Wind farms production under wake conditions

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Introduction

Compared to solitary turbines, wind farms are characterized by interferences due to wake effects between the wind turbines resulting in power losses in the farm production. As a consequence, wind farm power losses from wake effects are intrinsic to the functioning of wind farms.
The global power loss of the farm varies with multiples parameters, such as the relative position of the wind turbines, their spacing, the terrain and the atmospheric turbulence amongst others. Quantifying the power losses is therefore of great importance to the understanding of the wind turbines production under wake effects. The processing and analysis of existing data can improve the comprehension of the operation of already installed farms as well as the new developments in wind energy.

Approach

Three different single lined wind farms (Farm1, Farm2 and Farm3) were used as test cases for the wake power losses analysis. The good alignment of the turbines of these farms makes possible the study of wake interaction when the wind sectors are close to the turbine alignments. The wind farms are characterized, mainly, by the following parameters: the number of wind turbines N in the farm, the rotor diameter D and the average non-dimensional spacing S/D between wind turbines, as show in Table 1.

	Number of WT, N	Rotor Diameter, D	Non-dimensional Spacing, S/D
Farm1	5	70 m	2.85
Farm2	3	82 m	3.4
Farm3	4	82 m	3.4

Table 1. Main characteristics of the wind farms

For our study we use SCADA data based on 10 minutes averages for the power of each turbine, the wind speed and the wind direction. A data analysis program has been specially developed for wind turbines performance analysis using SCADA data. The program allows its user to obtain information for a selected wind direction, wind velocity, for a given period of time, for multiple years and for multiple wind turbines.
In our study we have only selected the data of interest for the wake effect analysis. They correspond to the recorded data for the wind sector centered on the wind turbine alignment. Different wind

sectors centered on the turbine alignment were considered as well as several peculiar wind speeds, typically 6, 8 and 10 m/s +/- 0.5m/s.

Main body of abstract

The main objective of our work is to consider the power losses from wake effects in a wind farm. The power deficit can be characterized by introducing the wind farm efficiency E_W by comparing the averaged power produced by the farm to the maximum power observed in the farm P_{max} as:

$$E_W = \frac{\sum_{k=1}^{N} P_k}{N\, P_{max}}$$

where P_k is the power of turbine k. Here E_W is calculated for specific wind sectors. When there is no interaction between turbines as wake effects, EW is by definition equal to 1.
The evolution of the wind farm efficiency E_W (ETA) for Farm1 as a function of the wind direction is shown in figure 1.

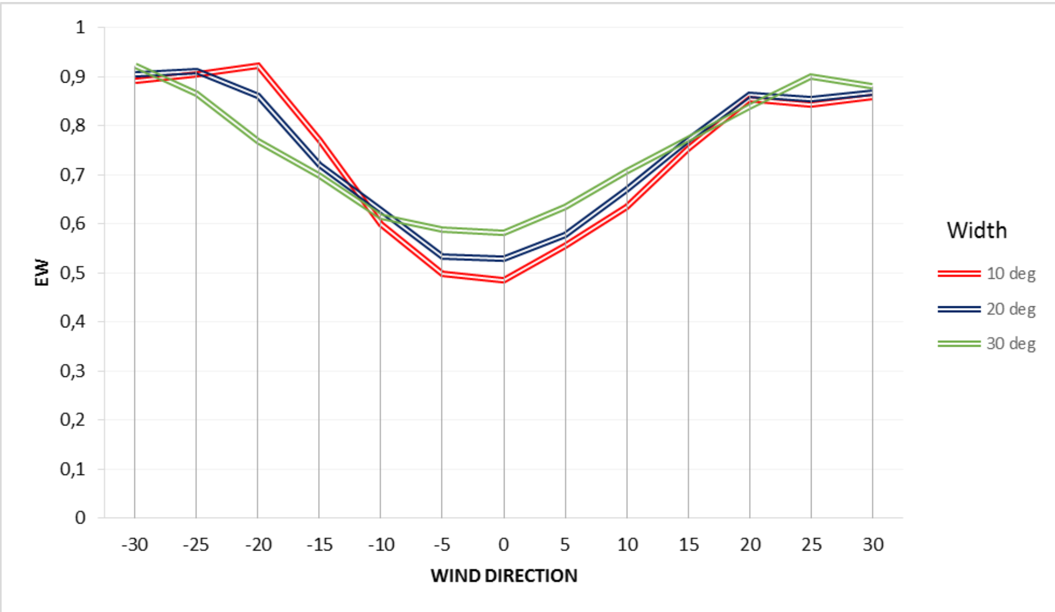

Figure 1. Evolution of the wind farm "wake efficiency" EW for Farm1 as a function of the wind direction. The angle is 0 when the wind direction is aligned with the farm alignment. The wind sectors +/-5°, +/-10° and +/-15° are shown.

Different wind sectors are shown in order to test the sensitivity of the arbitrary choice of the wind sector width on the reported results. Reducing the wind sector width improves the accuracy but it reduces the number of data. The evolutions of the efficiency E_W for the wind sectors +/-5°, +/-10° and +/-15° show very similar behaviors. As expected, the efficiency is minimum when the wind is aligned with the turbines and the deficit is almost symmetrical with respect to the turbine alignment. The deficit is less important for the wind sectors +/-10° and +/-15° since they provide a coarser description of wake effects. In the following the wind sector +/-5° is used for discussing wake effects.
The energy produced by the turbines of the cluster are now compared to the energy produced by the head turbine. For this purpose the power of each turbine is normalized by the power of the head turbine. The evolution of the corresponding normalized power for the 3 wind farms is shown in

Figure 2. Different wind conditions are reported in each figure: the power losses for all the wind conditions as well as for three different wind speeds respectively 6, 8 and 10 m/s +/-0.5 m/s.

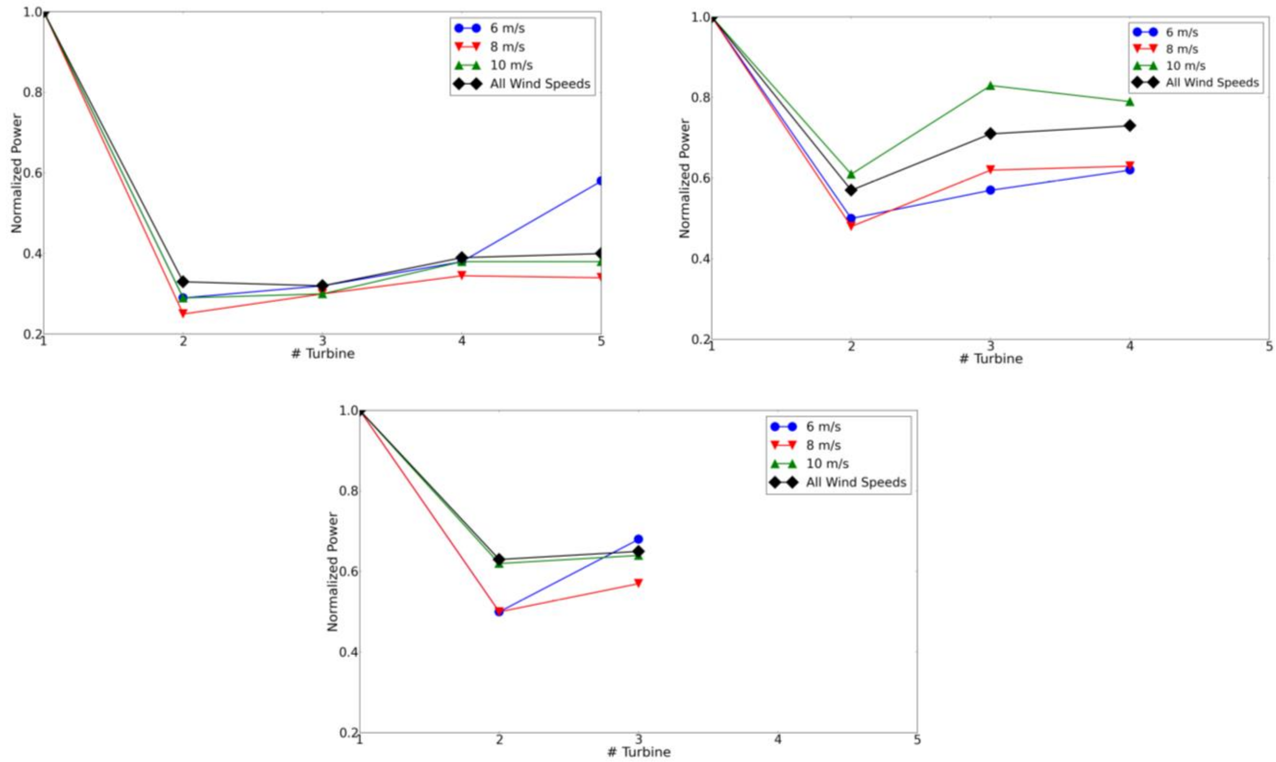

Figure 2. Normalized power on the wind turbine cluster of the wind farm Farm1 (top left), Farm3 (top right) and Farm2 (bottom) for the wind speeds of 6, 8 and 10 +/- 0.5 m/s and for the case where all wind speeds are taken into account.

There is a clear loss of power for all the turbines located in the wake. The difference is mainly observed between the head turbine and the second turbine and then the power of the successive turbines is almost constant. The most deficit occurs for the intermediate wind speed of 8 m/s.

One of the most important parameters in wake effects is the spacing between the wind turbines. We represent, on the figure 3, the influence of spacing on the power difference between the first and second wind turbines for six study cases: the 3 wind farms studied and 3 different results found on the literature.

One can say that the power difference remains constant for a spacing comprised between 3 and 4 diameters. The case of the wind farm Farm1 presents a normalized power loss that is significantly superior to those of the other cases. It seems to exist a critical spacing under which the power losses become even more relevant.

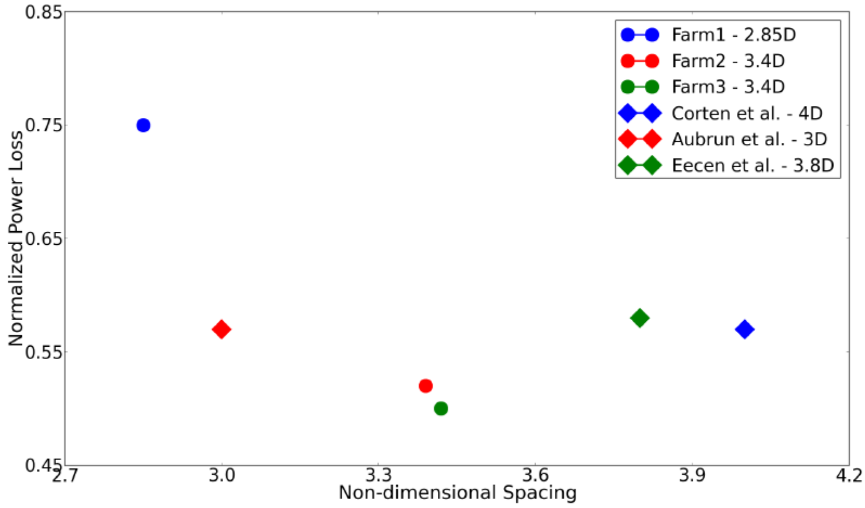

Figure 3. Evolution of the Normalized Power Losses with the non-dimensional spacing of the wind turbines. Our results are compared to those found on the literature: [8], [2] and [11].

Finally, we consider the following particular situation. Farm1 has experienced long periods of time where one of the wind turbines (the 4th on the cluster) was stopped. Choosing only the data corresponding to that conditions one can use the same type of analysis as before but for this particular case. The statistical validity of the results is assured by the quantity of available data under these conditions.

The evolution of the normalized power in the cluster for the 2 study cases (all working wind turbines and 4th wind turbine stopped), is shown in figure 4.

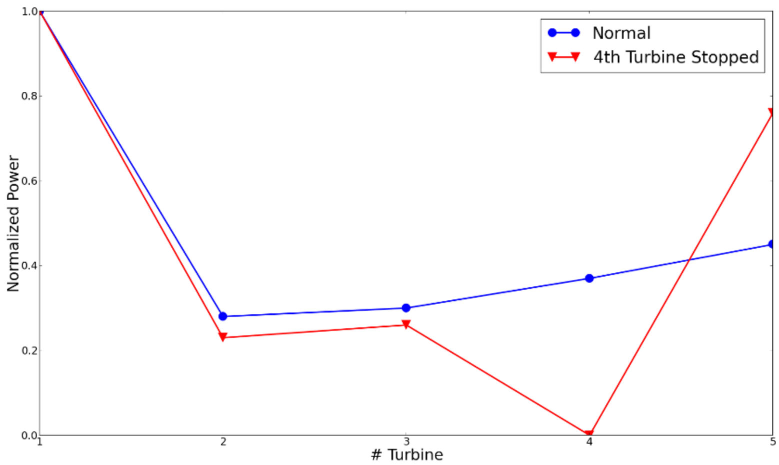

Figure 4. Comparison of the normalized power of the cases: (1) all working wind turbines and (2) 4th wind turbine at a stop.

Comparing the results for both cases one can conclude that the last wind turbine is capable of recovering 30% of the power production when compared to the normal functioning case. This observation emphasizes one important question that has been addressed in some recent research works concerning the optimization of a wind farm production when wake effects are present. In other work, it seems possible to modulate the wake effect in order to improve the global production.

Conclusions

Our work presents the quantification of wind farm power losses due to wind turbine wake effects for 3 wind farms. We were able to investigate the influence of different parameters of a wind farm on the wake power losses by representing an efficiency parameter and the normalized power production of the wind turbine cluster. We investigated the wind sectors impacted by the wake effects as well as the influence of the wind speed and the wind turbine spacing.
A case of a stopped wind turbine on the cluster shown a recovery in production by the downstream wind turbine. Even though the global production of the wind farm did not increase, our results tend to show that an optimization of the wind farm production can be obtained by limiting the wind turbines production on the cluster.

Learning objectives

Operational wind farm optimization in wake conditions still needs improvement. In this purpose our goal was to better understand the influence of each parameter using SCADA data in order to identify conditions where gains in production are attainable.

References

1. M.S. Adaramola and P.-A. Krogstad; *Experimental investigation of wake effects on wind turbine performance* ELSEVIER, 2011.
2. S.Aubrun, Ph. Devinant and G. Espana; *Physical modelling of the far wake wind turbines. Application to wind turbine interactions*. EWEC 2007, Milan, 2007
3. R.J. Barthelmie, K. Hansen, S.T. Frandsen, O. Rathmann, G. Schepers, K. Rados, W. Schletz, A. Neubert, L.E. Jensen and S. Neckelmann. *Modelling the impact of wakes on power output at Nysted and Horns Rev*. EuropeanWind Energy Conference,Marseille, France. 2009
4. R.J. Barthelmie, S.C. Pryor, S.T. Frandsen, K.S. Hansen, J.G. Schepers, K. Rados, W. Schletz, A. Neubert, L.E. Jensen and S. Neckelmann. *Quantifying the Impact of Wind Turbine Wakes on Power Output at Offshore Wind Farms* Journal of Atmospheric and Oceanic Technology. 2010
5. R.J. Barthelmie, S.T. Frandsen, M.N. Nielsen, S.C. Pryor, P.-E. Rethore and H.E. Jorgensen. *Modelling and Measurements of Power Losses and Turbulence Intensity in Wind Turbine Wakes at Middlegrund Offshore Wind Farm*. Wind Energy Journal, 2007.
6. R.J. Barthelmie, L. Folkerts, G.C. Larsen, K. Rados, S.C. Pryor, S.T. Frandsen, B. Lange and G. Schepers. *Comparison of Wake Model Simulations with Offshore Wind Turbine Wake Profiles Measured by Sodar*. Journal of Atmospheric and Oceanic Technology, 2006.
7. J. Bartl, F. Pierrela and L. Saetran. *Wake measurements behind an array of two model wind turbines.* ELSEVIER Journal, 2012.
8. G.P. Corten, P. Schaak and T. Hegberg. *Velocity profiles measured above a scaled wind farm.* EuropeanWind Energy Conference, London, 2004.
9. A. Crespo, J. Hernandez and S. Frandsen. *Survey of Modelling Methods for Wind Turbine Wakes and Wind Farms*. Wind Energy Journal, 1999.
10. G.Espana. *Etude expérimentale du sillage lointain des éoliennes axe horizontal au moyen d'une modélisation simplifie en couche limite atmosphérique*. Ecole doctorale sciences et technologie, Orleans. 2009
11. P.J. Eecen, S.A.M. Barhost, H. Braam, A.P.W.M. Curvers, H. Korterink, L.A.H. Machielse, R.J.Nijdam, L.W.M.M. Rademakers, J.P. Verhoef, P.A. van derWerff, E.J.Werkhoven and D.H. van Dok. Measurements at the ECN wind turbine test locationWieringermeer. EWEC, Athens, 2006.

12. S. Frandsen, R. Barthelmie, S. Pryor, O. Rathmann, S. Larsen and J. Hojstrup; *Analytical Modelling of Wind Speed Deficit in Large Offshore Wind Farms*, Wind Energy journal. 2006
13. A.C. Pillait, Dr. J. Chick and V. de Laleu; *Modelling Wind Turbine Wakes at Middlegrund Wind Farm*. EWEA, Barcelona, Spain, 2014.
14. B. Sanderse; *Aerodynamics of wind turbine wakes - Literature Review*. Energy Research Center of Netherlands. 2009.
15. L.J. Vermeer, J.N. Sorensen and A. Crespo. *Wind turbine wake aerodynamics*. ELSEVIER Journal, 2003.