Wind Energ. Sci. Discuss.,
https://doi.org/10.5194/wes-2019-65-RC2, 2019

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Interactive comment on "Analytical model for the power-yaw sensitivity of wind turbines operating in full wake" *by* Jaime Liew et al.

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Received and published: 4 November 2019

article

In this paper, a new analytical model for the estimation of power loss of a wind turbine operating in yaw while being exposed to the wake of an upstream turbine is presented. Here, the power-yaw loss coefficient from the established power-yaw loss function is adapted to match wake inflow conditions in addition to uniform inflows. For this, the path that each blade segment follows through the wake wind field is considered to calculate a blade segment effective wind speed. The model is tested for a wake inflow generated using Large Eddy Simulations (LES) and a wake inflow generated using the dynamic wake meandering (DWM) model, and a validation against aeroelastic simulations is done using the same inflow conditions.

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Discussion paper

The paper is structured in the following way: An introduction summarizes existing studies of power losses due to yaw misalignment while also pointing out the lack of consideration of wake effects. Then, the theoretical considerations the model is based on are presented, followed by the methods used to test and validate the model, the results of the analysis including an example of the consequences of the mismatch, a discussion and a brief conclusion that summarizes the main findings.

Overall, I think the results presented in this paper are both interesting and relevant as they can be used to optimize the procedure of power estimation in wind farms with simplified models, as well as to optimize control algorithms that use wake steering.
Some comments that I believe would improve the overall quality of the paper can be found below. Additionally, while the overall idea of the paper becomes clear and the results are comprehensible, the text would in some sections benefit from being more precise and straightforward, and the text should be checked with respect to language and also typos.

Major Comments

1.
p.1-2: Here, the terms ''power-yaw sensitivity", ''power-yaw loss function" and 'power-yaw loss coefficient' are introduced. While the authors are establishing a name for the already existing description, the terminology is only used on the first two pages. I think that if one introduces new terms, one should consistently use them.

2.
p. 2/ l. 3: P_0 is not introduced, please clarify whether P_0 is the power with respect to the free inflow or the inflow of the respective situation where the formula is applied (e.g. wake inflow).

3.
p. 2/ ll. 14: First, it is written, that '"The wake recovery rate is highly dependent on turbine spacing and ambient turbulence intensity"' and directly afterwards it is mentioned that '"It was found that α is maximum for a turbine located approximately 4 rotor diameters (4D) downstream of another turbine when in a full wake situation"' - as the ambient conditions determine the wake evolution, it should be pointed out that α is maximum 4D downstream in the situation that was investigated but that this distance might vary depending on the inflow conditions of the upstream turbine.

4.
p. 3/ ll. 11: I think that this paragraph needs some work. First, this paragraph is together with the following paragraph used to motivate the necessity of considering a wake inflow for the calculation of α. However, the idea is discussed within the framework of wake steering, which is discussed in the previous paragraph. An integration into the previous paragraph could probably help the readability as one aim of an optimized α is a higher precision of the power optimization procedures used for wake steering. Second, the "trade off of wake steering" is a bit vague and also, the aim of wake steering is power production optimization. Third, the term "power gain loss" is not clear to me in this context. Do you mean the trade-off between power losses due to yawing the upstream turbine and the power gain of the downstream turbine?

5.
p. 4/ l. 4: r_R is mentioned the first time here but introduced on page 5

6.
p. 4/ fig. 1: Was this wind field generated by the DWM model? It should be specified that the inflow conditions of the wake generating turbine are uniform.

7.
p. 5/ ll. 20: '"Fig. 2 shows the waked wind field for various downstream distances."' Figure 2 shows the radial variation of the wind speed and its derivative for different downstream positions in a wake generated by the DWM model.

8.
p. 7: While D is used as variable for the rotor diameter on page 2, it is used here as variable for the downstream distance. As D is usually used for the rotor diameter, a different variable for the downstream distance should be used.

9.
p. 7: Methods: In the introduction, the four different test cases are explained. As the aeroelastic simulations are used to validate the analytical modes, I would mention this again here.

10.
p. 8/ l. 12: I would mention that the wake deficit profile generated by the DWM model is depending on the downstream distance.

11.
p. 10/ l. 11: '"...where N is the number of time steps in the LES wind field, and N is the desired azimuthal discretization (in this case, N = 500)"' I guess that M is the number of time steps.

12.
p. 11/ l. 4: '"... is present at a low turbine spacing between 3D and 5D"' the maximum values are between 3D and 4D.

Minor Comments

1
p. 1/ll. 19: '“ Part of the discrepancy and uncertainty might stem from unintentional yaw misalignment (or yaw error) of turbines inside wind farms.”' This sounds like an assumption of the authors to explain the uncertainty. Connecting this idea with the fact that yaw misalignment occurs regularly (following sentence) could improve the readability: '“As unintentional yaw misalignment (or yaw error) of turbines inside wind farms occurs frequently, this could explain the discrepancy and uncertainty partially. For example, Mikkelsen et al. (2010) reported yaw error on a turbine in freestream wind conditions of up to 20âŮę during a measurement campaign of approximately 3 hours.”'

2
p. 2/ l. 12:: a new paragraph for the discussion of the power-yaw loss coefficient with respect to wake inflows would emphasize the new focus.

3
p. 3/ l. 3: '“...to determine the trade off of directing a wake”' It would be nice if the sentence was more precise, e.g. '“... to determine the trade-off between power losses due to yawing the upstream turbine and the power gain of the downstream turbine...”'

4
p. 3/ l. 5: '“... is adjusted based on the **blade** pitch angle of the yawed turbine”' - while it should be clear from the context that the blade pitch is meant, I would specify this since new works on floating turbines discuss the pitch, yaw and roll movements of the turbine.

5
p. 7/ l. 16: states that downstream positions between 2D and 14D were investigated, but figure 6 does only show results from 3D downstream.

6
p. 8/ll. 5: '"the first set uses..."', '"the second set uses..."': I would prefer '"simulation"' over '"set"'.

7
p. 8/ll. 7: '"downstream distance"' and '"turbine spacing"' are used synonymously; here I would prefer the term '"turbine spacing"' over '"downstream distance"'.

8
p. 8, 3.1.2 LES wake: – several parameters are not introduced (α (this variable should be renamed), ϵ, L and Γ, and R)

9
p. 9, fig. 4: the color bar depicting the wind speed deficit is incomplete as it lacks the yellow colors occurring in the LES results.

10
p. 9 – 3.2 Analytical calculation:
As in 3.1, it was mentioned that cases (1) and (2) are explained, it should be mentioned, that in the following, cases (3) and (4) will be discussed.

11
p. 11/ l. 14: '"...is due to the strong positive curvature of U (r)..."' it could be added here '"is due to the strong positive curvature of U (r) at small turbine spacings (cf. Fig. 2)"'

12
p. 12/ l. 1: "'To highlight the significance of the results in Fig. 6, a wind farm layout consisting of two turbines with a spacing of 6D is considered"' I would probably use

a different formulation, for example "'To give an example of deviations in the power estimation that result from using a constant α as compared to using the new, adapted α, a wind farm layout consisting of two turbines with a spacing of 6D is considered"'

13
p. 13/ ll. 21: '"theoretical formulation"' - before, '"analytical model"' was used.

Typographical/Grammar

If you list several sources, it would be nice to add an "'and"' instead of a "';"' as the separation between the last two sources.

p. 1/ l. 5: (+ other positions in the text) '"waked" does not exist in this context, instead of '"waked wind field", you could use '"wake" or in the context of this paper '"wake inflow"

p. 1/l. 2/3: '"the unintentional yaw misalignment increase**s** for turbines operating in the wakes . . ."'
p. 1/l.18: '"Often, the wake effects and therefore the power production are not accurately modeled when employing engineering wake models **which** includes substantial uncertainty"'
p. 1/ll. 21: '"However, McKay et al. (2013) ha**ve** shown yaw misalignments of up to 35âŮę for turbines operating in **the** wake**s** of aligned upstream turbines based on field measurement for a 6 month period"'
p. 2/l. 5: '"free wind **wind**"'
p. 3/l. 21: '"DWM **model**"'
p. 4/ l. 6: '"as **the** yaw angle..."'
p. 6/ l. 2: '"based **on**"'
p. 7/ l. 4: '" is the power output **of** a turbine **for a** yaw misalignment γ and a down-

stream distance D"'
p. 13 / l. 11: '"high fidelity wake profile**s**"'