To:	Referee #3
Subject:	Detailed response to suggestions for revision or reasons for rejection
From:	The authors
Date:	August 16, 2024

Many thanks for your detailed comments and questions regarding our Brief Communication. In this response, we have included your comments/questions (black font, italics) followed by our response (red font). When references are used, they can be found in the submitted revised manuscript or full citations are given in this response.

Please note that on January 19, 2024, the authors provided a detailed response (12 PDF pages) to the reviewers' comments and questions. The response is archived as AC1 on the discussion tab of the paper's webpage entry. Note that while the paper was submitted as a Research article, it was re-classified as Brief communication by WES prior to review, which limits the number of pages we can use. Whenever a point you raised has significant overlap with the January 19 response to reviewers #1 and #2, we indicate so by citing Author's Response AC1. Note also that on February 29, 2024, a revised paper version (with tracked changes in blue font) was uploaded after major revision decision from the first round of reviews. Currently, this first revised paper is not publicly available in the discussion section of WES, but we assume this version is the one you've reviewed.

Reviewer: "The paper presents an extremum-seeking control (ESC) method to estimate the optimal tip-speed ratio. The application is well-suited for degraded blades. The topic is interesting and relevant for readers of Wind Energy Science. The paper is clear and well-written. I have some comments regarding the methodology. Typically in below-rated wind region, the K-omega2 law is used to maximise the power. Please see ([1], Section 3.1). In the paper, a PI tip-speed ratio/rotor speed set-point tracking controller is used, where the rotor speed set-point is computed by the estimated tip-speed ratio by ESC and the rotor-averaged wind speed. There are shortcomings and contradictions with this method, particularly with the assumption of a degraded blade."

Authors: Thank you for noticing the clarity and well-written exposition of our paper. We agree with you that the K-omega2 law is an appropriate control law to maximize power. For this reason, we have first published the use of LP-PIESC for tunning the torque gain parameter K in Kumar and Rotea (2022; DOI: 10.3390/en15031004). The purpose of the current Brief was to demonstrate that LP-PIESC can also be used to estimate other controller parameters (in this case we chose TSR set point) besides the torque gain parameter K.

Reviewer: "My concern is regarding the rotor-averaged wind speed, which could be obtained from an estimator, as suggested in the paper. But with the assumption of blade degradation, the aerodynamic properties (Cp surface) in the estimator model would be different to the ground truth. Thus, the estimated wind speed would be inaccurate. See [2]. Even though the tip-speed ratio can be accurately estimated by ESC. There is still a need to correct the estimator model, taking into account the degraded blade aerodynamics, to provide an accurate wind speed. This shortcoming wouldn't exist if the K-omega2 law was used in the first place. Perhaps the authors could include some discussions regarding the choice of K-omega2 law and tip-speed ratio tracking torque controller."

Authors: Your concern is warranted. There is no point in identifying the correct TSR set point if the estimated wind speed used to compute the actual generator speed set point is wrong. This would be the case if any wind speed estimator/observer uses the power coefficient without any correction for blade degradation. This is why, as stated in line 85 of the Brief communication we said: "*In our simulations, ROSCO takes wind speed estimate \hat{v} from the rotor disk average (RtVAvgxh) calculated by OpenFAST*." While this is not practical in a real application, we did this to eliminate the use of any observer parameters that could change with blade degradation. In this way, we can demonstrate how LP-PIESC can identify the correct TSR in an ideal scenario. Due to space limitations, we are not able to expand on [2] and other recent references that have the potential to circumvent this problem using machine learning or sensors. A statement to clarify this point has been added in red font after line 85, which also addresses your question "*on how to obtain the wind speed estimate in real life, especially with a degraded blade.*"

Reviewer: Other comments:

1. "Literature studies on extremum seeking control, especially its application in wind energy, are lacking. I think it is important as this is a paper about using ESC. For example, [3] is one of the earliest used ESCs in turbine control. The study [4] used ESC in a large-eddy simulations. [5] performed a full-scale test with ESC. [6] proposed LiDAR-assisted ESC without knowledge of optimal tip-speed ratio."

Authors: Please note that [3] was already cited in the Brief. We have included (see additions in red font) [3] and other existing references in the introduction as well as [4,5,6].

2. "*Page 3. In this architecture, both the generator torque (τg) and the blade pitch angle (β) are governed by PI controllers." As discussed above, please elaborate on why the K-omega law was not used."*

Authors: As mentioned above, LP-PIESC for the K-omega^2 law is already published in Kumar and Rotea (2022; DOI: 10.3390/en15031004).

3. *“Page 3. “In our simulations, ROSCO takes wind speed estimate ˆ v from the rotor disk average (RtVAvgxh) calculated by OpenFAST.” Based on the discussion above, please comment on how to obtain the wind speed estimate in real life, especially with a degraded blade.”*

Authors: A practical (but potentially expensive option) would be to use a LIDAR as done in [6], which is a reference you provided. Alternatives based on machine learning techniques (such as [2]) are being proposed also but their practical application is not known to the authors. Please see the statement added in red font after line 90 of the second revision.

4. “*Page 6, Line 140. Please add some text to describe section 3 and section 3.1.*”

Authors: Thank you for the suggestion. Additional text has been added in red font.

5. *“Figure 6. I can see there is a sine wave on the tip-speed ratio, which is caused by the dither function in the ESC? If so, the generator torque tracking a sinusoidal tip-speed ratio will also exhibit the sinusoidal behaviour? Can you comment on that? Maybe with a frequency spectrum of the generator torque.”*

Authors: The time series of the generator torque is shown in Fig. 7 of the paper for the contaminated blade case. The spectrum of this signal after LP-PIESC is turned on (500 s) is shown below. The peak at the dither frequency (0.025 Hz) is clearly seen, but it is not the largest peak. This peak can be eliminated if the dither is turned off with an appropriate stopping criterion. We have not done this in the present paper; incorporating an appropriate stopping criterion is left for future work. Due to space limitations, we are not including the spectrum in the paper, but added a brief statement (red font) in the conclusions section of the revised paper.

References

[1] Abbas, N. J., Zalkind, D. S., Pao, L., & Wright, A. (2022). A reference open-source controller for fixed and floating offshore wind turbines, Wind Energy Science, 7, 53–73, https://doi.org/10.5194/wes-7-53-2022

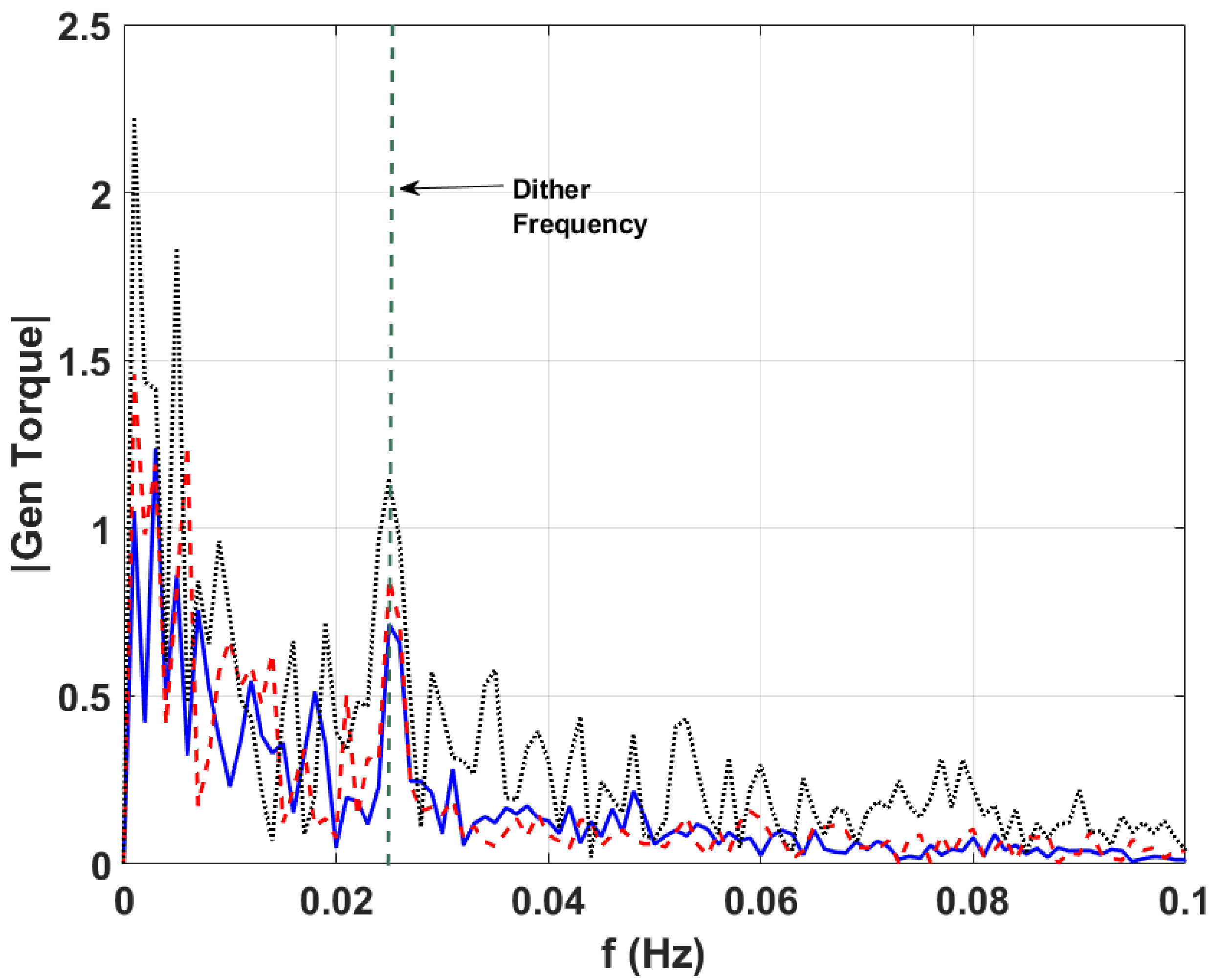
[2] Lio, W. H., Li, A., & Meng, F. (2021). Real-time rotor effective wind speed estimation using Gaussian process regression and Kalman filtering. Renewable Energy, 169, 670–686. https://doi.org/10.1016/j.renene.2021.01.040

[3] Creaby, J., Li, Y., & Seem, J. E. (2009). Maximizing wind turbine energy capture using multivariable extremum seeking control. Wind Engineering, 33(4), 361–388. https://doi.org/10.1260/030952409789685753

[4] Ciri, U., Rotea, M., Santoni, C., & Leonardi, S. (2017). Large-eddy simulations with extremum-seeking control for individual wind turbine power optimization. Wind Energy, 20(9), 1617–1634. https://doi.org/10.1002/we.2112

[5] Xiao, Y., Li, Y., & Rotea, M. A. (2019). CART3 Field Tests for Wind Turbine Region-2 Operation with Extremum Seeking Controllers. IEEE Transactions on Control Systems Technology, 27(4), 1744–1752. https://doi.org/10.1109/TCST.2018.2825450

[6] Meng, F., Lio, W. H., & Larsen, G. Chr. (2022). Wind turbine LIDAR-assisted control: Power improvement, wind coherence and loads reduction. Journal of Physics: Conference Series, 2265(2), 022060. https://doi.org/10.1088/1742-6596/2265/2/022060



To:	Referee #4
Subject:	Detailed response to suggestions for revision or reasons for rejection
From:	The authors
Date:	August 14, 2024

Many thanks for your detailed comments and questions regarding our Brief Communication. In this response, we have included your comments/questions (black font, italics) followed by our response (red font). When references are used, they can be found in the submitted revised manuscript or full citations are given in this response.

Please note that on January 19, 2024, the authors provided a detailed response (12 PDF pages) to the reviewers' comments and questions. The response is archived as AC1 on the discussion tab of the paper's webpage entry. Note that while the paper was submitted as a Research article, it was re-classified as Brief communication by WES prior to review, which limits the number of pages we can use. Whenever a point you raised has significant overlap with the January 19 response to reviewers #1 and #2, we indicate so by citing Author's Response AC1. Note also that on February 29, 2024, a revised paper version (with tracked changes in blue font) was uploaded after major revision decision from the first round of reviews. Currently, this first revised paper is not publicly available in the discussion section of WES.

Some of your comments below (including references to Figures) lead the authors to believe that your review makes reference to issues in the original manuscript, which is publicly available in the discussion section as https://doi.org/10.5194/wes-2023-144. As stated in the above paragraph, the first **revised** version (dated February 29 by the publisher) of the paper is not currently publicly available, but we assume you have access to it and cite it below in our response to your comments.

Reviewer: "This paper presented a wind turbine torque controller that can track an optimal/suboptimal TSR value for below-rated region due to the change of the blade aerodynamic properties over time. A novel LP-PIESC scheme is proposed to calibrate the TSR set point value.

There are numerous other works have been done in this field. For example, there is one work here (https://dx.doi.org/10.1088/1742-6596/2265/2/022060), and another work investigated the wind speed estimation, which should be considered as a fundamental *base in order to make the LP-PIESC algorithm work. (10.1088/1742-6596/75/1/012082). Those previous studies should be included in the literature study part."*

Authors: The first reference is relevant and has been added as suggested also by reviewer 3. The second reference uses the power coefficient Cp to obtain the wind speed, which is not desirable in our context due to the changes in Cp under blade degradation. Blade degradation can also affect the parameters used in the observer to estimate aerodynamic torque. (See section 3 of 10.1088/1742-6596/75/1/012082 for further details)

Reviewer: "Furthermore, I think that the major contribution of this paper is the LP-PIESC scheme, which supposedly can provide faster convergence.

I have the following general comments:

1. *The LP-PIESC scheme is not well described;*
2. *The tuning procedure of the scheme is not well explained;*
3. *How is the gradient obtained?*
4. *How will the novel LP-PIESC work without the wind speed estimation or, as the author mentioned, without the pre-knowledge of physical model?"*

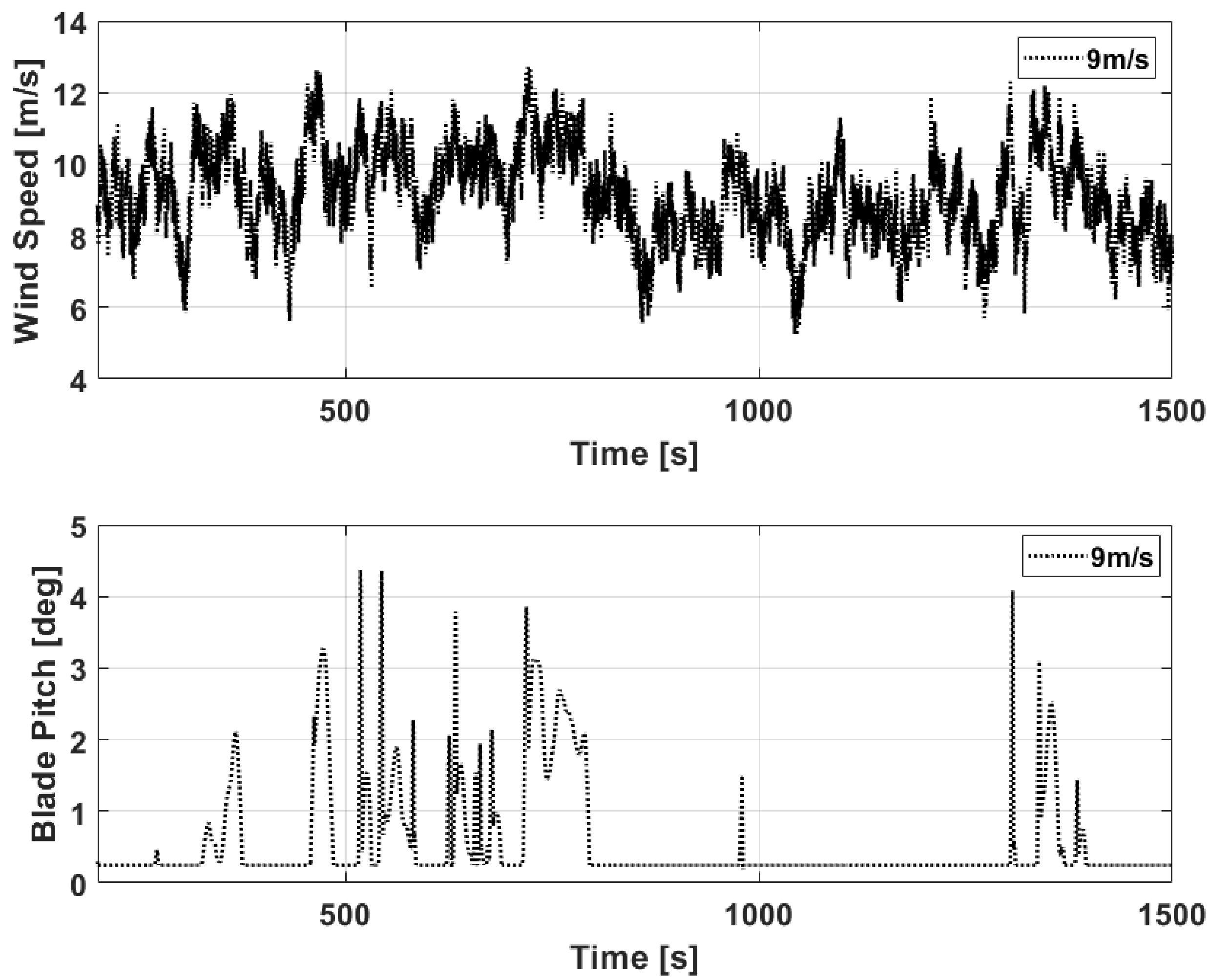
Authors: We believe that these points were already addressed in the first revision of the paper dated February 29. A description of the LP-PIESC was provided in section 2.3 and appendix A. The tunning procedure is simulation based; this was explained also. However, given your comment in item 2, we provide more details about tunning at the end of appendix A. Point number 3 has already been addressed in the first revision of the paper – see appendix A.

Item 4 is important. There is no point in identifying the correct TSR set point if the estimated wind speed used to compute the actual generator speed set point is wrong. This would be the case if any wind speed estimator/observer uses the power coefficient without any correction for blade degradation. This is why, as stated in line 85 of the Brief communication we said: "*In our simulations, ROSCO takes wind speed estimate \hat{v} from the rotor disk average (RtVAvgxh) calculated by OpenFAST*." While this is not practical in a real application, we did this to eliminate the use of any observer parameters that could change with blade degradation. In this way, we can demonstrate how LP-PIESC can identify the correct TSR in an ideal scenario. Due to space limitations, we are not able to expand on this issue, but we recognize that the use of sensors (e.g., LIDAR) or recent advances in machine learning could produce accurate estimates of wind speeds without using model parameters that can change with blade degradation. A statement to clarify this point has been added in red font after line 90 of the second revision. Note that our emphasis is providing empirical evidence to support the claim that LP-PIESC can find important turbine parameters such as optimal TSR or the torque gain in the k-omega^2 control law (see https://www.mdpi.com/1996-1073/15/3/1004). Such evidence justifies continued research on the use of ESC-like methods to adapt turbine parameters when changes happen.

"Reviewer: Some more detailed comments:"

• *"In Fig. 8, the LP-PIESC controller is turned on at 500s, and then it seems to converge to a value of tip-speed-ratio not the same as the TSR set point. What does this happen? Can you explain this?"*

Authors: For the reasons given in this reply, the authors do not know which Figure 8 you are referring to (original manuscript or revised version 1 from February 29). Having said that, none of the figures show lack of convergence when the turbine is below rated wind speeds. The drops you see in the actual TSR (and Cp) occur at wind speeds above rated. In this case, the ROSCO activates the pitch controller as shown in the paper (Figure 7 of second revision) and also in the Figure below.



• *“Figure 7 only shows the time series of wind speeds at 7, 8 and 9 with TI = 10%, and it does not bring more added value to the paper. So please consider removing it.”*

Authors: This is not correct. Figure 7 (first revision) shows key turbine time series: Generator speed, Generator Torque, Power and Blade Pitch time series. The original manuscript does have wind speeds in former Figure 7, but the original manuscript is not the one that should be reviewed in the second round. Your review is a second round and should be based on the revised manuscript we submitted on February 29, 2024.

• *The LP-PIESC algorithm is not described clearly even with the help of Figure 5, it is not clear how the gradient estimation is performed.*

Authors: Again, you are referring to the original manuscript. Figure 5 with the block diagram of the LP-PIESC algorithm has been deleted in the revised manuscript submitted on February 29. The algorithm description is in section 2.3 and appendix A of the revised version. Presumably you also read the author’s response AC1 at https://doi.org/10.5194/wes-2023-144-AC1.

• *Some of the symbols in the Fig. 5 are not explained, which raises many questions to the reader/reviewer to accept the theory soundness of this algorithm. For example, what does θ represent? This is an important parameter of your algorithm. Please explain this*

Authors: Again, your comment applies to the original manuscript, which is the wrong version to review in the second round. The block diagram of the LP-PIESC was removed after the first review, and replaced with equations and explanations in the main text and the appendix.

• *Section 2, the author mentioned "The algorithm is gradient-based, which can adjust the tunable parameters to maximize a system’s performance index in real-time without any physical models." I think this is not true. The ROSCO controller, which the author couples to, contains the wind speed estimation, which requires the pre-knowledge of physical models. Please explain this.”*

Authors: We have addressed this comment already. See the response to your second comment, item #4. See also also the author’s response to first round of reviews AC1 at https://doi.org/10.5194/wes-2023-144-AC1