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PossPOW: Possible Power of Downregulated Offshore Wind power plants

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DTU

Abstract

One of the ancillary services that wind power plants can offer is reserve power which is achieved via downregulating the turbines. A verified methodology to calculate the possible or available power of downregulated offshore wind farms is the aim of the **PossPOW** project. While the available power calculation is straight-forward and widely known for a single turbine, it gets rather complicated for the whole wind farm due to the change in the wake characteristics derived from the downregulated operational conditions. In fact, the wake losses created by the upstream turbine(s) decrease during downregulation and the downstream turbines see more wind compared to the ideal (or normal) operational case. Currently, Energinet.dk, UK National Grid and other Transmission System Operators (TSOs) have no real way to determine exactly the available power of a whole wind farm which is down-regulated. Therefore, **the aim of the present project is to develop a verified and internationally accepted way to determine the possible power of a down-regulated offshore wind farm** using multi-disciplinary approaches. To be able to do that, the rotor effective wind speed has to be estimated and input to a wake model that simulates the normal operation of the wind farm.

Wind Speed Estimation

Using the general power expression; $\mathbf{P = \frac{1}{2} \rho\, C_P(\lambda, \theta)\, \pi\, R^2\, U^3}$

Active Power $P_{measured}$ →
Rotational Speed $\omega_{measured}$ →
Pitch Angle $\theta_{measured}$ →

Aerodynamic backward calculation of wind speed

→ *Incoming Wind Speed* U_{inflow}

↑ *Temperature & Pressure*

The power coefficient approximation of Heier[1]

$$C_P(\lambda, \theta) = c_1 \left(\frac{c_2}{\lambda_i} - c_3\theta - c_4\theta^{c_5} - c_6\right) \exp\left(\frac{-c_7}{\lambda_i}\right)$$

$$\lambda_i = \left[\left(\frac{1}{\lambda + c_8\theta}\right) - \left(\frac{c_9}{\theta^3 + 1}\right)\right]^{-1}$$

The coefficients in the expression, c_1 to c_9, strongly depend on the blade shape, in other words, the turbine type. They have been adjusted according to the turbines in the case studies, partially using the research of Raiambal et.al.[2] and partially the dataset itself.

The wind speed was calculated for each turbine iteratively using **Horns Rev-I** offshore wind farm and **NREL 5 MW** single turbine simulations[3]. Both cases have been investigated using **second-wise datasets** extracted during both normal operation and under curtailment.

Conclusions

The PossPOW project has been described and the intermediate results of the first period were presented. An aerodynamic backward calculation of wind speed methodology using active power, pitch angle and rotational speed measurements was proposed. The modelled rotor effective wind speed profile was compared to the nacelle anemometer measurements and the power curve wind speed estimations for Horns Rev case and to the simulated wind flow for NREL 5MW case. The model is verified based on the good agreements achieved during normal operation and downregulation for both turbine types which are aerodynamically different.

Future Works

To consider the changing wake effects for normal and down-regulated operations, the estimated rotor wind speed values of upstream turbines, which are not affected by the wake, are to be taken as inputs to the wake model to calculate the wind speed for the downstream turbines. Then the velocity deficit and therefore the possible power output of the wind farm can be calculated. However, most existing wake models have only been used to acquire long term, statistical information and verified using 10-min averaged data. Therefore, re-parameterization of wake models will be performed such that the parameters in the model such as wake expansion and "sweeping" speed will be calibrated for different averaging time scales using second-wise data obtained from Horns Rev.

Acknowledgements

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2. Raiambal, K. and Chellamuthu, C., 2002, "Modelling and Simulation of Grid Connected Wind Electric Generating System", *Proc. IEEE TENCON*, p.1847–1852
3. Jonkman, J., Butterfield, S., Musial, S. and Scott G., *Definition of a 5-MW Reference Wind Turbine for Offshore System Development* NREL/TP-500-38060 National Renewable Energy Laboratory, Golden, CO (2007)

Horns Rev *Normal Operation*

The algorithm is tested using the dataset provided by Vattenfall which covers a 35-hours period where the whole operational range is contained i.e. below cut-in to above rated region.

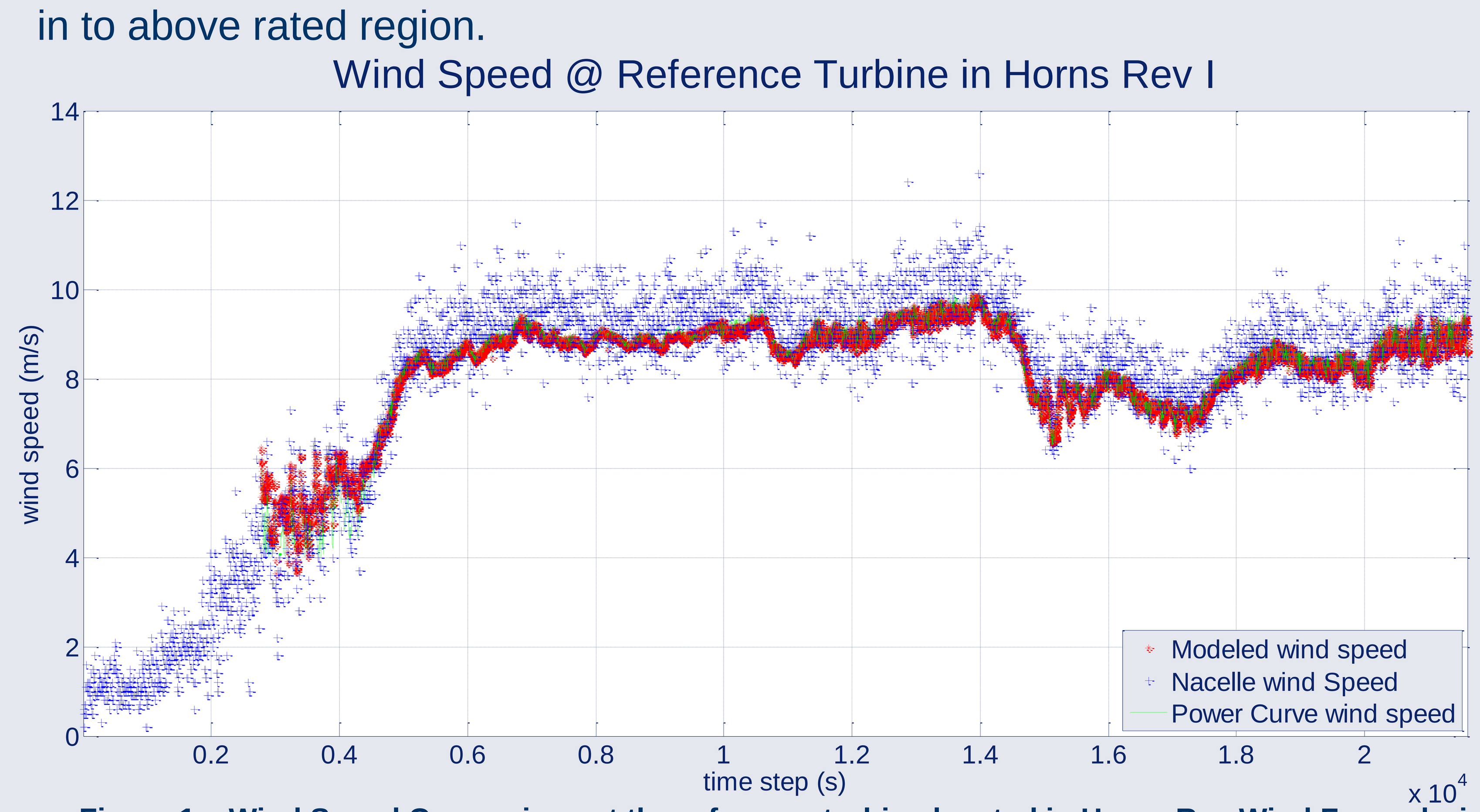

Figure 1 – Wind Speed Comparison at the reference turbine located in Horns Rev Wind Farm, during normal (ideal) operation

In Figure 1, the nacelle wind speed refers to the nacelle anemometer measurements and power curve wind speed is the wind speed calculated using the active power signal and the ideal power curve provided by the manufacturer.

Horns Rev *Down-Regulation*

The second dataset from Horns Rev covers approximately 2 hours of data extracted during down-regulation. In Figure 2 (a), it is seen that after the wind speed has reached the rated wind speed, the turbine is (pitch) controlled to maintain the rated power. After a while, turbine is downregulated which in total lasts approximately one hour. The comparison of the wind speed information gained from the nacelle anemometer measurements and the modelled power coefficient for that period is presented in Figure 2(b).

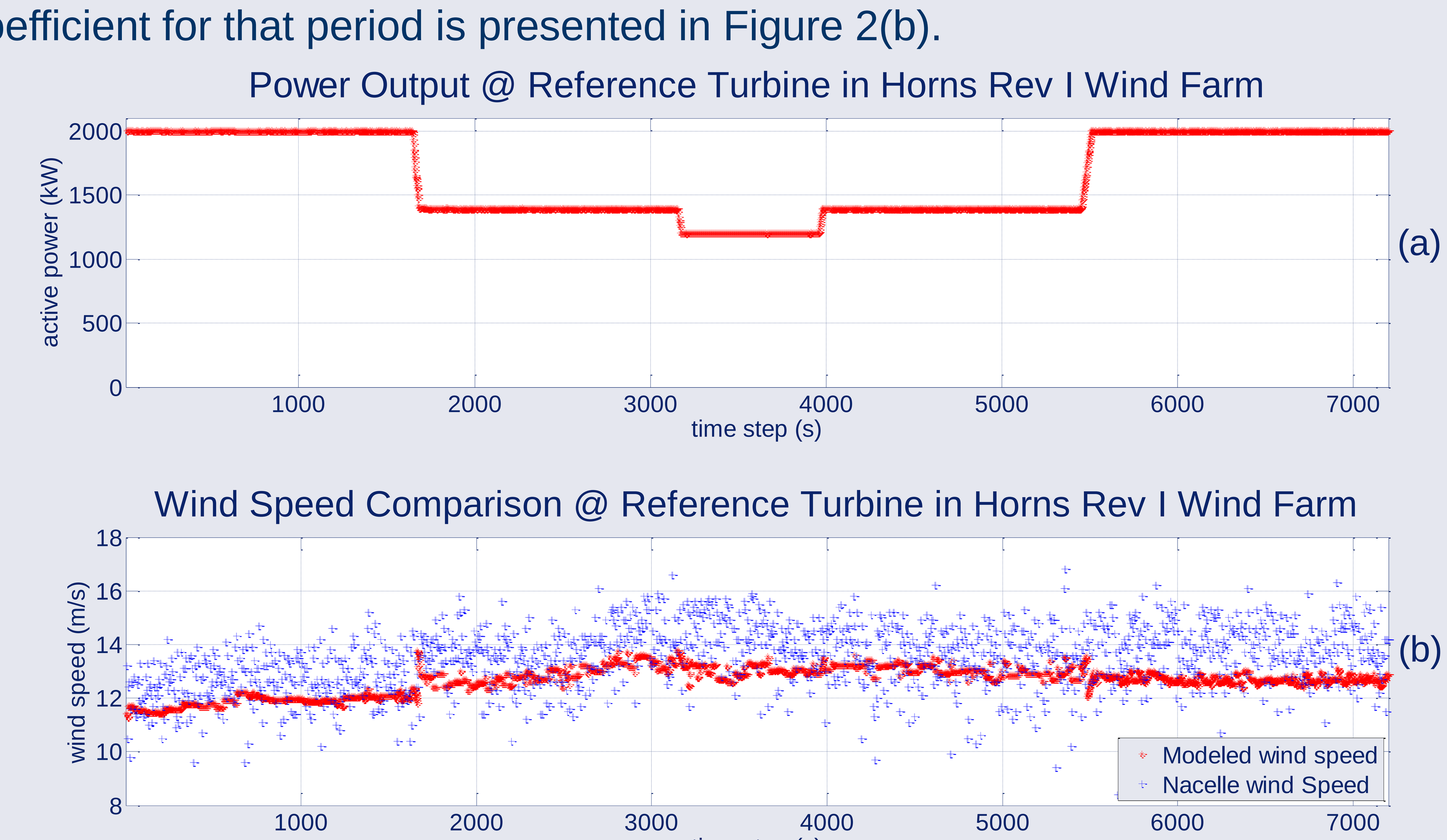

Figure 2 – (a) Power Output (b) - Wind Speed Comparison of the reference turbine located in Horns Rev wind farm during downregulation

If a comparative analysis is performed between Figure 1 and Figure 2(b), it might be said that the deficit between the wind speed values obtained using the nacelle anemometer measurements and the model stayed approximately the same under ideal and downregulated conditions. Therefore, the estimation of the wind speed using the created algorithm for downregulation periods can be justified by assuming that the power curve wind speed is representative enough.

NREL 5 MW

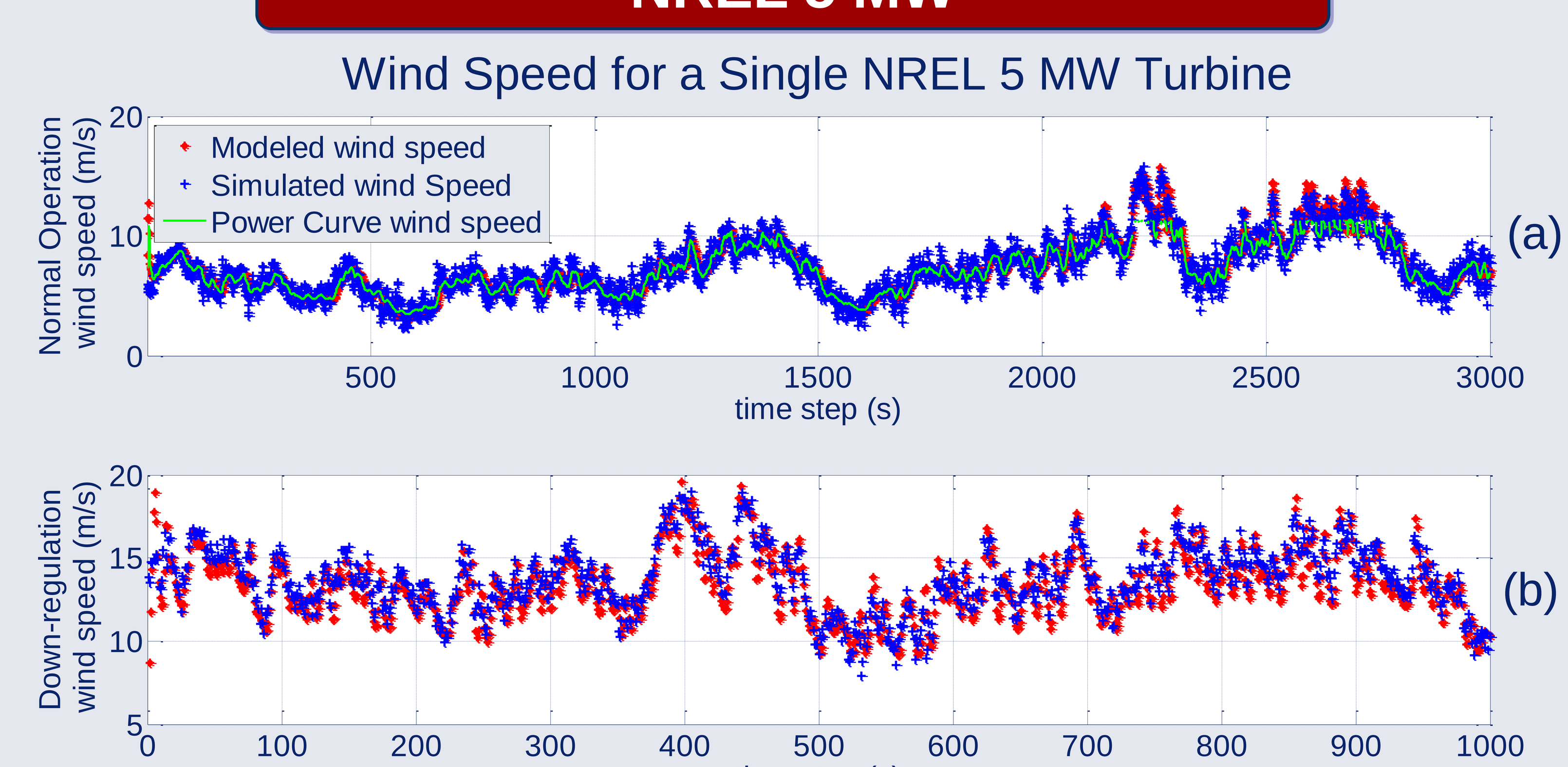

Figure 3 – Wind Speed Comparison of a single NREL 5 MW turbine during (a) normal operation (b) 50% downregulation

In Figure 3, it is seen that the model is able to reproduce the simulated wind profile hitting the NREL 5 MW turbine for both normally operated and downregulated cases.