Development of a SCADA-driven model to quantify wake effects within a windfarm

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Introduction

Wake effects do not only affect the power production of wind turbines, but also have an important influence on the fatigue life consumption of wind turbines.[1] Therefore it is important to gain insight into the wake flows and quantify the effects on e.g. power production and fatigue life consumption through a windfarm. This can not only be done by simulations but also by developing models, based on data of an operational windfarm. This contribution will show a correlation between the wake effects on a turbine and the free wind speed and wind direction and quantify the power losses due to wake flows in a windfarm. This quantification will be very important in the detection of underperforming wind turbines and to extrapolate fatigue life in the windfarm.

Approach

In this contribution, the wake effects within the offshore windfarm Northwind are examined. Northwind is located in the North Sea, outside the Belgian coast, and consists of 72 Vestas V112-3.0MW turbines. The layout of Northwind can be seen in Figure 1. As one can see, the turbines are not positioned in a regular array but in one particular direction, the rows are more or less parallel to each other.

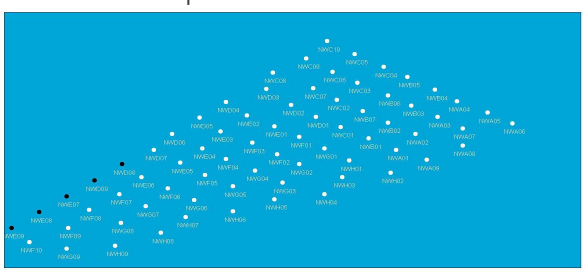

Figure 1: Layout of Northwind farm

The main data used for the quantification of the wake effects within Northwind comes from the meteorological data within a subset of the turbines' SCADA. In the current analysis we consider a year's worth of measurements for wind speed, wind direction and power, all 10 minute averages.

A first analysis tells that effects on a turbine due to wake flows, are especially dependent on free wind direction and free wind speed. Since the SCADA-data only contains turbine-specific measurements and data coming from a met mast or a LIDAR are not available, a SCADA-driven approach to approximate the free wind speed and wind direction was developed. As the approach is only based on SCADA-data and the exact layout of the farm, it is easily applicable for any windfarm.

In this analysis the effects of wake flows on power production are investigated and quantified. The purpose is to generalize these effects on other parameters as well, by developing a model quantifying wake effects within a windfarm. With this model it is possible to calculate power losses due to wakes or to extrapolate load and lifetime measurements on fleet leaders to other turbines in the farm.

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[1] "Monitoring the consumed fatigue life of wind turbines on monopile foundations", Wout Weijtjens, et al., EWEA Offshore 2015 Copenhagen

Main body of abstract

Many parameters of interest, such as the power production and fatigue life consumption, are directly affected by the wakes in a wind farm. So to better monitor power losses and structural health a better understanding of the wake flows and their effects is necessary. For this contribution the wake effects are investigated based on SCADA-data of about one year, containing 10 minute averages for wind speed, wind direction and produced power.

The effects of the wakes a turbine is subjected to, depend on the free wind speed and the free wind direction. Hence it is important to estimate those parameters from the turbine-specific measurements available in the SCADA-data. It can be seen that wake flows affect wind speed and wind direction measured at the nacelle of a turbine. Therefore when calculating the free wind speed and free wind direction for a farm, the only turbines considered for the calculation should be those subjected to free wind. However, these turbines subjected to free wind vary with the varying wind directions.

Once an estimation for free wind direction and wind speed is obtained, one can quantify the effects of wake on e.g. power production. Figure 2 shows a strong dependency of the actual power normalized to the expected power (based on the free wind speed) on the free wind speed itself when the turbine is subjected to wakes. The 5 turbines depicted in Figure 2 are shown in black in Figure 1. The exact free wind direction for which this figure is obtained is shown by the red arrow in Figure 3. When doing an equivalent analysis for another wind direction (shown by the white arrow in Figure 3), one can see the results differ quite a lot for some turbines: Figure 4. In this last figure, one can clearly see turbines 1 and 3 are subjected to free wind, while turbines 2, 4 and 5 see wakes coming from other turbines. From this the conclusion can be made that wake flows, and the effect of it on the turbines subjected to those, highly depend on the free wind speed and the free wind direction.

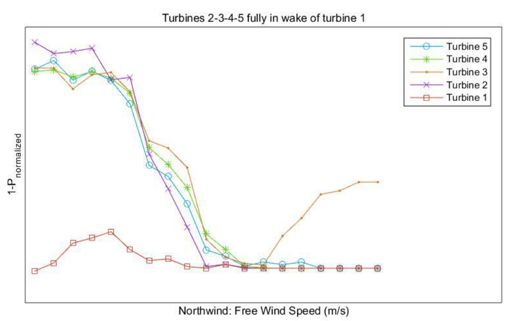

Figure 2: Change in normalized power for changing free wind speed, when turbines shown are subjected to each others wake flows

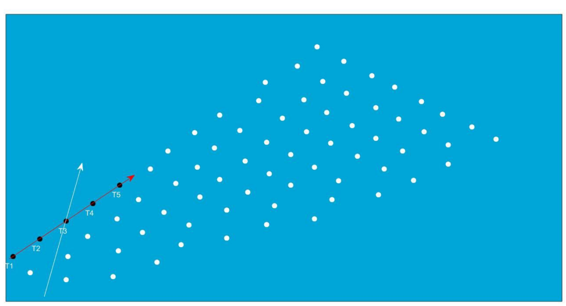

Figure 3: Two different free wind directions for which normalized power in calculated in function of free wind

speed

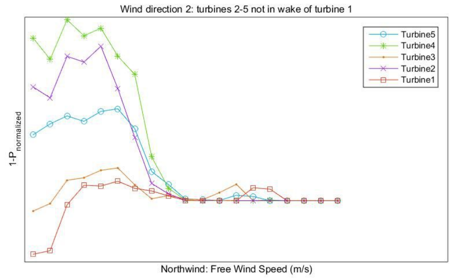

Figure 4: Change in normalized power for changing free wind speed, for a wind direction for which the turbines are not subjected to wakes coming from each other

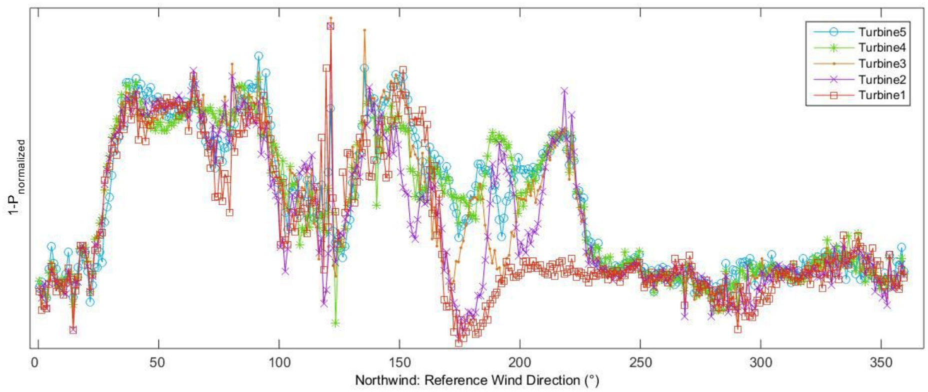

Figure 5: Change in normalized power for changing free wind direction, for certain wind speed range

Figure 5 shows the dependency of the nomalized power on the free wind direction for a certain range of free wind speed.
The selected subset of turbines to demonstrate the correlations shown in Figures 2,3,4 and 5 is a simple example since one can intuitively understand how the wakes are flowing in that direction. However, the problem becomes more difficult and less intuitive when taking a look at turbines surrounded by a lot of other turbines and wind directions for which one cannot easily understand how wakes will flow.

The purpose of this contribution is to develop a model which quantifies the effects of wakes within the entire windfarm based on the free wind speed and wind direction. This model should be built entirely based on SCADA data. Due to the noisiness of the SCADA data, an approach is needed to average results over turbines with similar wake effects in a particular wind direction. When taking a look at a layout of a windfarm where turbines are placed according to a regular grid, similar turbines will be easier to find based on intuition than for a windfarm where turbines are placed more randomly. The purpose of this research is to find similar turbines regardless the layout of the windfarm.

This kind of quantification of the effects of wake flows on the power production of turbines is very important when trying to detect underperforming wind turbines. Since wind turbines subjected to wake flows tend to produce less power, one could conclude that there is no problem if every turbine subjected to wakes produces less than expected based on free wind speed. By quantifying the production loss expected by those wake flows, one can calculate the expected production more accurately based on the wakes observed at the turbines, and thus detect underperfoming wind turbines earlier.

For example, when taking a look at Figure 6, one expects turbine 2 to produce more than it did. This would probably not be detected when the turbines were not compared to the expected behaviour coming from the SCADA-driven wake model, and thus an underperforming wind turbine would not have been detected. The green line shown in Figure 6 shows the behaviour one would intuitively expect. While on the other hand, using the approximations for the expected power production (including wake effects), the lost energy can be calculated and this turbine should pop up because the value for lost energy would be higher than expected.

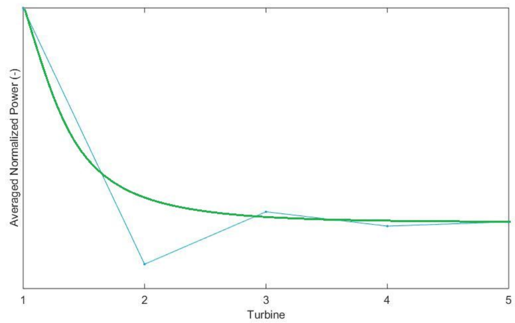

Figure 6: Averaged normalized power (wrt the first turbine) for 5 turbines standing in each other's wakes (red wind direction) for a specific wind speed range, together with the intuitively expected change (green line)

Conclusion

Wake flows within a windfarm affect directly several parameters of interest, for instance power production and fatigue life consumption. Thus to improve performance or structural health monitoring, a quantification of wake effects is needed. A first analysis shows wake flows depend on free wind speed and free wind direction. Since those parameters are not part of the available dataset, a SCADA-driven approach is conducted to approximate them.

The results in this contribution show a non-linear correlation between wake effects and the free wind speed and wind direction. In this abstract the effect of the wake flows on the power production is already demonstrated for some turbines and some wind directions. Since the effects change for every wind direction and every wind speed, a proper model is needed to quantify these effects.

The main part of this model is to find turbines subjected to the same wake flows and thus having the same effects due to wakes. Such a search for similar turbines is relatively easy done by intuition on windfarms with a regular layout, but cannot be done intuitively for windfarms with more random layouts.

This quantification of wake effects can be very important to estimate the expected fatigue life consumption or to detect underperforming turbines. By estimating the expected energy loss due to wake effects, turbines with even higher losses immediately pop up as underperforming.

Learning objectives

The main goal of this contribution is to quantify the effects of wake flows on the parameters of a wind turbine, e.g. power production. This quantification is performed using a subset of the SCADA-dataset and in such a way it can be easily applied on a different farm with a different layout. Results show a non-linear correlation between, on the one hand, normalized power and, on the other hand, free wind speed and free wind direction. These results can be very useful to detect an underperforming turbine easier or to determine an expected fatigue life consumption.