Turbine Nacelle Anemometers - A Valuable Resource for Forecasting and Operational Assessment

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Abstract

Sparsely located met towers, often waked by wind farm turbines for significant periods of time, are typically the only source of met data used for wind forecasting and operational wind resource assessments. Turbine nacelle anemometer data is often relegated to second class status because of the anemometer's location behind the turbine blades.

Analysis of an Upper Midwestern wind farm indicates that significant improvement in on-site wind speed characterization can be obtained by using appropriately filtered and averaged turbine nacelle anemometer data. These data can also be used to observe and quantify wind farm wake effects. We present the results of our work here highlighting a year of recent wind farm operation.

Objectives

The collection of accurate wind speed data at existing wind farms is challenging at best. Wind farm met towers are rarely placed in completely wake-free locations. Additionally, complex terrain and land constraints can further hinder accurate free-stream wind measurements.

Because of these challenges, wind farm owners and wind forecasting providers are investigating the use of turbine nacelle-mounted anemometers for the gathering of wind speed data. The most significant flag raised with this practice is the disturbance of the wind flow by the rotor and nacelle [1].

In this study we compare turbine nacelle anemometer wind speed measurements with on-site met tower wind speeds at a mid-sized Upper Midwestern wind farm to illustrate the value of turbine nacelle anemometer measurements.

Methodology

An Upper Midwestern wind farm with 27 GE 1.5 MW SLE turbines was chosen for this work (fig. 1). Dominated by a northwesterly wind flow, this site has a single met tower (with two anemometers) which is often waked by wind turbines located just to its west.

Turbine nacelle anemometer, site met tower and substation power data were collected at ten-minute averaged intervals for one year and analyzed for this study. It is also important to note that no correction for rotor and nacelle wake effects [2] was applied to the turbine anemometer data beyond the proprietary corrections applied by the turbine manufacturer.

After applying the proper QA/QC measures to these data (e.g., to flag curtailments, icing events and other suspicious data) two methods were used to estimate the wind farm power production. The first method was to run site met tower wind speed data through the GE 1.5 SLE power curve (fig. 1) and scaling it by the site availability count. The second method involved averaging all available nacelle anemometer wind speeds, then running the average nacelle speed through the GE 1.5 SLE power curve and scaling it by site availability count to obtain site power production estimates.

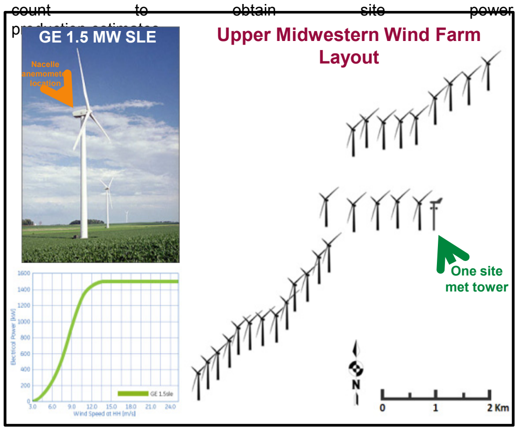
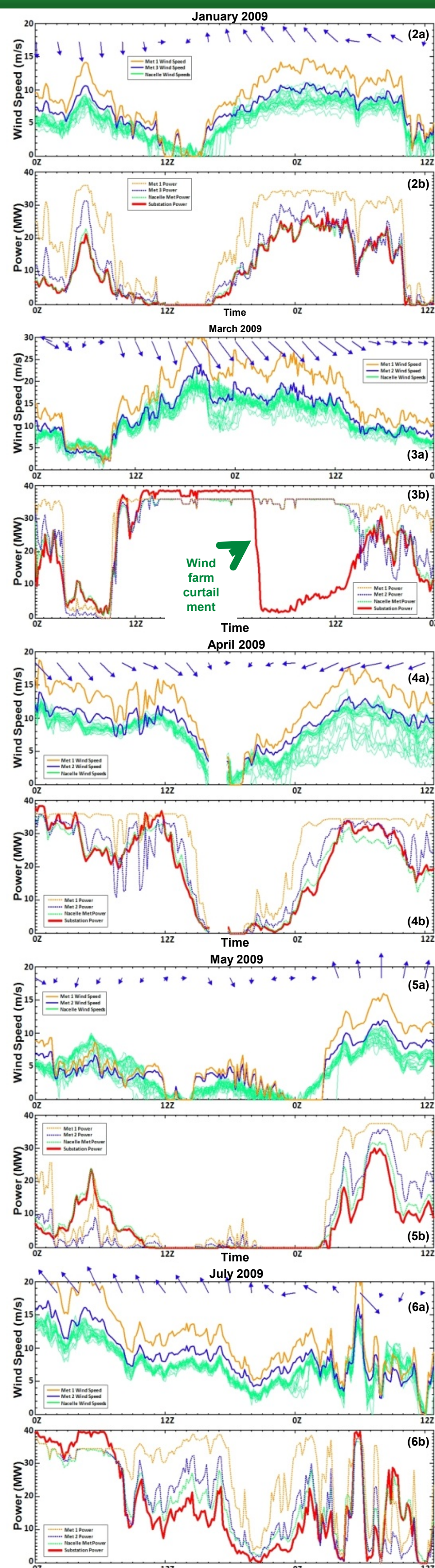


Figure 1: Upper Midwestern wind farm layout, GE 1.5 MW SLE turbine picture and associated power curve.

Results

Figures 2-6 depict time series of wind speeds and power production from five different time periods. Illustrated on the power production figures are significant improvements in predicted power estimates by way of the nacelle anemometer method. Other highlights include the smoothing effect nacelle anemometers have on the power production estimates and the illustrations of wind farm wake effects (as noted by the spread of the individual nacelle anemometer wind speeds). Overall there is excellent agreement between substation and nacelle anemometer-derived power production.

Results



Figures 2-6: Selected (a) nacelle anemometer and met tower wind speed and (b) power time series plots from January, March, April, May and July of 2009.

Results

Figure 7 highlights the translation from wind speed to power via the two different methods (depicting approximately 42,000 data points). Here we see a tighter distribution of points around the manufacturers power curve derived by the nacelle anemometer methodology [3].

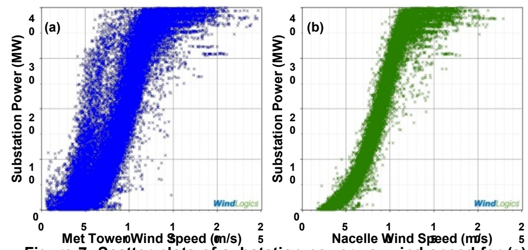


Figure 7: Scatter plots of substation power vs. wind speed for (a) met tower #2 and (b) nacelle anemometer.

Figure 8 illustrates the improved relationship between wind speed-derived power and substation power derived from the two methods with R-squared improving from 0.81 to 0.97.

Figure 9 shows the monthly averaged values of nacelle anemometer, met tower and substation power values. The overall biases for the two methods are +2.4% (nacelle) and +10.2% (met tower) above the substation power numbers. Though not shown here, a significant source of error for both methods was traced to inaccurate turbine availability information.

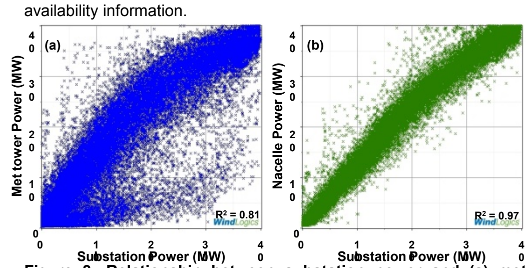


Figure 8: Relationship between substation power and (a) met tower #2 and (b) nacelle wind speeds. R-squared values are listed on figures.

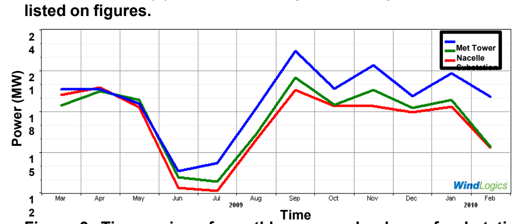


Figure 9: Time series of monthly averaged values of substation power and power derived from met tower #2 and averaged nacelle wind speeds.

Conclusions

Initial results from this study indicate that nacelle anemometer wind speeds can be used to provide reasonably accurate approximations of wind farm power production. Significantly less scatter was observed in the power curves generated from the nacelle anemometer data than from the power curves generated by the site met tower data.

This increased precision in power curve estimates suggests that an average anemometer-based wind speed method (i.e., "virtual met tower") might be useful in helping to better characterize the wind flow at a wind farm. This could be especially advantageous for wind farms that are geographically disbursed or located in complex terrains where significant on-site variability exists in wind speeds.

Future work will entail investigating the effects of larger wind farms on this methodology and also looking at the impacts of multiple point virtual met towers (derived from nacelle anemometer measurements within a wind farm) on wind speed characterization.

References

1. Masson C, Smaili A, "Numerical Study of Turbulent Flow around a Wind Turbine Nacelle", Wind Energy, 2006; 9:281-298
2. Albers A, Klug H, Westermann D, "Power Performance Verification", Proceedings of EWEC 99, Nice, 657-660
3. Smith B, Link H, Randall G, McCoy T, "Applicability of Nacelle Anemometer Measurements for Use in Turbine Power Performance Tests", AWEA 2002, Portland, Oregon (CD-ROM)