The Power Curve Working Group's Assessment of Wind Turbine Power Performance Prediction Methods

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Challenges of Power-Curve Modeling and the Power Curve Working Group

- A wind turbine power curve is often only strictly valid for a subset of all atmospheric conditions (i.e., the inner range), while wind turbines also operate in other scenarios (i.e., the outer range). Hence, modeling the power output in real-world conditions is a fundamental challenge.
- For example, the power deviation matrix (PDM) in Figure 1 displays an overprediction of power production using a reference power curve when wind speed (WS) and turbulence intensity (TI) are both low. Many experts use the PDM approach to observe any systematic bias in power curves and correct this in energy yield models.
- The mission of the Power Curve Working Group (PCWG) is to bring together wind industry stakeholders to help identify, validate, and develop ways to improve modeling of wind turbine performance in all atmospheric conditions.

The Share-3 Exercise

- To search for the optimal power-curve modeling method, the PCWG launched the third iteration of its intelligence-sharing (Share-3) exercise. In 2018, we collected and analyzed 55 data sets of power performance tests from nine industry collaborators. Herein, we compare four trial modeling-correction methods against a reference baseline method, which is an interpolation to derive an inner-range power curve after applying density correction:
  - Density and turbulence (Den-Turb), which is International Electrotechnical Commission-61400-12 compliant
  - Density and two-dimensional power deviation matrix (Den-2DPDM), using WS and TI
  - Density and augmented turbulence (Den-Augturb), which derives empirical relationships of power-deviation residuals after applying the Den-Turb method
  - Density and three-dimensional power deviation matrix (Den-3DPDM), using WS, TI, and rotor wind speed ratio (an estimate for wind shear).

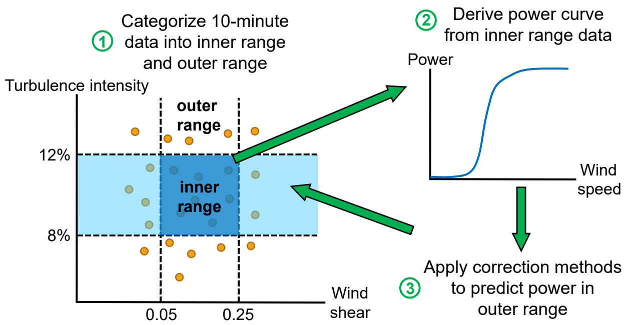

Figure 1. Illustration of the Share-3 exercise

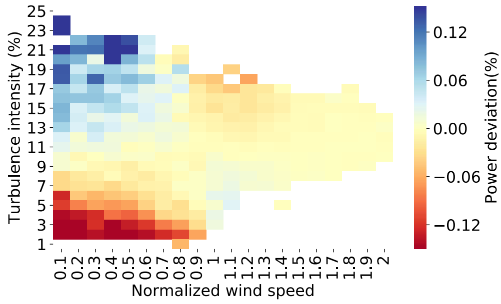

Figure 2. A power deviation matrix

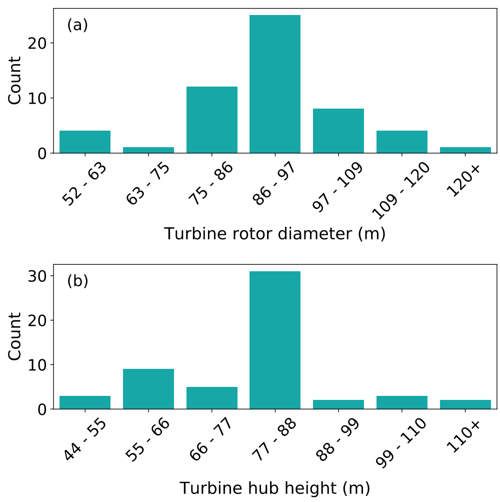

Figure 3. Metadata of data sets

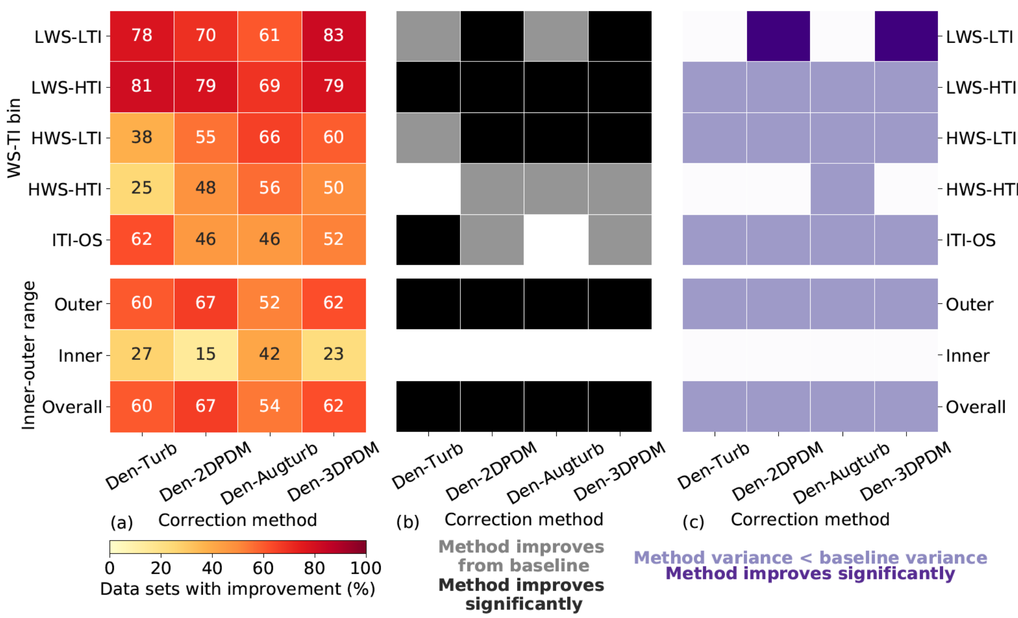

Figure 4. (a) Heat map of the four trial methods' improvement fractions (in error reduction) upon the baseline method for the WS-TI bins and the inner-outer ranges; (b) heat map illustrating whether a trial method yields a smaller prediction error than the baseline on average in each inflow condition (grey) or not (white), and whether the result is statistically significant after performing the one-sided matched-pair t-test with an alpha of 0.05 (black); (c) heat map representing whether the error variance of a trial method is smaller than the error variance of the baseline method in each inflow condition (light purple) or not (white), and whether the result is statistically significant after performing the Levene's test with a significance level of 0.05 (dark purple); the WS-TI conditions are categorized as low (L) and high (H), and ITI-OS represents inner-range TI and outer-range shear (light blue box in Figure 2)

Key Takeaways

- In the outer range, all of the trial correction methods exhibit skills in reducing errors of power-curve modeling over the baseline method.
- The trial methods are more accurate at predicting power production than the baseline at low wind speeds (in terms of error reduction), even though the high wind-speed scenarios correspond to larger contribution to turbine power production; the trial correction methods are as imprecise as the baseline (in terms of variance reduction).
- This analysis demonstrates the importance as well as the implications of data sharing and should encourage future industrywide collaborations.
- As of September 2019, a manuscript on this work is in preparation for *Wind Energy Science*.

For more details, please refer to the PCWG web page at https://pcwg.org and the PCWG analysis tool at https://github.com/peterdougstuart/PCWG.

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