REVISION TO MANUSCRIPT DRAFT

Wind Energy Science Discussion

Comparison between upwind and downwind designs of a 10 MW wind turbine rotor

The authors would like to thank the two reviewers for their time and for the useful feedback. All provided input indeed contributes to the improvement of the paper.

A list of point-by-point replies to the reviewers' comments is reported in the following.

Reviewer #1

Numbered comments

1. *[**Reviewer**] Can you explain why this blockage effect is favorable, with respect to power/loads?*

   [**Authors**] The benefit is claimed by Kress et al., 2015[1], and it refers to AEP. This increase is explained by a redirection of the flow towards the outboard part of the blade due to the presence of the nacelle located upwind. The flow speeds up towards blade sections characterized by thinner and more efficient airfoils and, as a result, a higher AEP is produced. An experimental campaign on sub-scale models showed an increase in AEP equal to 5% against an increase of 3% of rotor thrust. A similar concept is behind GE's ecoROTR[2]. The actual benefit in full-scale wind turbines is yet to be investigated. Research activities within IEA Wind Task 40 aim at a more precise quantification of the potential benefits.

   The text in Sect. 1 was modified to incorporate the above comments.

2. *[**Reviewer**] How the AEP has been computed, how large is the uncertainty. 0.7% seems to be small compared to the uncertainty in the calculation*

   [**Authors**] It is true that a variation of 0.7% may look small, especially when subjected to a variety of uncertainties such as in the case of wind turbine simulation. Nonetheless, it should be remarked that a variation in the AEP of 0.7% between two rotors characterized by the same rotor diameter, both optimized in terms of twist and control, both of class I (where the contribution of region III to AEP is not marginal) and both subjected to the same wind is not negligible. In addition, the trend is consistent between the rotors with the baseline diameter (UW vs DW) and the rotors with the longer blades (UW5 vs DW5). Finally, tests computed with steady-state wind conditions corroborate the results.

   The text in Sect. 3.3 was modified to better support the claim of the 0.7% increase in AEP.

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[1] Kress C, Chokani N, Abhari RS. Downwind wind turbine yaw stability and performance. Renewable Energy, 2015;83:1157-1165. doi: 10.1016/j.renene.2015.05.040

[2] https://www.ge.com/reports/post/126500095500/the-road-to-ecorotr-how-building-a-better-wind-2/

3. *[**Reviewer**] Activity*

   [**Authors**] The misprint was corrected.

General comments

1. *[**Reviewer**] Please describe in more details the assumption in the simulation study, for example in the wind regime, turbulence intensity, wind shear*

   [**Authors**] All simulations respected the IEC guidelines. Text is added at the beginning of Sect. 3.1 to briefly explain each Design Load Case (DLC) and to refer to the IEC standards.

2. *[**Reviewer**] How many seeds have been used to generate the turbulence inflow, is the number large enough to support the 0.7% AEP increase stated in the paper*

   [**Authors**] As stated in Sect. 3.1, only one turbulence seed was used to limit computational costs. Including more seeds would certainly produce some variations in the figure of 0.7% but would not change the trends shown in the paper. The consistency in the increase of the AEP is confirmed by simulations performed with a steady-state wind.

   Text was adjusted in Sect. 3.1 to better explain this point, and in Sect. 4 with a recommendation to run in the future the full load analysis as prescribed by the international standards.

3. *[**Reviewer**] What kind of tower shadow model has been used for the downwind case*

   [**Authors**] The tower shadow is computed based on an empirical model described in Powles, 1983[3]. This approach models the wake behind the tower using Δ, which is the maximum velocity deficit at the center of the wake as a fraction of the local wind speed, and W, which is the width of the tower shadow as a proportion of the local tower diameter. These quantities are defined for a given downwind distance, expressed as a proportion of the local tower diameter. For other distances, W increases, and Δ decreases, with the square root of the distance.

   The reference to the model was added in Sect. 2.1 of the paper.

4. *[**Reviewer**] How large is the uncertainty of the blade cost model of Sandia. Will the uncertainties increase the model is used for 10 MW wind turbine blade, for which the cost model is not calibrated.*

   [**Authors**] The SANDIA blade cost model, such as any cost model available in the public domain, is affected by a multitude of uncertainties. Nonetheless, conclusions similar to the ones reported in the paper would be drawn by looking at physical quantities such as blade mass and AEP. This is indeed the main reason why these quantities are reported in Fig. 4 together with blade cost and CoE. A note in this sense was added to the text.

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[3] Powles SRJ. The effects of tower shadow on the dynamics of a HAWT. Wind Engineering, 7, 1983.

5. *[**Reviewer**] Using active coning will introduce uncertainty in the cone angles, meaning each of the blades may have slightly different cone angle. How would that impact the loads?*

   [**Authors**] A misalignment in the individual cone angles of the three blades would be extremely problematic generating mass and load imbalances to the whole turbine system. This is the main reason why individual flapping is not included in the present work, as explained in Section 2.3. It is nonetheless true that even with collective flapping, some misalignment could occur and would be a major concern.

   This aspect was added to Sect. 3.4, which discusses the critical aspects of DW5LA.

6. *[**Reviewer**] What is the impact of downwind configuration on the tower loads*

   [**Authors**] The ultimate and fatigue fore-aft moments measured at tower base were added to Figure 4. A discussion on the loads at tower base was added to Sect. 3.3. This comment is indeed very useful, as fatigue loads on the tower do experience an increase of a few percent points for configurations DW and DW5.

7. *[**Reviewer**] Will pitch activities of downwind turbine increase turbulence?*

   [**Authors**] In this study, downwind rotors are not characterized by a more pronounced pitching activity compared to the equivalent upwind designs. Therefore, we do not expect a special effect on turbulence due to pitching in a downwind turbine.

8. *[**Reviewer**] Complex terrain is not just an upflow angle, often flow characteristics may have also significant impacts on the loads*

   [**Authors**] This is absolutely true. The present paper does not however recommend complex terrain as a solution compared to flat terrains. The paper rather claims that downwind rotors may offer superior performance compared to upwind configurations in sites characterized by upflow conditions. More detailed studies should investigate the impact of loads due to unsteady inflow in complex terrains. This aspect was added in Sect. 4.2 among the recommendations for future work.

Reviewer #2

1. *[**Reviewer**]: As acknowledged by the authors, one critical parameter of the aerodynamic analysis of downwind rotors is the modeling of the blade tower interference. The authors mention that the model used in the analysis of the downwind configuration differs from the one used in the analysis of upwind rotors. It would be nice to comment on the validity of this model. A short comment and a reference to some earlier development would be sufficient as the above model could be critical for the consistent prediction of the fatigue loads, especially in the wind speeds range where coning is not activated.*

   [**Authors**] This aspect is pointed out by both reviewers, see point 3 of the General Comments of Reviewer 1. A specific reference (Powles, 1983) was added to Sect. 2.1.

2. *[**Reviewer**] In the same direction, it is mentioned that nacelle anemometer wind speed measurements are inaccurate and therefore some rotor equivalent wind speed could be estimated (most probably based on loads measurements if I'm not mistaken). It would be nice to provide an estimate of the uncertainty of the wind measurement if such a method is applied (I guess/hope that this uncertainty decreases as higher frequencies of turbulence are filtered out). Has this uncertainty been taken into account in the control loop of the active cone or you have considered perfect wind speed measurements?*

   [**Authors**] In this study we have not integrated the rotor measurements to predict the wind speed, but we rather assumed point measurements at the nacelle top.

   The comment of the reviewer is however interesting, as it highlights the importance of more precise measurements of the wind and how this increased accuracy may differently impact different rotor configurations. The authors will keep this suggestion for future work in consideration.

3. *[**Reviewer**] It is not perfectly understood how the radius of the blade was extended. Was that done by increasing the length of the blade or by increasing the radius of the hub keeping the same blade length? If the length of the blade is changed how the planform was scaled up?*

   [**Authors**] For configurations UW5 and DW5, the hub is left untouched and the blade planform is stretched. The twist is then re-optimized to ensure good airfoil efficiency along blade span. At this point, loads are re-computed and the blade internal structure is re-sized.

   Such approach is chosen thanks to its simplicity, in contrast to a full aero-structural optimization process. It is true that this choice may introduce some penalty in the design of the longer blades mounted on the UW5 and DW5 configurations. To alleviate this issue, the comparisons have indeed been mostly conducted between UW and DW as well as among UW5, DW5 and DW5LA, where the penalty, if any, affects the blades in the same way.

   Section 3.2 was modified to better explain these aspects of the design.

4. *[**Reviewer**] Why the radius increase was fixed to 5%? Perhaps it would be preferable to leave the radius a free parameter in the optimization and find the optimum radius for every configuration. Perhaps in this way you could better exploit the mass reduction of the downwind coning concept by increasing as much as possible the energy yield.*

   [**Authors**] It is true that a more rigorous approach would consist of a complete redesign of the machine, where among other optimization variables the rotor radius should be left free to minimize the CoE. This is indeed the approach followed in other works that adopted the same optimization framework, such as Bortolotti et al., 2016[4] and Bortolotti et al., 2018[5].

A simplified approach as the parametric study reported in the present paper is however considered to be more useful at this stage. A change in the rotor radius causes massive changes in all parameters of the turbine, and the interpretation of the results of an automatic optimization may rapidly become challenging. Instead, a pre-defined exploration of the solution space does not offer the possibility to identify an optimum configuration, but helps understand the trends and suggests areas of investigation that are worth further design efforts.

This being said, a recommendation for future work in the area of aerostructural optimization of downwind rotors was added to Sect. 4.

5. *[**Reviewer**] It is not clear how would the coning system operate in the case of grid loss especially if this is combined with storm conditions. Analyzing parked operation at 30deg misalignment implies that the yaw system is not active. Would it be possible in this case to cone the blades?*

   [**Authors**] This is a very good point: a grid loss would be extremely problematic for an actively controlled rotor coning such as the one modelled in configuration DW5LA. This aspect was added among the critical ones discussed in Sect. 3.4.

6. *[**Reviewer**] It would be instructive for the reader to know which are the driving DLCs for the different loads. Some information is given in 3.4. Perhaps it would be nice to indicate the DLCs in plot 4b.*

   [**Authors**] We agree with the suggestion and Figure 4b is now split into two distinct figures, showing a list of ultimate and fatigue loads. The ultimate loads are accompanied by the indication of the DLC.

   It is important to notice that this comment of Reviewer 2 not only improved the content of the paper, but also helped spotting a mistake in the paper. In Sect. 3.1 of the original submission, we wrote that the list of DLC included DLC 1.1, 1.3, 2.3 and 6.2. This was a misprint, as DLC 1.3 were not part of the subset of simulations included in this study. The text in Sect. 3.1 has now been corrected.

Minor comments and editorial

1. *[**Reviewer**] Page 2, line 3, add blade prebend*

   [**Authors**] Prebend is added to uptilt and cone angles as a mean to increase tower clearance.

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[4] Bortolotti P, Bottasso CL, Croce A. Combined Preliminary-Detailed Design of Wind Turbines. Wind Energy Science, 2016;1:1-18. doi: 10.5194/wes-1-71-2016

[5] Bortolotti P, Bottasso CL, Croce A, Sartori L. Integration of multiple passive load mitigation technologies by automated design optimization—The case study of a medium-size onshore wind turbine. Wind Energy. 2018;1–15. https://doi.org/10.1002/we.2270

2. *[**Reviewer**] Page 5, line 10, you could add any deterministic asymmetry of the inflow and rotational sampling of turbulence*

   [**Authors**] It is absolutely true that deterministic asymmetries of the inflow and rotational sampling of turbulence further complicate load alignment. This is however somehow included in the wind speed change, which results in changes to F_t. We therefore believe that the simplified explanation of Sect. 2.3 can remain the same.

3. *[**Reviewer**] Page 7, line 3, replace "availably" by "available*

   [**Authors**] The misprint is corrected.

We have taken the opportunity to make several small editorial changes to the text, in order to improve readability. A revised version of the manuscript is attached to the present reply, with the main changes highlighted in blue.

Yours sincerely,
The authors