Wind Energ. Sci. Discuss.,
doi:10.5194/wes-2017-4-AC1, 2017

Interactive comment on "Field Test of Wake Steering at an Offshore Wind Farm" *by* Paul Fleming et al.

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Received and published: 20 March 2017

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Response to review 1

Paul Fleming, Jennifer Annoni

March 20, 2017

We thank the reviewer for their time and suggestions. We have endeavored to respond to all suggestions, which we document here, and accompanying latexdiff (see supplemental pdf) document showing changes (note that the revised figures are included, but not highlighted by latediff).

Excellent new work on a topical subject.
Thank you for this comment.
Page 3 line 3, bad wording: "The positive results motivate further encourage into the design"
This has been corrected
Page 5 line 23, losses should be loses
Corrected
Table 1: "initW D" units should be given, presumably degrees.
Fixed

Section 4 para 1: "minimal sensitivity to wind speed" - is this likely to depend on Ct, especially above rated?
In the original look-up table produced, there was a wind speed dependency, however,

we noted that the selected yaw offset values were not very different, such as to justify the added complexity of including a wind speed measurement, especially because the measurement of nacelle-mounted anemometer in misaligned conditions might be unreliable.

"not much benefit at very high and very low wind speeds" - how can the reader see this - is there a reference?

Figure 5., for example in

Gebraad, P., Thomas, J. J., Ning, A., Fleming, P., Dykes, K. (2016). Maximization of the annual energy production of wind power plants by optimization of layout and yaw-based wake control. Wind Energy. http://doi.org/10.1002/we

Speaks somewhat to this point, the central idea being that at very low wind speeds there is in general very little power, and at very high wind speeds, a waked turbine may still be in above-rated winds, meaning that there is no opportunity for improvement

Section 4 para 2: "for turbine loading and safety reasons, the maximum yaw misalignment was limited to 25 degrees". How was this limit determined?

This limit was determined by test engineers at Envision to be at least safe over the span of the experiment. A full set of load cases were run for the conditions expected to occur during the period of the experimentation, and the limit decided such that a good test would be provided for the approach while ensuring no turbine failure consequences to the customer with statistical certainty.

"counter-clockwise of the wind" - counter-clockwise when viewed from above ?

That is right, made this clear in text

"because it has been demonstrated to be more effective" needs an explanation or reference

Added text and reference to address this point

Fig. 4: what does the width of the blue band represent?

Explanation added to legend

Section 5, para 2: "reduced to 1-minute averages" - What averaging is used by the yaw controller, and what hysteresis? Does the reference turbine spend significant numbers of 1-minute periods misaligned by a number of degrees until the yaw control kicks in to correct it? Could this affect the conclusions?

This averaging is only done in post-processing. The exact implementation of the yaw controller was not shared with researchers at NREL, however, as mentioned in the paper, it was important for safety reasons that the controller was disabled at sustained winds above 10 m/s with some interpolation between.

Equation 2: Is a cube law actually a good fit, given that there are variable losses etc.? Is N supposed to be a constant, or is it wind speed dependent?

A cube law describes the theoretical relation between wind speed and power in below-rated operation, and we include the minimum function to then include the saturation region. N is constant across all turbines, we assume all turbines have the same optimal C_p, rotor area and efficiency.

Page 10 line 17: in last sentence of paragraph, it is not very clear what was actually done in FLORIS.

Added clarifying text

Fig. 6: presumably the plots show the fitted values of 'a'? It seems that SCADA-ON produces significantly more power at the upstream turbine over most of the range. Why, and could this be favourably biasing the result?
This is likely due to several factors. The first is as discussed in earlier section, the loss of power because of yawing is lower on these turbines, and so we would not expect much difference, in other words, noise may be high relative to signal. Further, as is shown in Fig 5, that typical amount of realized offset is less than idealized, further reducing the difference.

For example, the mean offset achieved, according to Fig.5 is around 5 degrees, with the 75% interval ending at 15 degrees, with an pP exponent of 1.41, these would respectively yield power losses of only 99.5% and 95.2%.

If we focus on the region where FLORIS predicts a net increase, from -20 to -12 it is not the case that the upstream turbine power in yaw misalignment always exceeds the power of the baseline case. That said, near -27° for example, there is a clear benefit from this improvement that is not expected as the reviewer points out, and more data would almost definitely revert the trend back to little change.

Finally, given the spread in data, it is also helpful to focus on the banded regions, rather than the specific mid-points, and note that for the most part of the region of highest interest (-20 to -10 where the control is meant to be activated) the bands overlap for the upstream turbine, completely separate for the downstream turbine, and have large non-overlapping regions on net.

Figures 6-8: "the amount of days" should be "the number of days"
Fixed

General comments: Turbine loading is barely mentioned, and yet it could be crucial. What are the loading implications on the upstream turbine of the large yaw offsets?

How do the downstream turbine loads change? Might they even increase due to partial wake immersion? Maybe the experiment did not include load measurements, but in view of its importance this should at least be mentioned, and any appropriate references provided.
Addressing loads was outside the scope of this work, except in ensuring the safe operation of the turbines during the test. However, we are aware of and/or are involved in several related research projects into this question and have added a paragraph of discussion on loads to the conclusion.

What range of ambient turbulence intensities were experienced? Something should be said about this. It potentially makes a big difference to downstream wake dissipation. It also drives wake meandering, which again is not mentioned but could have significant effects.
Turbulence intensity is a crucial part in analyzing wake steering strategies. In this study, we did not include turbulence intensity as a parameter for wake steering, because it was not included in the engineering model FLORIS used to design the strategy. However, in the future, this will be necessary to maximize the benefit of the wake steering strategy. A new version of FLORIS under development does account for the effect of turbulence intensity, and even added turbulence intensity, however, this was not ready at the time of the experiment.

It should as be reiterated that this is an offshore wind plant and turbulence intensity is generally lower than onshore wind plants.