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Accounting for the Effect of Turbulence on Wind Turbine Power Curves

Andrew Clifton (NREL) and Rozenn Wagner (Danish Technical University)

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OBJECTIVES

Wind turbines operate in a wide range of atmospheric conditions. It is essential to be able to model turbine power performance as conditions change. Power curves made using the method of binning can accommodate shear using the equivalent wind speed (Wagner et al. 2011). However, turbulence also affects turbine performance (Figure 1). This poster presents lessons learned using methods that can include the effect of turbulence.

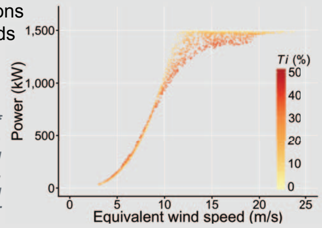

Figure 1. The effect of turbulence intensity (Ti) on the power produced by the WindPACT 1.5-MW turbine, simulated with TurbSim and FAST

TWO METHODS TO ACCOUNT FOR TURBULENCE

TURBULENCE RENORMALIZATION

The turbulence renormalization method of Albers (2010) assumes that wind speed in a 10-minute period follows a Gaussian distribution described by the mean wind speed and the turbulence intensity, and that the mean turbine power in that interval is a function of the distribution of wind speeds in the interval. These assumptions allow a model to be created from power performance test data (Figure 2). After calibration, the model can be used to estimate turbine power output at any wind speed and turbulence intensity.

This method is proposed for inclusion in the next International Electrotechnical Commission (IEC) standard for Power Performance Testing of Wind Turbines (IEC 61400-12-1). For details, see Clifton et al. 2013.

RANDOM FORESTS

This machine learning tool uses power performance data to train an ensemble of decision-tree models of power versus wind speed, shear, and turbulence (Figure 3). Other variables can be added to the model as well.

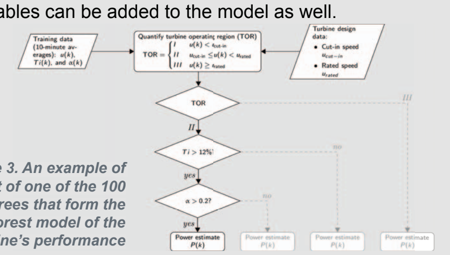

Figure 3. An example of part of one of the 100 decision trees that form the random forest model of the turbine's performance

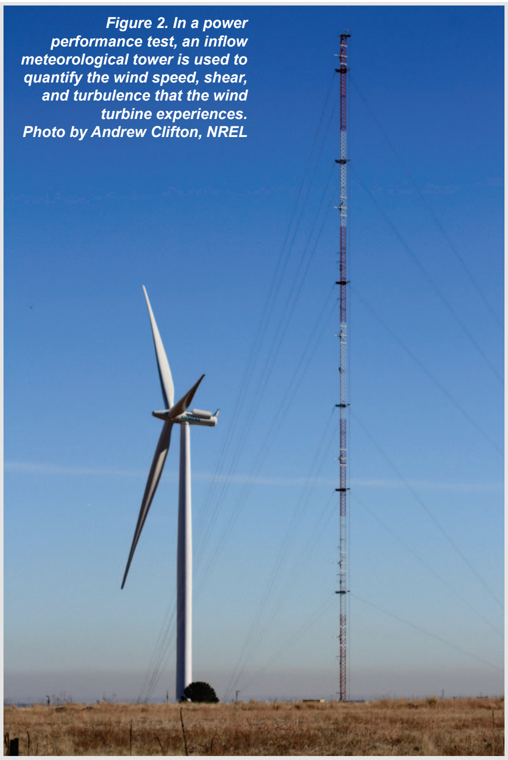

Figure 2. In a power performance test, an inflow meteorological tower is used to quantify the wind speed, shear, and turbulence that the wind turbine experiences. Photo by Andrew Clifton, NREL

USING THE TURBULENCE RENORMALIZATION METHOD

To test the turbulence renormalization method, the data set is split into two subsets according to the hub-height turbulence intensity. One subset is used to train the model, and results are tested against the other subset (Figure 4 and Figure 5).

Although the method captures the deviation in the power output as the turbulence changes, the magnitude of the effect is overpredicted. This leads to large errors around rated speed when this method is used with the WindPACT turbine data.

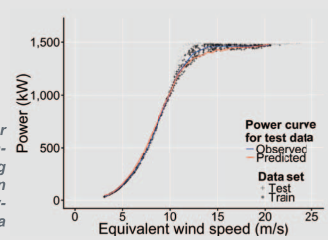

Figure 4. Power predicted for high-turbulence wind using the renormalization method trained on low-turbulence data

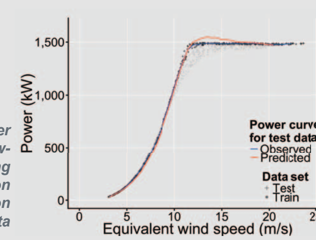

Figure 5. Power predicted for low-turbulence wind using the renormalization method trained on high-turbulence data

USING THE RANDOM FOREST METHOD

The random forest method can only predict data that lie within the bounds of the conditions that the model was trained on. An example of their use is to reduce a large power-performance data set to power curves for specific turbulence intensities (Figure 6).

Ideally, a random forest model of turbine performance would be trained with data from a site that experiences a wide range of wind speed, shear, and turbulence. This model could then be used at many other locations.

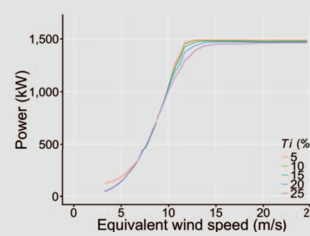

Figure 6. Power predicted for different turbulence intensity levels using the random forest method trained on the whole power-performance data set

For more information, e-mail andrew.clifton@nrel.gov or rozn@dtu.dk. See also:

Albers, A. (2010). "Turbulence and shear normalisation of wind turbine power curves." *European Wind Energy Conference Proceedings*.

Clifton, A.; Kilcher, L.; Lundquist, J.K.; Fleming, P. (2013). "Using machine learning to predict wind turbine power output." *Environmental Research Letters*.

Clifton, A.; Wagner, R. (2014). "Accounting for the effect of turbulence on wind turbine power curves." *The Science of Making Torque Proceedings*; June 18–20, 2014. Copenhagen, Denmark.

Wagner, R.; Courtney, M.; Gottschall, J.; Lindelöw-Marsden, P. (2011). "Accounting for the speed shear in wind turbine power performance measurement." *Wind Energy*.

IS THERE A "BEST" METHOD?

All of the methods have advantages and disadvantages:

- The method of binning is well-known and is today's standard approach. However, it cannot account for the effect of turbulence on performance.
- The turbulence renormalization method is physics-based and can predict performance outside the range of previously seen conditions. However, this model overestimates the effect of turbulence.
- Machine learning tools can be used with very large data sets and account for many variables at once; however, they do not work well when new conditions are very different than the training data set.

More research is required to develop models that combine the flexibility of physics-based modeling with the ability of machine learning to analyze large data sets.

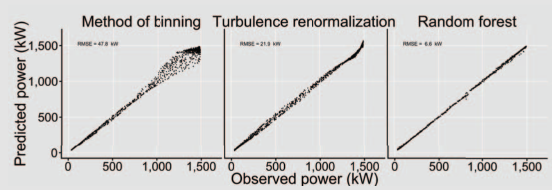

Figure 7. Comparison of actual power with predicted power for a single data point. The rest of the data set is used to train the performance model.

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