

Response to Reviewer Comments

Devon Todd

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Response: We thank the reviewers for their time and comments. We believe that the changes suggested by the reviewers have strengthened the review. The following sections address the specific changes made to the text highlighted in red, our response comments highlighted in blue, while text included to provide context is left in black.

1 Reviewer 1

2 General Comment

Comment: The article tries to give an overview on the participation and support to future power systems. Although it's logical that not everything is treated in detail, as it is a review article, the article is very superficial and unclear in most parts. On the other hand, the comparison between the UK and the EU context is a positive element. The title mentions "future" power systems, but some elements described in the article are already implemented and applied in current wind farm operation. However, the current practices are hardly mentioned nor analysed.

We thank the reviewer for their observations. We have made changes throughout the manuscript in response to the reviewer's comments, which we believe have improved both the clarity and overall quality of the review. The primary focus of this review is the growing need for flexibility in future power systems resulting from reduced synchronous generation, the potential role of Flexible Wind Farm Control (FWFC) in addressing this challenge, and the key research and implementation gaps that must be addressed to enable wider adoption of FWFC. We acknowledge that many of the capabilities discussed are already implemented to some extent through grid-code

compliance, ancillary service participation, and current wind farm operational practices. To clarify this point, additional discussion has been added to the introduction. However, detailed information regarding how commercial wind farms are controlled and operated remains limited due to data availability and commercial confidentiality, making direct assessment of current industry practices challenging. The responses to further comments below also help to address this more general comment.

Lines 77-80: Many of the capabilities discussed in this review are already implemented in current wind farm operation through grid code compliance and ancillary service participation. However, these capabilities are typically secondary to power maximisation, which may change as the needs of power systems evolve. This review therefore focuses on flexible operation, its role in future power systems, and the key research gaps that must be addressed to enable wider adoption of Flexible Wind Farm Control.

2.1 Specific Comments

2.1.1 Section 2.1

Comment: The section on flexibility (2.1) is quite limited, e.g. industrial flexibility is not explicitly mentioned. The section does not give a good overview of the most relevant kinds of flexibility and the grid and market incentives for flexible operation (of wind farms, in this case).

Response: We agree that the section can benefit from a deeper discussion on other forms of flexibility (i.e. industrial flexibility as highlighted by the reviewer), as well as the current market incentives and general lack thereof for flexible operation.

Lines 98-106: Here, the flexibility of an energy system is defined by its ability to maintain the energy balance. There are two main areas of flexibility depending on its source, which are supply-side flexibility and demand-side flexibility. Supply-side flexibility, is the ability to adjust supply to meet demand. Demand-side flexibility involves consumer side participation through adjustment of flexible demands such as heat pumps, electric vehicles, and industrial/commercial demand flexibility (e.g. load shifting of energy-intensive processes in response to a request from the system operator) (Golmohamadi, 2022). From the supply-side, there are numerous optional and mandatory mechanisms that allow generators to contribute to the overall stability of the grid. For example, synchronously connected generators which inherently provide inertia, and reserves from energy storage, along with ancillary services, such as voltage regulation and frequency support. However, wind energy is not typically well placed to participate in

these mechanisms.

Lines 110-116: Under current market incentives, such as CfDs, wind farms are incentivised to maximise production, which in turn disincentivises participation in flexibility markets due to lost revenue and increased operational costs (Badesa et al., 2025). As such future power systems with higher levels of renewable penetration may require a restructuring of the current CfD and flexibility markets to further incentivise flexible operation (Badesa et al., 2025; Cole et al., 2023). In times of surplus wind energy, there are currently few options other than to curtail output. During such periods, flexibility can be provided using energy storage to divert excess generation within the installed storage capacity. However, there are substantial cost implications in the construction and operation of the necessary storage.

2.1.2 Section 2.2

Comment: In the section on stability (2.2) it is not clear why a division is made between primary and secondary response (2.2.1) on the one hand and tertiary response and reserve services (2.2.2) on the other. Also the first category (including FCR and aFRR in EU) represents reserves. The sequence of the different responses and reserves and the relations with forecasting and energy markets (e.g. day-ahead, intra-day) and imbalance settlement are not well explained.

Response: Thank you for this comment, we agree that the text could more clearly explain why we have chosen these divisions. Our choice to cover primary and secondary in one subsection and tertiary and reserve in another subsection is due to their respective response times (as shown in figure 1) and the triggers for their response (automatic vs manual). Clarifying statements have been added to make the distinction clearer as well as the specific definitions used in the review. While, FCR and aFRR are reserve services, their specific purposes are best aligned with our chosen definitions of primary and secondary frequency responses. We have added the text below to clarify our choice of division.

Lines 124-126: Section 2.2.1 covers faster acting automatic responses (primary and secondary), while section 2.2.2 covers the slower tertiary response from reserves secured ahead of time through day-ahead and intraday markets, informed using forecasts.

Lines 129-130: The most common terms seen for frequency response within the literature are illustrated in Fig 1, which serve as the definitions used throughout this review.

Lines 150-152: It should be noted that while FCR and aFRR are listed as 'reserves' their mechanisms are aligned with primary and secondary response, as defined in Ullah et al. (2024).

Comment: In 2.2.1 (explanation of Fig. 1) a "fault" is mentioned, but it is not explained what is meant by this. (The "fault" is, e.g., the loss of a production unit in this case.)

Response: We agree the additional information improves the clarity of what is being discussed, as such an additional statement has been added. The section in question has also been moved to section 2.2 to improve overall clarity.

Lines 130-132: In the event of a fault causing a sudden imbalance between supply and demand (e.g. the loss of a production unit or a major load) there is typically an inertial response which lessens the impact of the fault (A-B). Primary frequency control (B-C) is then used to stabilise the system frequency.

2.1.3 Section 3

Comment: In Section 3 (Policy), Table 4 is hardly explained. E.g. in the "Hydrogen Evolution" scenario, the statement "High levels of dispatchable hydrogen plants which reduces the need for renewables and nuclear" is not explained. The production of hydrogen by means of renewable or nuclear power seems not to be considered.

Response: Thank you for this comment, we have improved the text to explain this more clearly. The descriptions of the different scenarios have been improved, along with a better explanation of the table itself and where further information can be found.

Lines 236-239: Table 4 provides a general overview of the future scenarios described in detail within the FES 2025 documentation, with the scenarios being listed in order of greatest to lowest installed capacity of wind and solar – an in-depth break down is provided in Tables 1 and 2 of the FES documentation (NESO, 2025d).

Scenario	Description
Holistic Transition	Strong consumer engagement and supply-side flexibility with the highest proportion of renewable capacity and little hydrogen for dispatchable power.
Electric Engagement	Increased demand side flexibility through consumer engagement, with high supply-side flexibility and large amounts of nuclear, renewables, bioenergy and CCS.
Hydrogen Evolution	High levels of supply side flexibility from dispatchable hydrogen, produced primarily using electrolysis (from renewables and nuclear) and gas reformation, along with increased nuclear energy for base load.
Falling Behind	Some progress is made towards net-zero but is ultimately not sufficient, with Great Britain still relying on fossil fuels to meet demand.

2.1.4 Section 4

Comment: In section 4, the wind turbine control options are insufficiently described. The generator types considered are even not mentioned (except in one sentence in 5.1).

Response: Thank you for this comment. The comment has been interpreted as referring to the control options found within section 4.2 and relevant changes have been made. We acknowledge the importance of generator types on the electrical aspects of control and their influence on the mechanical aspects (i.e. the prime mover). However, as the paper’s focus is primarily on the mechanical (rotor-side) control of turbines and farms, we have added a statement acknowledging the impact of generator type on rotor side control, with accompanying references which include further information as necessary.

Lines 257-261: At the turbine level, control tends to be split into two main areas; the first concerns the prime mover and includes adjustment of blade pitch, rotor shaft torque, and nacelle yaw. These are commonly used for power maximisation but could also be used to reduce power output, or to modify the wake and subsequent air flow through the wind farm. The second concerns the power take-off, and includes problems such as protection of the electrical components as well as reactive power balance and battery storage for grid support (Dai et al., 2022; Chen et al., 2023; Song et al., 2025). For power take-off, generator topologies are the main focus (e.g. Doubly Fed Induction Generators and Permanent Magnet Synchronous Generators), and power electronics (e.g. back-to-back converters). Larger modern wind turbines typically use PMSGs with back to back converters or, for smaller turbines, DFIGs, which have limited impact on the prime mover, which is the focus of this review. Readers are directed to Fernández-Bustamante

et al. (2021), Buller (2025) and Dai et al. (2022) for further information.

Lines 262-265: WFC is a common term that covers a wide range of applications, as discussed in Knudsen et al. (2015) who also provide a general schematic for WFC operation (Fig 2). A control layer is added above the turbine level that provides **additional commands for the turbine level controllers to implement i.e.** a power reference to be targeted by each turbine based on turbine data, available power from the wind speed, and power demand from the network operator.

Comment: The phrase "necessitating adjustment of the blade pitch to achieve a target mechanical power" (line 280), that power control is only possible when (also) pitching is applied, while (in a certain operating region) the power can be controlled by torque/speed control of the generator only. There are no figures showing the topologies of the complete wind turbine system including the power-electronic converters for implementing the control strategies. The control strategies mentioned in Figure 3 are hardly described.

Response: We can see how the phrasing could be misinterpreted, we have significantly reworked this section for clarity. As the scope of the review is primarily focused on the mechanical control of turbines and farms we opted for a simplified diagram which omits power electronic to keep the focus on the main aspects of mechanical control. The control strategies in figure 3 have now been described in more depth and with more direct reference to the figure to improve clarity and understanding.

Lines 307-308: The power output of a wind turbine is controlled at a turbine level, solely using the sensors of that turbine. To enable FWFC, a turbine's controller must be altered to allow the power to be adjusted.

Lines 291-301: Mechanical power take-off, P_m , and mechanical generator torque, T_m , are directly linked by the shaft speed, ω , whilst the aerodynamic torque from the wind is a function of the air density, ρ , rotor radius, R , the wind speed, V , and the power coefficient, C_P , itself a function of tip speed ratio, λ , and collective blade pitch angle β . At an equilibrium operating point, the aerodynamic power and power take-off must match and so, neglecting losses,

$$P_m = T_m \omega = \frac{1}{2} \rho \pi R^2 V^3 C_p(\lambda, \beta), \quad (1)$$

Because the generator power is a function of torque and speed, and the aerodynamic power (for a given wind speed) is a function of rotational speed via the tip speed ratio, reducing the power output of a wind turbine with no alteration to the blade pitch angle necessitates a change to both torque and speed to ensure an equilibrium operating point. Outwith maximum power capture there are two possible equilibrium operating points for a given (reduced) power demand. However, if blade pitch angle is also varied, then the set of equilibrium operating points is greatly expanded, and a wide range of equilibrium operating

points are available to achieve a set power output, so long as that power output is less than the maximum available power.

Lines 317-329: Fig 3 demonstrates the three ROSCO control options for a 10 % power reduction. Torque control ('R.Torque') alters the rated torque of the wind turbine only. As such, below the new rated torque there is no change in power output. When above the new rated torque, the turbine pitch controller maintains the rated speed and so the rated power is reduced. This method is the green dotted line in Figure 3. For speed control ('R.Speed') the rated speed is changed but the rated torque and the pitch control prior to rated wind speed remains the same as baseline operation. Hence, there is necessarily an increase in generator torque in below rated wind conditions to maintain an equilibrium operating point. It is worth reiterating that 'speed control' achieves the change in power through manipulation of the generator torque and pitch to affect a change in speed. This method is the amber dashed line in Figure 3. Pitch control ('R.Pitch') increases the minimum blade pitch angle, directly reducing aerodynamic power capture by altering the power coefficient. This method is the red dash-dot line in Figure 3. Speed and torque control options are only effective in above rated operation. Pitch control is only effective below rated wind speed. Hence, if control of power across the operational envelope is required the controller must switch between different control modes, and the transition must be handled appropriately. For farm-wide distribution of set points to achieve a desired farm power output, switching between operational modes is required (NREL, 2025).

2.1.5 Section 5.3

Comment: In section 5.3 the "event" considered in is not explicitly mentioned. What is the power imbalance (ΔP in equation 3) exactly? (From an electrical point of view, the power injected in the grid equals the electrical power consumption.)

Response: The following changes have been made to clarify the "event" and what ΔP is.

Lines 403-404: where ΔP is the size of the power imbalance as a result of a fault (e.g. the loss of a production unit or load tripping) Fernández-Bustamante et al. (2021)

2.1.6 Section 6 and 7

Comment: In sections 6 and 7, some aspects such as the possible negative impact of a control actions on mechanical loading and fatigue are shortly men-

tioned. However, higher maintenance costs and life time reduction due to control actions for a flexible operation are issues wind farm operators are already considering today.

Response: Thank you for highlighting this small but important omission. While operators typically consider loads to some degree the research surrounding FWFC performed by academics typically does not. Their focus is primarily on showing their strategies work and often do not include loads analysis. However, we acknowledge that operators may have concerns regarding increased pitch duty (for example) when operating partially curtailed compared to full power. As partial curtailment typically reduces the mean thrust on the rotor, and therefore typically reduces operational loads compared to baseline operation, the load profile could indeed be different, impacting on operations and maintenance. If curtailment is via turbine shut down (and start-up) then this will, again, have load implications that could be negative compared to baseline operation. We have added content to highlight this fact. It is not uncommon for operators to take simpler approaches to flexible control strategies, such as distributing power amongst turbines without considering turbine loads. An additional paragraph has been added to section 6 to demonstrate this point as well as some changes to section 7. We have also added a paragraph to the introduction clarifying that the gaps are primarily from academic literature.

Lines 77-80: Many of the capabilities discussed in this review are already implemented in current wind farm operation through grid code compliance and ancillary service participation. However, these capabilities are typically secondary to power maximisation, which may change as the needs of power systems evolve. This review therefore focuses on flexible operation, its role in future power systems, and the key research gaps that must be addressed to enable wider adoption of Flexible Wind Farm Control.

Lines 516-522: With such a wide array of control techniques, particularly for frequency control, it is important to understand how these strategies affect turbine loading, component fatigue, and lifetime relative to conventional operation. Although OEMs consider loads in the design of their controllers, in the case of curtailment, operators will typically apply a simplistic method such as even distribution of curtailment across all turbines in the farm, without consideration of turbine loads and fatigue. It has typically been the assumption that curtailment reduces loads overall through shutting down turbines (full curtailments) or reducing the mean thrust (partial curtailments). However, the implications of different operating strategies (i.e. partial vs full curtailments) are not fully understood yet, such as loads from increased pitch duty versus those from repeated start-ups and shut-downs.

Lines 540-542: Alongside academic advances and policy changes, greater data availability and field tests would facilitate better understanding of the benefits of Flexible Wind Farm Control, as well as its impacts on wind turbines and the degradation of their components **under realistic conditions**. In the short term, further work is needed to **quantify** the load impacts of flexible control strategies **relative to current industry practices**, along with the creation of models that are both computationally efficient and incorporate essential dynamics such as turbulence and degradation.

2.2 Technical Comments

Comment: The manuscript contains some incomplete and unclear sentences:

- line 82: Before presenting the final conclusions in section 7.
- line 143: Which, poses a problem for TSOs.
- line 283: For below rated operation, through an increase to the minimum pitch angle.
- line 326: By managing the active power (mechanical power) output in a manner that provides the necessary for power electronics to adjust reactive power (Song et al., 2025).

Response: The following changes have been made to address the reviewer’s technical comments. It should be noted that the sentence formerly on line 326 is not present in the revised manuscript.

Lines 85-87: With the foundation set, we can then explore the uses of FWFC in more depth in section 5, with a summary of identified research gaps in section 6, **before presenting the final conclusions in section 7**.

Lines 155-156: There is no way to know exactly what the energy demand or generation (mainly wind and solar) will be at any given moment, **which poses a problem for TSOs**.

Lines 374-375: By managing the active power (mechanical power) output, **head-room can be created for power electronics to adjust reactive power (Song et al., 2025)**

Comment: The quality of some figures should be improved, e.g. Figure 1

The quality of figures 1 and 6 (now figure 5) have been improved

3 Reviewer 2

3.1 General Comments

Comment:First, the review is very heavily focused on recent articles (since 2020) and omits a number of relevant papers from the mid-2010s outlining technical approaches for things like APC and power reference tracking. I certainly would not recommend to remove the most recent papers that are already cited, but I think including discussion of early implementations of some of these ideas (and, if relevant, how and why they have evolved) would strengthen the review nature of this manuscript and better “synthesize the status of knowledge based on a systematic literature review” (as described in the manuscript types page of Wind Energy Science). As one example, van Wingerden et al.’s “Active Power Control of Waked Wind Farms” is authored by several researchers who were quite active in this field and cites a number of other relevant papers (I am not one of the authors of this paper/have nothing to gain from its citation). Table 5 would also benefit from the additional of relevant papers from the extended time period of the literature review.

Response: We thank the reviewer for the suggestion, we agree that the additional references and discussion on how the fields have changed can strengthen the review. We have added additional references, discussion on older papers, as well as discussion on how the focus of research within the field has changed over time. The analysis of older work has clarified the trajectory of research within flexible wind farm control.

Lines 294-297: Hence, farm-level power demands can achieved through commands sent to each turbine, as demonstrated in early work on farm-wide power reference tracking by van Wingerden et al (2017) which demonstrated how feedback control can be used to improve power reference tracking performance at the wind farm level. It was demonstrated that even in a highly waked wind farm power tracking is possible, and that the chosen set points have a significant impact on *Damage Equivalent Loads* (DELs), thus they should be considered in WFC applications.

Lines 325-328: It was found by Aho et al. (2016) that while de-rating turbines using power reference tracking generally decreased DELs. Pitch control resulted in the largest reduction in DELs, whilst torque control had higher DELs when compared to pitch control, but was better at tracking the power reference

Lines 426-430: Loza et al. also showed how research agendas have shifted overtime, with much of the earlier work being focussed on solely primary control (Kou et al., 2015; Hayes et al., 2016), while more recent articles have shifted to focus on inertial response and hybrid systems (Mishra et al., 2023; Gu et al.,

2024). Despite the more recent work on hybrid systems, the authors suggest that more research is needed towards developing hybrid frequency control strategies which combine the different time scales.

Lines 451-456: A review by Khurshid et al. (2024) showed that hybrid systems have received more attention in recent years. Early work was primarily concerned with integrating complimentary wind and solar technologies (i.e. Yang et al. (2007); Chen et al. (2007)), while over time there has been a gradual shift to include even more generation sources (such as wave and tidal) and BESS to offset even more of the inherent intermittency of renewables (i.e. Benlahbib et al. (2020); Dezhdar et al. (2023); Masoumi et al. (2020)). The trend showcased in Khurshid et al. (2024) is likely due to the maturation of newer technologies.

Comment: Second, the manuscript has quite a broad scope and covers most topics only fairly superficially, which seems appropriate for a review article, but occasionally delves into much more detailed descriptions that seem a bit out of place. For example, the detailed review of the techniques available in (Abbas et al., 2024), including the figure of the various signals (Figure 3), goes well beyond the more conceptual Figure 4. I was left wondering if there is an intent to offer some specific contrast between the (Abbas et al., 2024) and (Stock and Leithead, 2022) techniques; if so, it would be more clear to the reader if similar plots were included for each. Similarly, Table 3 (EU) and Table 4 (UK) show much different levels of detail and ways of thinking about wind contributions to the grid, leaving the reader to wonder if there is some meaning in the ways the two regions are thinking about wind integration or if there is another reason for the contrast. (Presumably the same categories of technologies shown in Table 3 would apply to both.) A third example is the delving into the details of how long it takes for overall load reduction to be positive according to (Ziegler et al., 2024) around line 250; while of course this information is relevant to using FWFC, it is far more detailed than descriptions of many of the other references cited. Is there some particular reason this information is especially important to the review?

Response: Thank you for this comment - we agree that a review necessitates a broad look at the literature and precludes deep analysis across the research area. Regarding the two control approaches that are described in more detail, these approaches present alternative methods of achieving flexible operation within the literature (as opposed to OEM methods which are not publicly shared). The ROSCO method is publicly available and is included as part of the FAST aeroelastic simulation software. It is the most commonly used method within academic research and so we present a more detailed review of its operation compared to the method in Stock and Leithead, which is provided as an alternative, but less commonly utilised approach. The methods are not intended to be compared and contrasted directly, instead, the difference between the two serves to

highlight that different methods are available and could potentially be being used by operators, who do not readily share details of their approaches. As such, care must be taken when extrapolating from results in the literature or from field data. This also highlights one of the research gaps (the need for loads analysis for FWFC strategies) now outlined at the end of the review.

Regarding the tables, the same categories shown in Table 3 for the EU would likely be suitable for application in the UK. However, the separate tables and level of detail are predominantly because of how the two regions are approaching wind integration. The EU as a whole has recognised the capabilities for wind energy to better participate in supply-side flexibility. However, the UK primarily focuses on interconnectors, storage, and dispatchable generation (hydrogen, gas, etc). To make the point clearer we have added some text to highlight where the UK is instead expecting to receive flexibility from.

We agree that the discussion on Ziegler et al., 2024 was more in depth than necessary, especially since the results were non-generisable. In response to the comment we have removed the specifics on the exact break even point for loads, and have instead generalised the discussion.

Lines 343-350: The core differences in approach between the ROSCO and PAC methods highlight that the exact method used to implement FWFC can vary greatly in the literature. ROSCO sets individual power demands for each turbine, whilst the PAC sets changes in power; ROSCO alters the control strategy of the turbine to achieve a change in power, whilst the PAC uses an increment in torque to move the power set point then ameliorates any change in speed due to the torque increment using pitch; ROSCO replaces the full envelope controller, whilst the PAC acts as an augmentation. The methods used by manufacturers and operators are not widely shared and could be similarly disparate. Consequently, care must be taken to fully understand the implemented control method when extrapolating from FWFC approaches in the literature, particularly as the specific of the control implementation could significantly influence turbine loading and lifetime.

Lines 247-248: However, unlike the EU, the UK has neglected wind energy as a potential source of flexibility, instead the focus is on flexibility provided from interconnectors, storage, and dispatchable generation (i.e. Hydrogen, natural gas, and hydropower).

Lines 281-283: Although, it was noted in Ziegler et al. (2024) that load reductions are only positive after a certain amount of time has passed, due to increased loads when transitioning between operating regions

3.2 Specific Comments

Comment: many abbreviations are defined multiple times in the manuscript or defined but then not used consistently later (e.g., the reversion to spelling out Wind Farm Control and Flexible Wind Farm Control) in the final pages instead of using WFC and FWFC

Response: We thank the reviewer for pointing this out, we have made sure to remove repeated definitions and resolved the consistency issue. In the conclusions we have made a deliberate choice to avoid abbreviations, as readers will often refer to conclusions when assessing if the paper is relevant. Avoiding abbreviations makes this easier to do.

Comment: I am not sure if this is because some of the citations were published without years, but occasionally it is difficult to discern the reference in (Author, Year) format when there is no year provided or when a year is sometimes attached to a letter but not consistently (see (NESO, 2025c) in the caption for Table 2 and (NESO, c) on line 154 for example.)

Response: Upon double checking the citations the reviewer was correct in that the citations were published without years as these are web pages. The citations are inline with the journal style guide.

Comment: The image on p. 2 would benefit from a caption or key descriptors. For example I am left wondering why no signals are shown for two of the future scenarios, and why the power plant has two “lightning” (electricity) symbols now and 3(?) in the future – is there a meaning I should take from that difference?

Response: The image on p.2 is a graphical abstract and to be used as the key figure for the paper. Hence the lack of caption and placement in the paper, three scenarios show how FWFC could participate in future power systems i.e. improved stability, hydrogen co-location, and carbon capture. Headers have also been added to the different scenarios in the graphical abstract to improve understanding

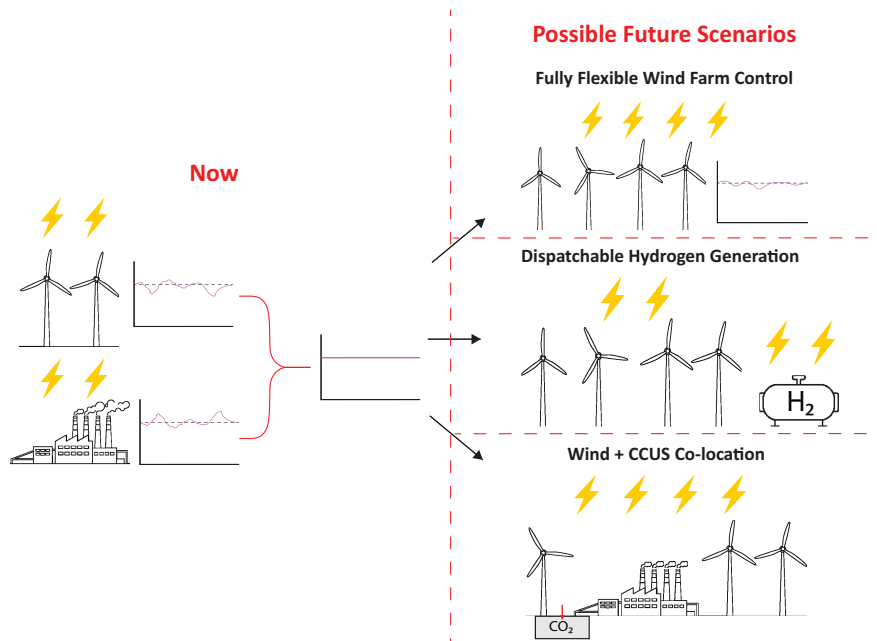
Comment: line 92: missing “Section” before 2.2

The word section has been added

Comment: Figure 1 would benefit from more information in the caption, at a minimum indicating that this is a typical curve in response to a fault

Response: The authors agree and the caption has been lengthened

Typical frequency response curve following a fault and subsequent recovery through the different levels of frequency response (Inertial, Primary, Secondary,



and Tertiary)

Comment: “Which, poses a problem for TSOs” (line 143) is not a complete sentence

Response: This comment was also made by reviewer 1 so no further changes have been made than those outlined previously

Lines 155-156: There is no way to know exactly what the energy demand or generation (mainly wind and solar) will be at any given moment, which poses a problem for TSOs.

Comment: in the Table 3 headings, should the 3rd column be something like “Compensates for periods of vRES shortage”?

Response: While the headings currently match those given by ENTSO-E we agree that this is a good clarification to add and we appreciate the suggestion. It has been amended as suggested.

Changed heading to “Compensates for periods of vRES shortage”

Comment: lines 200-201: I am most familiar with BESS meaning battery energy storage system, not batteries *and* energy storage systems as stated

Response: The reviewer is correct and we have updated the text

Changed definition to Battery Energy Storage System

Comment: Table 4 would benefit from a more descriptive caption, perhaps including a term like “possible” (future pathways) or “options” (for the future). Further, it was not immediately clear why Hydrogen Evolution would reduce the need for renewables; is that in comparison to the Holistic Transition and Electric Engagement (vs. compared to today)?

Response: Given the similarity with Reviewers 1, the changes made are also relevant here. We would also like to say that the reviewer is correct that the decreased need for renewables (for meeting demand) is in comparison to the other scenarios, as additional dispatchable generation is provided by hydrogen. We have added the additional statement below to make it clearer that the decrease in in renewables to meet demand.

Lines 243-244: In contrast, Hydrogen Evolution has the greatest amount of flexibility, as a result of a lower need for renewables to meet demand due to increased dispatchable hydrogen.

Comment: line 319: do you mean “outside” or “beyond” instead of “outwith”?

Response: The use of outwith is intentional. It is a synonym for the suggested alternatives from the reviewer within Scottish English, typically meaning beyond or outside of something, which is permitted based on the journal’s English guidelines.

Comment: Figure 5 is missing spaces before (in both the x and y axis labels

Response: The figure in question was not produced by the authors and has been included as part of a creative commons licence.

Comment: I did not find Figure 6 to be especially informative; if there is an important point for the review, perhaps a revised explanation of the figure would make that more clear.

Response: We appreciate the honest feedback on the usefulness of the figure. As such it has been removed from the revised manuscript.

Comment: The sentence on line 436 is incomplete

Response: The change below was made

Lines 495-497: Through a combination of workload scheduling (load shifting) and use of batteries to smooth fluctuations, the authors maximise renewable energy participation, though there is scope to incorporate WFC to aid the battery

in smoothing power fluctuations.

Comment: Perhaps related to my comment about the overall synthesis of the literature, I do not agree that this review clearly outlines “the gaps in the current literature” (lines 460-461). I do believe these gaps could be made more clear in a revision.

Response: We agree that the gaps could be made clearer. To resolve the reviewers comment we have clearly stated the gaps throughout the review as well as a bulleted list included within section 6.

Lines 333-336: To understand in detail how power set-point control for curtailment can impact overall wind farm performance it is critical to model the control implementation accurately. When comparing to the ‘industry standard’ method it is therefore critical to have a good understanding of how current wind farms are controlled. However, it is difficult to asses against ‘industry standard’ methods due to a general lack of data availability and data privacy from operators. As a result, proper assessment of the suitability of academic approaches against industry standards is difficult (Hur and Leithead, 2016; Lim et al., 2022; Stock and Leithead, 2022).

Lines 443-430: Much of the frequency control work reviewed relies on simplified turbine and farm models and neglects important dynamics such as turbulence and wakes. Furthermore, the effects of frequency control strategies on turbine loads are not well understood. Before FWFC control strategies can be implemented, it is essential to go beyond technical feasibility and understand how these strategies impact loads, fatigue, and lifetime.

Lines 512-515: Within current FWFC literature, most studies focus on technical feasibility, relying on simplified turbine and farm models that neglect critical dynamics such as turbulence and wake effects.

Lines 498-501: While co-located and hybrid systems have received more attention lately, similar to literature on frequency control much of the work focusses on technical feasibility as well as optimisation. The impacts of FWFC strategies on turbines as well as asset degradations (e.g. batteries and electrolyzers) remains under-investigated. The lack of loads analysis, degradation, and critical dynamics, creates uncertainty around the practical suitability of the proposed strategies.

Lines 526-532: Overall the key gaps in the current literature, are as follows:

- The need for load/degradation assessments of Flexible Wind Farm Control strategies using representative cases
- Improved models which incorporate turbulence and wake effects

- Further investigation of multi-service hybrid approaches for ancillary services
- Limited benchmarking against industry standards due to industrial data privacy
- Limited validation through field testing