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WIND ENERGY SCIENCE DISCUSSIONS

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

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Response to review 2

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

General comments: This paper presents experimental power production results when considering two turbine combinations and yawing of the upstream turbine in a commercial offshore wind farm. The paper is reasonably written and publishable as a "discussion paper". I'm rather new to this journal and format, and I'm not sure if one of the goals is to have papers published quickly. The experimental data gathered in this paper are indeed relatively recent and are certainly of interest. However, further analysis perhaps including other data that might be associated with the data already presented would make the paper much stronger.

Thank you for your frank feedback. We unfortunately are not able to collect further data as this project has ended. We also recognize that because the experiment was run at a commercial offshore wind farm with various constraints, all the sensing we could have wanted was not available, and the turbines could not be controlled in the fashion (with control alternating regularly on and off) and could not be accommodated at this time.

We have attempted to make clear acknowledgments of the limitations of these results in the text.

We do however hope to show value in providing these results from a commercial wind farm.

The current paper only presents power data and the trends are not particularly strong. The main results are given in Figures 6 through 8 of the paper. In Figure 6, at the main wind direction of interest (-20 degrees), the yawed (SCADA-OPT) upstream turbine actually produces more power than the non-yawed (SCADA-BASE) upstream turbine.
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.

In Figure 7, these two cases show about the same power production at the main wind direction of interest (50 degrees).
The caption of this plot indicated power was not correct and has been improved. A turbine spacing of 8.5 diameters is at a range where we expect wake-steering to be a challenge, even in idealized simulations. The text describing the figure gives a more nuanced description.

A more complete analysis would also evaluate the differences in wind turbine structural loads between the various cases to more fairly assess any associated costs of using wake steering to increase power capture.
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.

Specific comments:
1. Since there are not that many equations and variables in this paper, it would be better to choose more succinct one-letter variables rather than long variable names like "yawLoss" and "initWD". When written in 'math mode', these could represent the product of many variables represented by the individual letters. Even "pP" looks like p times P.
In this case, if it's ok with the reviewer, we prefer the more expressive, long, notation, since as you say, there is not that many equations. pP is used for consistency with other papers.

2. In the figures, the power look to be plotted in normalized form. The authors should

state what they are normalized to, their own maximum power (as seems to be the case in the "Turbine C1 Power" plot in Figure 3) or some other power reference value (as seems to be the case in most other power plots in the paper).
For Figure 3, explanatory text has been added to the caption.

For figures 6-8, text has been added to the explanation of equation 2 to more clearly describe the fitting and normalization process.

3. In the figures, units should be given when needed. For instance, the "Turbine C1 Offset" plot in Figure 3 should indicate "(degrees)". And similarly for many other plots in the paper.
Fixed.

4. In general in the figures, use larger font sizes for the axis labels.
Fixed.

5. In the upper plot in Figure 6, it generally looks that "SCADA-BASE" yields more power than "SCADA-OPT". Is there an explanation for this? If you only look at subsets of the data where "SCADA-BASE" and "SCADA-OPT" yield much closer power levels to each other in the upper plot, then are there still the "promising" results for the corresponding subsets for the lower plots?
For similar reasons as the responses above on this topic, In figure 6., in the region from -20 to -12 where the controller is mostly expected to be active, the upstream turbine bands basically overlap, which could be interpreted as not significant change given data, where the downstream bands are completely un-overlapped – a significant change –, yielding a partial overlap between the bands on the total power.

In the same figure, around -27 degrees, indeed since the controller is not expected to be operating, the improvement is most likely due to the variation occuring in the

upstream turbine..

6. There are several sentences that are quite confusing, and the authors should carefully proofread and make sure that each sentence is easy to understand. For instance, the sentence on Page 12, lines 30-31: "Yet, the spread of results completely overlaps with the region of the optimized controller occupying the upper portions of the baseline range." After re-reading this several times and looking at Figure 7, I'm still not completely sure what the authors mean. Do they just want to say "Yet, the spread of results of the optimized controller occupies the upper portions of the baseline range." ?
This sentence in particular has been re-written, and more generally, the paper will pass through an additional independent review to check style more deeply.

Similarly, the last sentence on Page 12: "As noted earlier, when turbine D3 is waked by turbine R1 at 54 degrees, it is the deeper wake, being 8.5D spacing and no noticeable change in wake loss occurs, pointing to wake steering being the primary cause of change." What does each of the words "change" refer to? Between what and what?
Thank you for pointing this out, with this I had hoped to make the point that similarly to C1-D2, this is a wake loss with a distance of 8.5D, except that in this case there is no wake steering applied. In this case the power of the waked turbine is not changed between the baseline and optimized case, which suggests that the change in downstream turbine power in earlier cases, can be attributed largely to wake steering and less to seasonal variation.

The text has been revised.

7. How much difference does 1 degree make in whether a wake impacts the downstream turbine? The diagram in Figure 2 indicates that D2 is at 51 degrees relative to

C1 and that D3 is 81 degrees relative to C1. Yet, Figures 7 and 8 and the corresponding discussion in the text refer to "50 degrees" and "80 degrees" as the main wind direction to worry about. Further, in discussing Figure 7 looking at the C1-D2 pair, the text on Page 12 even says "To the left" of 50 degrees, "the baseline case grows smaller ... The power is low despite no wake ... " So one degree off, and there is no wake from C1 hitting D2 anymore? How much to the left are the authors really referring to? It might be useful to provide information on how many degrees is needed in each pairing before there is effectively no wake.

The data has been binned to 5-degrees, and so 1-degree increments are often within-bin, and within the probably margin of error of a nacelle wind vane.

The statement to the left means starting from 50 degrees and progressing leftward.

Technical corrections: a. In the last sentence of the introduction, use a different word than "feedback" ... perhaps "evaluation"?

Fixed

b. Be consistent with variable names. The variables k_d and k_e sometimes appear as K_d and K_e.

All set to k_e and k_d.

c. In Table 1, for parallel structure, perhaps label the Envision turbine as "Envision 4 MW". Also, the values for the variable "initWD" are presumably given in degrees? And all the other variables are dimensionless?

Changes all made, non-labeled are dimensionless

d. In Figure 3, given the legend, the curve in the lower left plot should be red.

That is true, this is fixed.

e. In Figures 6 through 8, the legend label "SCADA-OFF" should be "SCADA-BASE" and "SCADA-ON" should be "SCADA-OPT".

This is fixed.

f. Figures 6 to 8, lowest plots: I would suggest removing the word "unique" and just use "Number of days" as the y-axis label. I'm not sure what "unique" is meant to indicate. It made me think that if a day was counted for "SCADA-BASE", then it could not be also counted for "SCADA-OPT", though I don't think that is true.

The point of the word unique, is to stress that these are not number of days, as in, 24-hour periods, but since the fits were made on a per-day basis, how many separate days contain the necessary condition to construct such a fit? If this were changed to "number of days", the fear is misinterpretation of for example 10 days implies 240 hours, which it does not.

g. Figures 6 to 8, caption: "amount of days" should be "number of days"

Fixed

h. The ordering of references might be improved. For instance, why is Fleming 2014b not right after Fleming 2014a?

The provided journal latex class determines the order, I'm not sure how it is done.

i. Is the Trujillo et al. reference a journal paper, a conference paper, a report, or a personal correspondence?

Journal article, this citation has been improved