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Interactive comment on "Numerical and Experimental Simulation of Extreme Operational Conditions for Horizontal Axis Wind Turbines Based on the IEC Standard" *by* Kamran Shirzadeh et al.

Anonymous Referee #2

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This paper aims to show a process chain to generate gusts and shear flows in the WindEEE Dome.
In the introduction, the problematic of gusts and shear flows in wind energy application are discussed and the measures proposed by the IEC 61400-1 are introduced. Next, the process chain is presented by generating a numerical model of the setup, validating the model and introducing the experimental setup. Then, the results are presented. First, the static shear flow results are shown, and then, the dynamic results are presented by explaining the numerical procedure to obtain the generator settings

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and comparing the experimental results to the IEC standard.
Overall, this study can be seen as a first proof of concept of the capability and the limits of the WindEEE Dome to generate gusts and shear flows. The possibilities of flow generation with the WindEEE Dome are highly interesting and valuable for experiments. However, this study faces several issues that need to be addressed before publication. The introduction lacks motivation/comments on why doing experiments and why doing a new setup as well as commenting on existing setups and recent developments. There is also no comment on how simulations can/will be used to complement this study.
Also, I am missing a clear objective of this study in the introduction. As this paper serves as a proof of concept, this should be emphasized.
The Methodology lacks structure and it should be pointed out clearly that the idea of this study is to

a) generate a test chain where a new numerical model of the WindEEE Dome can be used to predict fan settings so that inflow conditions can be modeled/prepared before the experiment

b) give a proof of concept of the capability of the WindEEE Dome to generate roughly IEC conform gusts/shears and the capability of the numerical model to predict fan settings correctly

In the Results section, the mean velocity evolution of the three extreme wind cases (extreme operating gust and extreme vertical/horizontal shear) is presented. It is shown that properties roughly similar to the IEC recommendations can be achieved. For experiments in the future, I would recommend to show the reproducibility of the flows.
There are many points in the paper that need addressing, and they can be found in the following. Also, the paper needs language editing.

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Grammar/language
l. 3 "WERE operated“
ll. 14: this sentence is quite long and the second part needs rephrasing
l 49 "smaller gusts . . . cause“ (not causes)
l. 95: analyze not analysis
l. 125 "Another capability at the inlet wall utilizes fans with adjustable. . .“ => another feature are the fans with adjustable. . ..
l. 146 parameterS
l. 203 time scale
you are writing XXm/s (no space), XX m/s (space) and XX seconds - please use equal convention for all cases
l. 243 "that ARE examined“
l. 244 "Using the tuned numerical model setups, the V-c and H-c domains were used“
l. 263 "resulting in a . . .“ (not "an“)

Abstract
The goal of this work as well as some results should be pointed out more clearly. Currently, the description of the WindEEE Dome is dominant, and while the setup is very impressive, it might be good to keep the details to the setup section. This will shift the focus towards the study that was performed.

ll. 19: HAWT is not introduced while all other abbreviations are introduced, in addition, as HAWT stands for horizontal axis wind turbine, it reads " horizontal axis wind turbine scaled turbine“

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Introduction
l. 27 "low carbon energy" => "renewable energies" ?
l. 29 "life time"

ll. 31 "Therefore, the design of wind energy systems must consider extreme environmental conditions with statistically accurate return periods."
It was shown that extreme conditions occur more often in the ABL than predicted by a Gaussian distribution by Wächter et al. (2012), however, the statistics used in the IEC standard for the prediction of the probability of extreme events are Gaussian statistics. Matthias Wächter, Hendrik Heißelmann, Michael Hölling, Allan Morales, Patrick Milan, Tanja MuÌĹcke, Joachim Peinke, Nico Reinke Philip Rinn (2012): The turbulent nature of the atmospheric boundary layer and its impact on the wind energy conversion process, Journal of Turbulence, 13, N26

ll. 35 The 50 year return period is both noted in the third and fourth edition of the IEC 61400-1: "For the steady extreme wind model, the extreme wind speed, Ve50, with a recurrence period of 50 years, and the extreme wind speed, Ve1, with a recurrence period of 1 year, shall be computed as a function of height, z, using the following equations:. . ." [IEC-61400-1 ed. 3, p. 25ff]
For the EOG, a return period of 50 years is actually named.
Further, none of the four editions of the IEC 61400-1 standard appears in your sources even though you are using formulas and name all existing editions of the standard.

I can not follow your argumentation why the second version of the IEC standard should be chosen over the third (or fourth, depending on when the experiments were carried out) since the main difference of the EOG is that $\beta = 3.3$.

ll. 39 While steady state wind tunnel tests may be more common, dynamic tests have been carried out in aerodynamics for a long time and in wind energy research, the setups have improved a lot over the past years, too (see comment to ll. 96 for some literature)

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l. 50 What is the "gust slicing effect"?

ll. 50 "These small gusts also can cause instabilities in the power output of wind turbine generators. For a small electricity network, these instabilities in power generation can cause serious problems for managing power transmission and distribution."
A source is needed for this statement.
What about the impact of large gusts on the power output and grid stability?

ll. 52 "The worst case is when a peak gust wind speed is higher than the wind turbine cut-out speed, which if prolonged enough can cause the control system to abruptly stop the wind turbine (Hansen, 2015)."
I assume, that "worst case" refers here to the high loads that this situation results in, however, before, you are writing about the stability of the grid which may be confusing.

ll. 54 "The most reasonable solution would be an adjustable generator load or adjusting blade pitch angles after detection of the gust"
This sentence is a bit misleading as a system must be in place in order to detect the wind field approaching the rotor. You could rephrase the sentence, e.g. "Ideally, the wind field approaching the turbine is measured so that the turbine control can adjust the generator load or blade pitch accordingly"
Could you also please comment on whether a control system with pre-monitoring would be sufficiently fast to react to EOGs?

ll. 64 "If extreme enough, the blades may experience a phenomenon known as dynamic stall (Hansen, 2015;Gharali and Johnson, 2015). All these together will result in instability and reduction in power generation, as well as highly dynamic fatigue loads on the system"
dynamic stall may also occur in case of the EOG. What do you mean by "instability in power generation"? Maybe, "high fluctuation in power generation" would be more accurate?

ll. 67 "These transient shears can happen for similar reasons as uniform gusts, but

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mostly happen within wind farms, where the wind turbines sometimes operated in the wakes of other operating up-stream wind turbines“
With respect to shear, the main problem is that downstream turbines may partially be exposed to the wakes of upstream turbines.

ll. 71 "This standard also defines a classification for commercial wind turbines based on a reference wind speed and turbulence intensity, in a way that covers most on-shore applications. The Turbulence Intensity (TI) is defined as the ratio of the standard deviation of wind speed fluctuations to the mean 10 min averaged wind speed. TI levels of16Please cite the edition of the IEC 61400-1 standard. While in the top, you are claiming to use the gust definition of the second edition, these wind turbine classes are from the third edition (and they have been expanded in the fourth edition).
Please specify, that in the definition of the turbulence intensity, both the standard deviation and the mean velocity are calculated for the respective 10min interval.

ll. 78 I_{ref}, t, σ_u, $\bar{V}$,Z and Z_{hub} are not introduced

ll. 96 "Experimental investigations are typically limited to steady state conditions (Snel et al., 2007; Sørensen et al., 2002).“
The introduction is generally lacking an overview of devices capable of generating unsteady flows that have been used in the past also for the generation of gusts. I also think that a broader overview on how wind tunnel experiments address certain turbulent aspects to have a more realistic setup should be mentioned. Some points that could be addressed (The citations in the following are meant as help to give an idea of what has been done, the are meant as a suggested starting point which does not mean all need to be cited):

- There are different kinds of steady state experiments: Some are carried out in uniform laminar or turbulent inflow and some are carried out in boundary layer flows.

- The active grid has been used to generate turbulent inflow conditions that have more dynamic and higher variation (e.g. Jin (2016) Effects of Freestream Turbulence in a Model Wind Turbine Wake, Li (2020) The near field of a lab-scale wind turbine in tailored turbulent shear flows, Rockel (2017) Dynamik wake development of a floating turbine in free pitch motion subjected to turbulent inflow generated with an active grid)

- Aerodynamic experiments have been carried out in sinusoidal flows/using pitching and/or plunging airfoils to investigate dynamic stall which is also found on wind turbines (setups for sinusoidal flows: e.g. Tang (1996), Wei (2019), experiments on airfoil: e.g. Choudhry (2014) An insight into the dynamic stall lift characteristics (and sources)).

- There have been several experiments in unsteady conditions, often generated by active grids, both for whole rotors and for airfoil investigations:
  Petrović et al (2019) Wind tunnel setup for experimental validation of wind turbine control concepts under tailor-made reproducible wind conditions
  Wester (2018) High Speed PIV measurements of an adaptive camber airfoil under highly gusty inflow conditions
  Schottler (2017) On the impact of non-Gaussian wind statistics on wind turbines – an experimental approach
  Neunaber et al (2017) Comparison of the Development of a Wind Turbine Wake Under Different Inflow Conditions
  Sakar and Haan (2008) Design and testing of Iowa State University's AABL Wind and Gust Tunnel
  Neunaber and Braud (2020) Characterization of a new perturbation system for gust generation: The Chopper

ll. 97 "Only a limited number of studies have looked at transitory or turbulent wind conditions (Peinke et al.)"

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The citation does not give information on the year and the journal. Also, the authors are not cited in correct order.âĂÍIt appears to be a proceeding paper from the EWEC 2004 and is therefore again not state of the art.

Methodology WindEEE Dome

p. 5, fig. 2 the text is not readable in A4 format, ti is too small

ll. 111 "A render of the inner shell of the test chamber for straight flows is shown in Figure 2a. The test chamber is in turn surrounded by an outer shell. It has a total 106 fans, including 60 fans installed on one wall and 40 fans over the other five peripheral walls. There are also 6 larger fans in a plenum above the test chamber."
The readability could be improved

ll. 115 "To simulate a straight flow, the louvers at the top and peripheral sides of the test section are closed and the flow goes from the 60 fans to the center of the test section and then through the mesh of the wall at the opposite end, before passing through heat exchangers and recirculating over the top, back to the 60 fans' inlet."
The louvers at the top have not been mentioned before.
Is figure 2b showing the "normal wind tunnel" configuration? Does the air circulate as shown in figure 2a, or 2b, or both in this configuration? Are the 6 fans in the plenum used in the straight configuration to reach higher velocities?

ll. 121 "The power set-points of the 60 fans can be adjusted by a spreadsheet file with 60 columns. The numbering of the fans starts with the top left fan, row by row ending with the bottom right fan in Figure 2. The operating software at the facility can read the spread sheet file and switch power set-points as fast as 2Hz."
I do not think that mentioning the organization of fan control data in spreadsheets adds necessary information, you could also write "The power set-points of the 60 fans can be adjusted by the software as fast as 2Hz"

l. 124 "due to rotational inertia of the fans and electrical current filtering it takes 3 s"

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Does this mean that it takes 3s for the flow to adjust or 3s for the fans to adjust?

Numerical Flow Analysis Setup and Tuning/Validation

This part is missing some structure that helps the reader understand the procedure (this is how I understand it):

1. you want to have a "numerical setup“ so that you have some guidance on how to set the fan power and how to optimize the simulation
   - you define a domain
   - you generate different meshes
   - you run the simulation and validate it with experimental data, then you optimize the simulation and finally you know which mesh is suitable while sufficiently accurate
2. you use the optimized simulation to generate a look-up table of the fan power

table 1: The caption could be more precise

l. 145 it would be helpful to mention that you have 3 meshes (and probably why you have 3 test cases)

l. 152 referencing to table 1 or introducing V and V-c would improve readability

ll. 155: Where are the 13/31 m/s found? In the center of the test section? Are these the data from experiments? Does that mean that the inlet fan velocity in the simulation corresponds to 16.5 m/s in order to reach the 13/31 m/s in the experiments?

l. 168 this is the first time that you mention that an ABL profile is aimed for

figure 4: where are these profiles measured/simulated?

Experimental setup for velocity measurements

ll. 190 "..to measure three velocity components with measuring range from 2 to 45 m/s with $\pm$0.5 m/s accuracy (Turbulent Flow Instrumentation Pty Ltd). In this study the average wind velocity was 5 m/s, therefore all of the wind measurements have 10The source is not appearing in your references.
You are mixing accuracy and uncertainty which are two different things.

l. 197/fig. 7: As you show the turbine in fig. 7, I would recommend rephrasing this sentence to really emphasize that the turbine is NOT used in these experiments.

Gust length and time scaling
ll. 203 please comment on why you are choosing 4 loops of a blade tip vortex

l. 206 $L = 4 \cdot L'$ is missing as definition (T as well)

ll. 220 this paragraph is confusing:

- do I understand correctly, that TSR = 1.1 and u = 5m/s are the working conditions of your model wind turbine, and that these conditions are chosen to match the maximum speed at which your gust can be generated due to the inertia of the system? If so, why do you do the argumentation of the gust scaling if in the end, you will alter the TSR because you cannot generate rapid gusts? I understand this paper as proof of concept and since you are generating the shortest gust possible, the argumentation is probably better placed in a paper where you are actually using the turbine.
- Why are you commenting on how to improve the Re mismatch? Are you planning to do this? Can you actually change the fluid in the WindEEE Dome? You could comment on the consequences of low Re for your experiment as an alternative.
- l. 228 "In this setup, the ratio of the length and time scale become 5.23 and 2.61 respectively." I would place this sentence in l. 223 or 224

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ll. 234 you should emphasize that you use the new gust duration T instead of the IEC gust duration T

ll. 235 could you give a citation where this gust has been simplified? Also, it should be added that the important part is the amplitude by which the wind increases (here from 3.5 m/s to 9.5 m/s in 1.25 s (2.4 s IEC)) - the drop should therefore not simply be ignored

Results and discussion

figure 10 Do I see correctly that only the central 20 fans are used when the contraction nozzle is installed?
=> found information in l. 268
=> Did you only use the central 20 fans when doing the simulations (e.g. tab. 3)?

l. 252 / figure 11 "Figure 11 shows the average velocity at each probe including the range of standard deviation"
what do you mean by "range of standard deviation"?
if I interpret the figures correctly, you have turbulence intensities of up to 50% (fig. 11 c, 1.5m height: $V \approx 5m/s$, $\sigma \approx 2.5m/s$. You argue that this is due to vortex forming. Could you please comment on possible consequences during your experiment?

ll. 257 "The largest error exists in the horizontal shear case.."
If you are referring to the standard deviation with "errors", I would like to point out that the standard deviation of a turbulent flow is not suitable to serve as an error as the fluctuations are inherent to the flow and the standard deviation gives an idea of the strength of the fluctuations.

figure 11 d / equation (8) "relative difference" is more accurate than "relative error" for describing the difference between the measurements and the IEC standard

Unsteady experiments

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For the EOG, have all fans be operated?

ll. 267 Again, I don't see a point in mentioning the spreadsheet - the information that all fans except for two rows were run at 39

l. 271 "Therefore, the file has many rows of 39Above, you are stating that only 5 columns of fans are used, I would imagine that therefore, 40 out of 60 fans are not in use?

ll. 277 "For example if we put the fan power setups for the extreme condition at the 11th and 12th row in the file, the event start happening“
As a reader, I have no idea, what fan row 11 and 12 of the spreadsheet correspond to, and it is also not important. This is not a manual on how to run the wind tunnel but a presentation of the setup and the results.

figure 12

- the writing is too small
- is this a phase average? Did you verify the reproducibility of the gust?
- it appears that one cobra probe does measure a significantly lower velocity (more than 0.5 m/s you give as probe accuracy) than the other sensors: There is a bump in fig. 12 d-g. Since both vertical and horizontal measurements have been performed, this appears to be a problem with the probe rather than an alteration in the flow field (probe F for hor. measurements/ D for vert. measurements - but since F and D are symmetrically ordered around the center, it might actually be the same probe with different labelling?). Did you make sure the cobra probes are calibrated the same way or test the measured velocity variation between the probes?

figure 13

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- it would be helpful to remind the reader that B-H are the probe names and that positions can be found in figure xx
- you could comment on the fluctuations that are visible in fig. 13a and c since they are increasing with increasing height of the sensor

ll. 300 "Based on Figure 13d for the EOG generated with changing fan powers, the velocity at the upper height in the test section is not achieving a totally uniform flow condition(time series from probe H).“
Did you check how the raw data looks? Considering the rather broad moving average window of 0.2s / 400 data points, the "hole“ at t = 35s might stem from some not collected data points which may for cobra probes occur if the flow leaves the measurement area (too high/low velocity/ too large flow angle)

ll. 301 "However, the desired peak factor has been generated“
while the ration V/V_{max} may be similar to the IEC EOG, you do not achieve the amplitude. Also, a comment on the rise and fall time as compared to the IEC EOG would be interesting.

Conclusions
ll. 327 "By ignoring the sudden velocity drops in the theoretical gust profile, the generated gusts would become identical to the standard.“ I disagree because your amplitude is lower while the rise and fall times are higher.

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