The Impact Assessment of Atmospheric Stability at a South American Wind Farm.

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ABSTRACT

This present paper provides the technical analysis performed with Vestas's advanced tools on a wind farm site in the Atacama Desert region of Chile. The wind speeds at the site, and its variability due to the height elevation, is highly dependable on various influential factors. An important factor to show the effect of wind speed increasing or decreasing due to height above ground level, is the wind shear, that is highly influenced by the atmospheric stability. The analysis is carried out using the In house Vestas Mesoscale data to verify the stability at the site. The on site measurement data from Masts and LIDARs confirms the risk of stability on the shear profile with the Vestas Mesoscale data. The risk of stability on wind speed prediction and wake loss effects with Annual Energy production estimate are quantified. Furthermore, a comparison of load predictions using Mast and in house Vestas Computational Fluid Dynamics package was done in order to understand the impact of Loads for the proposed wind turbines at the site.

Keywords: Annual Energy production, shear, atmospheric stability, loads assessment.

1. INTRODUCTION

Atmospheric stability is a measure of the atmosphere's tendency to encourage or deter vertical motion. The main driver for the atmospheric stability is the difference in temperature between air and surface.

Stability conditions influence directly in the vertical mixing, wind shear, speed-up effects and turbulence. In unstable conditions, for instance, a lifted air parcel will be warmer than the surrounding air in the same altitude, and its resistance to vertical displacement will be lower, thus increasing the vertical motion, or mixing

Vertical motion is directly correlated to different types of weather systems and their severity. The following changes occur to the wind flow due to atmospheric stability:

- Surface warms and cools through diurnal and seasonal cycles
- Features such as, low-level jet, katabatic flow, appear
- Air near cold surface becomes cold, heavy
- Turbulence shuts down, shear increases, atmosphere is stable
- Situation is not stationary, wind and turbulence profiles undergo significant changes in time

2. STABILITY STUDY AT THE SITE

Vestas Siting Universe (VSU) is an unique tool developed by Vestas, that is used for the wind data analysis. In the study, VSU was used to analyze both data from the measurement mast and the LIDAR equipment at the site. The following figures (**Figure 1** to **Figure 3**) show the mean wind speed and shear profiles at the measurements heights for the measurement mast, LIDAR and Vestas Mesoscale modeling, respectively.

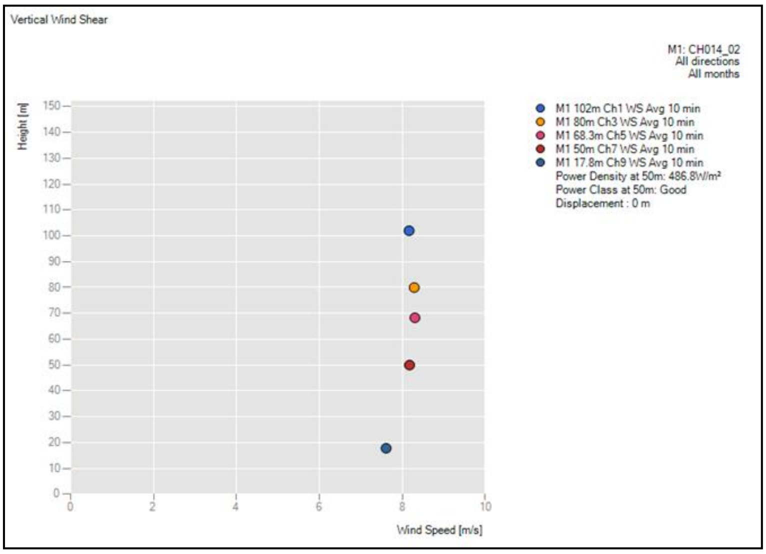

Figure 1 – Shear profile quantified in Mast

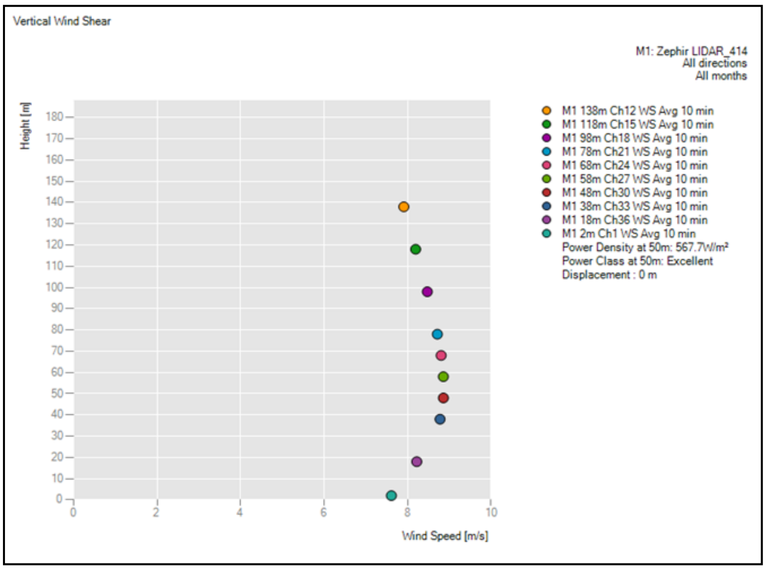

Figure 2 – Shear profile quantified in LIDAR measurements.

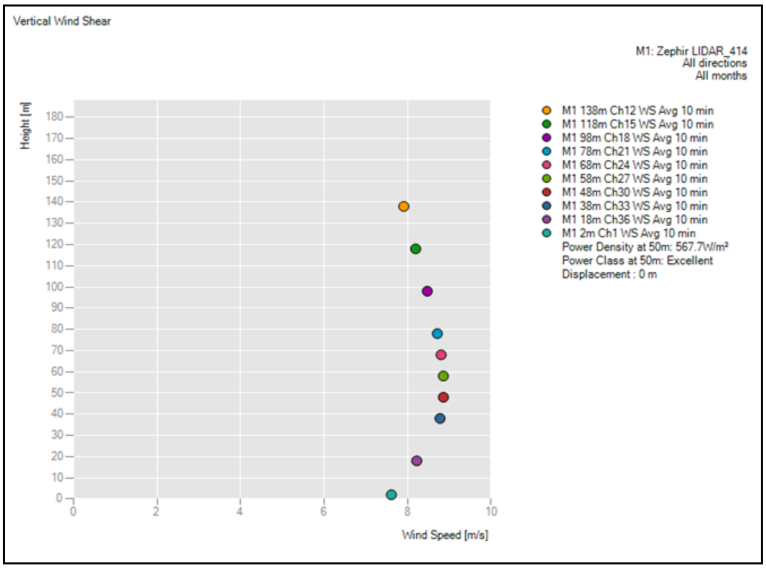

Figure 3 – Shear profile quantified in Vestas Mesoscale data.

The heating of the air over the course of the day increases the temperature gradient in the boundary layer, which in turn increases the mixing of the air. The following **Figure 4** shows the wind speed variation between day and night periods.

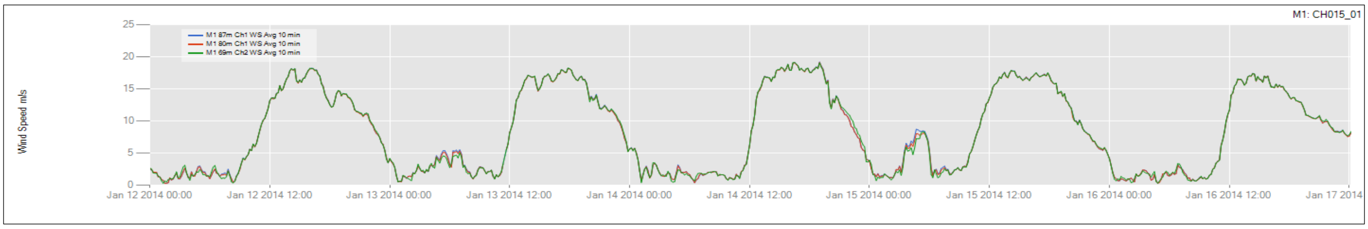

Figure 4 – Wind speed daily variations between day and night.

Another observed effect in the measurement data was the "bi-Weibull" wind distribution. This specific phenomenon occurs due to the variation of diurnal and nocturnal wind regime. **Figure 5** shows the wind distribution of the measurement mast and the Weibull fit. Despite being observed, this specific characteristic was not part of the present study.

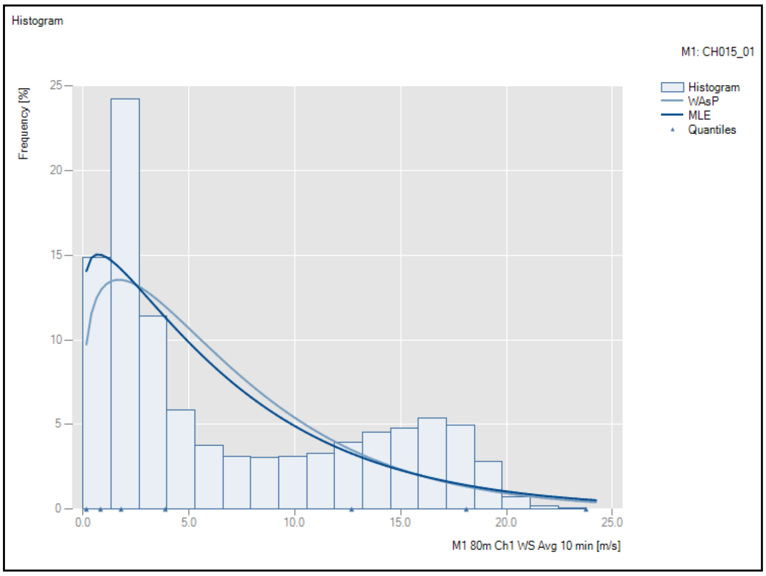

Figure 5 – Weibull representation of measured data

3. STABILITY WITH FOCUS ON AEP ESTIMATE:

Due to the lack of high quality temperature gradient measurements in the meteorological mast, Vestas mesoscale data was used to determine the atmospheric stability. The following heights and parameters were used:

- 120m Temperature
- 80m Wind Speed
- 80m Wind Direction
- 40m Temperature
- 0m Temperature

Potential gradient (Te Comp 10 min), is calculated by the VSU with Wind speed at 80 m and Wind direction at 80 m. Te Comp is explained as follows:

$$\frac{\partial\theta}{\partial z} = \frac{T_{120} - T_{40}}{80m} + 0.8\ [\frac{K}{80m}]$$

Equation 1 – Potential gradient

Where:

< 0 : Unstable

0 : Neutral

> 0 : Stable

Important: $\partial\theta/\partial z$>0.8 K/80m means temperature inversion; very stable atmosphere.

4. RISK EVALUATIONS AND RESULTS

A. Focus on Annual Energy Production :
B. Focus on Wake loss in Wind farm.
C. Focus on Loads evaluation in Wind farm.

A. FOCUS ON ANNUAL ENERGY PRODUCTION:

The aforementioned reasons show the atmospheric stability directly affects the flow modeling through the site area, influencing the Annual Energy Production (AEP). The following **Table 1** shows the comparison between the calculated percentage of wind speed with stable conditions and the measured data and Vestas Mesoscale data, with focus in the AEP.

Table 1 - Focus on Annual Energy Production

Stability	Meso scale result (%)	Mast Result (%)
Wind speed above 4 m/s	44.22	46.86

B. FOCUS ON WAKE LOSS IN WIND FARM.

The atmospheric stability has a big influence in the turbine induced wake effect within the wind farm. It is known that during stable conditions, the wind speed deficit due to wake effect is higher than that of unstable conditions. The following **Table 2** shows the comparison between the calculated percentage of wind speed with stable conditions and the measured data and Vestas Mesoscale data, with focus on Wake losses in Wind farm.

Table 2 - Focus on Wake loss in Wind farm

Stability	Meso scale result (%)	Mast Result (%)
Wind speed above 7.5 m/s	43.45	43.99

C. FOCUS ON LOADS EVALUATION IN WIND FARM.

The site suitability of the wind turbine to a specific site is a critical step of the development of a wind farm. To guarantee the suitability of the wind turbine to a site, Vestas performs a loads assessment to evaluate the risks of the lifetime operation of the wind turbines in the site´s specific conditions.

In complex sites, Vestas uses CFD software to model the flow in the site area. For this study, Vestas used CFD level 1. **Figure 6** shows the several levels of calculations that can be performed by Vestas CFD modeling.

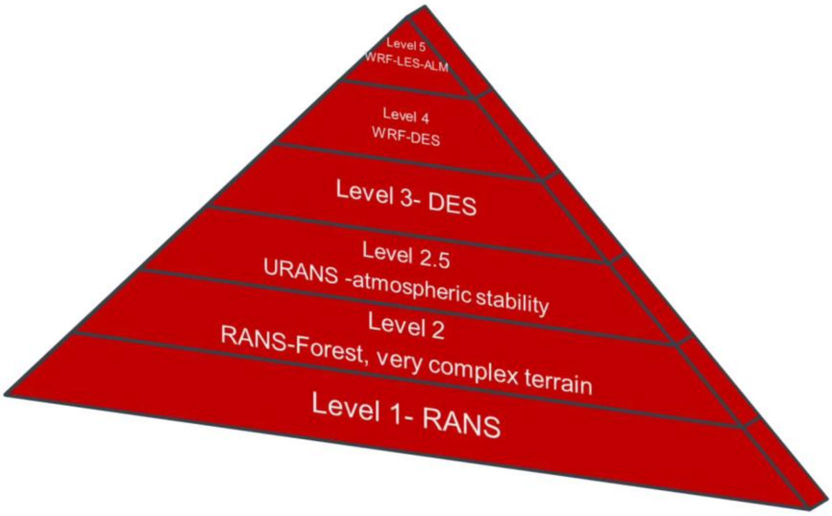

Figure 6 – Vestas CFD levels

The following Table 3 shows the comparison between the average results for one component of the loads evaluation in wind farm using the mast data and using the CFD modeling.

Table 3 Loads evaluation in Wind farm

Source used for calculation	**Minimum load exceedance (%)**	**Maximum load exceedance (%)**
Loads using Mast data	98.7	104.3
Loads using CFD Level 1	97.9	103.5

5. CONCLUSION

Stability is calculated on both Meso scale and Mast data.

Observation made: The high wind speeds are typically due to low level jet reaching the mast level, and that's where the 120m vs 80m is important.

In most of the onsite measurement masts the effects of stability could not be captured well because of the lower measurement height. But, usage of Vestas mesoscale data helps to quantify the risk of shear in the entire rotor plane.

Also in the case of stability issues presented in the site, the loads results obtained from the mast data are over predicted when compared to the usage of CFD results.

FUTURE WORK

Assessment of the “bi-Weibull” distribution in the Wind and Site analysis.

Assessment of more refined CFD levels for the loads estimation.

REFERENCES

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APPENDIX

BIOGRAPHIES

Nandha kishore S R – was born in Nellikuppam, India, 27-April 1990, Obtained Post Graduate Diploma in Wind Resource Assessment, fully sponsored by National Institute of Wind Energy (NIWE) and supported Indian Wind Turbine Manufacturers Association (IWTMA) at Amrita University, Coimbatore, India, year 2012. He has a Bachelors of Engineering in Electrical and Electronics Engineering, Anna University, Chennai, India Year 2011. Major Field of study is Renewable energy.

He was published on the work titled "Wind forecasting for grid code compliance" With the Journal of Renewable and Sustainable Energy, American Institute of Physics, sponsored by BITS Pilani, Risø DTU National Laboratory for Sustainable Energy and Danish Agency for Science Technology and Innovation. View online: http://dx.doi.org/10.1063/1.4850256

Areas of interest includes Wind and Solar Resource Assessments, Environmental Impact assessments and Forecasting projects.

Mr. Kishore certified with Six Sigma Green Belt from Indian Statistical Institute, Bangalore. And recipient of Best Paper Award at 3rd International Wind Conference and Exhibition (WE2020) (Year 2012). Received the INNOMINDS Award, conferred by SRM University for the effective contributions in wind and solar energy (Year 2010)..

Renato Loureiro Goncalves – was born in Rio de Janeiro, Brazil. He has a Brachelor´s degree in Mechanical Engeneering from the Universidade Federal do Rio de Janeiro.

He has been heavily involved in the Wind Industry and has worked directly in the development of several wind farms in Brazil and around the world. He has worked for developments and consultancy companies, and since 2016 is working at Vestas, and is responsible for Wind and Site studies.