Reliable empirical analysis of effects of turbulent air in an operating wind farm based on unreliable SCADA-data

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Abstract

Turbulent air does not only affect the **power production** of wind turbines, but also has an important influence on the **fatigue life consumption** of wind turbines[1]. Therefore it is important to gain insight into the turbulent air flows and **quantify the effects** on e.g. power production and fatigue life consumption through a wind farm. This can not only be done by simulations but also by **developing models**, **based on data of an operational windfarm**. This contribution will summarise a **first analysis** regarding the turbulence observed at the Northwind offshore windfarm outside the Belgian Coast and show a correlation between the effects of turbulent air on a turbine and the free wind speed and wind direction.

Introduction

Many parameters of interest, such as the power production and fatigue life consumption, are directly affected by turbulent air flows in a wind farm. So **to better monitor power losses and structural health a better understanding of the turbulent air flows and their effects is necessary**.

In case of performance monitoring an example is given in Figure 1. As one can see turbine 2 performs less than expected and can be detected when the influences of turbulent air are included in the calculation of expected power production.

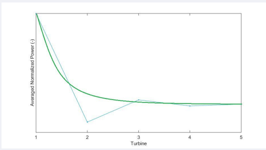


Figure 1: Averaged normalized power (wrt to first turbine) for 5 turbines standing right behind each other, for a specific wind speed range, together with the intuitively expected change (green line)

In this contribution, the turbulent air within the offshore windfarm Northwind is examined, based on a subset of the turbines' SCADA-dataset.

Facts Northwind: 72 Vestas 3MW V112 turbines

Used parameters 10-min SCADA: averaged wind speed, standard deviation of wind speed, averaged power, averaged wind direction

Visualisation

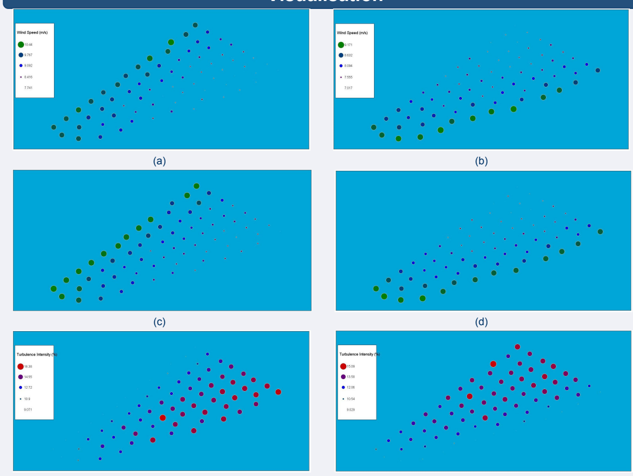
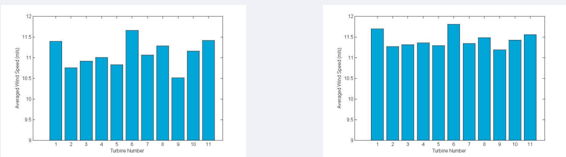


Figure 2: Visualisation of effects of turbulent air on (averaged) windspeed (a,b), (averaged) power production (c,d) and (averaged) turbulence intensity (e,f) in the windfarm for 2 wind sectors: western winds (a,c,e) and southern winds (b,d,f), measured by a reference wind turbine.

Calculate reliable windspeed

While conducting this analysis, some flaws of SCADA-data pop up. The most important one is the unreliability of the anemometer, used to measure both the windspeed and the winddirection. In the original SCADA-data a difference of more than 1 m/s can be observed (Figure 3a) for turbines for which the expectation is to see almost no difference.



(a) Original SCADA-data (b) Rotor Effective Wind Speed Estimations

Figure 3: Averaged windspeed, measured at 11 turbines subjected to free wind. The expectation is to see little difference.

First steps will have to be taken to calculate a reliable value for the windspeed, by using:

$$P = \frac{1}{2}\rho C_p(\lambda,\theta)\pi R^2 U^3$$

$$\lambda = \frac{\omega R}{U}$$

P	produced power (W)	θ	blade pitch angle (°)
ρ	air density (kg/m³)	R	radius of turbine blades
C_p	power coefficient (-)	U	windspeed at hub height
λ	tipspeed ratio (-)	ω	rotational speed of rotor

In this formula, the unknown parameter is the power coefficient C_p. To calculate this, following model will be used:

$$C_p = c_1\left(\frac{c_2}{\lambda_i} - c_3\theta - c_4\theta^{c_5} - c_6\right)e^{\frac{-c_7}{\lambda_i}} \text{ with } \lambda_i = \left[\left(\frac{1}{\lambda + c_8\theta}\right) - \left(\frac{c_9}{\theta^3+1}\right)\right]^{-1}$$

Here, the coefficients c_i will be fitted first to a dataset of several months, including all turbines of the farm. Preliminary results show the difference reduces (Figure 3b).

Estimation free windspeed and free winddirection

This first analysis tells that effects on a turbine due to turbulent air, 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.

Figure 3 shows the windspeed measured at the nacelle of a turbine itself is influenced by turbulence, Figure 4 shows an influence on the turbine's measurements of winddirection as well. Therefore, for the approximation of free wind speed and free wind direction, only turbines subjected to non-turbulent wind are considered. However, these turbines subjected to non-turbulent wind vary with the varying wind directions.

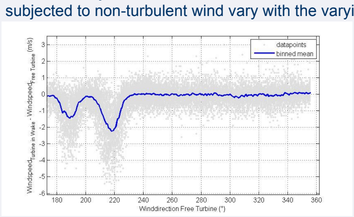


Figure 3: Difference in windspeed vs. free winddirection. The dips correspond to the directions for which a turbine in free wind induces turbulent air flows towards the turbine investigated.

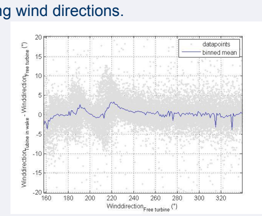


Figure 4: Difference in winddirection vs. free winddirection. For the directions for which a turbine in free wind induces turbulent air flows towards the turbine investigated, a S-shape can be observed.

Effects on power production

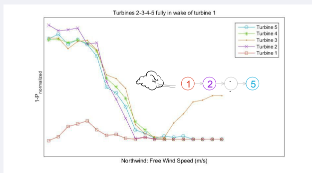


Figure 5: Power loss vs turbine number in line. This figure shows a strong dependency of the actual power normalized to the expected power (based on the free windspeed) on the free windspeed itself when the turbine is subjected to turbulent air. The 5 turbines depicted in Figure 4 are all standing right behind each other.

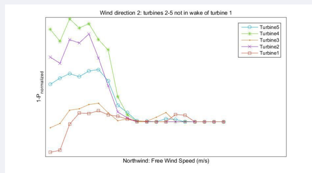


Figure 6: Power loss vs turbine number. This figure shows the actual power normalized to the expected power for the same 5 turbines, but this time the selected wind direction is changed. In this figure turbines 1 and 3 are clearly subjected to free wind, while turbine 2, 4 and 5 still observe turbulence coming from other turbines.

Conclusion

Turbulent air 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 the effects of turbulent air is needed**. A first analysis shows these effects **depend on free windspeed and free wind direction**. Since those parameters are not part of the available dataset, a SCADA-driven approach is conducted to approach them.

In this poster the effect of turbulent air 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.

This quantification of the effects of turbulent air can be very important to estimate the expected fatigue life consumption or to detect underperformning turbines.

Future Work

Further optimization to calculate the Rotor Effective Wind Speed Estimation will be needed. Moreover, as mentioned before, a proper model to quantify the effects of turbulent air is needed. The main part of this model is to find turbines subjected to the same turbulent air flows and thus having similar effects. 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.

References

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

Acknowledgements

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