We wish to thank Mattias for his time and comments on our paper. All his comments were very useful, and he has made some important observations. Replies below are in red text. Changes to the paper are also in red text in the PDF.

Reviewer comments

The research idea and greatest addition of the paper is, as I interpret it, the benefit of a reduced and simplified technical part in combination with the financial aspects of providing secondary frequency control. This inorder to answer the question of how much money could be made, by a wind turbine owner operating its wind turbine in a derated operation, by offering ancillary services in the form of frequency control to the market.

Great work has been done to implement the PJM (but also NRC) performance score, the impact on the profitability could be clarified. The financial analysis leaves a lot more to be desired. More details are needed on the PJM ancillary services market (e.g. more information on how it works in practice, payments received, the ratio between capacity payments and performance payments).

The section about the PJM ancillary services market has been expanded. We also included a reference which examines the PJM regulation market in the context of new generation technologies. We have not repeated much of the referenced text for the sake of brevity.

The approach of combining the technical assessment and financial analysis is interesting but needs further work to represent a substantial contribution to scientific progress. Whilst it is the authors' aim to deliver high-level methods, this is too high-level to be of much value. Furthermore, the paper, as it is presented, would probably be of more value to wind-developers rather than system operators, which is the outlined intention of the authors.

This is incorrect but we have included additional context where relevant (Sections 1.2, 1.3 & 1.4). The primary focus of the paper is system operators. The primary aim of the paper is to make public a granular analysis of wind turbine response when providing AGC. This is currently missing in the published literature and there exist publications based on performance scores calculated from an NREL simulation i.e. not field data. Our aim is to make performance data available for future research so that it can be based on field measurements as opposed to simulations.

The overall aim of the paper is not clearly stated, and seems to change focus from TSO/ISOs to owners of windfarms.

See reply above. This is now corrected.

It would be interesting to see the contribution to: "[1]: Eldrich Rebello , David Watson, and Marianne Rodgers", Performance Analysis of a 10 MW Wind Farm in Providing Secondary Frequency Regulation: The technical difference between the derated operation from a type 3,4 or 5 WT, being pitch based, has no added difference or scientific value. The value of seeing a single turbine compared to the 5 presented in [1] is limited.

We disagree. Although the method of rotor speed control between IEC turbine types is often through blade pitch, there is significant difference in the electrical power delivery method and therefore the measured electrical response. The revised manuscript expands on this point and includes diagrams of IEC Type 3 and 4 wind turbines.

Similar work chapter, sentence 5-14 could be cut completely (due to lack of coherency/power variations/control options and as written erroneous, power electronics) or replaced with wind related frequency control papers. Or even an expansion of the similarities of [1].

We have expanded Section 1.2 to be clearer. Some of these changes were in response to comments from other reviewers.

The Limitations are well thought through, even though it would be interesting to observe the added ware on pitch actuators due to the proposed regulation. This since added maintenance would be a result of the suggested scheme.

We agree however more data is required to comment on this. A more significant problem is that the internal data logging interval on the wind turbine used was 30s. For an accurate measure of pitch travel (in degrees), 1s or better sampling is required.

AS a part of the motivation of the work, it is mentioned that :" *Our work is intended to make operational data public to allow for greater scrutiny by system / grid operators and to give grid operators an unbiased method of comparison between turbine technologies*". The interest should rather be on the owners of the turbines to get operational data, which they could get from wind turbine retailers.

We disagree. As mentioned in the revised manuscript (Section 1.2), there is an inherent conflict of interest in wind turbine OEMs publishing these numbers. Further, turbine OEMs simply comply with system operator rules and are unlikely to participate in an unbiased performance review (as proven by the lack of public data).

CISO is given several abbreviations in the paper and should be "California Independent System Operator".

Corrected.

1.6. Test site and location, would benefit from removing the text regarding the battery. For coherency reasons, since it is not used in the paper at all there is no point in mentioning it (also shown in Figure 3), apart from possibly a last section on Future work in Conclusions.

Revised text. Figure 3 (now Figure 4) also revised.

2.1 AGC filtering section, is interesting but it would be interesting to see how the filter impacts the PJM/RRC-score. Furthermore, Reference article: [2] Rebello et. Al 2018, "Developing, implementing and testing up and down regulation to provide AGC from a 10 MW wind farm during varying wind conditions" for the sizing of the 11 kW standard deviation is not solid. The standard deviation differs greatly depending on location (surface roughness), hub height and average wind speed.

Text revised (See section 2.1). We agree that the standard deviation value calculated is valid only for this turbine in this particular site.

Figure 3 would benefit from adding the AGC filter, updating frequencies of (AGC-signal and T-setpoint).

Revised to include update frequencies.

Table 1. Should contain Test 2*, the clarity of the section is not improved by removing it. That the test numbers are "kept consistent with other project documentation" is not that reasonable for a reader not associated with the other parts of the project.

Revised.

Figure 6. Please separate the "regulation"-earnings into performance and capacity.

Revised.

Regarding Figure 8. The error is always positive, and the regulation region seems to be often way above the power target. What is the main reason for this?

This was an oversight in the figure legend. The error shown is the absolute value of error between the target power and the measured power. The figure is difficult to read when the actual error value is plotted (values are small and therefore misleading).

The nature of the regulation region is due to the nature of the AGC signal used. Note from Figure 6 (b) that the regulation signal is negative more often than it is positive.

The paper appears to assume that delivering 80 kW of regulation in the PJM market means that 80 kW of capacity needs to be reserved (40 kW above and 40 kW below the operational midpoint). However, according to PJM Manual 12 Section 4.4, it appears that this would have been counted as 40 kW regulation rather than 80 kW. Would this imply that the revenues from regulation presented in the paper should be divided by 2?

You are correct. The source of our confusion was Exhibit 14 on page 51 of PJM manual 12. The revenue numbers are now revised but the reduction is less than 50%. This is due to slightly increased income from the energy market.

The underlying reason for the financial calculation in the paper appears to be to compare the lost energy-market revenues due to curtailment to the revenues that would have been obtained from the PJM regulation market if the wind turbine sold regulation as often as feasible. However, since the PJM market co-optimizes energy and ancillary services, it should be possible to offer the wind turbine to the market in such a way that regulation bids would clear only during hours when it is more profitable than selling energy (assuming zero marginal cost for the incremental energy bid).
Therefore, would it not have been more interesting to investigate how often regulation bids would have cleared and how much extra revenues this could generate?

This is a valid question but is unfortunately beyond the scope of this paper. We choose to focus primarily on making time-series performance data public. The regulation market income calculated in this paper represents and upper limit on the possible income from the regulation market. This follows from assumption #5 in Section 4.1 i.e. the turbine's regulation market bid is always accepted when it is able to provide regulating power.

From the PJM manuals it is unclear whether PJM would accept the methodology for calculating the performance score outlined in the paper. The default operational midpoint appears to be the 5-minute market setpoint. Under some circumstances the resource owner can send alternative operational midpoints to PJM (see Manual 12, 4.4.2). Would a wind turbine qualify for this?

This is possible but is uncommon. At the moment, PJM generators change their operational midpoint a few times an hour, at most. Part of the reason is that wind generators do not currently provide AGC on the PJM market.

Moreover, the assumptions on how and when regulation is or can be provided should be explained further. It would also be beneficial to add a discussion on the probability of regulation being provided at each hour that the hourly average power is above the regulation offer and how many hours per year that this is likely to occur.

We have expanded on the assumptions in Section 4.1 to be clearer. We have also added numbers (%) to show how often the wind turbine is able to provide regulation (Point #4).