Author’s comments:

We thank the reviewer for their time and efforts in reviewing our paper and acknowledge their feedback.

We feel, however, that much of this review is based on a misunderstanding of the context and value of our work. The purpose of our work is not to document a new control algorithm or a new method of providing a grid service. Its goal is to add real-world, empirical data to existing work and to allow further studies to be more realistic instead of being based on assumptions and limited data. The value in this is that the turbine technology used is commercially available and is not experimental or a one-off installation. Note that several other works use wind turbine performance scores derived from an NREL (National Renewable Energy Laboratory) test turbine i.e. one that is not commercially available.

We do not claim that the ability to provide AGC from wind generators is either new or novel. Instead, we claim that although the capability exists, it is either not utilised or under-utilised. Even when under-utilised, publicly available analyses are limited. Some of these are referenced in our paper. It is wrong to claim that ‘*The study would have been better informed with a more detailed literature* review*’* as the literature for our specific demonstration is extremely limited.

In other words, it is established that wind farms and wind turbines are able to vary their active power outputs in response to an external control signal. What is missing is an analysis of how well they are able to do this. What is the tracking error? What income can be obtained from providing such a service? What are the benefits to the power system? What are the long-term impacts on turbine components? Is a DFIG wind turbine better than a full-converter design? There are many unexplored issues and feel that it is premature to dismiss our work by claiming that *‘this already is part of the operational framework of many energy systems across the world’.*

For context, we direct the reviewer to similar studies cited in our paper such as:

a. *Lew, Debra, et al. "Wind and solar curtailment: International experience and practices."* – See specifically Figure 4 and note that no analysis is provided. The figure is sourced from a presentation and is offered as-is.
b. *Loutan, Clyde, et al. Demonstration of essential reliability services by a 300-MW solar photovoltaic power plant.* – This is very similar to our work and is relatively recent, proving our point about the lack of empirical data analysing ancillary services at a granular level
c. *Azpiri, Inigo, Clara Combarros, and Juan C. Perez. "Results from the wide-area voltage and secondary frequency control performed by wind power plants."* – This was a larger-scale demonstration of providing AGC from wind farms. Note that the analysis of the results is basic and that no financial analysis is performed.

Specific comments are addressed below:

1. This is not a study of primary frequency response or inertial response. Our analysis is specific to secondary frequency regulation, sometimes called AGC (automatic generation control).
2. We are aware of DTU’s work in estimating the power available in the wind however, this is not the goal of this study. The goal of our work is to document and make public an analysis of the ability of a wind turbine to provide AGC. Our algorithm is simple by design.

3. We acknowledge the limitations of using a single wind turbine. We will, expand section 1.3 - Limitations to make the limitations more explicit.
4. Please be aware that organising a test campaign, especially one where power targets change every 4 seconds is not easy. The lack of published data is testament to this. There is, however, an abundance of simulation-based research work and simulations that draw on data from test turbines showing how even a single wind turbine can provide a service such as AGC. Data from commercial wind turbines is limited and our study is an attempt to change this.
5. *Setting a 10% regulation band is not state of the art for offering this type of services. The low scores stem from this flaw and misrepresent the abilities of wind* - The 10% regulation band was chosen to be consistent with existing work in this project and this is explicitly mentioned.
6. Note that despite some low scores, we demonstrate that much better performance is possible by using a larger regulation band (Test 2* - 200 kW regulation offer). We also demonstrate that tracking error remains relatively constant and that the percentage error is reduced with a larger regulation region. The reviewer's concern is already addressed in the paper. We disagree about this misrepresenting the capabilities of wind generators.
7. We disagree about the comparison with fossil-fuel generators (in terms of performance scores) being wrong. (See replies above)
8. Once again, we emphasise that real-world data is invaluable in future work and is difficult to obtain. Part of this barrier is the cost of infrastructure, the reluctance of owners to make their infrastructure available for research work and the reluctance of wind turbine OEMs to make such analysis data public.
9. Further, our previous work has already demonstrated providing AGC from a wind farm (as opposed to a single turinbe) but please bear in mind that conducting such a demonstration even on a single wind turbine is already difficult and conducting it on a wind farm is harder still.
10. Much of the suggested literature:
    a. Deals with services other than AGC (mostly primary frequency response)
    b. Is simulation-based instead of using empirical data

    Please see the table at the end of this document.

11. The reviewer correctly claims that many grid operators have codes for wind generators to provide ancillary services. We do not dispute this claim. Even if extensive field testing preceded the introduction of these codes, much of the analysis is not public knowledge, specifically around secondary frequency regulation (AGC). Note that we are referring specifically to ancillary services, not regulation reserves.
12. Several grid operators (or system operators):
    a. Have competitive ancillary service markets which technically allow the participation of wind generators but see close to zero participation from wind generators (PJM, for example). In other words, even if wind generators are allowed to participate, they do not.
    b. Have competitive ancillary service markets that exclude variable generators by design
    c. Simply mandate that wind generators be able to respond to an AGC signal when commanded. A good example of this is AEMO's (Australian Energy Market Operator) markets in Australia. A public analysis of how often such a feature is used and what its benefits are is often limited or non-existent.

d. ENTSO-E's secondary control reserve regulations (linked here: https://www.entsoe.eu/fileadmin/user_upload/_library/publications/entsoe/Operation_Handbook/Policy_1_final.pdf) do not specifically disqualify wind generators from participating the regulation market but where can find an actual analysis of their performance? How good or bad are wind generators are providing AGC, both up and down? Note that this is distinct from a negative control reserve which simply involves a relatively constant power curtailment. Providing AGC in a manner similar to fossil-fuel generators is a topic on which data and analysis is limited.

13. *Problems are being referred to, as e.g. wake effects and available active power, and being dismissed as out of scope. It would be good to have them at least referenced* – We acknowledge that these are issues are beyond the scope of our work and have already provided a starting reference to the topic (See section 1.3 – Limitations, for example).
14. *It is unclear why AGC signal filtering is necessary and how it complies with PJM market rules* – The specific need for AGC signal filtering is covered in section 21. – ACG signal filtering. We will clarify the implications of this filtering as related to PJM market rules in a future revision of the paper.
15. *At several stages, choices are not reasoned (e.g. why not use the P available of turbine?)* – We ill add reasons for this in a future revision of the paper. The reason behind this specific point is the error in the turbine's estimate of available active power.
16. *Why start with "Test2" as the first one. That doesn't make sense* – This is a trivial point. We specifically mention that we use the chosen test names to be consistent with other documentation from the same project.
17. *The prices and revenues for the PJM market drop seemingly out of nowhere and must be introduced to the reader, if the paper is to be read outside the US context.* – We will add more context to the PJM market mechanisms in a future revision.

We question the validity of the suggested references as the majority appear to be unrelated to our work. A large proportion of the existing literature focuses on the issue of system inertia with high levels of wind generation and so deals with primary frequency response.

https://www.zhb-flensburg.de/dissert/jansen-malte/ (See page 63 for literature review table).	Relevant and was used in the preparation of this work, including the literature review table. Some of these references are cited in our works. The existing literature, however, has the exact drawback specified in our work i.e. it is largely simulation based and evaluates the broader-implications of providing control reserves / frequency regulation from wind generators. We agree with the broad claims but our work is more granular and is intended to serve as an input to studies such as those listed in this thesis.
Economics of control reserve provision by fluctuating renewable energy sources – Malte Jansen	This is relevant to our work but is one step ahead i.e. it looks at the economics of providing control reserves from variable

	generators (wind, solar etc) on a competitive market. Only negative secondary control reserve is considered.
https://www.iee.fraunhofer.de/content/dam/iwes-neu/energiesystemtechnik/de/Dokumente/Studien-Reports/20140822_Abschlussbericht_rev1.pdf (in German but very relevant to the topic)	-
System Inertial Frequency Response estimation and impact of renewable resources in ERCOT interconnection - Sandip Sharma ; Shun-Hsien Huang ; Ndr Sarma	This focuses specifically on primary frequency response (aka fast-frequency response) from wind generators and is not relevant to our work.
A review on frequency support provision by wind power plants: Current and future challenges - A.B.Attya, J.L.Dominguez-Garcia, O.Anaya-Lara	Once again, this focuses on primary frequency response, not secondary frequency response. Further, this is entirely simulation-based and does not use empirical data.
Kinetic energy and frequency response comparison for renewable generation systems	Once again, this focuses on primary frequency response, not secondary frequency response.
http://www.posspow.vindenergi.dtu.dk/	We are aware of this project but estimating the power available in the wind was not the focus of our work.

Author’s comments

We emphasise that although the question of providing various ancillary services from wind generators has been addressed before (albeit at a largely theoretical level), it has not been addressed at a granular level i.e. it has not been examined in the level of detail presented in our work. The broad questions of which other sources can provide AGC in a more cost-effective manner is not our focus. We focus solely on evaluating the ability of commercially available wind generation technology to provide AGC. Addressing topics such as when a wind turbine cannot provide AGC and forecast errors are beyond the scope of this work.

Specific comment: In the reviewer’s opinion, it is really not a good idea to ask the wind turbine to provide continuous AGC unless there is no other alternatives, which indicates a poor system design from the very beginning

The question of providing AGC from a wind turbine is very important to the design of a fossil-free grid and we feel that this does not indicate ‘poor system design’. Whether or not a wind turbine is the best choice for providing regulation at any point is a separate question.

The question of de-rating a wind turbine to provide AGC is reasonable but this is not one that is directly relevant to our work. We focus primarily on the ability of the wind turbine to provide up- and down-regulation. How to improve this is a separate discussion entirely. This issue is already dealt with in the introduction to the paper.

The idea that other generation sources can provide AGC is valid but this does not invalidate the need to investigate the ability of wind generators to provide AGC.