Sensitivity analysis of wind turbine fatigue reliability: effects of design turbulence and the Wöhler exponent (Manuscript number: wes-2023-47)

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Response letter to referee #2 comments (Manuscript number: wes-2023-47):

We would like to thank the reviewer for the positive feedback and for helping us improve the work by sharing important thoughts and comments. All comments are addressed, and a revised version of the article is prepared. In the following, all comments from reviewer #2 are mentioned, with the response from us after each.

Comments and responses:

'This is a very well documented study, which is of value to the community and of particular practical relevance. My only comments refer to minor clarifications, as follows:'

- Figure 1 is necessary, but somehow overly simplified. Consider enriching it to fully account for the procedure and the parameters/variables involved in the simulation.

This is a very fair comment. Thank you. Figure 1 is now updated and moved to the beginning of the 'methodology' section.

- In order to carry out a parametric analysis, the study has to be framed within a very specific context. It would be good to summarize in one position all of the simplifying assumptions made and how these may impact generalization of the outcomes (e.g. only blade flapwise and tower base fore-aft load channels considered - would considerations exist for further quantities? what is the effect of using FORM?).

Some additional results are added for the case of Siemens 2.3MW and The limitations for generalization of the results are added within a specific context to the 'Discussion section' as below points:

'

1. *Design class of the wind turbine: The thickness of the tail in the lognormal distribution is dependent on its standard deviation. The standard deviation of the distribution in different cases of NTM is a function of the reference turbulence level (see Eq. (3) to Eq. (8)). This means that there is a possibility that the results of the current study change with the wind turbine class. One case of lower reference turbulence intensity equal to 0.1 is tested in the current study showing the same trends. However, we encourage similar studies on different classes of wind turbines to track the possible differences in the trends and results. In addition, the annual mean wind speed is shown to influence the variability of the long-term fatigue loads and thus, overlap between different cases of the study. We suggest further studies on the lower mean wind speeds and the combination of the class with other changes.*

2. *Additional averaging of data in case of full distributions: A potential concern with the results is the difference in sample size for the different cases. There are more 10-minute simulations involved in estimations in cases 2 and 3. A larger sample size naturally decreases the variance in the $DEL_{lifetime}$ evaluations due to the law of large numbers (see (Mozafari et al., 2023) for more details). To investigate whether this is significant, we checked the effect by using different combinations of seed numbers, and the corresponding effect on the trends is negligible. However, we encourage testing of different calculation approaches to track any possible changes in the variability of fatigue loads in cases of using full distributions of the turbulence.*

3. *Other load cases: Among the standard design load cases related to fatigue, idling, and power production with fault also include the Normal Turbulence Model in the IEC standard. It is valuable to perform the same study considering these other load cases and their corresponding probabilities. In addition, considering all relevant load cases for fatigue (including shutdowns and start-ups) can change the long-term fatigue distributions and trends and should be considered in future studies.*

4. *Specificity of the wind turbine response: The main study uses the DTU 10MW wind turbine as the case study. The size and design of the wind turbine and its controller's design affect the turbine's response to a specific wind input. The Siemens 2.3 MW wind turbine (with a smaller size) but similar controller and class is checked, and the results show the same trends in distributions of the long-term fatigue load. In future studies, testing other wind turbines with a different type of controller and also using other aeroelastic simulation tools is beneficial.*

5. *Variability of the material properties and damage accumulation rule: The coefficients of variation: The variability of the initial material fatigue strength and Miner's rule are taken from the literature. Updating these two inputs can change the levels in the sensitivity analysis.*

6. *Variability of the fatigue loads: The only variable in defining the fatigue loads is the variation in the turbulence inputs; while this elaborates the shares of load uncertainty due to this specific variation, the sensitivity results can change when considering other sources of uncertainty on the load side.*

7. *Method of reliability assessment: The first-order reliability method performs well in very low probabilities of failure and less accurately in higher failure probabilities. Doing the same reliability analysis using Monte Carlo instead of FORM can provide more accurate reliability estimates if computational resources are available (see appendix for a detailed explanation regarding computational expenses of MC).*

8. *Offshore versus onshore: The study contains aeroelastic simulations with only wind inputs (onshore case study). However, in the case of offshore, the effects of wind turbulence on the structure response change, especially in the case of tower loads. Thus, we recommend performing the same study for offshore cases to investigate the possible changes in the trends.'*

- Moreover, how does this choice of a specific model (e DTU 10MW is an offshore wind turbine from IEC standard class 1A, IEC 61400-1, 2019) impact the generalization of results to further typical designs?

The change in the response of the wind turbine due to turbulence change depends on the controller. In addition, the turbulence class defines the benchmark scenario. These two aspects are emphasized again in the discussion now (points #1 and #4 above)

- How is the negligence of the start-up or shutdown events expected to impact the overall computation. Is a separate study dedicated to these short-term by high impact effects perhaps meaningful on this issue in the future?

This relevant point is added to discussion point #3 now. Thank you for mentioning.

- It is appreciated that further simulations are executed for sanity, e.g., " We re-performed the study for a lower reference turbulence intensity more suitable for offshore cases (0.1) and the trends were the same in terms of DEL distribution biases". However, these should be reported (e.g., in an Appendix).

This is a fair comment. The results for one example case (Tower base with m=3, all cases), are now added to appendix (Figure A1).

- For ensuring transparency and contributing toward open science, it would be meaningful (and highly valuable) for the authoring team to additionally publish the generated dataset and make it openly available.

This is a very good suggestion. The data is now uploaded to Gitlab with the link below:

Paper3 · main · Shadan Mozafari / PhD research papers · GitLab (dtu.dk)

However, the data for Siemens check case are not added to the above folder because of confidentiality.

- It would be helpful to comment in the Conclusions section, how the design of (simulated) experiments may influence the drawn conclusions and to elaborate on the aspects that could be refined/improved in future/further studies.

Thank you for your fair comment. This is now added to the conclusion ending. However, a more detailed explanation is added to the discussion section (mostly focused on point #2 in the discussion).

Minor Comments

- I very much appreciate the clear and concise writing style. Some (few) typos are present and it would be important to conduct a thorough proofreading for catching these and further ensuring a consistent notation for the symbols used in equations.

Proofreading is done again. Thank you.

- It would be good to ensure that brackets have a size that is appropriate to the enclosed quantity every time (e.g. for fraction, they should be bigger)

Applied and revised now.

- From an aesthetics point of view, it would be preferable for font types and sizes to agree with the caption style and size.

Thank you very much for your attention and valid comment. We fully agree with you. However, all the font and styles are based on the journal template setups.