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Wind variability study for a complex wind farm site in India

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Abstract

The paper presents the retrospective analysis of 25 years of wind speeds and power prediction using numerical whether prediction model at a complex terrain site in Kerala. The simulated data from the model has been validated using on-site/observed data for the same location obtained from C-WET mast. The model has been fine tuned so as to bring it closer to the observed value by using variance and bias. It is felt that by blending the best of direct onsite measurements with the atmospheric model techniques will give a reliable, credible and comprehensive understanding of the wind resources which will help in maximizing the performances of the wind farms developed in complex terrains with reference to the Indian context thus mitigating the risk of underperformance.

Keywords: Wind, numeric weather prediction model, mesoscale model, wind resource.

Introduction

Wind is the driver of numerous financial income streams including the ones through power production agreement, renewable energy credits, production tax credits and other sources of revenue related to the production of wind energy. Generation of electrical energy from wind can be economically achieved only where a significant wind resource exists. In the Indian context, if wind energy has to contribute substantially in the next decade then the long term wind resource variability needs to be thoroughly understood especially for complex terrains. The essential aspect for the success of any wind energy project is to understand and quantify the wind at that particular location. While wind is free, weather driven renewable energy source, its variability must be fully understood throughout the development and financing process of the wind farm project so as to ensure its long term economic viability. In recent years, mesoscale atmospheric modeling has become an increasingly accurate and accepted tool for evaluating the wind variability and the financial viability of the wind energy projects with special emphasis to complex terrains.

Due to the cubic relationship between wind velocity and output energy, sites with small percentage differences in average wind speed can have substantial differences in available energy (Gipe, 1995). As such thorough and accurate monitoring of wind resource at potential sites is a critical factor for deciding the wind turbines. In recent years, atmospheric modeling has become an increasingly accurate and accepted tool for evaluating the financial viability of wind energy projects (Elliott *et al.*,1987). In short, all interested developers share a mission critical need to accurately evaluate how the most important variable-the wind resource- will impact the viability of the project in the long term.

The paper attempts to throw light using numerical weather prediction model that is validated by using on-site meteorological data which will help us to move a step further for making a reliable estimation of wind resource/power generation suiting to the complex terrain in Indian context.

Model simulation

The assessment of wind resource at a complex site in Kerala state, Idukki district was carried out based on the 25 years of simulated data 1983 to Dec 2007 using mesoscale weather prediction model. The model was configured using the nested grids to simulate the wind resource at the said complex terrain site. The grid was selected in such a fashion so as to capture the synoptic weather events and also to allow model to develop regional, thermally-driven circulation. The map showing the inner 4.5 km resolution is shown in Fig.1. The bold red box shows the boundary of the valid study area and the black dots indicates the grid points with 4.5 km resolution the yellow dot /dot inside the box represents the location of the C-WET meteorological mast.

Long term wind resource assessment

Monthly mean variability of wind speed

The long term model simulated wind resource analysis for the past 25 years (1983-2007) was carried out at C-WET meteorological mast (AWEA, 1986) at a height of about 80 m and the time series of mean monthly variability of wind speeds is shown in Fig. 2 for the entire 25 years of the model data (red line/line with vertical peaks). The blue line / horizontal thick line indicates the average simulated wind speed of 6.53 m/sec and the green line indicates the 24 month running mean.

Annual mean variability of wind speed

The time series of annual variability of mean wind speed at C-WET mast location is shown in Fig. 3, the blue line / vertical peaks and dips denotes the long term average wind speeds over all the 25 years (6.53 m/sec).

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Fig.1.Map showing 4.5 km resolution of numerical weather prediction model domain.

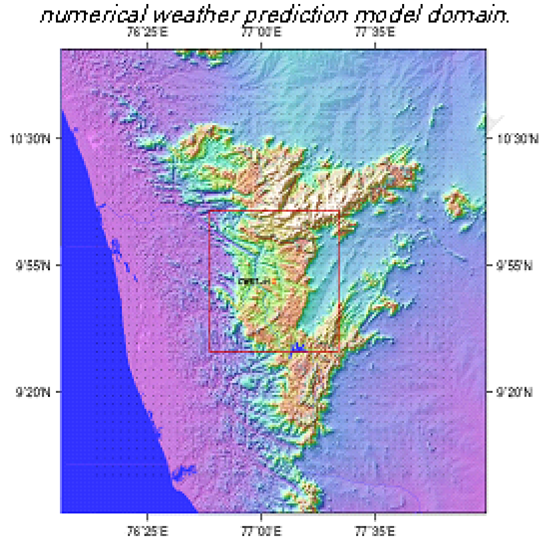

Fig. 2. Time series of monthly average 80 m wind speed at C-WET mast for the 25 years of model data

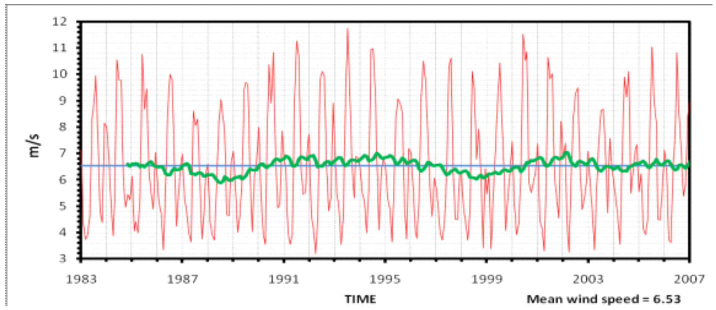

Fig. 3. Time series of annual mean wind speed at C-WET mast

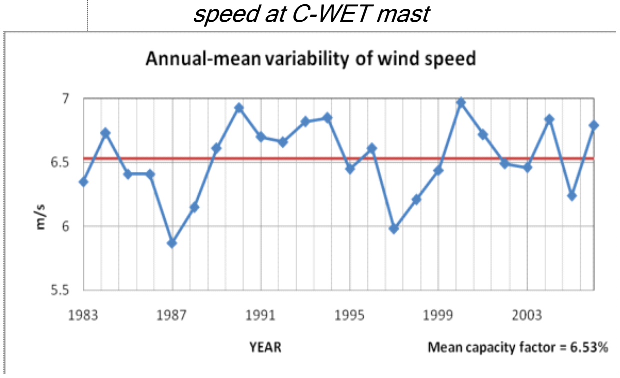

Fig. 4. a to d. Time series of 3 months seasonal average wind speeds at C-WET mast location

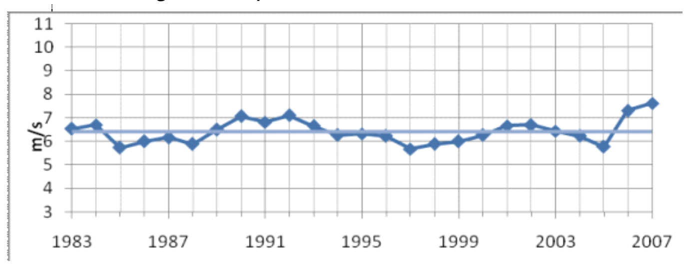

Fig. 4-a

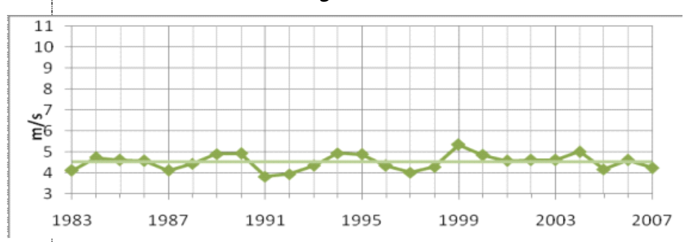

Fig. 4-b

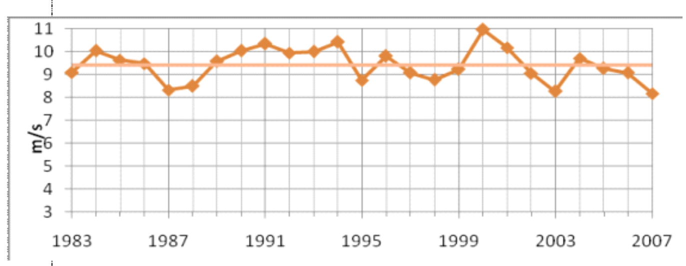

Fig. 4-c

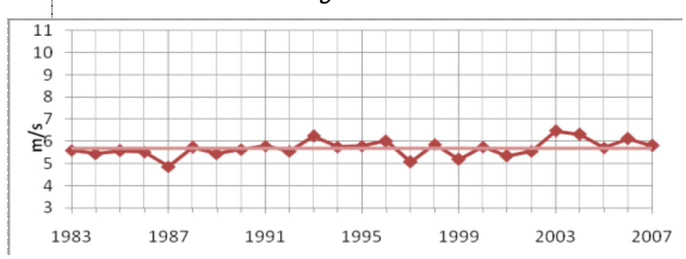

Fig. 4-d

Fig. 5. Wind rose of wind direction at C-WET mast.

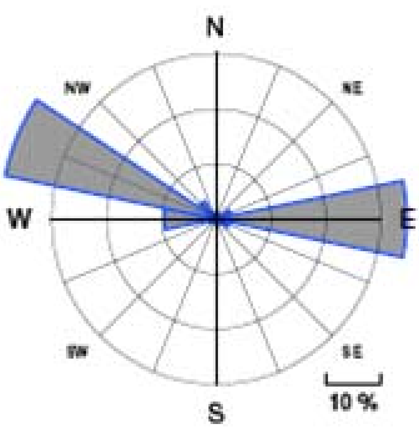

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Fig. 6. Hourly distributed histogram, with a fitted weibull distribution of A = 7.37 and K = 2.08, using all 25 years of model data.

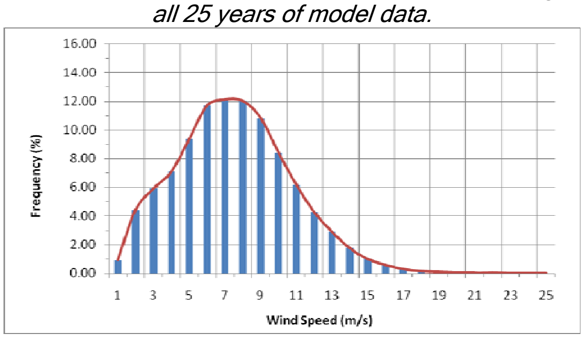


Fig. 7. Time series of monthly average 80 m power capacity at C-WET mast for the 25 years of model data

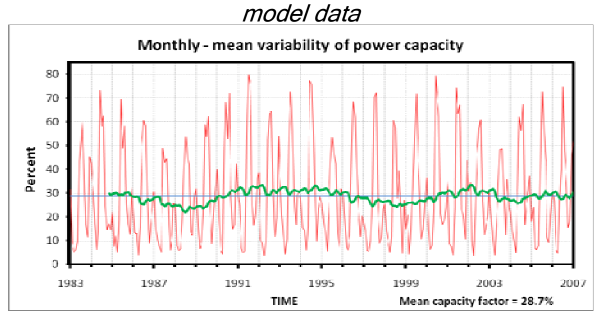


Fig. 8. Time series of annual mean power capacity at C-WET mast.

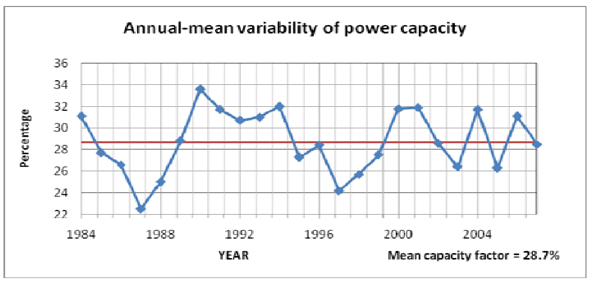


Fig. 9a-d. Time series of 3 months seasonal average power capacity at C-WET mast location.

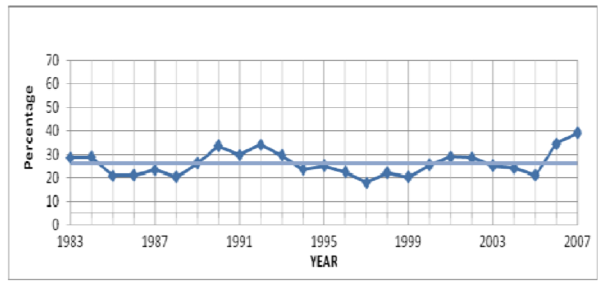


Fig. 9a

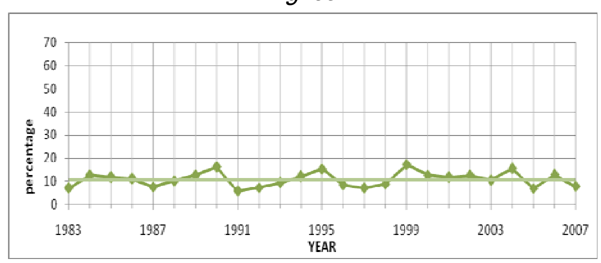


Fig. 9b

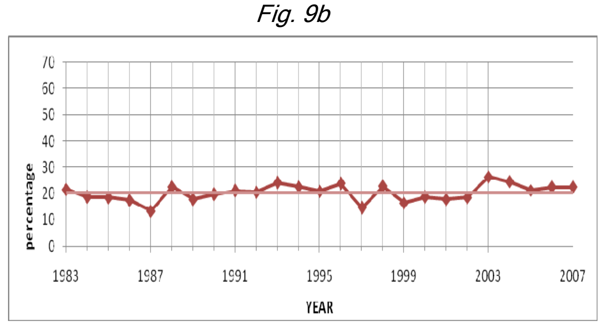


Fig. 9c

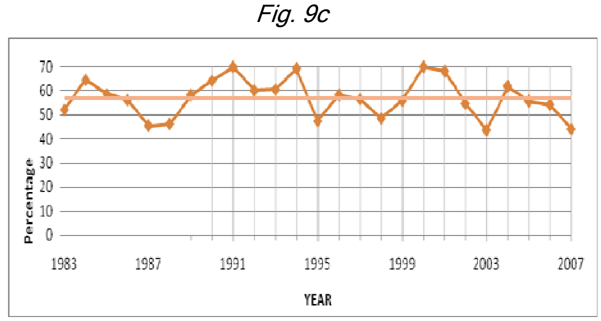


Fig. 9d

Fig.10. Histogram using all 25 years of model data.

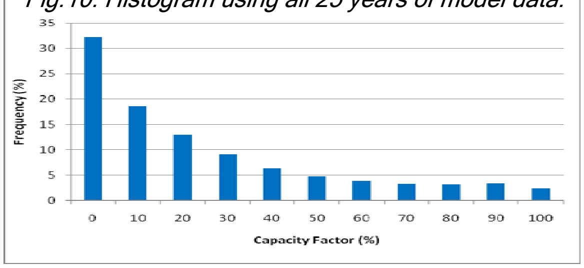


Fig.11. Power rose of simulated power capacity at C-WET mast.

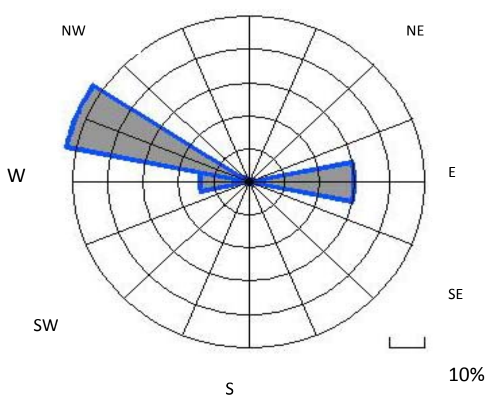
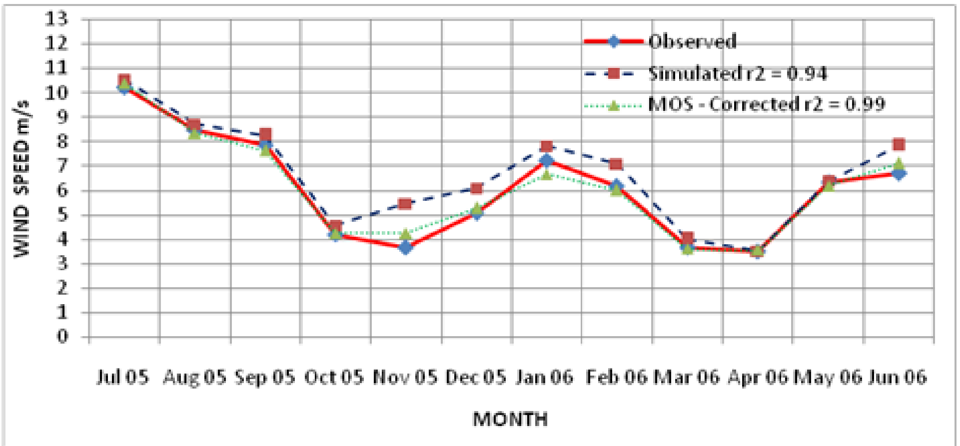


Fig.12 Comparision of the observed, simulated Wind Speed at C-WET mast



Seasonal mean variability of wind speed

The time series of three months seasonal wind speeds measured at the C-WET mast is shown in Fig. 4. The seasons are divided into Dec, Jan, Feb (Fig. 4a), Mar, Apr, May (Fig.4b), Jun, Jul, Aug (Fig.4c) and Sep, Oct, Nov (Fig.4d).

Wind direction distribution

Wind direction distribution as a wind rose for the mast site locations measurements is shown in Fig. 5. Directional bins are 22.5 deg. wide and the radial contour interval is 10% wind speed occurrence. The pre-dominant wind direction is from W-NW and E directions respectively.

Wind Speed distribution

The distribution of simulated wind speeds with respect to wind direction at mast site locations and the long term average histogram of the hourly distribution of simulated wind speeds with the weibull distribution fitted with scale (A) and shape (K) parameters are depicted in Fig. 6.

Long-term power capacity assessment at C-WET mast location

The long term power capacity assessment has been carried out using model simulated values at a height of 80 m, located at C-WET meteorological mast. The simulated data set for the last 25 years (1983-2007) has been used and the power capacity has been estimated for a 1.5 MW turbine operating at a height of 80 m.

Monthly mean variability of power capacity

The numerical weather prediction model output (Hiester & Pennell, 1981) that had been statistically corrected is used to compute the power capacity data. The monthly variability of the mean power capacity is depicted in Fig. 7 based on the 25 years model data. The red line/line with vertical peaks shows the time series of monthly average power capacity at 80 m height for the entire 25 years of model data, the blue line/horizontal thick line indicates the long term average over all months and the average simulated power capacity is 28.7%, the minimum of annual mean power capacity is 22.5% and maximum is 33.6%. The standard deviation of the annual average power capacity is 2.86%.

Annual mean variability of power capacity

The time series of annual mean variability of power capacity at C-WET mast location is shown in Fig. 8, the blue line / vertical line with peaks denotes the long term average power capacity over all years (28.7%).

Table 1. Formatted data, observed, simulated and MOS corrected.

Month	Observed (mean of all available observations)	Mean of simulated model output for times with observations	Bias (simulated - observed)	MOS - corrected (Mean of MOS - corrected output for times with observations	Availability %
July 2005	10.21	10.54	0.33	10.39	94.2
Aug 2005	8.51	8.70	0.19	8.34	99.6
Sep 2005	7.86	8.25	0.40	7.63	99.6
Oct 2005	4.20	4.55	0.36	4.26	98.5
Nov 2005	3.66	5.45	1.79	4.24	99.6
Dec 2005	5.07	6.09	1.02	5.26	99.2
Jan 2006	7.20	7.82	0.62	6.66	99.6
Feb 2006	6.16	7.09	0.93	6.00	100.0
Mar 2006	3.65	4.00	0.38	3.60	98.7
Apr 2006	3.48	3.52	0.04	3.55	98.3
May 2006	6.31	6.38	0.07	6.19	99.1
Jun 2006	6.70	7.84	1.14	7.10	38.1
All	6.04	6.62	0.58	6.04	93.7

Seasonal mean variability of power capacity

The time series of three months seasonal power capacity at the C-WET mast is shown in Fig. 9. The seasons are divided into Dec, Jan, Feb (Fig.9a), Mar, Apr, May (Fig.9b), Jun, Jul, Aug (Fig.9c) and Sep, Oct (Fig.9d).

Power capacity distribution

The distribution of simulated power capacity at C-WET mast location and the long term average histogram is depicted in Fig. 10.

Power direction distribution

Simulated power capacity for the C-WET mast is shown as a power rose depicting the percentage of total power in each sector and is depicted as Fig.11 using all 25 years of model data. The directional bins are 22.5 deg. wide with a radial contour interval of 10% power capacity. The maximum power is extracted from W-NW direction.

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Validation of model results at C-WET mast

The quality of numerical weather prediction simulations to be used in the assessment at a single point (C-WET mast location) within the study area has been examined. The average observed wind speed (for all valid observational times) at 50 m above ground level during the 12 months of the period of record is compared to a modeled 50 m wind speed. The observed wind speed has an average value of 6.04 m/sec with an hourly standard deviation of 3.31 m/sec and the modeled wind speed has an average of 6.62 m/sec with a 3.12 m/sec standard deviation for the same time. A multi linear regression model output statistic (MOS) has been used to reduce the bias and adjust the variance of the simulated data with respect to the observed winds. After applying the statistical model with simulated date the MOS corrected mean wind speed is 6.04 m/s and hourly standard deviation is 3.12 m/s which almost matches with C-WET meteorological mast data. The aim of the verification was to improve the model ability to reproduce the observed variability of wind resource at daily and monthly timescale. Thus, an approximate 12 months data (Jul 2005-Jun 2006) from 50 m C-WET mast was used in the analysis to assess the quality of the model simulations at 50 m level.

Model validation statistics

A comparison of the observed, simulated and model output statistically corrected monthly mean wind speed at 50 m C-WET meteorological mast is plotted as shown in Fig.12. The months missing data greater than 25% of available observations are not plotted.

The formatted data indicating observed, simulated and model output statistically corrected (MOS) monthly mean wind speed at 50m met. mast is as shown in Table 1.

The comparison of the monthly mean wind speed indicates the simulate model values are almost nearer to that of the onsite measured wind speeds thereby the accuracy of the model can be relied on for long term historic wind speed measurements particularly in context to the complex terrains and the meteorological mast measurements can be avoided which are both time consuming as well as costly process.

Conclusion

The numerical weather prediction model used at C-WET mast location for this complex terrain has been fine-tuned/calibrated so as to bring it closure to the observed/measured on-site values by reducing the variance and bias. The long-term quality and characteristics of the wind resource at proposed site is the primary economic driver for the viability of the wind project. A relatively small investment in a comprehensive fuel analysis program, designed to increase your level of investment in paralleled with increasing levels of confidence in the wind resource, will help maximize the performance of the development while also mitigating the risk of underperformance.

As the standards of financial due diligence increases, so does the ability to take advantage of cost-effective, state-of-the-art wind resource assessment technologies to increase the level of confidence in the viability of your project. Blending the best of direct on-site measurements with advanced atmospheric modeling techniques gives a reliable, credible, and comprehensive understanding the wind resource that will fuel the project over its entire lifetime.

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