Uncertainty Quantification of the Real-Time Reserves for Offshore Wind Power Plants

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1 Introduction

In a future with even more wind power in the grid than the recent record of 140% instantaneous penetration [1], wind power plants will have to contribute to the safe operation of the power system through delivery of ancillary services. One of those ancillary services is reserve power, which is achieved by down-regulating the wind farm from its maximum possible power. The estimation of that maximum possible (or available) active power under down-regulation is crucial as it is the amount of up-regulation potential which can be traded as reserve power on the ancillary services market.

The PossPOW project (Possible Power of down-regulated Offshore Wind power plants) developed a real-time power curve of available power for offshore wind farms for use during down-regulation [2]. The Concert project aims to quantify and finally reduce the uncertainty in reserve power, bringing the PossPOW algorithm and the state of the art forecasting methods together.

2 Approach

In order to test the PossPOW algorithm, a series of dedicated experiments are conducted, in which two of the upstream turbines in Horns Rev-I offshore wind farm are curtailed under specific inflow conditions. Here in this study, the results of these down-regulation experiments together with the normal operational data from Thanet and Lillgrund will be used to evaluate the model outputs and perform an inverse uncertainty quantification, which is to be compared with the quantification and propagation of the input uncertainties as well as the parameter uncertainties embedded in the PossPOW algorithm.

3 Main Body of Abstract

Due to change in the wake characteristics during curtailment, the estimation of the available power of a wind farm under down-regulation is a complex process, especially for high resolution data. The state of the art industry practice is to aggregate the possible (or available) power signals from the individual turbine SCADA, which does not take into account the reduction in the wake losses thus over-estimates the production capacity.

The determination of the possible (or reserve) power with the PossPOW algorithm works as follows: firstly the second-wise upstream wind speed is estimated, since it is not affected by any wake. Then the upstream wind is introduced into the wake model, adjusted for the same time resolution, to simulate the power losses that would occur during nominal operation.

The PossPOW algorithm uses only 1 Hz turbine data as inputs, namely power, pitch angle, and rotational speed. The method is applied and validated on Horns-Rev-I, Thanet and Lillgrund offshore wind farms as well as the NREL 5MW simulations, under both normal and curtailed operations. The

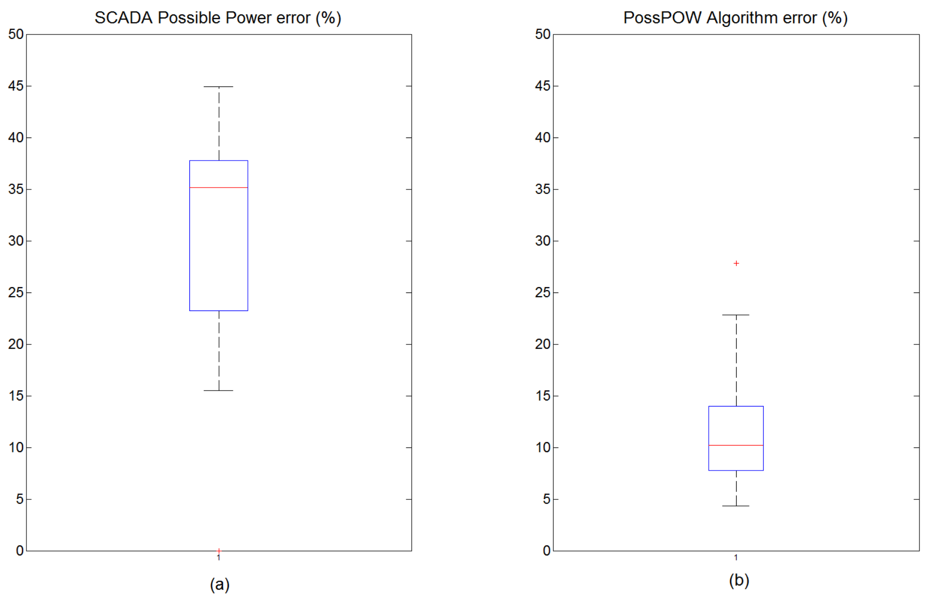

Figure 1: Median (red line), 25th and 75th percentiles (edges of the box) of the percentage error of (a) the SCADA Possible Power and, (b) the PossPOW algorithm

reduced wake that is occurred due to down-regulation is replaced by the wake model which estimates the velocity deficit for nominal operation.

As mentioned earlier, the validation of the algorithm under down-regulated operation was performed using experiments in Horns Rev-I where the PossPOW algorithm is compared to the current industry practice and shown to perform significantly better. In fact, it is seen from Figure 1 that the median of the SCADA possible power signal error is approximately 35% where the distribution is also broad indicating higher uncertainty. On the other hand, the PossPOW algorithm seem to reduce that error significantly down to 10% with a considerably narrower distribution.

To quantify the uncertainty in the real-time available power estimated by PossPOW, the first approach is to investigate the quantification and propagation of the input uncertainties as well as the parameter uncertainties in the algorithm, which is a complex and computationally intensive process for realistic engineering simulations. A variety of methodologies are available in literature, from basic convolution techniques [3] to commonly used Monte Carlo simulations [4], to more sophisticated stochastic spectral Galerkin approaches [5, 6, 7]. The implementation of the most suitable method(s) for the propagation will yield the ”traditional” uncertainty quantification of the real-time available power estimated by the PossPOW.

The other approach, which is to be implemented in this study, is based on the comparison between measurements and model outputs where the width of the modelling error distribution signifies the model uncertainty and the mean indicates the model bias. The error distribution acquired from the experimental results, as shown above, will be enriched using the normal operational data from Thanet and Lillgrund offshore wind farms, as well as Horns Rev-I, where the available power is identical to the active power due to the optimal operation. This kind uncertainty assessment is purely based on data analysis, thus claimed to be objective.

In order to improve the statistics, the bootstrap method will be implemented to the time series following a circular block re-sampling procedure [8], in a similar fashion to Nygaard et al. [9], to systematically quantify the uncertainty in real-time available power.

4 Conclusion

The PossPOW algorithm converts the incident wind on the rotor to a free stream wind speed for the upwind turbine, advects it with newly developed real-time wake models to the next turbine, and calculates the power of this turbine under normal conditions, taking the local turbulence intensity into account. A preliminary data-based uncertainty quantification of this algorithm, which is the only verified real-time wind farm scale available power estimation today [2], is presented. The previously performed down-regulation experiments in Horns Rev-I have been found promising in terms of higher accuracy and lower uncertainty compared to the good industry practice of estimating the wind farm scale available power. The data-based uncertainty assessment is to be finalized with the addition of normal operational data points and the results will be compared to the conclusions of the traditional uncertainty quantification methods.

5 Learning Objectives

- Real-time available (or reserve) power estimation - possible uses and challenges
- Implementation of the bootstrap uncertainty quantification to real-time data
- Data-based uncertainty quantification of the reserve power estimates through PossPOW algorithm

References

[1] Arthur Neslen. Wind power generates 140% of Denmark's electricity demand. *The Guardian*, 2015.

[2] Tuhfe Göçmen. *Possible Power Estimation of Down-Regulated Offshore Wind Power Plants.* PhD thesis, Technical University of Denmark, DTU. Department of Wind Energy, 2016.

[3] Cornelius Frank Dietrich. *Uncertainty, calibration and probability: the statistics of scientific and industrial measurement.* CRC Press, 1991.

[4] Zsolt Sándor and Péter András. Alternative sampling methods for estimating multivariate normal probabilities. *Journal of Econometrics*, 120(2):207–234, 2004.

[5] Jon C Helton, Jay Dean Johnson, Cedric J Sallaberry, and Curt B Storlie. Survey of sampling-based methods for uncertainty and sensitivity analysis. *Reliability Engineering & System Safety*, 91(10):1175–1209, 2006.

[6] Norbert Wiener. The homogeneous chaos. *American Journal of Mathematics*, pages 897–936, 1938.

[7] Roger G Ghanem and Pol D Spanos. *Stochastic finite elements: a spectral approach.* Courier Corporation, 2003.

[8] Dimitris N Politis and Joseph P Romano. A circular block-resampling procedure for stationary data. *Exploring the limits of bootstrap*, pages 263–270, 1992.

[9] Nicolai Gayle Nygaard. Systematic quantification of wake model uncertainty. In *EWEA Offshore Conference, Copenhagen*, 2015.