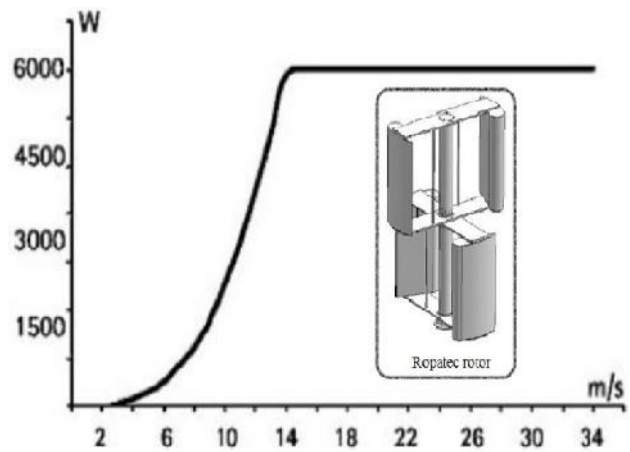

Figure 9: Diagram of Ropatec rotor along with its power curve [17]

Table 1 Technical specifications of different vertical axis wind turbines [17, 19, 20]

Sl no	Turbine name and type	Parameter	Value
1	Ropatec Wind turbine (hybrid Darrieus and Savonius turbine)	Start-up wind speed	1.9 m/s
		Cut-in wind speed	2 m/s
		Rated wind speed	14 m/s
		Rated output on axis (at 14 m/s)	6 kW
		Cut off wind speed	None
		Survival wind speed	75 m/s
2	Darrieus turbine by Solwind	Start-up wind speed	1.5 m/s
		Cut-in wind speed	3.7 m/s
		Rated output wind speed	10 m/s
		Survival wind speed	53 m/s
3	Hybrid Darrieus and Savonius (2 stage) turbine	Start-up wind speed	1 m/s
		Minimum power generation wind speed	2 m/s
		Cut-in wind speed	3 m/s
		Rated wind speed	13 m/s
		Cut out wind speed	15 m/s
		Survival wind speed	60 m/s
4	Hybrid Darrieus and Savonius rotor	Start-up wind speed	2 m/s
		Cut-in wind speed	2 m/s
		Cut out wind speed	None

In Table 1 different parameter values have been listed based on which appropriate vertical axis wind turbines could be selected to generate useful power for a low wind speed region like the present place.

CONCLUSIONS

The main objective of this study is to determine wind energy potential of Silchar (Assam, India) by using different models over a period of four years from 2008-2011. The conclusions which can be drawn based on the present study are:

- In Silchar, significantly low wind speed is observed, the highest being 1.48 m/s at 10 m height and 1.69 m/s at 25 m height near the end of dry season i.e. in the month of March. In general better average wind velocity is observed in the period from February to July when the wind velocity always remains above 1 m/s.
- During the month of March, the average power density is found highest which are about 2.1 W/m^2 and 3.2 W/m^2 at 10 m and 25 m respectively. Therefore based on these obtained data, the present place falls in a low wind speed region.
- Wind rose diagram reveals that most frequent wind velocity ranging from 1-2 m/s in Silchar city blows from North to North-East and South to South-South western direction.
- Weibull model fits the recorded wind speed data better than Rayleigh's model to measure the probability density distribution for the time period 2008-2011.
- ARIMA model gives good wind speed prediction level within an acceptable limit. Therefore, single ARIMA model is found useful for prediction of wind speed data of Silchar city. By using this model, future wind speed data for every year on monthly basis can also be predicted.
- The possible turbine designs that could be installed in low wind speed terrain such as the present place have also been explored.

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NOMENCLATURE:

c :Weibull scale parameter (m/s)

f(v) : average probability of observing a wind velocity

F(v) : cumulative distribution function

k :Weibull shape parameter

n: total period of wind data collection over a month

P/A: average available wind power per unit area (W/m^2)

v_i : record of diurnal wind velocity in a day

$\bar{v}$: monthly mean of wind velocities

v_1, v_2,: mean wind velocities at heights h_1 and h_2

Greek symbols:

Γ: gamma function

ρ: air density (kg/m^3)

∑: summation operator

σ^2 : variance