Article Response to referees' comments in WESC

Title: Power Fluctuations In High Installation Density Offshore Wind Fleets
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PART I - General comments

I.1. A detailed explanation of time series simulations for wind speed and turbine/plants simulations has been added.

I.2. The description of CorRES has been improved.

I.3. Improved description of high wind speed technologies.

I.4. An overall review of grammar, wording, and consistency has been carried out.

I.5. The referencing style has been aligned.

I.6. More detailed explanation in the results, discussion, and conclusion sections to illustrate the significance of the work for the industry.

PART II - Specific comments (scientific)

II.1. Improved description of the problem and motivation. The hypothesis of the research is stated. A clear connection between power fluctuations and turbine curtailment technology is stated.

II.2. The research gap is further explained, and the novelty of the presented work is rephrased.

II.3. Description of the scenarios has been enhanced.

II.4. The wake modelling approach used is explained in more details.

II.5. Abstract has been rephrased to include quantified results.

II.6. A discussion of the impact of curtailment technology in terms of capacity factors is added. Note that because the probability of observing high wind speeds (ws > 20) is low, there is no significant difference in terms of energy production for the two high wind speed operation types; this can be seen in Table 3.

II.7. Results and conclusion sections have been expanded. Emphasis is put into the relevance of this article for the scientific community and the industry. The objective of this article is not to study what is the optimal density of offshore installations to minimize power fluctuations, as the optimal spacing would be to spread the offshore fleet as far away as possible. In the context of an offshore wind energy fleet that has clear delimitation of location and area, we concluded that high wind speed operation is necessary to limit the extremes in the aggregated fleet power fluctuations, but this technology is not sufficient since the extreme fluctuations are still present in the ramping up after storms, the authors propose mitigation measures that can be implemented in plant or fleet level.

PART III - Technical corrections

A revised manuscript is under preparation that addresses most of the technical corrections suggested by the referees except for the following:

Introduction - line 34: "smoothing effect" is a term that is used in the large scale energy system modelling of wind energy that refers to the fact that fleet-level wind generation time series is smoother (fewer fluctuations) for fleets in which the plants are spaced further apart. The geographical smoothing effect is a consequence of the spatial correlation trends (decrease correlation as a function of the distance between locations) in both wind speeds and wind power.

Literature synthesis - line 117: Agora Energiwende's study reports the impact of installation density and wakes in the capacity factor of large offshore fleets in the North Sea; the motivation for our article is not that, but to study the impact of installation density, turbine technologies and wakes in terms of fleet-level power fluctuations.

Methods - line 133: High wind speed operation is commercially available on most wind turbine manufacturers. Each manufacturer implements the high wind operation with different control strategies, therefore the actual reduction in power at high wind speeds results in a different curve for each manufacturer.

List of changes using the original manuscript line numbering

Abstract

- 2: Consider using “offshore wind power fleet” interchangeably with “offshore wind power arrays”.
- 18: Replace “;” with “,” after “technologies”
- 18: Replace “bellow” with “below”

1. Introduction

- 23: Consider replacing “Belgium” by “Belgian” offshore wind power fleet and “will be by the end of 2020 “ by “is by the end of 2020”. It should be also noted how many

wind farms are there and that they are conventional bottom fixed offshore wind farms.

- 24: Belgian offshore wind fleet is by 2020 one of the areas with the highest installation density (approximately 10 KW/km2) ... Where? In the North Sea, or Europe? Pls. clarify. Also state what is an average offshore installation density per MW?
- 28: In the sentence “Previous studies..” pls. replace “;” with “,” after “while” .
- 33: Pls. synchronize overall text with the chosen form of the referencing (Harvard style of referencing). Ex- ample: Instead of “ . . .such as (Santos-Alamillos et al., 2017; Tajeda et al., 2018 etc.) it should be . . .such as: Santos-Alamillos et al. (2017), Tajeda et al. (2018), etc.
- *NO* 34: Consider replacing wording “smoothing effect” into “mitigating effect”.
- 41: Referencing: same comment as under (33). Referencing Pfenningar (2017) at the end of the sentence should be (Phenningar, 2017), so the sentence would read as follows: “A long term dynamical simulation of the offshore wind power generation is required to assess the impact of the extreme power fluctuations in the energy system (Pfenningar, 2017)”.
- 43: Pls. avoid personal language in the sentence: “To do this we propose. . .” and also we suggest to reformulate: “This research proposes a methodology for simulating. . . “.
- 45: The “stimulated “time series.. or The “simulated” time series? Pls. add at the end of the sentence that a full detailed model of the energy system is not “in the scope of this paper” (as to clarify to which scope).
- 45: Consider reformulating “offshore wind production” into “offshore wind ”.
- 47: Consider replacing “This article” with “This pa- per”. In the same sentence we propose to put a dot after: “This article includes several novel methodologies.”

2. Literature synthesis

- 66: Pls rephrase “is possible”.
- 69: Replace “an” in stochastic time series with “a” .
- 72: Consider reformu- lating word “trained”. Maybe “based”?
- 73: “too different” may be redundant, not clear the meaning, pls consider revising this part of the sentence.
- 82: Pls. reformulate to: “Examples of this approach are available in: . . .“
- 83: Pls. erase “a” in “using a meso- scale driven generation simulations” and also consider erasing “generation” as it may be redundant.
- 92: It is not clear what is the disadvantage of the mesoscale driven sim- ulations stated under (b)? It sounds more like an advantage. Pls. clarify. Also entire sentence not clear, we suggest to revise.
- 94: In (c) after “. . .is missing; which is nec- essary..” use “, ” instead of “;”
- 96: We propose to put a dot after “Stochastic models are designed to capture the missing wind speed fluctuations”. Then start a new sentence with “Veers (1998) demonstrated. . ..apparent spectra. . . after that replace “;” with “,” .. and proposed a methodology. . .

- 99: Pls. end the sentence after the word ”estimation”. New sentence to start with “Larsen and Kruger (2014) introduced . . ..”
- 107: We pro- pose to skip “well studied” in the sentence “The wake behind the turbine is well studied flow etc.” Also, in the same sentence put a dot after “turbulence downstream” and start a new sentence with Porte-Agel at al.(2020) provide a review of the work . . .
- 115: End of the sentence referencing, same remarks as under (41).

3. Methods

- 126: In the sentence “The two scenarios assume same rated power..” put the dot after “specific power” and then start the new sentence with “ The few MW range...”. Pls. explain what are different specific powers? Also explain further what are the 2 technologies A and B and what is the main difference between them (curtailment method or something else)? Is Tech A associated with the direct cut off only or it could also use HWS deep? If yes, pls. explain. Throughout the text it appears as Tech A is only used with direct cut off an Tech B with HWS for simulation reasons (which may not to be case as per Figures 11 and 12)? It appears there are only 3 scenarios regarding the fleet position, with different parameters (installed capacity, turbine technology, Tech A and B) and turbine storm shutdown technology. If yes, this is important to clarify in the beginning to avoid confusion later in the text. Figure 1: Pls provide more explanation of this figure in the text.
- 128: In sentence “The power curves from . . .” put “,” instead of “;” after “specific power”.
- 133: In the sentence “The HWS deep type . . .” it should be added if HWS deep operation technology was a novel method introduced by the authors (as it seems so) or it was used elsewhere, and if yes, it should be referenced.
- 135: How big is the neighboring Dutch fleet (in terms of installation capacity and also density)? If the data available pls. include here in the text.
- 135: Is there one installation scenario with three stages or three installation scenarios? Pls specify.
- 135-140: Pls provide data how big is BE2018 fleet in GW? Later in the text it appears as there are different geographical soothing for different installation scenarios. Pls. provide information here what is on average the distance between the WTGs in different fleet scenarios?

3.2 Modelling

- 144: Avoid using personal language such as “in our model”, instead use “in the model proposed in this research or similar”. Also pls. provide more detail on CoRES model chain.
- 175: Pls. connect the sentence “Where the coefficient a1 is a parameter “ with the previous one, starting “The stochastic model used to..” as it seems they both represent one segment.
- 187: Are the sentences “Sorensen et al. (2008) reported. . . “ and “Where $\alpha j\, k$ is the direction” connected ? If yes, pls. integrate accordingly.

- 220: Figure 4 to be better described.

- 3.2.3 Wind turbine/plant storm shutdown
- 236: In the sentence “In this Fig. it can be ..” pls . change as follows “ . . . of the individual turbine, which is a consequence. . .”
- 252: In the sentence “Model validation. . .” please replace “;” with “,” after “production distributions”, and erase “,” after “fluctuations distributions”.
- 259: Add “d” in the sentence ” The extreme values are better capture by CorRES. . .”. In the same sentence replace ”,” with “;”
- 263: Regarding the follow- ing part : ”(with wakes considered in the transformation from wind speed to power”) , pls. clarify which transformation is meant?
- 269: Avoid “our” simulations, impersonal language should be used as noted above.
- 282: Consider reformulating “Results for 37 years of simulation for the different scenarios . . .” into “Simulation results for 37 years of wind speed time series for the different scenarios . . .etc.”
- 283: In the sentence “The capacity factor of the Belgian offshore wind fleet is expected to increase. . .” Pls. explain why (due to larger turbines, curtailment technology, spacing , etc.?)
- 290: Table 3. (textual part) In the sentence “Capacity factors (Cf), etc..” please erase “;” after “and”. Also in the same text explaining Table 3, separate “37 years”.
- 297: Please put the dot after “. . .on the steepness of the power curve”. Start new sentence with “The distribution of low wind speed. . .” .
- Figure 11: If possible, reformulate title of the figure instead of “Power ramps not during HWS” to “Power ramps during LWS”. It seems that the BE 4.4 GW Tech B Direct cut-off was not presented in the graph (no green line) and if not pls. state so (there is a reference that Tech A and Tech B are so similar but if the results obtained for LWS are the same , it should be stated that depicting Tech B cut-off is omitted).
- 304: Pls. correct in “at high wins speed” into “at high wind speed”.
- 305: We propose that the sentence “In the 4.4 GW scenario, the 25 m/s direct cut off ...etc.” is linked with the succeeding part “, while BE 4.4 GW HWS deep shows the least extreme power fluctuations of all scenarios (so it becomes one sentence).
- 312: Sentence ”While similar extreme ramp . . .” seems to be incomplete, pls. revise.

- 314: Pls. explain why there was a reduction in power ramps between BE2018 and 2.3 GW scenarios?
- 315-318: The correlation with respect to geographic soothing and power fluctuation should be additionally justified (correlating the layout differences, curtail- ment technology, wakes, etc.).
- Table 4: In the textual part, pls. erase “;” before “and” .
- 3.3 Measured data for model validation and calibration Pls. specify here that only 3 years of measured data were available.

6. Discussions

- 322: Pls. indicate what are the rotor sizes per different scenarios? It should be also mentioned earlier in the section “Methods”, when scenarios and variables were intro- duced.
- 320 -325: Pls. explain further the correlation between increase in CF for 4.4 GW scenario and decrease of power fluctuation for the same scenario. Here it is mentioned that this happens due to distance but it is actually due to a decreased wakes effect.
- 326: In the sentence “There is a trend to have the most..” please replace “;” with “,” and replace “such” with “so” – “so that it is possible to lose 75% of installed capacity etc. Also consider reformulating word “trend”.
- 329: The sentence ” Extreme up-ramps are more likely . . .” is suggested to be revised as follows: “Extreme up-ramps are more likely to occur than similar size down ramps, because the wind turbine storm shut- down technologies only mitigate the shutdowns and not the restart part of the power curve”.
- 331: Pls. reformulate “should be considered” into “should be addressed”.
- 334: Pls. consider reformulating “geographic distribution of installations” into “geographic location of the installations” .
- 336: Consider reformulating sentence “Even though the t-distribution. . .” as it seems to be incomplete.
- 340: Pls. end the sentence after “in the presented approach”.
- 343: Pls put “,“ after “Belgian-Dutch fleet..”
- 347: Pls. correct “out of the scope for this study “ to “out of the scope of this study” .
- 348: In the sentence “To further reduce . . . a stochastic availability model should be considered”, pls. sug- gest which model, is it a novel one (as recommended to be conducted by a separate research)?

7. Conclusions

- 356: Pls. consider reformulating “helped better” .
- 359: Pls. correct to “high wind speed events” .
- 364: In the sentence “Even though the most extreme power fluctuations . . .” pls. change the punctuation. We suggest to put after “shutdown” a coma and replace “this” by “which”. Also erase “such” in “there is such a tightly packed wind power fleet”.
- 371: In the sentence “geographical distribution of installations. . . is a good candidate”, pls. consider reformulating “candidate”.