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Interactive comment on "Towards practical dynamic induction control of wind farms: analysis of optimally controlled wind-farm boundary layers and sinusoidal induction control of first-row turbines" *by* Wim Munters and Johan Meyers

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We thank the reviewer for his/her constructive comments and are pleased with the positive assessment or our work. We have addressed the specific comments made by the reviewer as described below. We hope that the revised manuscript can now be accepted for publication.

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1. Reviewer: *One comparison that came to mind reading the paper, is that the results*

show very little value in optimizing the most-downstream turbines, and in general, improvement in power comes from modifications upstream, and that self-optimization is not possible. This stands in contrast to a result such as:

Ciri, Umberto, Mario Rotea, Christian Santoni, and Stefano Leonardi. "Large Eddy Simulation for an Array of Turbines with Extremum Seeking Control." In American Control Conference. Boston, MA, 2016.

Where the TSR of downstream turbines is re-optimized for wake conditions (and the upstream turbine is left as is at the end of the optimization). It would seem the difference in modeling methods and/or how turbine control is implemented yields the different results, but I believe it would be worth discussing the difference, for example around the paragraph beginning with "The figure shows that the first row (R1)..." on page 12.

Response: This is an interesting comment. It is correct that the difference originates from the way turbines and their controls are modeled in the current study compared to that of Ciri et al. The reference disk-based thrust coefficient $C_T' = 2$ used here actually implies intrinsic self-optimization of blade pitch and generator torque to local flow conditions, even though these actions are not resolved by our current actuator disk formulation which directly controls C_T'. In case these degrees of freedom would be resolved, for instance using an actuator line model as in Ciri et al., the ESC from the latter study could e.g. be used to optimize torque controller gain in order to achieve an effective $C_T' \approx 2$.

We have included the fact that the reference case already implies self-optimization in the revised manuscript as follows (p 4, line 21):

" A conventionally (greedily) controlled wind farm with steady $C_T' = 2$ was defined as a reference case. **Note that this would correspond to a farm with ideal turbines for which generator torque is being controlled dynamically to track the maximum power point at the Betz limit perfectly. In a real turbine controller this may, e.g., be achieved with the extremum seeking control proposed by Ciri et al. (2017).**

Several different optimal control cases were defined, ... "

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2. Reviewer: *Figure 3/related text: Would another way to describe Ct2 vs Ct3 be that Ct2 can only lower the thrust, while Ct3 is allowed to raise it?*

Response: Indeed, this is correct. We have mentioned this explicitly in the revised manuscript as follows (p. 4, line 26):

" ... and the maximal thrust coefficient $C'_{T,\text{max}} = 2$ or 3, **with thrust forces that can respectively only be reduced (underinductive), or also increased (overinductive) compared to the Betz optimum at** $C'_T = 2$ (see Eq. 5). "

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3. Reviewer: *"... NREL 5MW rotor with a 50% increase in chord length ..." does this imply the method is currently assuming the chord length is variable? Could this not be achieved by a change in pitch angle?*

Response: No, the method does not imply a variable chord length.

Current turbines are designed to approach maximum C'_T values around 2, corresponding to the Betz limit. Aiming to increase thrust by adapting the pitch angle would inevitably lead to severe efficiency losses due to stall on the turbine blades. Therefore, we provide an example of how an alternative turbine design (i.e. with an increased chord length and operational TSR) could attain a maximum C'_T of 3.5. Given such a turbine design, achieving thrust ratings $C'_T < 3.5$ is straightforward by pitching blades towards the feather position.

We have slightly modified the statement in the revised manuscript to avoid any confusion with regard to possibly having the chord length as a control variable. (p. 17, line 25):

" **For instance, considering the NREL 5MW blade profiles, the maximum thrust**

coefficient of 3.5 can be attained by slightly changing the rotor design, e.g. using a 50% increase in blade chord length and an operational tip speed ratio 25% higher than the original design value (see Goit and Meyers, 2015, Appendix A). Furthermore, given such redesign, dynamic reductions from this value could be realized through blade pitch control, for which actuation rates in the order of $10°/$**s are possible (see, e.g., Jonkman et al. 2009).** "

Note that this control strategy is not unique and is solely given as an indication for the technical feasibility of tracking the proposed C'_T waveform. In practice, we expect that this can also be achieved through a combination of generator torque and blade pitch control. This is subject of ongoing investigation.

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