Technical University of Denmark

POSSPOW: Possible Power of Offshore Wind Power Plants

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Published in:
Proceedings of EWEA 2013

Publication date:
2013

PossPOW: Possible Power of Offshore Wind power plants

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1. Introduction

In recent years, the large offshore wind farms were designed as wind power plants, including possibilities to contribute to the stability of the grid by offering grid services (also called ancillary services). One of those services is reserve power, which is achieved by down-regulating the wind farm from its maximum possible power in order to quickly ramp production up. Due to the nature of the turbines the power can be ramped up quite quickly, within a few seconds. Already during the planning phase of the Nysted and Horns Rev offshore wind farms, the developers worked closely together with turbine manufacturers to get an extra signal in the SCADA data feed from the individual turbines called possible power. In normal operation, this would be the actual power, but during down-regulation it would give the possible power given the current wind regime. While in the Horns Rev controller it was called possible power, in the grid codes it is usually referred to as available power, therefore this nomenclature should be used further. This signal is quite reliable – the grid code of the System Operator of Northern Ireland SONI requires an accuracy of 5%, but in a down-regulated wind farm, the sum of the possible and actual power from a down-regulated wind farm is not the same as the regulation power reserve in that wind farm since turbines downwind of down-regulated turbines see more wind that would be there without the regulation. In order to be able to offer reserve power in the market, the System Operators need to be able to trust the level of reserves. However, currently Energinet.dk, UK National Grid and other Transmission System Operators (TSOs) have no real way to determine exactly the possible power of a whole wind farm which is down-regulated.

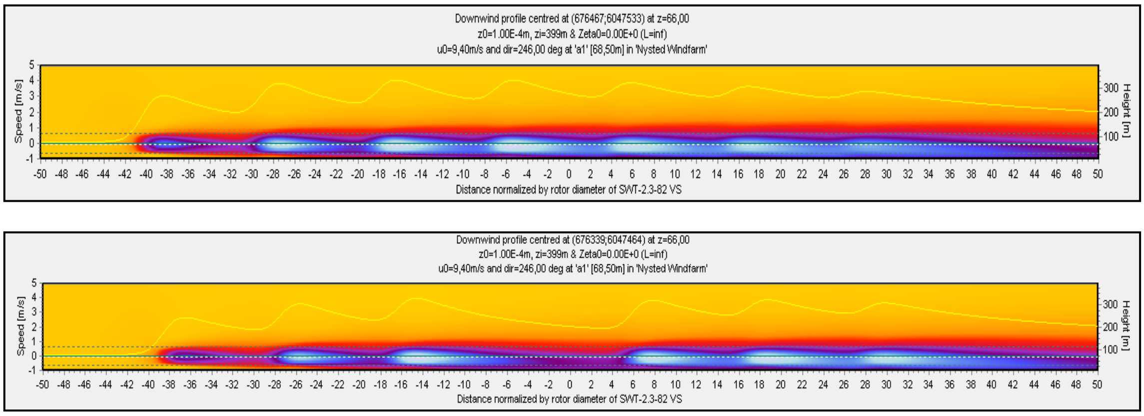

Figure 1: Wake effects due to the running turbines in a row of turbines in Horns Rev, calculated with Fuga. Upper plot: All turbines running. Lower plot: Fourth turbine offline.

Figure 1 shows the concept: in a situation where the fourth turbine is downregulated to zero, the fifth turbine in the row sees in the lower plot more wind than in the normal operation in the above plot. Therefore, the sum of the available powers of all turbines is larger than what actually is there.

2. The project

The technology we want to develop draws together models from various disciplines, including wake modelling of large offshore wind farms, aerodynamic models for wind turbines, stochastic model estimation and computer simulations. During the project, the findings will be verified on some of the large offshore wind farms owned by Vattenfall, and possibly in a DONG Energy wind farm too. Dedicated experiments to the wind flow in large offshore wind farms are planned. The knowledge of project partners Siemens and Vestas is going to be useful for the current implementation of the available power signal, and also a direct route to an eventual implementation of the developed signal in a farm controller. The project is supported by Energinet.dk under the Public Service Obligation, ForskEL 2012-10763.

3. Approach

Offshore wind power plants contribute to the system services of the power system (a.k.a. ancillary services) on equal footing to other power generation technologies. At times, there is more money in the reserve power market than in the actual selling of wind power [1], which makes it attractive to down-regulate the wind power plant and sell the differential capability to the grid instead. However, while modern wind turbines can estimate their power generation capacity depending on the measured wind, the pitch angle, power and rotor speed to about 5% accuracy (a requirement of the SONI grid code), the sum of the possible powers of the individual wind turbines in a wind farm is more than the available regulating power. This is due to the fact that a turbine in the wake of a down-regulated turbine sees more wind than would be available without the down-regulation, see Figure 1 for a conceptualisation. The downwind turbine thus estimates a higher possible power than really is available. The value of such reserve power can be higher than selling the power on the market. But an optimal balance between revenue from reserve power and produced power depends on a reliable estimate of the reserve power, in order not to waste green electricity. The really large wind farms usually placed offshore are very well suited to use this for additional income, as they are quick and can be down-regulated easily. Currently, since there is no reliable estimation of the possible power of a wind power plant available, the sum of the available powers of the single turbines is used. However, de facto rules of thumb including some extra down-regulation “for safety” are used. Additionally, the grid operator or TSO does not accept the value of down-regulation at face value, since there is no commonly agreed method for the estimation for the possible power.

In 2007 Stephane Eisen did a Master thesis at DTU with some of the partners involved in the project to find criteria and a simple model for the possible power from Nysted, but his algorithm never was implemented online or even tested [2]. Most of his deliberations can yet serve as a starting point for this project, which would involve wake modelling, dedicated experiments on offshore wind farms, and some insights into the optimisation of down-regulation algorithms, yielding a reliable and verified possible power estimate, which will be communicated to and ideally also accepted by TSOs.

The project is planned to get started with the analysis of data obtained from Horns Rev-1 and Nysted offshore wind farms followed by identification of the periods and assessment of quality. When evaluating the experiments, the characterization of the downregulation is also of great importance.

Wake modelling is necessary in order to take into account that the wakes will change when the wind farm is down regulated, compared to the wakes in the wind farm when it is set to produce maximum possible power. The proposed technique is to use the same wake model for two steps to calculate possible power in a down regulated case:

1) First, the ambient flow will be derived in the actual down regulated case, using wind turbines thrusts from the down regulated wind turbines. This is an inverse way of using wake models, using the wake flow as input and the ambient flow as output.

2) Secondly, the wake flow in the possible power case will be derived from the ambient flow derived in 1, using wind turbines thrusts in the possible power case. This is the normal way of using wake models, using the ambient flow as input and wake flow as output.

The PossPOW project will not develop new wake models, but identify which of the existing wake models are most useful for this application, and how to use them optimally for real-time use. The two models considered so far are the Dynamic Wake Meandering model [3] and the Fuga [4], both developed at DTU Wind Energy.

The basic idea behind the DWM model is a *split of scales* in the wake flow field, based on the conjecture that large turbulent eddies are responsible for stochastic *wake meandering* only, whereas small turbulent eddies are responsible for wake *attenuation* and *expansion* in the meandering frame of reference as caused by turbulent mixing. It is consequently assumed that the transport of wakes in the ABL can be modelled by considering the wakes to act as *passive tracers* driven by a combination of large-scale turbulence structures and a mean advection velocity, adopting the Taylor hypotheses. The wake attenuation, as described in the meandering frame of reference, is based on the thin shear layer approximation of the Navier-Stokes equations. It is based on physical first principles and accounts in a simplified resource saving, yet realistic manner for all essential scales of the wake flow field. It offers a *unifying* description of wake influences in the sense that both wind turbine *production* and *load* aspects can be dealt with when coupling the this flow model with an aeroelastic code; and the model is fast and easily applied with state-of-the-art aeroelastic codes.

More recently, a faster version called Rapid Dynamic Wake Meandering (RDWM) was developed, which is based on a database of pre-calculated DWM simulations combined together using the wind rose.

Fuga is a linearized flow solver developed for wake calculations in offshore wind farms. The model is based on a linearization of a full set of non-linear CFD equations. An ultra-efficient solver has been developed for the resulting equations. Fuga is about 1000000 times faster than a conventional CFD model which allows the model to be used online by the control system.

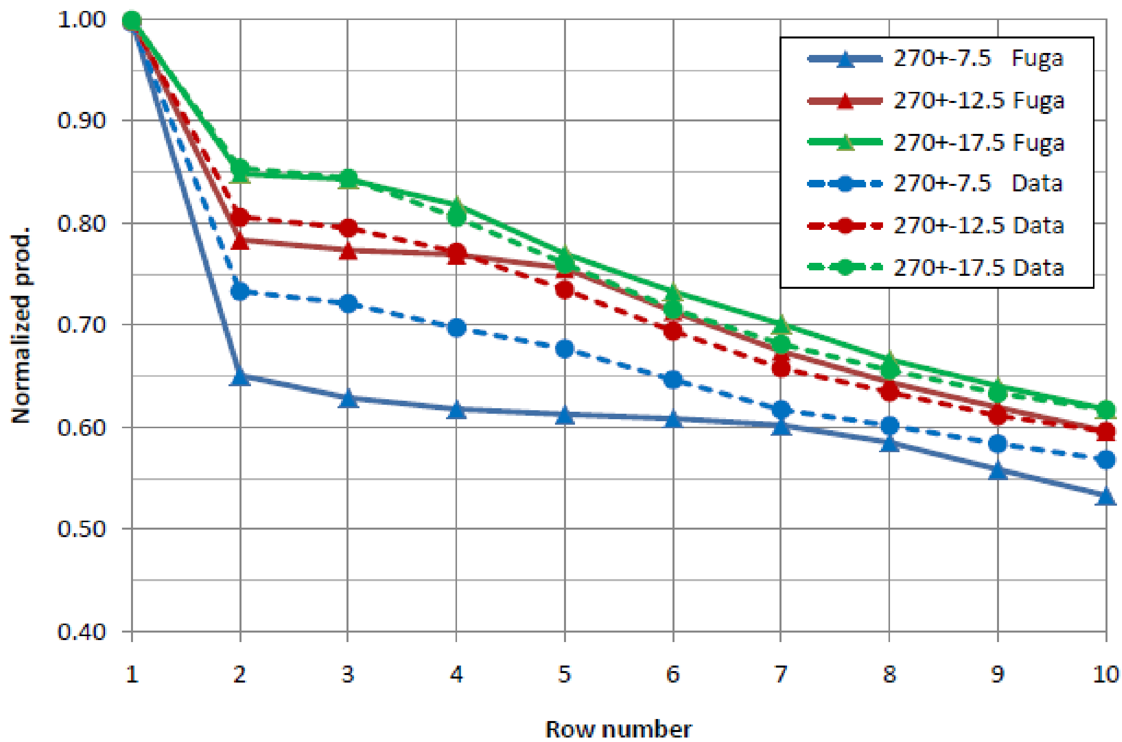

Figure 2: Validation of Fuga against data from Horns Rev 1. The data points show the normalized power production for a row of turbines that shadow each other, for wind coming from 270 +- 7.5, 12.5 or 17.5 degrees.

Fuga has been validated against measured 10 minutes average production data for a number of wind farms (Horns Rev 1, Nysted, North Hoyle, Lillgrund), in all cases with surprisingly good performance. Figure 2 shows an example of such a validation. The model results as well as data are presented as averages over wind direction and wind speed bins. The bin width is different in the three lines. One can see that the wider the sector, the better the fit. Fuga is therefore well suited for the prediction of e.g. annual production whereas the prediction of the production for a particular moment in time is associated with a large degree of uncertainty. To a varying extent this will be the case for any model when a relatively small set of meteorological parameters is used to describe fairly complex situations, i.e. it is unclear so far whether this behaviour is due to the fact that Fuga works with a single wind speed and direction representative for the whole wind farm, or whether other effects are at work.

After further investigations on wake models, improvements of model predictions can be made as far as deterministic causes can be identified. It is also possible that an intelligent use of SCADA data for the farm as a whole would enable a better characterization of the state of the atmosphere, e.g. by allowing for spatial variations, and thereby further reduce the scatter. Another point that needs to be addressed is the transient response of the farm both to meteorological fluctuations and to changes of control strategy.

Together with the wake models, aerodynamic models are considered where aerodynamic backward verification should be added to the velocity estimate process because the state of the wind turbine in terms of pitch angle and rotor speed can be used to estimate the wind speed at each wind turbine much more accurate than the wind speed measurements on the wind turbine nacelles. For this purpose, aerodynamic models will be applied in combination with model estimation. Most probably, simple (Cp based) aerodynamic models will be sufficient for this purpose.

Additionally, the atmospheric wind conditions should be obtained. In other words, it should be predicted how the wind under specific circumstances behave if there were not any wind turbines to create wake effects.

Finally, the models must be implemented in a computer simulation environment then tested and verified. It is important to develop the simulation environment in a structure, which allows to use different wake models in future applications of the PossPOW tool. It should also be considered that the end goal is to provide a tool which can operate in real time in a standard SCADA system, although this might not be achieved within this project.

4. Summary

The paper presents a new Danish project on the possible power from a down-regulated wind farm. Project partners are DTU, Vestas, Siemens, Vattenfall and DONG. We aim at a verified and internationally accepted way to determine the possible power of a down-regulated offshore wind farm, taking into account the meteorology and wake effects. Along the way, we also aim at improving the use of wake models for real-time cases. Please see posspow.dtu.dk.

5. References

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