

## ***Interactive comment on “Power Fluctuations In High Installation Density Offshore Wind Fleets” by Juan Pablo Murcia Leon et al.***

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Received and published: 20 November 2020

Review comments by Anders Wickström and Nermina Saracevic on the paper:

” Power fluctuations in high installation density offshore wind fleets” Juan Pablo Murcia Leon, Matti Juhani Koivisto, Poul Sørensen, Phillippe Magnant (2020)

### **PART I - General comments**

The paper proposes a specific methodology to investigate correlation between spatial location of the offshore wind turbines and low frequency power fluctuations above cut out wind speed as well as methods to curtail variations (fluctuations). Power fluctuations of high-density installation offshore wind arrays (farms) in Belgian fleet are studied as they pose a challenge to operation, maintenance and power production. Assess-

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ing the correlation between high density offshore wind farms and power fluctuations is highly relevant in view of the offshore wind capacity to be installed in the European seas by 2030 and beyond. To assess the correlation, the authors propose a novel model-chain: CorRES (correlations in renewable energy sources). The methodology is validated in respect to 2018 measured operational data of existing fleet (BE2018). The presented model was able to capture distribution of wind power variations and its spatio-temporal characteristics. This novel methodology represents a good contribution and adds up to a new scientific method in a way it can accurately predict distribution of power fluctuations in the offshore wind fleets. The paper follows a clear structure with well-presented topic, methodology, results and discussion points. The authors have concisely described how several new methodologies were developed and combined to create a model chain simulation in CorRES. However, more information is needed to explain wind speed time series simulation and wind turbine/plant storm shutdown simulation. Description of what is CorRES and how it operates as well as the High Wind Speed Deep technology would add to better understanding of the tools presented. In general, the paper could benefit from further improvements in regard to clarity, consistency, and precise and grammatically correct wording. Referencing other authors should be aligned throughout the text in the same manner according to Harvard style (as it seems the authors used this style). It is recommended to elaborate more on the results in the discussion and conclusion sections, in order to illustrate significance of the work for industry regarding the power oscillations.

### **PART II - Specific comments (scientific)**

It is recommended to revise the paper in line with following remarks: “Improve description of the problem, why the research is undertaken, what is the motivation and what are the objectives and hypothesis? What seems to be the problem with power fluctuations and turbine curtailment strategies? “Improve the explanation on what is the research gap and what it will contribute to the ongoing research, what novelties are there? “Improve on the description of the scenarios, discerning 3 (as per fleet

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size) and their characteristics (installed capacity, turbine size used, technology storm shut down used) – Pls. clarify how wakes modelling was integrated into the wind simulation? – Pls. provide quantified results in Abstract in regard to the purpose of the paper: “to quantify the distribution of the ramp rates as a measure of power fluctuation when extending the offshore wind capacity in Belgium”. – If possible, describe and quantify under the Discussions section the difference between using a modern curtailment technology (HWS Deep) and cut-off technology. How that reflects in terms of power output, how much we can save by applying HWS techniques? – Expand more on results in the Conclusions section. How the results could be relevant and useful for scientific community or industry? Based on the research, what should be the optimal density for offshore wind farms to avoid loss of power due to power fluctuations?

### PART III - Technical corrections

Recommended is technical correction of the text as follows:

#### 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

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overall text with the chosen form of the referencing (Harvard style of referencing). Example: 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. 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 paper”. In the same sentence we propose to put a dot after: “This article includes several novel methodologies.”

#### 2. Literature synthesis

Note: Reviewers didn’t check validity of the reference literature. 66: Pls rephrase “is possible”. 69: Replace “an” in stochastic time series with “a” . 72: Consider reformulating 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 simulations 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 necessary..” 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

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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 propose 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 et al. (2020) provide a review of the work . . . 115: End of the sentence referencing, same remarks as under (41). 117: Agora Energiewende reference on the capacity factor for offshore wind farms with high density is 30-50% which falls generally within offshore capacity, so this figure does not tell much about how wakes in high density wind farms affect the capacity factor and energy production. Is it possible to extract more specific data from this study of Agora Energiewende and directly link it to the impact of wakes to energy losses and consequently to capacity factor?

### 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 and Tech B with HWS for simulation reasons (which may not be the 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

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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  $a_1$  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  $\alpha_j$  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 following 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. ex-

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plain 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, curtailment 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 introduced. 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

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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. suggest 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”.

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Interactive comment on Wind Energ. Sci. Discuss., <https://doi.org/10.5194/wes-2020-95>, 2020.

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