Review: *Integer programming for optimal yaw control of wind farms*

Summary

This article presents the development of a method to split a wind farm into sections grouping turbines that are likely to be influenced by their upstream neighbours based on their relative positions, and the application of Integer Programming to optimise farms based on pre-computed evaluations of these sections. The idea would be of interest to readers of this journal, and the authors have included a significant amount of theoretical background as well as reporting the use of their method under varying configurations. However, there are several areas to be improved, including addressing whether this method is applicable to farms larger than the (relatively small) example cases used in the paper, and improving the descriptions of the methods used as they are insufficient to allow others to reproduce this work. Therefore, I recommend major revisions.

Major Comments

1. Method:
    a. Reproducibility:
        i. There is insufficient description of the overall process, and the paper would benefit from a flow-chart or pseudo-code of the entire process.
        ii. How is the constraint of having consistent yaw offset angles for turbines in overlapping sections applied in practice? If it is done sequentially through the sections, is there a difference in the results depending on how the sections are ordered?
    b. Solvers: Please include descriptions of both the SCIP and Gurobi solvers, including the differences between them as their performance is compared in the results.
    c. Trapezoidal Sections: Further details needed on the trapezoidal sections:
        i. Did the authors conduct any sensitivity studies on the trapezoid slope given that it is smaller than the reference angle given (line 283)?
        ii. (Alternatively) Did the authors verify that the chosen section shapes satisfy their criterion of containing wakes with >5% wind speed reduction for multiple yaw configurations? And for sections anchored at both upstream and downstream turbines?
        iii. What was the reasoning behind choosing to use the “upstream” sections rather than the “downstream” ones for the optimisations? Why are both described if they are not both used, and would they have changed the results if either can be used?
        iv. Can the authors comment on how well their method would adapt to wind farms that are not laid out in a grid pattern?
    d. Combinations: I believe the formula on line 355 should be $\mathbf{2}^{\boldsymbol{n_{WT,u}}} - \mathbf{1}$ (“non-empty section configurations”). Please correct this and any subsequent changes to the calculations in this section.
    e. Loading Components: Line 505 states that the weightings of the tower and pitch activity penalties are zero so I assume they have not been used in the optimisations. If this is the case there is no need to include them in the paper other than as potential future work.

2. Comparisons:
    a. Farm-Wide Optimisation: If possible, the results tables should include a comparison between the total power from farm-wide optimisation (i.e. IP without splitting wind farm into sections). This is briefly mentioned around line 545 but only for a single case.
    b. Timings: A clear comparison of the time taken for optimisations using the pre-computed sections vs the entire farm at once is needed. This would be more intuitive than the mathematical explanations.
3. Limitations:
    a. "Deeper" Wind Farms: It is acknowledged that the method only allows faster optimisation on wind farms increasing in size "orthogonal to the wind", but given that most real-life wind farms are much larger than the examples given in the paper, a discussion on how (or if) this method could be adapted for use with deeper wind farms is needed.
    b. Steady-State Models:
        i. The authors mention that the use of a dynamic model was perhaps unnecessary; have they considered what the time savings would be when using a steady-state flow model between optimisations with their method of splitting the farm compared to farm-wide?
        ii. Also, have the authors ensured that their sampling of the dynamic flows gave sufficient time for changes to propagate through the farm? And hence could be replaced with a steady-state model?
4. Paper Length: This paper is very long, it is recommended that the authors attempt to cut down the length of the paper and make the language more concise. For example, there are several "summaries" at the start of sections which are not necessary; also mentions of unnecessary specifics such as atmospheric details in line 48 and wind roses in line 375. The Appendix is quite long and often referred to in the main text, would it be more efficient to include only the necessary mathematics within the main text?
5. Contributions: The method of splitting the wind farm into smaller, pre-computable sections for faster optimisation is one of the main contributions here but is not much described in the Abstract and Concluding remarks. Please be sure to highlight this contribution in these sections.
6. Figures & Tables:
    a. Table 2: This table is very difficult to follow, even with the explanations and context from the caption, Table 1 and the surrounding text. A diagram of the example described in the text of the chosen consistent yaw offsets may help.
    b. Figure 6: This figure is very crowded with numbers and hence difficult to interpret; the raw yaw offset angles and power values per turbine are not useful to the reader (in the figure or caption). I suggest visualising the wakes of the turbines to demonstrate wake steering and removing the text on each turbine.

Minor Comments

1. General: Please ensure that all acronyms are defined once with the relevant capitalisation, and then used consistently throughout; particularly the acronym WFYP which is re-defined multiple times.
2. General: Do not need to capitalise words after a colon mid-sentence.
3. General: Please ensure that the angle is referred to as the "yaw **offset**" rather than the "yaw" angle where appropriate, e.g. on lines 200 & 261. Related to this, on line 24 I assume the angle being optimised is the "nacelle direction **relative to** the wind".
4. Line 4: "in **the** form"
5. Line 12: "**greenhouse**"
6. Line 25: Calling the total power the "most important objective" is subjective, other users may value e.g. signal tracking more.
7. Section 1: The description of wakes and yaw control is not very clear, please describe in more detail how yawing the turbines allows the farm to increase power.
8. Figure 1: The axis titles and colour bar titles (including units) are missing from the figure. The turbines themselves are difficult to see, could e.g. a thicker black line be added to represent the rotor?
9. Section 1.1: There are other papers that have "split up" wind farms into more easily optimised sections that could be referenced here such as "Dong & Zhao 2023 *IEEE Transactions on Industrial Informatics*" and "Bernardoni et al. 2021 *Journal of Renewable and Sustainable Energy"*
10. Line 45: Could the reference to a figure in a different paper be removed and the concept explained instead.
11. Line 86: Unclear on what the "accuracy of 1%" means – that the calculated power is within 1% of the true global optimum?
12. Line 110: "as **a** wind farm yaw problem"
13. Line 113: "we ~~provide to~~ include"
14. Line 139: "respectively" to what? Incorrect grammar.
15. Lines 150 & 279/280: The phrasing is difficult to understand, suggest changing to "…downstream turbine is 5% **or less**"
16. Lines 178, 346 & 534: "we remind **the reader** that" / "~~we remind~~ **remembering** that"
17. Line 180: Is there a reference or calculation for the 15 minute time scale given the yaw rate and wind speed e.g. does it ensure all changes have propagated through the farm?
18. Section 2.1.2: The "curse of dimensionality" is well known, this could just be a reference rather than a whole section.
19. Line 234: Surely standard IP solvers can handle black-box problems?
20. Line 262: Typo? I think "preservers" should be "**preserves**"
21. Line 270: I think it should be "**recurring**" rather than "reoccurring"
22. Figure 5: It would be helpful to see the effective farm depth and the section depths, possibly on this figure. Also, the double meaning of plot 5c is quite confusing – please re-word the caption as it reads like the farm is both yawed and under wind from 20°.
23. Line 465: What does "generally possible" mean here? Please remove un-specific language.
24. Section 3.2: Could you clarify how the different time scales are related (15 mins WFC interval earlier in the paper, 9 mins simulation time here, "middle 5 min" observation interval) – possibly in flow-chart of overall process. Are these observation times longer than the wake propagation times through the farm?

25. Line 495: Equation should have a reference number.
26. Line 505: Are the turbines individually weighted in the reward? If so this has not been made clear in the preceding text.
27. Section 4.1: There is not enough discussion on the effect of wind directions here given it is the section title.
28. Line 593: It should be acknowledged that the turbines do not have a wide choice of yaw offset angles, so it is not too surprising that many are identical.
29. Line 599: For certain wind directions (rather than speeds) there may be no / very few turbine-wake interactions so the optimal may be 0° for all / most turbines.
30. Line 625: Months of pre-computation would be a very long time, particularly if after farm installation the wind resource is not as expected (e.g. blockage) and WFC needs to be re-calculated. The authors mention that using a dynamic model was perhaps not needed, would using a steady-state model instead cut down the expected pre-computation times?