Wind Energ. Sci. Discuss.,
https://doi.org/10.5194/wes-2020-80-RC1, 2020

WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Field experiment for open-loop yaw-based wake steering at a commercial onshore wind farm in Italy" *by* Bart M. Doekemeijer et al.

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Received and published: 27 July 2020

Dear Authors,

Thank you for your contribution. I would like to acknowledge the challenges that always seem to arise when comparing measurements with simulations.

An interesting experimental dataset is compared with results from an equally interesting optimisation problem in which the authors present an open loop yaw steering control strategy with the aim to increase the net energy output of the wind farm. How-

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Discussion paper

ever, as a reader and reviewer, I am not convinced by all arguments with respect to the interpretation of the measurement and its comparison with the modelled results.

I've tried to summarize some of my concerns and questions below. Although some questions might be interpreted as an invitation to write another chapter or even other publication, that is not their intention. I appreciate the effort to keep the scope of the publication to a manageable level.

Elements that require brief additional considerations

- Based on figure 8, the measurements show a relatively large difference between the baseline and optimized case (up to a 10% increase in power production with wake steering), while the modelling shows only a 1-2% increase. This seems to indicate that for this turbine (WTG26) the wake steering is having a clear effect. However, in figure 9, for WTG E5, this can not be replicated. Why is that?
- You acknowledge loads are important in one short sentence all at the end. If they are important (of which I am quite convinced they are), shouldn't you also mention this either in the abstract and the literature review? I think it is perfectly acceptable to limit the scope of this publication to study the effects on power production. However, assuming that the wake steering concept can not be considered in a real production environment without taking loads into account, it should take a more visible role in the evaluation of your experiment and publication (in my opinion at least).
- Is there a specific reason why wake meandering is not discussed? I would expect wake meandering to be an important element in the context of wake steering, and it will have an impact on both power production and loads (considering partial wake conditions have a big impact on fatigue loads). How have you, or have others in the past, considered wake meandering when studying wake steering?

Since the modelling you present is based on steady state wake deflections, how would you expect (qualitatively) wake meandering to impact the power production when compared to a steady state modelling approach? Could this be an important focus area for future work?

- Have you considered any uncertainty (and/or a potential bias) in the wind direction measurement. If so, how would that affect the interpretation of figure B1 in particular, and the measurements in more general?
- If you where to re-plan the experiment again knowing what you know today, would you design it differently? Or in other words, based on your experience, how would you plan a follow-up experiment to address the challenges you have encountered?
- You briefly mention the measurements are in complex terrain. Could you elaborate further on why this might be very challenging in a validation measurement campaign?

Specific comments (see also marked comments in the annotated PDF):

- **Lines 49-50:** Sounds contradictory. I think it is quite clear why wake steering is not likely to affect the net energy production of wind farms in general. Howland et al (2019) for example summarize this quite well in their abstract/introduction. I understand that for certain cases (specific layout at a specific wind speed and wind direction) a dramatic power output can be obtained when employing wake steering and evaluating the effect on power production with a steady state wake deflection model. I also believe it is important to study that. However, I don't think it is correct to claim at this point in time that wake steering has a real potential to increase the net energy production of wind farms in general.

- **Lines 79-81:** A minor detail of course, but I think you can leave this statement out as it is not relevant for the paper. It also sounds like a snippet from the companies advertisement brochure ("global leader", "forefront").
- **Figure 2:** based on the [-] unit I assume data size is normalized in order to avoid disclosing too much sensitive information? Or is that referring to number of 10 minute averages (so unit is number of samples)?
- **Lines 102-104:** The surrogate model is based on a physical model I assume? One element is what the physical model can capture, the other how well the surrogate can re-capture the underlying data. To what is this statement referring to? This only becomes clear on line 155, maybe here you could refer to section 3.2 for more details on the surrogate model?
- **Line 112:** Completely agree, but as you already point out, a high quality reference measurement for wind speed, turbulence intensity and wind direction is required in a validation study context.
- **Lines 117-118:** Could you elaborate a little bit more what the context of these simulations are (model type, etc)?
- **Lines 139-142:** To my knowledge, the biggest hurdle would be certification, is that correct? I completely agree with the authors that a closed loop controller would be much more complex, however, technically it would not be prohibitively complex.

  I would imagine a wind turbine manufacturer will not open the controller up to its customers to perform these types of experiments. Knowing that the load certification process heavily relies on a well tuned controller, this is a reasonable precaution from the manufacturer side.
- **Figure 4:** Is each data point the 1 minute averaged wind speed?

Can you show a similar plot for the turbulence intensity and the wind direction?

Assuming you have access to the MET mast data, does it illustrate that, as you write on lines 120-125, it is simply too far away to be used reliably as an indication of free stream wind direction and speed?

Do you expect that this validation/correlation curve is independent of wind direction?

- **Lines 175-176:** I understand it is out of scope for this publication, but is it possible to add one or two sentences how different the "underlying equations" between the FLORIS and FarmFlow solvers are?

- **Lines 176-177:** For someone who is not a wind farm flow modeller expert this statement might not be obvious. Are there any references to back this statement? Or is it based on the author's general experiences as users and/or expert modellers?

- **lines 197-199:** Wouldn't this still result in a relatively broad range of operating an inflow conditions? I would be worried that all that averaging and aggregation will make it very difficult to make any clear conclusions since it won't be clear what exactly happens at which conditions.

  How do the results compare for much more limited datasets? For example, for a given sector/wind speed bin/turbulence intensity bin for which you have a fair amount of measurement samples? That could illustrate in a more detailed manner how the wake steering is visible in the measurements.

- **Lines 200-205:** Based on figure 3, I can see that WTG 10 and 11 are downstream turbines. I am confused with what this means for your measurements? If the turbine is being curtailed, I would expect that it would be less affected by the wakes upstream, is that correct?

Are you at liberty to share to what exactly the curtailed operation refers to (in terms of different pitch and RPM strategy)?

- **Figure 8:** How many data samples do you have in each bin, I assume that varies per bin? Is the range of turbulence intensities and wind speeds similar across the bins?

  How does the yaw measurement uncertainty compares to the applied yaw error?

- **Figure 10:** The model predicts a very small difference (baseline vs optimized), while the measurements show a very different picture. Further, the difference between the models seems to be smaller than the 95% confidence of the measurements.

- **Figure 11:** could you also indicate the average net gain (simple average over the considered directions, not including probability of occurrence)? It seems to be positive, is that correct?

- **Lines 285-287:** I am puzzled by this statement and it contradicts the general understanding I have of wind turbines. Wind turbines operating under a yaw error will have by definition less power output and are subject to higher fatigue loads. So how can it be beneficial to operate a turbine with a constant yaw error?

  I can understand the statement when assuming there is a bias in the wind direction measurements, or that the complex terrain results in a flow field that is very complex and produces counter-intuitive results. However, I don't see such a discussion here.

- **Line 289:** You place "free" between quotes, but what about loads?

- **Lines 290-291:** If there are large discrepancies between the measurements and the model, how can you conclude the surrogate model is able to predict the dominant wake interaction trends? I understand that the model is intended to do so (and effectively does in other cases), but that doesn't mean it is true for your specific case.

- **Line 313:** Agreed. I would suggest to split the conclusions chapter into 2: "conclusions" and "future work". In the "Future Work" section you could consider being more specific about what you suggest should be done to resolve specifically the shortcomings you've seen in your experiment. This could be valuable for future validation campaigns of the wake steering concept.

- **Figure 1B:** Is this a reasonable or comparable power-yaw curve when compared to other experiments, for example when looking at the data from Danaero, MEXICO, MexNext, etc?

  How have you verified the presented result is not due to a bias in the yaw inflow measurement?

Please also note the supplement to this comment:
https://wes.copernicus.org/preprints/wes-2020-80/wes-2020-80-RC1-supplement.pdf

Interactive comment on Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2020-80, 2020.