The effect of varying meteorological conditions on power production at a central North American wind farm

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1) Atmospheric Influences on Wind Farm Performance

Power generated by wind turbines is a function of wind speed. Typically, the wind industry uses a single metric to determine the atmospheric contribution to power generation – the wind speed measured by a cup anemometer on the back of the turbine hub (nacelle).[1] Recent studies have proven this technique inadequate in representing the power produced during stable conditions and low level jets episodes (LLJ)[3], and high wind shear.[2]

Wind shear can cause erroneous power predictions because single measurements can over or under represent the power available,[2] as shown in Figure 1. These conditions can also lead to increased turbulence and turbine wear. In this study we quantify the impact of boundary layer stability and wind shear across the turbine rotor disk on power production at a central North American wind farm.

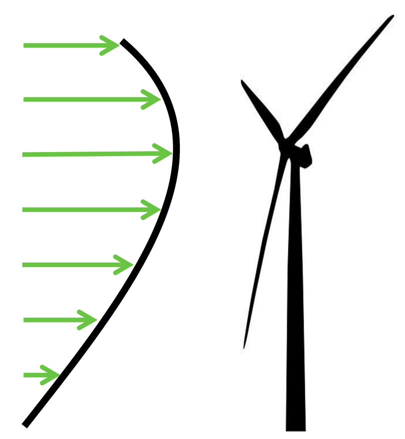


Fig 1: An idealized high shear profile with hub max.

2) Diverse Set of Instruments but Limited Meteorological Data Available at the Wind Site

Three data sources were available from the central North American wind farm (wind measurements were only available at 1 minute resolution):

a. 10, 30, 60m measurements of temperature, humidity, and wind speed and direction as well as 1m pressure from a 60m tower.
b. A profiling radar providing elevated measurements of winds.
c. Over 100 >1MW turbines with nacelle wind observations and power output readings.

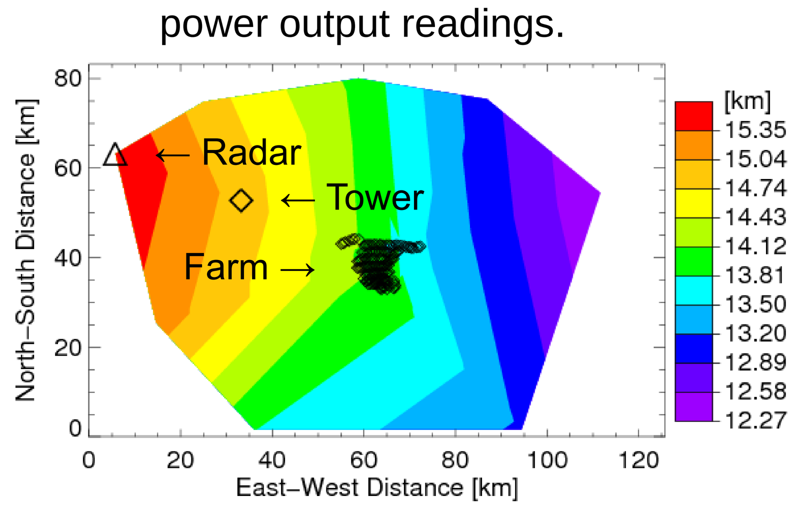


Fig 2: The topography of the wind farm and locations of the turbines, tower, and radar.

The full dataset was available during the months of April and May (meteorological Spring). 15-minute averages were computed to match up the three data sources. The farm has relatively mild terrain variations not exceeding 60m across its diameter, as shown in Figure 2.

References

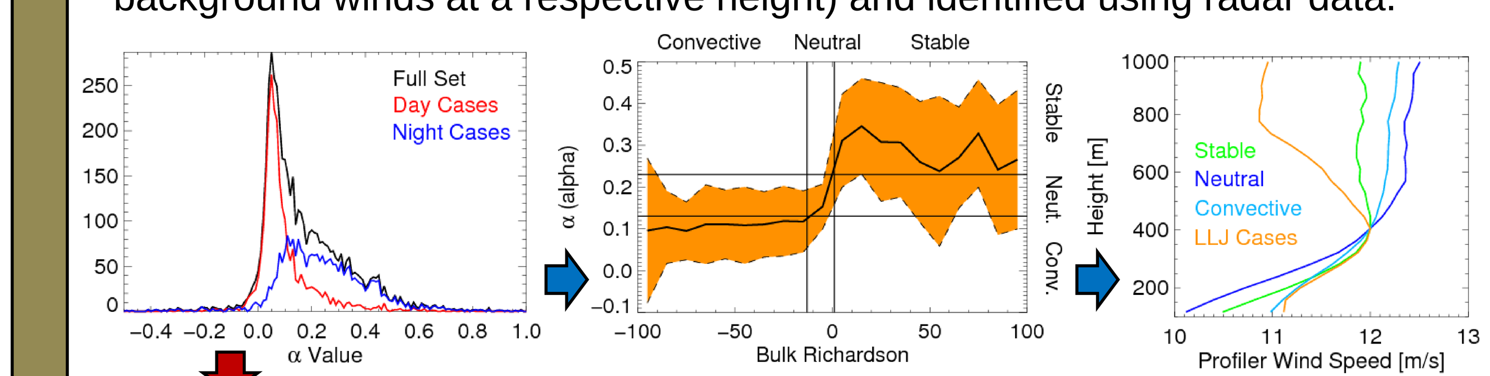
1. International Electromechanical Commission (IEC). *Wind turbine generator systems part 121: power performance measurements of grid connected wind turbines.* Draft Technical Report No, IEC 61400-121, 2003.
2. Wagner R, Antoniou I, Pedersen SM, Courtney MS, Jorgensen HE. The Influence of the Wind Speed Profile on Wind Turbine Performance Measurements. *Wind Energy* 2009; **12**: 348-362. DOI: 10.1002/we.297
3. Wharton S, Lundquist JK. Atmospheric Stability Impacts on Power Curves of Tall Wind Turbines – An Analysis of a West Coast North American Wind Farm. LLNL Technical Report LLNL-TR-424435, 2010.

3) Stability and Shear Classifications Were Defined Through Analysis of the Observations

Individual turbine power measurements were segregated by atmospheric conditions using two metrics: stability and shear. Stability classes were assigned for all times by calculating the Bulk Richardson number (not shown) and a power law exponent using tower data and this equation:

$$\left(U_{60m}/U_{10m}\right) = \left(60m/10m\right)^{\alpha}$$

where α relates the wind speed at two heights by the vertical distance between them. LLJ's were also defined (local maxima >2m/s above background winds at a respective height) and identified using radar data.



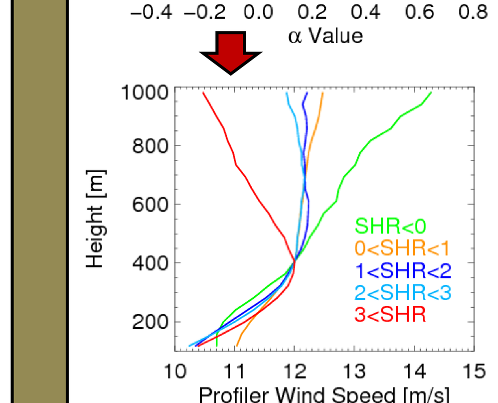


Fig 3: An illustration of the steps taken to get stability and shear classifications from the data. Shear was compared to profiler winds to ensure consistency with rotor level winds.

Shear was calculated by subtracting the projection of the 30m tower winds onto the 60m wind vector from the 60m wind itself. These height levels were used as they were closest in proximity to the rotor.

4) No Consistent Correlation Found Between Power, α

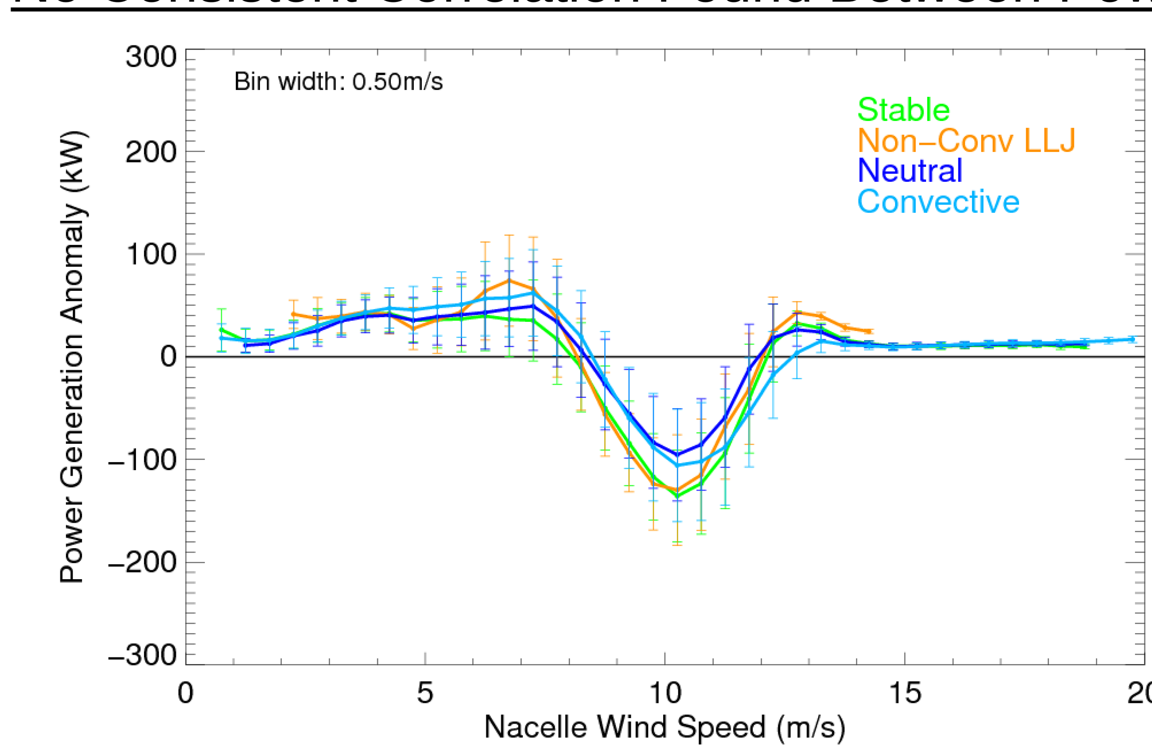


Fig 4: Power curves, based on α classes and LLJs, depicting the departure from the manufacturer's power curve (kW).

The result of this analysis using stability is largely inconclusive:

a. All observations exhibit the same pattern: under-performance at moderate winds speeds and slight over-performance otherwise.
b. There is no clear trend with increasing or decreasing stability.
c. Median absolute deviations are larger than the differences between classes – standard devs. (not shown) are worse due to outliers.

5) As 30-60m Shear Increases, Power Generation at Moderate Wind Speeds Decreases

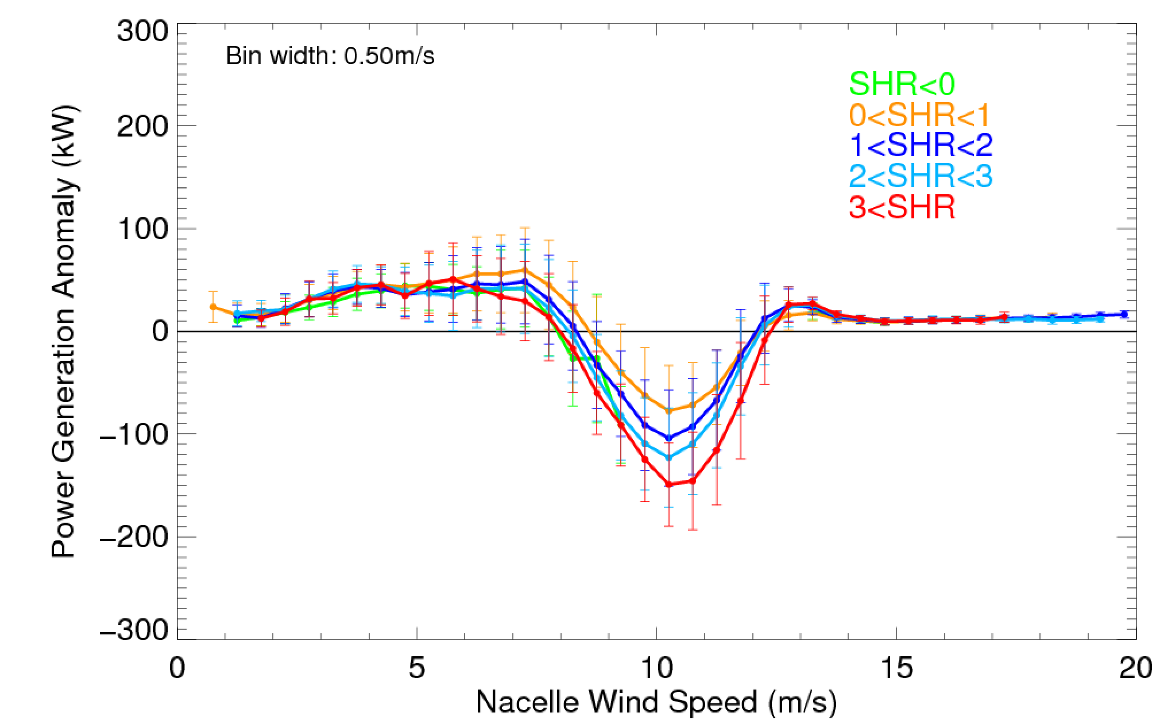


Fig 5: Power curves, based on shear, depicting the departure from the manufacturer's power curve (kW). Classifications range from negative shear to high positive shear.

In contrast to the stability study, this analysis shows promise:

a. At moderate wind speeds, high shear below the rotor disk causes decreases in power generation that scale with shear magnitude.
b. The median absolute deviations, while still significant, are lower than those encountered in the stability analysis.
c. Outliers are still an issue; standard deviations remain high.

6) Conclusions and Future Work

a. Clear trends were not apparent in our stability analysis.
b. Shear classes did yield a trend, but we are hesitant to make definitive conclusions without direct observations of winds across the rotor disk.

Future analyses would likely include remotely sensed data (such as lidar) to quantify rotor disk shear. Other seasons would also be examined – the trends in this work were found using Spring data and may not be representative of other time periods. Finally, examining other wind farms would be useful to determine if these results are site-specific.

Acknowledgements

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