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Interactive comment on "Effect of tip spacing, thrust coefficient and turbine spacing inmulti-rotor wind turbines and farms" *by* Niranjan S. Ghaisas et al.

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Review comments for "Effect of tip spacing, thrust coefficient and turbine spacing in multi-rotor wind turbines and farms" by Ghaisas et al. in Wind Energy Science, 2019.

Overall: The article present numerous LES of both single rotor and multi-rotor consisting of 4 turbines. The different turbine configurations are compared, including the effects of tip spacing in the multi-rotor, thrust coefficient asn turbine spacing for farm scenarios. Additionally, the authors compare to the analytical model by Bastankhah and Porté-Agel. The article follows a number of other recent articles on multi-rotors and provides new results. The article is generally well-written and the results are in-

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teresting, so the article is recommended for publication with revisions according to the comments below.

General comments:

1. Resolution and degree of detail.

- The number of grid points are given in Table 1. However, it would be beneficial to report what these values correspond to the actual spatial resolution. Please correct me if wrong, but as far as I can tell, the main grid of 256x128x160 grid points has a width of pi/2*1000m, i.e. the lateral discretization is 1570.8m/128 = 12.3 m. Same resolution in the vertical. This means that there are only 4 points for a single actuator disc and only 2 for a small rotor in the multi-rotor. Is this correct? Tip spacing clearings corresponding to approximately 0.6m, 1.2m, 2.5m and 3m are investigated. How are the effect of tip spacing properly resolved when the mesh is so coarse?

- Please rephrase your sentence in the conclusion stating: "are studied in detail for the first time.". This is stretching it too far in my opinion for several reasons:

a) It could be argued that the degree of detail was larger in the article by van der Laan et al. (2019) due to higher resolution and using actuator lines rather than actuator disc as well as changing thrust due to a more realistic controller. Likewise, several of the conclusions found here corroborates the findings of other previous studies, but your present article still has merit. Additionally, the majority of the conclusions investigate integral quantities, e.g. power or disk-averaged velocity deficits.

b) A recent article by van der Laan and Abkar (2019) also investigates multi-rotors in wind farms and find similar conclusions. Please include as reference and discuss when results are similar or different. This is mainly that the benefit of multi-rotors seems to vanish further into the farm, as seen in Figure 9(c)+(f). The authors should comment on this more, because it also explains why the analytical model ends up giving reasonable results further into the farm as it approaches the same level as for single rotor wind

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farms. Therefore, the conclusion by the authors "Wind farms comprised of multi-rotor turbines always show benefits over similar..." is perhaps also stretching the conclusions a bit as it does not show a benefit from the 4th turbine onwards.

2. Effect of CT. The authors discuss how a constant CT is used as opposed to the varying thrust level seen in van der Laan et al.(2019). Please comment on what is more realistic. Part of the discussion from the appendix on how to assess to CT could also be included in the main text.

3. Wake superposition. Wake superposition is not a trivial task and the focus of much research. The authors state in p. 5, line 124 that a new hybrid gives the best results. However, please elaborate on this, because it appears somewhat arbitrary. Best by what metric? It would be beneficial to include a comparison in an Appendix.

4. Reference/Comparison. Finding the appropriate reference for comparing a multi-rotor with a single rotor is not necessarily straightforward. Increasing the tip spacing a lot, has several implications for the presented results:

a) The upper multi-rotor will effectively see a higher wind speed than the single turbine and multi-rotor with smaller tip spacing. This will affect all the reported power increases, e.g. in Fig. 11.

b) As the tip spacing is increased, the wake merging is delayed and the authors state in p. 9, line 185-186: "...behave independently up to increasingly larger downstream distances". However, that means that it essentially becomes a comparison of a single wake behind a large rotor versus the wake behind a single small rotor. It can be seen in Figure 6(a) which also looks as if they would almost coincide if scaled properly by the corresponding rotor diameter and inflow velocity. Therefore, it seems that the conclusion by the authors is that is is beneficial to separate the rotors as much as possible, e.g. p. 15, line 285 "The benefit of 4-rotor wind farms increases with increasing tip spacing...". However, doing so would remove the potential benefial interaction of the tip vortices, which makes the wake break down faster, and hence recover faster. The

authors state that "...the 4-rotor turbine allows for greater entrainment". This is correct, but part of the increase might simply be an artifact of the reference no longer being appropriate. The question is if the entrainment from the center is more beneficial than the wake interaction? For details of the wake flow and how the wake interact to facilitate a faster breakdown, please see the published presentation with DOI by Andersen and Ramos-Garcia from WESC, 2019.

5. Analytical Model - The text in p. 19, line 310-313 does not seem to match Fig. 13: "Fig. 13(b) also show a similar sensitivity to the value of sigma"? It appears that sigma=0.28 gives better results for the velocity deficit, but worse for the power. Please explain this, because power should be proportional to Uˆ3.

Technical Corrections:

- p. 1, line 20. Please define the "planform energy flux"

- p. 2, line 28-29: I doubt the cubic scaling laws were first realized in 2012. Please rephrase or find older reference.

- p. 2, line 33: "Overwhelmed" appears a odd choice of word. Please rephrase.

- p. 2, line 46: It is a little unclear which article "this paper" refers to, i.e. van der Laan et al. (2019) or Chasapogiannis et al. (2014). For the former, it is not entirely correct that the study by van der Laan et al. only considered isolated multi-rotors as it shows how the wind farm area can be significantly reduced due to faster wake recovery which inherently deals with multiple multi-rotors. Please rephrase accordingly.

- p. 3, line 71+74: What are the "standard" here? Or what would the non-standard be? Perhaps it would be beneficial to elaborate on the simulations framework.

- p. 3, line 98-99: Please specify what this correspond to in physical time.

- p. 4, line 80: It is unclear to me how you simply state that the SGS stresses can simply be neglected? Does that mean you're effectivley turning of your SGS model?

Please clarify.

- p. 6, line 131-33: Does equation 4 not give the deficit, rather than "mean velocity"? Please define u_tot

- p. 8, Fig. 3: Please be consistent in plotting. The linewidth in the symbols change from left to right, i.e. symbols are less clear.

- p. 11, line 195: "Grazing" appears a odd choice of word. Please rephrase.

- p. 15, line 158-261: Please rephrase these sentences. It does not appear as if turbine 3 in Fig. 11(f) produce "appreciable larger" power than for a single rotor.

- p. 15, line 268-270: The authors state "It is seen that P2-5 is larger for all 4-rotor wind farms...". This is not correct. If you look at Figure 10(c) there is actually a cross-over for the 3rd turbine, where the single rotor produces more. Be careful, when you do the aggregate statistics, because it gets lost. Please rephrase.

- p. 16, Fig. 9: The axes on Fig. 9(a)+(d) seems wrong? If the velocity deficit is normalized, should the axes not be between 0 and 1?

- p. 17, Fig. 10: Please improve the figure. It is very difficult(impossible) to tell the lines apart as the symbols are so large that they cover the full vs broken lines. Comment on the cross-over at the 3rd turbine.

- p. 18, Fig. 11(b): Only three lines are visible. Please explain/comment in the text.

- p. 19, line 328: Typo. Correct to "reproduced".

- p. 20, Fig. 13: The axes on Fig. 9(a)+(d) seems wrong? If the velocity deficit is normalized, should the axes not be between 0 and 1?

- p. 21-22, Fig. 14-15: Please include explanation of the red values and how they are computed. Figures should be self-contained.

Additional references:

1. van der Laan, M. P. and Abkar, M.: Improved energy production of multi-rotor wind farms, J. Phys.: Conf. Ser., 1256, 1–11, https://doi.org/10.1088/1742-6596/1256/1/012011, 2019.

2. Andersen and Ramos-Garcia: Dynamic Analysis of the Multi-rotor: Performance and Wake, WESC, 2019 https://doi.org/10.5281/zenodo.3357790

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