Response to Referee Comment #2, wes-2024-83, 30 Sep 2024

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We sincerely thank the editor and the referee for reviewing our manuscript and providing constructive feedback to improve our manuscript. We have revised the manuscript accordingly. Below are the original comments from RC#2 in black and our corresponding responses in blue.

This study introduced a methodology for input torque estimates based on identification of operational deflection shapes of a wind turbine gearbox using fiber-optic strain sensors and Multivariable Output-Error StatesPace (MOESP) subspace identification. A brief literature was given to motivate the current research. Needed theoretical discussions were provided along with a description of the test gearbox, which is composed of three planetary stages and one parallel stage. Experimental data was collected from an end-of-line test bench and used in the development and assessment of the proposed methodology. The reviewer has some comments as detailed below. The few critical for the authors to address are bolded. The manuscript is recommended to be revised before it can be considered for publication by the journal.

1 Abstract:

- line 5: "framework" may be better replaced by "method"; input torque "measurements" may be better expressed as "estimates".

  We have chosen the term "algorithm" instead of "framework" which we believe is more precise and have erased the term "measurement" for clarity. We agree with the term "torque estimate" as already used in line 12 of the abstract.

- line 8: "consistent" might mean agreement with expectations here. Please reword to make it clear.

  We have reworded this sentence for clarity; we meant that the estimated values were consistent regardless of the identification parameters chosen to run the algorithm, see Sections 4.1 and 4.2.

- **line 14: statement on "operational deflection shapes over time" being proposed to enhance condition monitoring appears not substantiated in the manuscript but only briefly discussed as one of future benefits. Please consider removing or rewording.**

  This comment aligns with Referee #1. We agree that this is a potential future application of the method developed in the current article. We have removed the last sentence of the original abstract and made a clearer statement for future research recommendations in the Conclusions section.

2 Introduction:

- line 37: please elaborate on "the influence of surface friction."

  This sentence explains the reason behind the trend to increase the hub height of wind turbines, which was mentioned a few sentences before. We are referring to the influence of the ground on the inflow wind conditions and how modern turbines tend to be taller to exploit better incoming wind flow conditions. We have slightly modified the sentence for clarity.

- lines 38-39: in the sentence, "more power ... enhancing reliability", it appears the first two phrases apply to a plant and the next two phrases apply to individual turbines. Please clarify.

  The sentence in lines 38-39 refers to one of the reasons for increasing the power of individual turbines, but in this case, we are referring to the reliability benefits at plant level; We have reorganized and reworded the sentences for clarity.

- line 40: "a substantial cost reduction in costs" appears not having a direct causal relationship with "large rotors", which appears directly leading to improved energy production or revenue.

  We have modified the sentence to make it more clear that one of the motivations to move to larger rotors is the fact that energy production tends to grow faster than the costs and therefore generally larger wind turbines have lower lCoE. The new sentence reads: "The increase in energy captured by the rotor is bigger than the increase in overall turbine costs because blade lengths can be increased while many other costs remain fixed, generally leading to lower LCoE in larger turbines".

- line 68: please double check whether the torque is estimated by using generator currents.

  This point has also been addressed in a comment from RC#1. Estimating mechanical torque from electrical currents is discussed in lines 67-70 as an alternative to direct measurements. In our opinion, this is not an appropriate alternative because it cannot capture torque fluctuations in damaging events, such as an emergency stop where the mechanical brake is applied. We have also added here the uncertainties associated to the unknown power losses in the generator and the gearbox, which vary with torque and other operating conditions.

- lines 75: please consider adding the technology from AeroTorque (https://www.pttech.com/aerotorque-torsional-dampers/).

  We were not aware of this technology. Based on our current understanding, it appears to be a device designed to mitigate peak loads and torsional oscillations. However, it does not seem to provide measurements of these loads. Without in-depth knowledge of this device, we have elected not to include it in the current article. Nevertheless, we will investigate this suggestion further to better understand its capabilities.

- **lines 109-111: the statement appears not substantiated in the manuscript. Please consider removing.**

  We agree and have removed the statement from the explicit contributions of the article as this comment aligns with the comments from Referee #1. We have reworded this statement, out of the contributions, to emphasize the potential applications of torque measurements for consumed life estimation and operational deflection shapes as an indicator for fault detection. The conclusions section has also been slightly modified to emphasize this remark.

3 Subspace system identification framework:

- It appears this section is on the methodology not a framework, please rename the section title accordingly.

  We agree and have changed the title to be more precise. The new section title is now "Formulation of subspace system identification method".

- line 121: is "estate" a typo? Please double check.

  Corrected.

- line 127: is "innovation signal" supposed to be "excitation signal"?

  We have chosen a so-called innovation state-space representation described in equations 1 and 2. This can be derived from a general state-space representation with process and measurement noise. The excitation signal is the input signal $u(t)$. The term innovation signal refers to $e(t)$ as defined in line 127. We have modified this section, starting with a general state space representation and explicitly explaining how the influence of the unknown input $u(t)$ is modeled inside the extended system matrix $\bar{A}$. The innovation representation is introduced later for identification purposes.

- line 150: please define variables in Eq. (6).

  We agree that the variables A^{sys}, A^{b} and A^{per} were not properly defined and we have added their definition to the revised manuscript.

4 Experimental setup:

- **line 222: is the proposed sensing technology supposed to be robust and easier to commercialized?**

  We believe it is, as discussed in the introduction, fiber-optic sensing is already extensively used in other wind turbine components like blades. Fiber-optic sensors based on FBGs have a proven track record and have been commercially available for a long time. Interrogator technology is evolving rapidly, and promising developments may reduce their costs, making them more attractive. Regarding robustness, we are very satisfied with the performance of the sensors. This was one of the key items in a recent extensive field validation campaign, which we wish to publish soon.

5 Identification of operational deflection shapes:

- line 317: please add a brief explanation on model validation not considering Kalman filter.

  We have added a sentence to make it more clear how we are using the one-step-ahead predictor defined in Equation 10 without the Kalman filter. Without the Kalman filter the states of the system are defined only by system matrix and the initial conditions. That it why we consider the behavior as an autonomous system oscillating from a non-zero condition. Because the identified damping for all deflection shapes is very small, the modules of all states show very little variation (Figure 13).

- **page 24, Figure 17: please consider adding a comparison against torque estimated using SCADA data.**

  We don't fully understand this comment. In the test bench used for the experiments presented in the article, the test bench SCADA uses the signals from the torque transducers installed between the high-speed shafts of the gearboxes and the electric motors. In Figure 17, we already plot the "Test bench torque sensors" from the torque transducer signals as the mean of the equivalent torque at the low-speed shaft.

6 Conclusions:

- **Plese add a brief discussion on the potential impact, in terms of both commercial and R&D, of the presented methodology.**

  We agree and have added a sentence to emphasize the benefits for a fleetwide implementation in commercial wind turbines and also the use during validation of new products.

Again, we thank the reviewer for the positive feedback.