wes-2021-144- Responses to Anonymous Referees 1, 2, and 3 Comments

	Reviewers' comments	**Reply to the editor**
Anonymous Referee 1	1. The authors have presented the methods and applied and demonstrated that for a mean wind speed of 18 m/s. However, 18 m/s is not the wind speed that would cause the most fatigue damage and the occurrence probability is relatively low. Therefore, the authors should add/replace results from mean wind speeds that are more representative to demonstrate the capability of the controllers. It would be necessary to show the behaviour of the wind turbine under rated wind speed. Here it can be seen how the controllers will perform in this transition region when the wind speed can be below rated and above rated. This can be used also to demonstrate and validate the switching behaviour that the authors mentioned in the manuscript.	The stochastic wind profile with very high turbulence intensity (17%) has been used to demonstrate the robustness of the controller around the transition region (10-14 m/s) as well as around the cut-off wind speed (23-28 m/s), as illustrated in Fig. 5a. It is true that occurrence probability for high mean wind speeds is relatively low. However, the object of this contribution is to demonstrate the ability of the controller to adapt to the prevailing state-of-health (estimated lifetime), which is more applicable in high wind speed region due to high structural loading. Performance of the lifetime controller below the rated wind speed and transition region is not the object of this work. Therefore, we refer to another work of our group (Do and Söffker 2020). Robustness of the controller has been demonstrated. Additionally, will be proven using a near-rated stochastic wind profile (mean wind speed- 14 m/s, TI- 13.8 %), which has a higher occurrence probability.
	2. The switching behaviour and implementation in the controllers as mentioned in the manuscript	We understand the reviewer's interest. An additional figure and an accompanying explanation will be included to illustrate the switching behavior.

	should be described with more details.	It is important to note that two levels of switching are implemented. The first level, which is used for switching between different IPC controllers is defined based on the incoming hub-height stochastic wind speed, in which predefined wind speed bins (see Table 2, column 3) are used for thresholding and or activating a suitable IPC controller, as stated in L211-212. The second level of switching is for adapting the full-state feedback and observer gains of the lifetime controller (aIPC) based on the estimated lifetime of the blades to achieve the targeted lifetime, as explained in L228-234. Related additions will be given in the revised manuscript.
	3. Another question that needs to be clarified is whether the constant switching of the controller will cause additional dynamics to the response of the wind turbine. Especially when the wind turbine is operating in the transition region.	Constant switching is introduced to mitigate periodic loading of the blades due to wind shear using independent pitch signals while targeting a predefined damage level. On the contrary the transient response of the wind turbine is improved by switching between appropriate controllers in response to wind speed variations, as stated in L 211-212. Although the proposed lifetime controller has been demonstrated to work satisfactorily in the transition region, it must be stated that switching response between regions 2 and 3 neither is nor was the goal of this work.
	4. The performance of the controller for the given turbine shown in Figure 8 of the manuscript seems to indicate that the rotor speed can deviate as much as 20% from the rated rotor speed (20 rpm) and the power can deviate more than 30% from the rated power (1500 kw). This is usually not possible as the	An IEC Type A stochastic wind profile, shown in Fig. 5a, with very high TI of 17 and a mean wind speed of 18 m/s is used to excite the closed-loop dynamic response of the wind turbine. This high value of TI has a realistically low occurrence probability in most turbine sites. It drives the dynamics of the wind turbine in speeds above the cut-off wind speed of 25 m/s, at which point the HSS brake should be deployed to avoid overspeed and exceedance of electrical limits of the generator.

	overspeed protection will kick in as soon as the rotor speed is more than 110% of the rated rotor speed. The same would be applicable to the power since the generator protection will kick in to protect the overheating of the generator. Therefore, the controller should be retuned to meet the standard performance requirements regarding overspeed and power deviation.	Due to the theoretical character of this kind of work, the HSS brake is disabled for simulation. Enabling it should remedy this problem. It is expected that dynamic simulations with more realistic wind profiles (lower TI and wind speeds) will not manifest this challenge. Having mentioned this, the lifetime control scheme shows better rotor speed and power regulation compared with RDAC controller (without lifetime control in aIPC). This is observed since the lifetime controller actively switches between defined levels of load mitigation and speed regulation trade-off based on the estimated lifetime. See L241, Fig. 5b. An additional statement for the interested reader will be given in the improved manuscript.
	5. In Table 2 and in the text, the authors use the steady wind speed and prevailing wind speed to decide the switching of the controller that were tuned for different wind speeds. How are these wind speeds defined and how are they calculated in a continuous operation of the wind turbine, especially if one takes into account that the stationarity assumption of the wind does not really apply in reality.	It is important to note that the steady wind speeds given in Table 2 column 3 (together with associated pitch angle and rated rotor speed) are only used as operating points for extracting linear state-space models used for designing each of the five IPC controllers. However, a stochastic wind profile with a mean wind speed 18 m/s and TI of 17 is used for simulating the closed-loop dynamic response of the wind turbine. Predefined wind speed bins (column 2) are only used for thresholding based on the prevailing/ incoming wind speed (i.e., the hub-height wind speed of the stochastic wind profile) to establish an appropriate IPC controller to be utilized in continuous operation. It is important to mention that the assumption that hub-height wind speed is precisely known is not realistic, however, since this is only used realize switching between different controllers in aIPC controller, inaccurate anemometer measurements should suffice.

		Suitable additive formulations are added into the contribution.
	6. The authors have considered the flapwise bending moment for the blade, while the edgewise bending moment also play an important role in the fatigue damage of the blade. One should consider the total bending moment of the blade for the estimation of the fatigue damage. The same should apply also to the tower fore-aft and side to side bending moment.	Yes, this is correct: blade edgewise and tower side-side bending moments contribute to the total fatigue damage of the blades and tower, respectively. This is an interesting additional idea, which falls outside the claim of this contribution. However, the novelty of this work is to demonstrate the application of lifetime estimation of wind turbine components as a state-of health indicator to establish a trade-off between load mitigation and speed regulation, which guarantees a given damage at a desired lifetime (10 minutes in this case). Although the concept has been demonstrated using one damage scenario in each component, this can be expanded to incorporate other fatigue driving loads. In this contribution, blade flapwise and tower fore-aft bending moments are chosen since they are the main structural loads that drive fatigue damage of respective components in above-rated turbine operation. It is unfortunate that we could not to include these ideas in this contribution, but we will consider this in our next research. Thank you for the idea.
	7. The wind field used for the validation of the method is not described sufficiently. It is not clear whether the stochastic wind field is coherent over the rotor plane and the question remains whether one single realization of the stochastic wind field is representative enough to	The stochastic wind profile used in contribution is not coherent over the rotor plane. The wind field properties include a mean wind speed of 18 m/s with a TI of 17. It has vertical wind shear with a power law exponent of 0.2. Additionally, changes in wind direction simulate yaw misalignment. While a single wind profile might not be sufficient to demonstrate the robustness of the control scheme, a wind speed with 18 m/s (in between cut-in 12 m/s and cut-out 25 m/s wind speeds) and corresponding high TI is chosen to cover most operating conditions in the above-rated regime.

	demonstrate the robustness of the controller.	However, this might not be fully representative. An additional near-rated stochastic wind profile (as mentioned before) will be included to demonstrate this robustness. Related results and information will be added to the contribution.
Anonymous Referee 2	The submitted paper proposes a new approach to include an optimized lifetime consumption calculation as an integrated part of a control strategy to mitigate the loads on rotor blades and tower. After a very detailed description of standard fatigue calculation methods, the integrated control approach is presented, which is based on a Robust Disturbance Accommodating Controller (RDAC), published in previous papers by the authors. As a reference turbine, the NREL 1.5 MW model has been chosen, the simulation tool is FAST. Linearization around several operating points above rated wind speed is proposed, for each of these points the controller is optimized, with switching mechanisms foreseen to allow a realistic operation under changing wind conditions. The results of the controller implementation are presented for	Thanks to the reviewer for summarizing our work.

	an average wind speed of 18 m/s and demonstrate that for both the blades and the tower the accumulated fatigue damage can be reduced simultaneously, claiming to have no negative effects on the power performance.	
	While the overall approach of this paper shows impressively the potential of improved controller schemes taking into account lifetime consumption, some details need to be clarified. In the description of the NREL turbine models it is mentioned that the number of degrees of freedom is reduced, here the author should be more specific and explain their decision.	The assumption made was that by simply stating the states included in the linear model in Eq. 4, L 141-142, one would directly know which DOFs are enabled. The reasons for selecting the states related to the DOFs are given in L 138-139 as structural load reduction in the blades and tower as well as rotor speed regulation. We will modify the related text in the paper to help the reader to understand that.
	It is not clear what type of wind model is used and why the analysis is limited to just 18 m/s average wind speed. Showing the impact of more relevant lower wind speeds around rated and demonstrating the switching mechanism would be interesting.	The IEC von Karman stochastic wind profile (generated in TurbSim) having type A turbulence characteristic is not coherent over the rotor plane. The wind field properties include a mean wind speed of 18 m/s with a TI of 17. It has vertical wind shear with a power law exponent of 0.2. Simulation results obtained using a near-rated stochastic wind speed (mean wind speed- 14 m/s, TI- 13.8 %) will be included and related statements given. It is important to note that two levels of switching are implemented. The first level, which is used for switching between different IPC controllers is defined based on the incoming hub-height stochastic wind speed, in which predefined wind speed bins (see Table 2, column 3) are used for thresholding and or

		activating a suitable IPC controller, as stated in L211-212. The second level of switching is for adapting the full-state feedback and observer gains of the lifetime controller (aIPC) based on the estimated lifetime of the blades to achieve the targeted lifetime, as explained in L228-234. A figure and an accompanying explanation will be included to illustrate the switching implementation.
	It is pretty obvious that directly related load components as flap-wise for the blade and fore-aft for the tower correlate in their behavior. Also taking into account the edgewise loads and the related tower movements would complete the picture.	This is an interesting additional idea, which falls outside the claim of this contribution. While blade edgewise and tower side-side bending moments contribute to the total fatigue damage of the blades and tower, respectively, this work seeks to demonstrate the application of lifetime estimation of wind turbine components as a state-of health indicator to establish a trade-off between load mitigation and speed regulation, to guarantee a given damage at a desired lifetime. Although one damage scenario for each component has been used to demonstrate this, the idea can incorporate other fatigue driving loads. In this contribution, blade flapwise and tower fore-aft bending moments are chosen because they are the main structural loads that drive fatigue damage of respective components in above-rated turbine operation. Thank you for the idea. Unfortunately, we did not consider these ideas in this contribution. This will be considered in our future work. Related statements will be added to the manuscript.
	The very high dynamics of the torque/speed signal need to be explained.	The stochastic wind profile used in this contribution has a very high TI of 17 and a mean wind speed of 18 m/s. This high value of TI realistically has a low occurrence probability in most turbine sites. It drives the dynamics of the wind turbine in speeds above the cut-off wind speed of 25 m/s, at which point the HSS brake

		(which is not simulated in this work) should be deployed to avoid overspeed and exceedance of electrical limits of the wind turbine. It is expected that dynamic simulations with wind profiles having higher probability of occurrence (lower TI and wind speeds) will not manifest this challenge. Therefore, simulation results obtained using an additional near-rated stochastic wind field will be included.
	The baseline control strategy for the comparisons needs to be described in more detail – is it RDAC with or without IPC?	The baseline controller is the RDAC without lifetime control in aIPC (i.e., only switching based on incoming wind speed). This clarification will be made in the content. Both the RDAC and aIPC controllers have been described in detail in section 3.2. We will add related statements to make this clearer to the reader.
	To compensate for some more additional results, the introduction can be shortened by referring to standard literature instead of explaining in detail the basics of fatigue calculation.	We thank the reviewer to get the ability to shorten the text here.
	Some spelling errors should be eliminated, e.g. guarantee instead of guaranty etc.	The paper is written in American English, hence, there is no need to change this. Independent from that, we will additionally check the text again.
Anonymous Referee 3	The paper presents a suggested adaptive control strategy that could be applied to limit the fatigue damage accumulation in selected wind turbine components, for the wind speed range where the turbine control is based on pitch regulation. The paper shows how the suggested controller strategy successfully limits the loads in a	We thank the reviewer for giving their overview of our contribution and pointing out its limitations. To address this, responses to the specific comments are given below.

	few scenarios, however it fails to show the overall significance of the new strategy with respect to the entire operating envelope of the wind turbine, and does not show any quantitative assessment of the impacts of applying the suggested strategy. A new version of this paper would need to focus significantly more on the validation and performance evaluation of the suggested strategy. A few clarifying comments are below:	
	I don't think the paper title is correct. There are no prognostics discussed in the paper whatsoever, it is rather load mitigation. Hence I would instead call it "Adaptive control strategy for load-based lifetime consumption control of wind turbines"	The prognostic idea in this contribution is that damage limit for a wind turbine component (rotor blade) is established beforehand and the lifetime controller seeks to arrive at the specified damage after a given lifetime (600 secs) by proactively varying the tradeoff between different load mitigation and speed regulation levels, as explained in L220-230. This tradeoff is achieved using a lifetime estimate (which is the SoH indicator) obtained from an online damage evaluation model, which relies on an online RFC (see section 2.2). Based in the argumentation we believe that the title is a suitable one.
	It is hard to judge the practical significance of this method. It works only for wind speeds above 12m/s, which in reality only occurs about 25% of the time on a typical site.	It is true that a wind turbine will spend most of its operational life in region 2 and that the occurrence probability of wind conditions above 12 m/s is low, at about 0.25. However, considering that at these wind speeds cause higher structural loads/ stress range (focus of this work) as well as a higher number of fatigue cycles (due to higher rotor speed) in the WT components, the overall contribution to damage accumulation is significant. This becomes clear if Eq. 2 and a generic S-N curve is brought to view.

	I suspect that if this approach is also applied at lower wind speeds, the power output may be reduced. These and any other limitations need to be clearly outlined.	For reasons mentioned before, the claim of this contribution is lifetime control of WTs operating in above-rated conditions. However, if this approach is to be considered for lifetime control in region 2, the objectives will have to be modified. Given that the main objective in region 2 is maximum power extraction, which leads torsional variation in the drivetrain, load mitigation in the drivetrain should be considered. Therefore, the proposed strategy can be applied for lifetime control by trading off between LSS/HSS torsional load mitigation and generator torque. To make the limitations of our claim clearer to the reader we will detail this with additional comments.
	There is no quantitative assessment of the performance of the suggested procedure. How much exactly are the loads reduced, what is the increase in the pitch actuator duty cycles, is the behaviour robust and consistent over different realizations? This needs to be shown both for individual wind speeds, but also the total effect over the turbine lifetime needs to be estimated.	We thank the reviewer for suggested addition for quantitative performance evaluation of the proposed control strategy. Standard deviation is used for evaluating load reduction (L245-250). An additional wind field realization will be used to assess robustness of the proposed strategy near-rated wind speeds. DELs will also be used to evaluate its performance over the lifetime of the wind turbine.
	The English needs some checks - there are some spelling issues to correct like “guaranty” instead of “guarantee” but also others	The paper is written in American English, hence, there is no need to change this. Independent from that, we will additionally check the text again.