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Wind turbine wakes; power deficit in clusters and wind farms.

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Summary: The purpose of this presentation is to present recent power deficit analysis based on wind farm measurements. The power deficit is used to validate wind farm prediction models for different inflow conditions.

ABSTRACT

Grouping two or more wind turbines results in a loss of energy production when the turbines operate in the wake of each other. The size of the wake deficit depends on wind direction, wind speed, turbulence, spacing, atmospheric stratification and operational characteristics of the wind turbine. Since the wake deficit can result in 10-20% power loss, it is extremely important to include modeling of the wake deficit in the wind farm optimization process.
Recent analysis of the wake deficit [1, 2] has been based on SCADA (Supervisory Control And Data Acquisition) recordings, obtained as 10 minute statistics from large wind farms. The recordings, used in this preliminary investigation, have been obtained from an offshore wind farm with a rectangular shape and rather uniform inflow conditions due to long offshore fetch. Performing wake deficit analysis on wind farms, situated in pastoral or complex terrain is much more complicated due to local terrain and thermal effects.
The power deficit is determined as 1- power ratio between two operating wind turbines [2]. A deficit distribution as function of the inflow direction is shown in Figure 1. The width of the distribution depends on the ambient conditions and the rotor thrust, while the maximum deficit depends on spacing and ambient turbulence as illustrated in Figure 2. Figure 2 demonstrates a distinct near-linear relationship between the maximum power deficit and the turbulence intensity where the level and the slope highly depend on the wind turbine spacing. In Figure 2 this is shown in terms of the number of rotor diameters (D) separating wind turbines (here 7 or 10.5 D, where D=70 m).

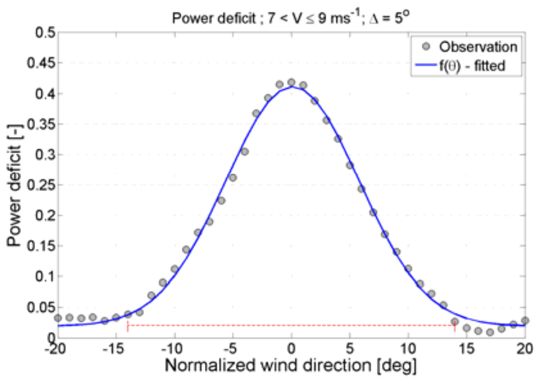

Figure 1: Example of measured power deficit between 2 operating wind turbines.

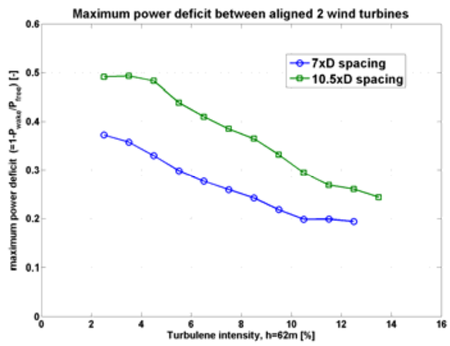

Figure 2: max deficit as function of turbulence intensity for two different spacing.

The average power deficit for 30° inflow sectors has been determined along rows consisting of 7 - 10 turbines. The deficit increases downstream and converges towards 0.35 - 0.4 as illustrated in Figure 3. The “>20D” sector is the only flow sector with a “free” entrance, but due to lateral wake movements and expansion the deficit still converges towards 0.4. Decreasing the size of the flow direction sector will result in a faster increase in the power deficit because of the focusing of the analysis closer to the wake center and the approximately Gaussian nature of the power deficit curve. A turbine spacing of 7D combined with a 5° flow sector will result in a deficit of 0.4, approximately 7D behind the free stream wind turbine, and this deficit level is almost constant through the wind farm. Furthermore the power deficit distribution demonstrates a strong correlation with the atmospheric stability and how the wake is wider and deeper during very stable conditions caused by decreased turbulent mixing of the wake. The wake is wider in the stable case, the maximum power deficit at the center of the wake is slightly less than for the remaining near-neutral and unstable cases. The turbulence intensity is broadly similar for all stability classes except for stable and very stable conditions according our analysis [2].

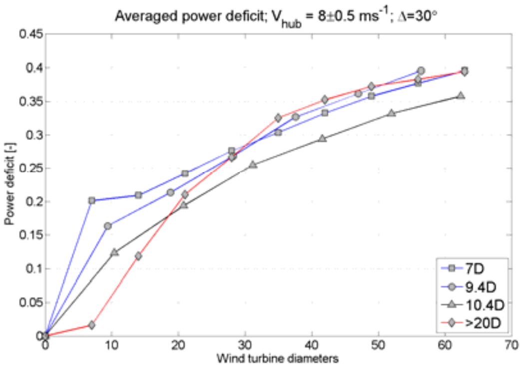

Figure 3: Averaged power deficit along rows of turbines - as function of spacing.

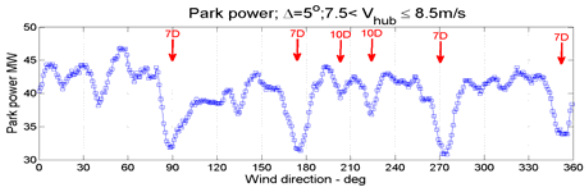

Figure 4: Power production for a wind farm at 8 m/s as function of flow direction.

The wind farm power distribution has been determined for a complete 0-360° inflow sector with a resolution of 1°, Figure 4. The wind farm power represents all kind of atmospheric conditions including a mean wind turbine availability of 95%. The distribution shown in Figure 4 demonstrates the importance of the wake deficits occurring in four distinct 20° sectors corresponding to 7D spacing whereas10D spacing results in comparatively minor power reductions. The recorded distribution results in 80% wind farm efficiency compared to stand-alone turbines, but without including the weighting from the wind rose. The dominant wind sector is between 210-330°, which will result in a small increase in the wind farm efficiency due to the symmetry of this wind farm.

CONCLUSION

The level of power deficit is strongly dependent on the wind turbine spacing; as turbulence intensity increases, the power deficit decreases. The power deficit is determined for four different wind turbine spacing distances and for stability classified as very stable, stable and others (near neutral to very unstable).
The mean power deficit depends on the mean wind speed, wind turbine spacing, turbulence intensity and the stability conditions. Our analysis shows general tendencies in the relationship between power deficits, wind speed turbulence and stability. The relationships between wind speed, turbulence intensity and atmospheric stability offshore are complex. There is also a strong relationship between the wind direction and the atmospheric variables that influences the power deficit/wake width in addition to the turbine spacing.
The mean power deficit along single wind turbine rows is similar in the wind speed interval from 6 to 10 ms^{-1} and for the same inflow direction, but the maximum deficit decreases with increasing wind speed. The largest power deficit occurs between the first and the second wind turbines while the remaining downstream power deficit is small. The mean power deficit for other inflow sectors increases more slowly downstream—compared with the previous flow sector and the resulting power deficit in the far end of the wind farm decreases slightly.
The power deficit analysis combined with stability conditions demonstrates that very stable or stable conditions results in larger mean power deficits, whereas there is little difference in the mean power deficits for the other stability conditions (the near-neutral and unstable classes).

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