Authors' Response to Comments from the Associate Editor and Reviewers on wes-2025-240: "Integrated Control of Floating Offshore Wind Farms with Reconfigurable Layouts"

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We thank the Associate Editor and the reviewers for their thoughtful comments and careful evaluation of the manuscript. Their feedback has been very helpful in improving the paper. We have addressed all comments and revised the manuscript accordingly. All changes in the revised manuscript are highlighted in red, and our detailed point-by-point responses are provided below.

Note 1: We sincerely thank Reviewer 2 for the positive evaluation of the manuscript and for confirming that no further revisions were needed. We also appreciate the encouraging remarks from Reviewer 1. For brevity, purely positive comments are omitted below, and we focus only on those comments that required a response or revision.

Note 2: References added in this response document are listed at the end of the document. Their numbering is valid only within this response document; references in the revised manuscript follow the journal format.

Responses to Associate Editor

Comment: *As you can see, while one of the reviewers is happy with accepting your work, the other (reviewer 1) remains very critical. As the reviewer correctly points out, the combination of yaw and mixing control strategies leads to complex nonlinear interactions that may not well be presented with your current FLORIS model. To really improve your work, you'd need some serious validation of these combined control modes versus, e.g., LES data. If you however choose to not pursue such a validation (because of time/resource restrictions), then the minimum you should do is properly and much more visibly discuss the limitations of your work. It is now discussed in section 3.2.2, but is should be more prominently mentioned in the abstract, introduction and conclusion sections as well...*

Response: We thank the Associate Editor for this helpful guidance. We agree that the simultaneous use of yaw-based control together with Helix wake mixing or power derating involves complex aerodynamic interactions that are not fully captured by the present FLORIS model. Due to time and resource constraints, rather than adding LES validation, we addressed this concern in two ways. First, we made these limitations much more visible in the abstract, introduction, results discussion, and conclusion. Second, to assess the extent to which the main results depend on these less-established simultaneous combinations, we added conservative restricted benchmark cases for both the power-maximization and power-regulation studies, in which the combined use of these methods on the same turbine was not allowed. These restricted cases support the main qualitative conclusions of the manuscript by providing conservative lower-bound benchmarks based on validated models. Detailed results and discussions are provided in our responses to Reviewer 1.

Responses to Reviewer 1

1. **Comment:** *I would like to raise one important point regarding the integrated control strategy. The proposed approach combines wake steering, power derating, and helix mixing simultaneously. While this is an interesting and relevant direction, the interaction between wake steering and helix control is known to be complex, and their benefits may not combine linearly. In the current implementation, it appears that within FLORIS the effects of these control strategies are effectively superimposed. Since a standard version of FLORIS with default wake parameters is used, and no validation of the model predictions is provided, this assumption may lead to optimistic estimates of the overall performance. While the use of default settings is acceptable for standard FLORIS applications, additional validation (with LES) is needed to strengthen the results when combining helix control with yaw.*

   Response: We thank the reviewer for this important and insightful comment. We agree that the simultaneous use of wake steering and Helix wake mixing involves coupled aerodynamic interactions that are not fully captured by the present FLORIS model, and that this can lead to optimistic quantitative estimates of the resulting performance gains. Due to time and resource constraints, instead of adding LES validation, we added a restricted integrated-control case to examine the extent to which the main results depend on allowing this simultaneous combination as follows.

   Change in manuscript:

   4.2.2 Power Maximization: Direction-Averaged Performance

   To summarize overall performance across directions, Fig. 8 reports the average maximum farm power over all wind directions for inflow speeds between 4 and 10 m/s, expressed as the percentage change relative to greedy control. Several trends are evident. First, all strategies yield positive mean gains, indicating that wake-mitigation actions provide net benefits when averaged over the full 0-360 degrees direction sweep. Second, the fully integrated controller achieves the largest improvement at every wind speed, with the highest gain at 4 m/s (up to 6.5%) and gains remaining around 3.9% at 10 m/s.

   At the same time, as discussed in Sect. 3.2.2, the simultaneous use of yaw-based control and Helix wake mixing is more complex than the standalone application of either method, and this combined operation has not been extensively validated in the present FLORIS model. Therefore, the fully integrated case may provide optimistic quantitative estimates of the achievable performance gains. To further assess the main conclusions, Fig. 8 also includes a restricted integrated-control case that provides a conservative lower-bound benchmark for the fully integrated study. In this restricted case, for each wind direction, all turbines in the farm are constrained to use the same control method, either yaw-based control (turbine repositioning/wake steering) or Helix wake mixing. The chosen method may vary with wind direction, but the two methods are not used together within a given wind-direction case. Even under this restriction, excluding the simultaneous same-turbine use of yaw-based control and Helix wake mixing does not eliminate the benefit of integrated control, although the resulting

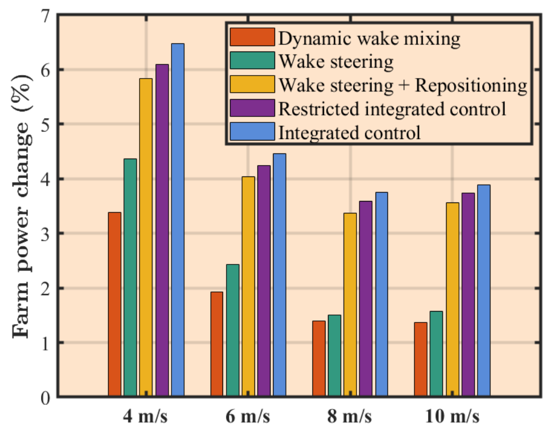

Figure 8: Average improvement in maximum farm power over the full 0–360 degrees inflow-direction sweep for wind speeds of 4–10 m/s, expressed as percent change relative to greedy control. Bars compare dynamic wake mixing, wake steering, wake steering + repositioning, a restricted integrated-control case, and the fully integrated-control case. In the restricted integrated-control case, for each wind direction, all turbines in the farm are constrained to use the same control method, either yaw-based control (turbine repositioning/wake steering) or Helix wake mixing. The selected method may vary with wind direction, but the two methods are not used together within any given wind-direction case. The restricted case is included to provide a conservative benchmark for assessing the influence of excluding simultaneous same-turbine yaw-based control and Helix wake mixing.

gains are smaller than those of the fully integrated case. These results indicate that the main qualitative benefit of the proposed integrated framework is preserved.

Among the remaining strategies, wake steering + repositioning provides the next-highest gains, followed by wake steering, and then dynamic wake mixing. The separation between wake steering + repositioning and wake steering alone highlights the additional value of exploiting crosswind mobility to reduce wake overlap beyond what can be achieved through wake deflection alone.

5 Conclusions

In power maximization mode, it delivered up to 6.5% higher total power compared to baseline operation, with the corresponding conservative lower-bound benchmark still achieving up to 6.1% improvement. In power regulation mode, it simultaneously tracked the prescribed farm-level reference and mitigated wake overlaps.

2. **Comment:**

A related point concerns the combination of wake steering with power curtailment. The manuscript adopts a simple derating approach, which does not account for the more complex aerodynamic effects highlighted in recent studies (e.g., Heck, Johlas, and Howland, 2023; Tamaro, Campagnolo, and Bottasso, 2024). This issue is less critical than the one discussed above, as recent versions of FLORIS include models that capture these effects. If possible, the use of these updated models would improve the physical consistency of the analysis. Specif-

ically, the rotor performance for a given yaw drops as the thrust coefficient is lowered by curtailment. Hence, I expect that adopting a constant cosine law exponent implies a biased estimation of the integrated control performance.

Response: Thank you very much for this insightful comment. We agree that the present combination of simple power derating and a cosine-law yaw-loss correction with a constant exponent does not fully capture the complex aerodynamic behavior that arises when yaw-based control and power curtailment are applied simultaneously. We also note that recent versions of FLORIS include more advanced operation models related to the work of [1] and [2]. Specifically,

- **Unified momentum model:** In the current FLORIS documentation, the unified momentum model uses only yaw angles as inputs, whereas our formulation introduces power derating through per-turbine power setpoint commands.
- **Controller-dependent model:** The current FLORIS documentation presents the controller-dependent model through yaw-misalignment examples and does not document its use with power derating commands; moreover, it states that results obtained using the reference turbine C_P and C_T tables should be considered demonstrative only. Although the underlying FLORIS function definitions appear to allow power setpoints to be passed to this model, that usage is not documented at the same user-reference level.
- **Mixed operation model:** The FLORIS mixed operation model is explicitly documented for the restricted setting in which each turbine may use either yaw-based control or power derating, but not both simultaneously on the same turbine.

Accordingly, we took a conservative approach and used the mixed operation model to construct a restricted benchmark. In response to Reviewer 1's comment, we addressed this modeling issue in two ways. First, we clarified this modeling limitation explicitly in the revised manuscript. Second, we added a restricted benchmark based on the FLORIS mixed operation model to examine performance when yaw-based control and power derating are not assigned to the same turbine. The corresponding revision is summarized below.

Change in manuscript:

4.2.4 Power Regulation with Wake Penalties

As discussed in Sect. 3.2.2, when yaw-based control and power derating are applied simultaneously to the same turbine in the present study, the power of the yawed turbine is evaluated by applying the correction $P_i \leftarrow P_i(\cos\theta_i)^{p_P}$ to the derated power, where $p_P = 1.88$ [3]. However, this representation remains approximate. Recent studies indicate that, for a yawed turbine, the power depends on the yaw angle, the thrust coefficient, and the control strategy governing the rotor, rather than being described by a single constant cosine-law exponent [1, 2]. Therefore, the combined effect of yaw misalignment and power derating is not fully captured by the present model.

To further assess the impact of this modeling limitation, we considered a restricted benchmark using the mixed operation model in FLORIS, in which each turbine was allowed to use either yaw-based control or power derating, but not both simultaneously. For the two representative cases considered here, the restricted benchmark still achieved the farm-level power-regulation objective while mitigating wake overlap, with results similar to those of the unrestricted integrated case. The detailed results are therefore omitted here for brevity.

Additional figure in response file only

For completeness, we provide the corresponding restricted-benchmark figure below. It is not included in the revised manuscript for brevity.

The restricted benchmark based on the FLORIS mixed operation model closely tracks the prescribed farm-level reference in both representative regulation cases and exhibits a wake-mitigation pattern similar to that of the unrestricted integrated case. In the left-inflow case, the downstream wake deficits remain alleviated, and the local inflow values stay close to those of the unrestricted integrated case. In the lower-left inflow case, the same qualitative wake-relief pattern is retained, with only minor differences in a few local inflow values.

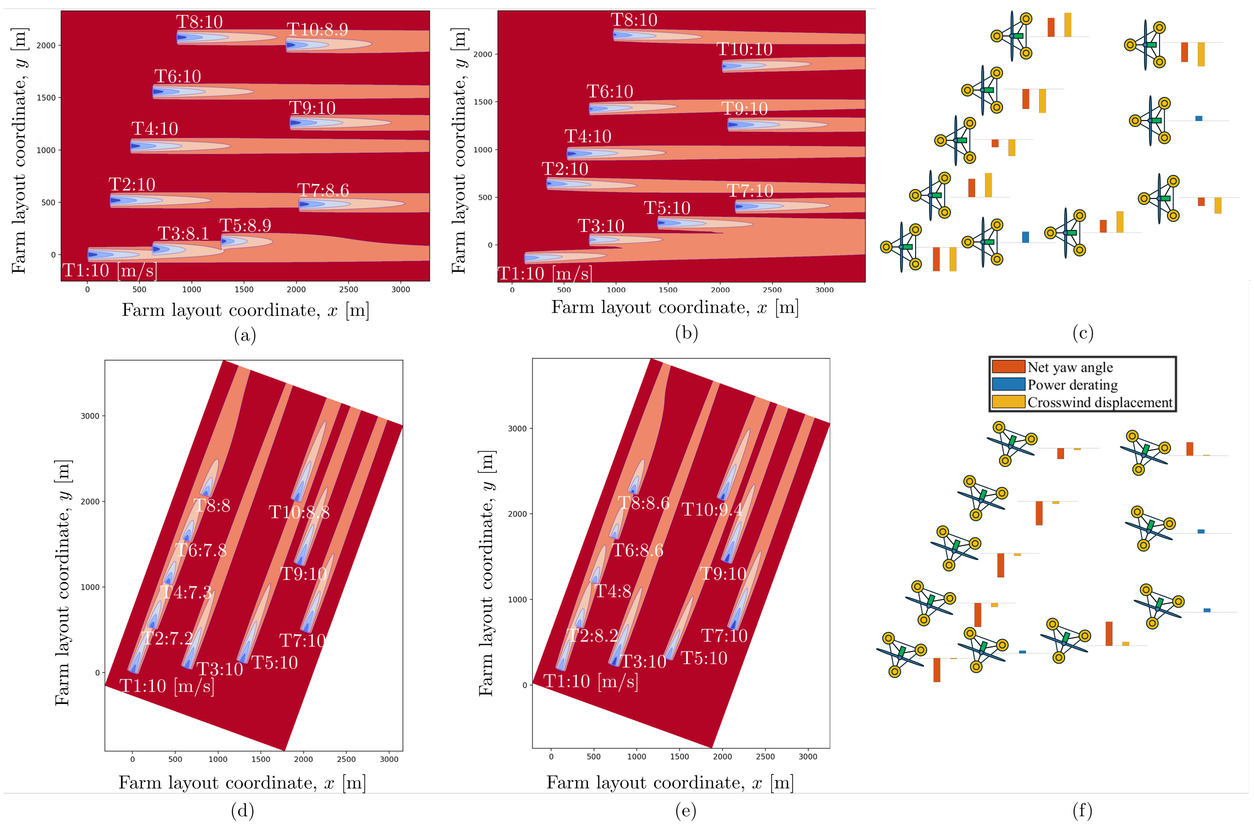

Figure: Representative power-regulation results at an inflow speed of 10 m/s for two inflow directions under the restricted benchmark based on the FLORIS mixed operation model. Panels (a)–(c) correspond to wind from the left with $P_{\mathrm{ref}} = 32$ MW, and panels (d)–(f) correspond to wind from the lower left with $P_{\mathrm{ref}} = 27$ MW. For each case, panels (a) and (d) show the hub-height wind-speed field under greedy control, and panels (b) and (e) show the corresponding field under the restricted integrated-control solution. Color denotes wind speed (red: near free stream; white/blue: wake deficits), and the numbers annotated near each turbine indicate the corresponding local turbine inflow velocity. Panels (c) and (f) summarize the control solution with per-turbine bar plots of net yaw angle, derating level $(5 \text{ MW} - P_{\mathrm{set},i})/5$ MW, and crosswind displacement. In this restricted benchmark, each turbine is allowed to use either yaw-based control or power derating, but these two actions are not assigned together to the same turbine. The results remain similar to those of the unrestricted integrated case, with the same overall wake-mitigation pattern retained.

3. **Comment:** *Addressing these points—either through additional validation (for instance with LES), sensitivity analysis, or discussion of the limitations—would further strengthen the manuscript and increase confidence in the reported performance improvements.*

   Response: Thank you for this helpful comment. In response, we strengthened the manuscript in two complementary ways. First, as discussed in our responses to Comments 1 and 2, we added restricted benchmark cases to assess whether the main qualitative conclusions remain valid even when the less-established simultaneous same-turbine control combinations are excluded. Second, we made the corresponding modeling limitations much more explicit in the abstract, introduction, and conclusion. The resulting revisions are summarized below.

   Change in manuscript:

   Abstract

   Numerical simulations using the flow redirection and induction in steady state (FLORIS) engineering wake model show that the integrated method consistently outperforms any individual strategy. However, because validation in the FLORIS model remains limited for cases in which yaw-based control, including turbine repositioning and wake steering, is applied simultaneously with Helix wake mixing or power derating on the same turbine, the corresponding quantitative gains should be interpreted with caution. We therefore also considered additional restricted benchmark cases in which these control actions were not assigned together to the same turbine. These cases provide conservative lower-bound benchmarks for the integrated-control studies, while still indicating that the main qualitative benefits of the proposed framework are preserved. These findings highlight the potential of integrated control to enhance the efficiency, flexibility, and adaptability of FOWFs, offering a promising pathway to overcome the limitations and improve the performance of standalone control methods.

   1 Introduction

   Simulation results across diverse wind conditions demonstrate that the integrated controller consistently outperforms any single control strategy. Nevertheless, the current FLORIS model has limited validation for operating conditions in which yaw-based control, including turbine repositioning and wake steering, is used on the same turbine together with Helix wake mixing or power derating. Accordingly, the corresponding quantitative improvements should be interpreted with appropriate caution. To further strengthen the assessment, we also introduced restricted benchmark cases in which such combinations were excluded. These benchmarks provide conservative lower bounds for the integrated-control studies and still demonstrate the main qualitative advantages of the proposed framework. These results underscore the potential of integrated control to enhance farm performance, reduce operational costs, and strengthen the economic viability of large-scale deployment of reconfigurable FOWFs.

   5 Conclusions

   Overall, these findings demonstrate that coordinating multiple control strategies (turbine repositioning, wake steering, power derating, and Helix wake mixing), rather than applying them in isolation, can significantly improve energy capture and enhance operational flexibility in FOWFs. This work highlights the potential of integrated control frameworks to overcome the limitations of standalone methods and to support the broader deployment of floating offshore wind energy. Potential future research directions include higher-fidelity assessment of cases where multiple control actions are applied together on the same turbine, as well as extension of the present framework toward control codesign. In particular, future work should further validate cases in which yaw-based control is applied together with Helix wake mixing or power derating on the same turbine, using higher-fidelity simulations such as large-eddy simulations, since such same-turbine combined operation has not yet been validated in the present study. Although the additional benchmark cases in this study support the main qualitative conclusions when these actions are not assigned together to the same turbine, further work along these directions would strengthen confidence in the quantitative predictions for the unrestricted integrated-control cases. In addition, the present framework can be extended toward control codesign: rather than assuming an FOWF is already installed, mooring system configurations could be optimized to ensure that at least a subset of turbines retains mobility under any wind condition, thereby further improving overall farm performance. Progress in these directions would further enhance the operational efficiency and economic viability of next-generation offshore wind energy systems.

References

[1] K. S. Heck, H. M. Johlas, and M. F. Howland, "Modelling the induction, thrust and power of a yaw-misaligned actuator disk," *Journal of Fluid Mechanics*, vol. 959, p. A9, 2023.

[2] S. Tamaro, F. Campagnolo, and C. L. Bottasso, "On the power and control of a misaligned rotor – beyond the cosine law," *Wind Energy Science*, vol. 9, no. 7, pp. 1547–1575, 2024.

[3] P. M. O. Gebraad, F. W. Teeuwisse, J. W. van Wingerden, P. A. Fleming, S. D. Ruben, J. R. Marden, and L. Y. Pao, "Wind plant power optimization through yaw control using a parametric model for wake effects—a CFD simulation study," *Wind Energy*, vol. 19, no. 1, pp. 95–114, 2016.