Reply to the comments of the Anonymous Referee #2.

Dear reviewer,

Thank you very much for your positive review and your valuable feedback.

We are very grateful for your comments.
All the unclear points mentioned in the review have been clarified in the next pages.

The following format of answering the questions was chosen:

- Question/Comment (from the reviewer)
- Text from the manuscript (the related text from the manuscript – if needed)
- Answer (reply from the authors)
- Changes (new/modified text added to the manuscript – if needed)

Please do not hesitate to contact us for any further information.
We are at your disposal and willing to improve further our manuscript.

Kind regards,
Nikolaos Stergiannis et al.

Comment 1

"It is mentioned that steady state simulations are carried out in the rotating frame. It is also mentioned that the tunnel geometry is included in the simulations. It is not clear how the two may be combined when the wind tunnel cross section is square. Perhaps the utilities of OpenFOAM mentioned include the implementation of sliding grids. If this is the case please specify accordingly."

Answer:

Thank you for your comment. This is now clarified in our manuscript. Further figures could be provided and included in the final manuscript if needed.

Changes:

The MRF regions are cylindrical and they are located inside the stationary squared region of the computational domain. The cyclic arbitrary mesh interface (AMI) was used in between the rotating and the non-rotating mesh regions. To limit any possible impact of the interfaces with the flow field, the MRF regions have been extended further downstream. In all the cases under investigation, the rotating frame regions include the rotor-hub geometries and all the wake regions downstream.

Comment 2

"One missing information regarding the ADM results concerns the axial induction. Was a measured power and thrust curve used? Please specify."

Answer:

Thank you for your comment. The axial induction factor that was used, is based on the measured Ct and Cp. This information is given in line 10, page 6:

"The coefficients Cp and Ct have been provided from the wind tunnel measurements and were used as inputs to the simplified models."

Comment 3

"I assume that inflow turbulence is similarly implemented in both models (FR and ADM). The plots in Fig.6 seem to suggest that in the ADM results the level of turbulence is higher upstream of the 1st rotor. Is this correct? And if so is there an explanation?"

Answer:

We could not see any indication of higher values for the cases of actuator disk models in Fig. 6. The inflow turbulence intensity is indeed similar for the both CFD approaches. We confirm that the same value of 1.98375 m^2/s^2 has been used in the inlet for both CFD approaches.

Comment 4

"It seems that the ADM models only accounts for thrust and not torque. Please specify. Furthermore, I believe that in Fig.5 the axial flow velocity is recorded and that the full rotor contours correspond to the azimuth averaged velocity. If so, it is important to also compare the axial force."

Answer:

The implemented actuator disk model in OpenFOAM uses the induction factor a to simulate the momentum sink in the flow field. The induction factor is calculated based on both the thrust and torque coefficients which are provided by the experimental measurements. While it is true that the induction coefficient is calculated from thrust and torque, the model is purely axial and does not include rotation. The full rotor contours were not averaged over the azimuth. This is a very good point that we have been also considering. It will resolve the drawback of the frozen rotor technique which produces a rotating wake that always stay in the same position. We are developing a post-process function to perform the averaging over the MRF regions for all the flow quantities. Relative results will be added to the final manuscript.

Changes:

…The coefficients Cp and Ct have been provided from the wind tunnel measurements and were used as inputs to the simplified models. While it is true that the induction coefficient is calculated from thrust and torque, the model is purely axial and does not include rotation.

Comment 5

"In Fig 6 the two models are compared in terms of k. I noted that the k-ε results from the full rotor simulations are not symmetric which implies that they are not averaged in azimuth. If so, then is such a comparison valid?"

Answer:

Thank you for pointing this out. It is similar to the second part of the previous comment. This is a very good point and we are currently working on a custom post-process function that will perform the averaging in azimuth. Contour plots will be updated in the manuscript.

Comment 6

"In Fig.8 the ADM results underestimate the acceleration seen in the measurements at both ends of the plot window. This is important when partial wake effects on the loading are of interest. Otherwise I agree that the k-ε RNG model out performs amongst the different models. Also in comparison to comment #3 it would be very useful if there are thrust or power measurements to make a comparison."

Answer:

Thank you for your comment. The observed acceleration seen in the measurements at the ends of the plot window is related to the physical presence of the wind tunnel walls. A

developed boundary layer combined with the blockage of the wind turbine will cause a local acceleration at the region between the rotor and the wind tunnel walls. In the CFD simulations the wind tunnel walls are modelled with slip conditions to ensure that all the gradients and the velocity vectors normal to the walls are zero assuming zero surface friction. It should be noted that the underestimation of the acceleration at both ends of the plot window is also observed in the blade resolved simulations since both CFD approaches are using the same computational domain and boundary conditions.
For the case of ADM the thrust and the power are imposed as inputs through their coefficients, therefore, such a comparison would be useful only for the case of the second wind turbine which operates within the wake of the upstream rotor.

Comment 7

"As also mentioned in the paper, the slow flow recovery seen in Fig.9 may be related to the evolution of inflow turbulence along the computational domain. Wind tunnel measurements on disks and small rotors indicated that by increasing the TI level faster recovery is obtained. Otherwise, in the specific set up, the k-ε realizable model performs rather well."

Answer:
We agree that the k-ε realizable model performs well at the far wake, but it is considered unreliable from the unphysical results of TKE that observed in the full rotor CFD simulations. Also, in the blade-resolved approach, it is the only model that fails to predict a "W-shaped" near wake velocity deficit. Therefore, we conclude that it's performance is rather good by accident.

Comment 8

"Finally, I would suggest to add in the last section that full rotor simulations should be also checked as regards the evolution of inflow TI."

Answer:
True statement, we will add this in the last section.

Conclusion from the referee 2

"The paper contains interesting results, but also some unclear points that need clarification. To my opinion, the corresponding revisions are important."

Reply: Thank you very much for your positive review. All the unclear points mentioned in the review have been clarified. Please do not hesitate to contact us for any further information.