The Load Level of Modern Wind Turbines according to IEC 61400-1

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Abstract. The paper describes some effects on the load level of state-of-the-art multi megawatt wind turbines introduced by the new edition of the standard IEC 61400-1:2005 „Wind Turbines – Part 1: Design requirements“. Compared to the previous edition, especially the extreme load determination has been modified by applying stochastic and statistical analyses. Within this paper the effect on the overall load level of wind turbines is demonstrated and occurring problems are discussed. Load simulations have been carried out for four state-of-the-art multi-megawatt wind turbines of different design concepts and from different manufacturers. The blade root bending moments and tip deflection have been determined by applying different extrapolation methods. Advantages and disadvantages of these methods and tail fittings for different load components and wind turbine technologies are discussed and interpreted. Further on, the application of the extreme turbulence model is demonstrated. The dependence of the load level on the turbulence intensity and control system, as well as the interaction with extrapolated loads is discussed and limitations outlined. The obtained load level is compared to the overall load level of the turbines according to the previous edition of the standard, IEC 61400-1:1999.

1. Introduction
The new international standard IEC 61400-1:2005 „Wind Turbines – Part 1: Design requirements“ [1] has been issued. Compared to the previous edition IEC 61400-1:1999 [2] several sections have been modified, affecting e.g. wind and turbulence classes and models, load case definitions, load analysis, control, protection and mechanical system and site assessment. Especially the extreme load calculations have been changed by replacing several load cases with deterministic wind models by load cases with stochastic wind models. Moreover, load determination has been changed towards a statistically based approach. At least blade root bending moments and tip deflection are to be extrapolated based on normal operating time series. This includes the wind distribution and its spatial variability in the analysis of operational loads.

For the design of the wind turbine these new approaches are a challenging issue. In order to provide cost efficient wind turbine technology one main question is the obtained load level according to IEC 61400-1:2005 compared to the previous edition. This is based on the task to find and to apply applicable and reliable extrapolation methods and how to find contemporaneous loads to extrapolated values. A second question concerns the required effort for the load determination.
The application of extrapolation methods and some occurring problems have been addressed by several authors. Genz et al. [3] compared simulated data with measured results of a 3.6MW variable speed variable pitch wind turbine. For the simulations a peak-over-threshold method (POT) was applied. Focus was laid on the choice of the threshold value. A fixed threshold value of mean value plus 1.4 times the standard deviation (as suggested in IEC 61400-1:2005) lead to poor fits of the distributions to the data points and to overly conservative results. Better fits were obtained by tail fitting, i.e. applying the distribution to high load data only. The Weibull distribution (and even better the Log-Normal distribution, amended later on by private communication) were found to deliver significantly better tail fits than Gumbel or GEV distributions. About 12 high load data points per wind bin (requiring about 10 seeds) were used for the fits. A weighting of the extrapolated values for every wind bin based on the wind bin probability was found to overweight the lower loads in low wind bins due to their higher probability. At higher wind bins the wind turbine control system had a limiting influence on the extreme loads. Von Mutius et al. [4] studied the effect of load extrapolation and the extreme turbulence model on variable pitch variable speed wind turbines in the size of 2MW to 5MW. A POT method with different threshold levels was combined with distribution functions as 2-parameter Gumbel and 3-parameter Weibull. Due to the load influencing effect of the wind turbine control system the fit of the distribution functions to the data points was difficult. The obtained loads differed up to 25%, depending on the fitting quality. As a second step the extreme turbulence was adapted to match the extrapolated loads. Compared to the overall load level of IEC 61400-1:1999 the blade and machine loads increased by 10% to 25%. Mutius et al estimated the increase in simulation effort compared to IEC 61400-1:1999 to a factor of six to seven. Due to these difficulties and the increase in load level, a requirement for review of the load extrapolation for variable speed variable speed turbines was formulated. Ragan and Manuel [5] applied the global maxima and the POT method (with variable threshold) combined with different distribution functions, as Generalized Pareto (GPD) and 3-parameter Weibull, to measured time series of a 1.5MW variable speed variable pitch turbine. The method of global maxima (only the maximum of each 10min time series is selected) resulted in very conservative results due to overweighting of low wind bin results. A variably adopted threshold for each wind bin delivered much better fits than the mean value plus 1.4 times the standard deviation. Although the GPD had a stronger theoretical basis for use with POT, the 3-parameter Weibull delivered better fits to the data points.

The difference between the overall load level according to IEC 61400-1:2005 in comparison to IEC 61400-1:1999 was investigated for a single wind turbine, see Freudenreich and Argyriadis [6]. Based on this work the present publication focuses on the effect of extrapolation and the extreme turbulence model for a larger variety of turbines. Load simulations have been carried out for four state-of-the-art multi-megawatt wind turbines of different design concepts from different manufacturers. The overall objective is to give indications of the differences in load level based on extrapolation and extreme turbulence model according to IEC 61400-1:2005 compared to IEC 61400-1:1999. Where possible, the differences are traced back to differences in the turbine design.

2. Main modifications in IEC 61400-1:2005
In the following, some modifications with effect on the extrapolation and extreme turbulence modeling of IEC 61400-1:2005 are highlighted. Please note that this list is not complete. The probably most severe changes have been made in the load case definitions. Based on Design Load Case (DLC) 1.1, extreme loads resulting from normal operating conditions with the Normal Turbulence Model (NTM) are to be extrapolated to a 50 years return period. Extrapolation has to be carried out at least for the tip deflection and the blade root bending moments in both directions. The partial safety factor for loads based on extrapolation has been defined to $\gamma_f=1.25$. Compared to IEC 61400-1:1999 several DLCs with deterministic wind conditions have been removed. Instead, the new DLC1.3 has been introduced, to be analysed with the new Extreme Turbulence Model (ETM). For DLC1.3 six different seeds for each wind bin need to be simulated, the characteristic load is defined to
be the mean of maxima of these six time series. The DLC1.3 partial safety factor for loads has been defined to \( \gamma_f = 1.35 \).

Significant parts of the turbulence intensity definition and turbulence classes have been re-defined as well, affecting both NTM and ETM turbulence models. Among other parameters, the turbulence classes including the reference value at 15m/s, the turbulence scale parameter \( \Lambda_1 \) and the lateral standard deviation \( \sigma_2 \) have been changed. Two turbulence models are recommended, the Mann uniform shear model and the well known Kaimal model but with a modified coherence decay factor. The isotropic von-Kármán model is not recommended any longer.

3. Application of the Standard

3.1. Extrapolation of Extreme Loads based on normal operation time series

Extreme load extrapolation alters the deterministic approach towards a statistical approach. Based on a number of maxima (or minima) of simulated time series, a 50 years return period maximum is to be extrapolated by using different methods. The extrapolation of loads is a challenge and requires significant effort to result in realistic and trustworthy results. By applying the load extrapolation analysis the following problems might arise, which have been partly outlined already in the literature review:

- The data base might be too small, but a significant increase is time consuming. The maxima can be obtained by choosing the global maximum of each time series (one data point per 10min simulation). All three blades might be considered to be independent, resulting in three global maxima per time series. Peak over threshold methods (POT) can be used to determine several data points per time series. However, the appropriate threshold needs careful adjustment for each single sensor and wind bin. Other measures to ensure independence between successive POT maxima, might be to separate different maxima e.g. by multiples of the lowest natural frequency of the turbine, by a number of rotor revolutions or by the mean gust period.

- An appropriate extrapolation method needs to be chosen and carefully applied. Otherwise excessive or at least unrealistic loads might result.

- In some cases the turbines’ control system introduces large non-linearities to the loads. Controllers may limit the extreme load level. For example, load measurement can be used to adjust blade setting or even shut down the turbine. Different data populations may occur, to be fitted separately. This tail fitting can be carried out by adjustment of the POT threshold value, or by optical identification of different data populations. Tail fitting can lead to arbitrary loads.

- The goodness of fit is difficult to judge. Mathematical methods might be misleading, optical evaluation might be preferred.

- Extrapolation does not provide contemporaneous load components.

3.2. Multiple Seed Analysis and Contemporaneous Loads

DLC1.3 has to be simulated with six different seeds for each wind speed bin. For each wind bin the characteristic load for each load component is the mean of maxima of the six seeds. The largest averaged value of all wind bins is selected to be the overall characteristic load. This means that the contemporaneous loads needed for stress analysis are lost. One method proposed in the standard is to directly analyse stress time series for every node or hot spot to be considered, calculate equivalent stress and then perform the processing to define characteristic design values. This is a challenge to data management.

As an alternative, the time series from the selected wind bin being closest with its maximum to the characteristic load is selected. It is then scaled with all contemporaneous load components to the characteristic load.
3.3. Adjustment of the Extreme Turbulence Model (ETM)
Extrapolation does not provide contemporaneous values for the remaining load sensors to be used for multiple axis stress analysis. IEC 61400-1:2005 suggests to replace the extrapolated loads by extreme loads derived from DLC1.3 time series. The basic requirement for this load case is to apply the Extreme Turbulence Model (ETM) with a given scaling factor $c=2$. In case these DLC1.3 loads exceed the extrapolated ones, the DLC1.3 analysis is finished. If not, factor $c$ shall be increased. For a simplified analysis procedure, DLC1.3 time series might be simulated for a number of $c$ values. The characteristic loads for all load components, for each blade and wind bin and for all values of $c$ are then calculated, according to the previous section. The amount of data is quite extensive: Several blade load components, three blades, about 10 wind bins, six seeds, about five values for $c$. The data are reduced for each single value of $c$: The maximum characteristic load of all three blades and then the maximum characteristic load of all wind bins is picked up. The safety factors for DLC1.3 loads $\gamma_f=1.35$ is applied (for extrapolation $\gamma_f=1.25$). For each load component (in the following case study: max tip deflection, max flapwise moment and min/max edgewise moment) the required value for $c$ is determined to match or exceed the extrapolated load. The maximum determined value for $c$ is selected. The final DLC1.3 loads are calculated for this $c$. Up to four different scaled DLC1.3 time series are obtained for further design load analysis.

As mentioned above, two problems might appear: An ever increasing turbulence intensity for the ETM does not necessarily result in ever increasing DLC1.3 loads. Extrapolated loads might not be exceeded for any factor $c$, e.g. due to sophisticated wind turbine control. Secondly, an obtained large factor $c$ results in physically unrealistic high turbulence intensity.

4. Case Study
4.1. Wind Turbines
A case study of four different turbines for an extrapolation and DLC1.3 load analysis is presented. The examined wind turbines are state-of-the-art, three bladed upwind, with pitch control and variable speed operating systems. All turbines have an operating range between cut in at about 4m/s and cut out at about 25m/s wind speed, resulting in about 11 bins of 2m/s width. Some overall design parameters are given in Table 1.

|                      | turbine 1       | turbine 2       | turbine 3       | turbine 4       |
|----------------------|-----------------|-----------------|-----------------|-----------------|
| rated power          | 2 to 3 MW       | 2 to 3 MW       | 2 to 3 MW       | 5 MW            |
| control strategy     | collective pitch, active vibration damping | collective pitch | individual pitch, no load measurement as feedback | collective pitch |
| wind speed class     | low             | low             | high            | high            |

In a first section the extrapolation methodology is described. Overall results are presented and discussed for all four turbines. Detailed results and parameter variations are highlighted for single turbines and load components. This is followed by the methodology and overall results of the ETM and DLC1.3 analysis and some detailed discussions. Finally, comparisons are drawn to the overall design loads according to IEC 61400-1:1999, where available.

The load components maximum flapwise bending moment, maximum and minimum edgewise bending moment and the maximum flapwise tip deflection are analysed.
4.2. Extrapolation Data Base, Fitting Methods and Results
The data base for the extrapolation consists of 30 time series of 10min each with different turbulent seeds. All blades have been considered to be independent, resulting in 90 data points for each of the about 11 wind speed bins. The following distributions and fitting methods have been used to derive extreme loads for a 50 years resp. 1 year recurrence period:

- 3-parameter Weibull distribution with fitting by statistical moments of the data, see Moriarty et al [7]
- Gumbel distribution with fitting by statistical moments of the data, see Gumbel [8] and [9], Cheng [10], Pandey and Sutherland [11]
- GEV (General Extreme Value) distribution using L-Moments, see Pandey and Sutherland [11], Palutikof et al [12]
- Log-Normal distribution, see e.g Bronstein and Semendjajew [13]

Tables 2 to 4 present the relatively wide range of obtained results from the listed distributions and fitting methods applied to turbines 1 to 3. All extrapolations are based on all 90 data points per load component, no tail fitting has been applied. The obtained values are normalized by the maximum overall loads resulting from the complete IEC 61400-1:1999 load catalogue. The loads and deflections are already multiplied with the different partial safety factors for loads.

**Table 2.** – Turbine 1 extrapolated loads as fraction of IEC 61400-1:1999 loads

|            | flap max | edge max | edge min | deflection max |
|------------|----------|----------|----------|----------------|
| 3-p Weibull| 1.07     | 0.90     | 0.95     | 1.12           |
| Gumbel     | 1.13     | 1.07     | 1.05     | 1.35           |
| GEV        | 1.10     | 1.25     | 0.98     | 1.18           |
| Log-Normal | 1.08     | 0.85     | 0.94     | 1.15           |

**Table 3.** – Turbine 2 extrapolated loads as fraction of IEC 61400-1:1999 loads

|            | flap max | edge max | edge min | deflection max |
|------------|----------|----------|----------|----------------|
| 3-p Weibull| 1.32     | 1.21     | 1.11     | 1.38           |
| Gumbel     | 1.50     | 1.33     | 1.17     | 1.62           |
| GEV        | 1.59     | 1.30     | 1.17     | 1.55           |
| Log-Normal | 1.25     | 1.13     | 1.05     | 1.34           |

**Table 4.** – Turbine 3 extrapolated loads as fraction of IEC 61400-1:1999 loads

|            | flap max | edge max | edge min | deflection max |
|------------|----------|----------|----------|----------------|
| 3-p Weibull| 1.20     | 0.90     | 1.14     | 1.20           |
| Gumbel     | 1.36     | 1.08     | 1.26     | 1.48           |
| GEV        | 1.21     | 0.95     | 1.15     | 1.21           |
| Log-Normal | 1.15     | 0.92     | 1.10     | 1.19           |
Some general tendencies can be lined out for the extrapolation of loads:

1. The extrapolated maximum tip deflection exceeds the IEC 61400-1:1999 level by 12% to 62%, followed by the maximum flapwise moment (7% to 59%). The extrapolated edgewise bending moments do not exceed the IEC 61400-1:1999 level for all turbines and fits.

2. For most load components the Gumbel fit results in highest extrapolated loads, for turbine 2 also GEV delivers remarkably high loads.

3. The load levels differ for different turbines. For turbine 2 a higher load level is obtained than for turbines 1 and 3. This might be caused by difficult fits in the extrapolation of turbine 2 or by comparably low IEC 61400-1:1999 loads of turbine 2.

The performance of the different distributions and fitting methods is supported by the results of turbine 4. For this case no IEC 61400-1:1999 loads are available for comparison. But instead, by courtesy of Patrick Moriarty, NREL, results from a one year simulation run are available. More than 48000 different 10min time series have been run, distributed over the wind speed bins according to the Weibull wind distribution. The overall maximum loads have been extracted. Out of the 48000 time series 30 simulations per wind bin have been selected arbitrarily for load extrapolation, similar to turbine 1 to 3. Table 5 lists the extrapolated loads for a one year recurrence period, being normalized by the overall maximum loads from all 48000 time series (one year simulation).

| Table 5. – Turbine 4 extrapolated loads for one year as fraction of one year simulated loads |
|-----------------------------------------------|----------------|----------------|----------------|
|                  | flap max | edge max | edge min | deflection max |
| 3-p Weibull      | 1.00     | 0.94     | 0.74      | 1.00           |
| Gumbel            | 1.17     | 0.97     | 0.82      | 1.18           |
| GEV               | 1.05     | 0.97     | 0.75      | 1.02           |
| Log-Normal        | 1.03     | 0.93     | 0.76      | 1.05           |

Except for the almost doubled rated power output, turbine 4 does not differ significantly in design and control system from turbines 1 to 3. Therefore, the tendencies obtained from turbine 4 might be generalized also for the previous turbines:

4. The minimum edgewise bending moment seems to be heavily underpredicted by extrapolation, the maximum moment only slightly.

5. The Gumbel fit overpredicts the extrapolated flapwise loads significantly, the edgewise loads moderately. This supports point no. 2.

6. Best fit is obtained for Weibull, followed by Log-Normal and GEV fits for both flapwise and the maximum edgewise loads.

As an example for a long term fit, Figure 1 displays the extrapolation results for the maximum flapwise moment of turbine 3. The 1 year and 50 years levels are included.
Figure 1 – extrapolated maximum flapwise bending moment of turbine 3

Figure 2a shows the data points and fits for rated wind speed bin 12m/s to 14m/s for the maximum flapwise moment of turbine 3. The data do not follow a linear or curved line, but have a kink. The extrapolation fits tend to match the bulk of the data at low loads (left hand side of data population), while the upper tail is difficult to fit. The Gumbel fit as a linear fitting method results in overly conservative results, while the Weibull fit tends towards the opposite. The goodness of fit of the different distributions is difficult to judge. An optical evaluation might come to the conclusion that the Log-Normal fit is best, followed by GEV. However, a mathematical judgement by using the Cramer-von Mises test, as described and tested by Cheng [14], comes to the conclusion that GEV performs better than Gumbel, followed by Log-Normal and Weibull. The clear non-linearity of the data raises the question whether the data on both sides of the kink might belong to different populations resulting

Figure 2a – normalized maximum flapwise bending moment of turbine 3, 2b – with tail fitting
from different turbine status. For Figure 2b a tail fitting has been carried out by cutting all data below the kink. The two branches in Figure 2a might result from the pitching of the blades, which alters especially the flap moment. It should also be kept in mind that turbine 3 employs an individual pitch control strategy, which might enforce the generation of different data populations. For the tail fitting case, Log-Normal and Weibull seem to behave best, only the last data point is disregarded as an outlier. The Cramer-von Mises test prefers GEV, followed by Weibull and Log-Normal. Similar to this wind bin the three following wind bins, up to 18m/s have been tail fitted as well (not presented here), while low and high wind bins do not clearly display different data populations. The longterm extrapolated maximum flapwise bending moments based on this tail fitting differs from results in Table 4: The Weibull and Gumbel extrapolated loads decrease by 5%, while Log-Normal remains nearly unchanged and GEV raises by almost 20%. For the maximum edgewise moment similar tendencies are obtained, while the minimum edgewise moment is hardly influenced by tail fitting. For the maximum tip deflection no satisfying tail fitting could be realized, except for the Weibull fit. For several wind speed bins unrealistically high or low results were obtained, possibly due to overweighted outliers. This is demonstrated by Figures 3a and 3b, showing the maximum tip deflection of turbine 3 for the wind bin 18m/s to 20m/s.

![Graph](image)

**Figure 3a** – normalized maximum tip deflection of turbine 3, **3b** – with tail fitting

Some conclusions and suggestions can be formulated:
- Outliers shall be retained in data, if they are valid data and no modelling error (to be checked).
- If different data populations can be identified, they shall be fitted separately, but keep in mind that tail fitting is arbitrary and shall be carried out with care.
- Choose the distribution resulting in the best fit to the entire population.
- Check confidence limits.
- Based on visual judgement the Log-Normal fits without tail fitting were chosen to be the most reliable ones, although Weibull extrapolated values match the 1 year simulated tip deflection and flapwise moment almost perfectly.
4.3. Extreme Turbulence Model (ETM) and DLC1.3 Results

For turbine 1 to 3 the DLC1.3 was calculated for up to five different values of \( c \) with \( 2 \leq c \leq 4 \) in steps of 0.5. Table 6 shows the obtained longitudinal turbulence intensities at the wind speed 15m/s for turbulence class A. \( I_{\text{ref}} \) for the Normal Turbulence Model (NTM) is added for comparison.

| \( c \) | TI at 15m/s |
|-------|-------------|
| 2.0   | 0.25        |
| 2.5   | 0.29        |
| 3.0   | 0.33        |
| 3.5   | 0.38        |
| 4.0   | 0.42        |
| NTM   | \( I_{\text{ref}} = 0.16 \) |

The turbulence intensity and scaling factor \( c \) has been adjusted, the DLC1.3 time series analysed according to section 3.3. Tables 7 to 9 list the results for the different values of \( c \) for turbines 1 to 3. Again, the loads are normalized by the IEC 61400-1:1999 loads.

### Table 7. – Turbine 1 ETM loads as fraction of IEC 61400-1:1999 loads

| \( c \) | flap max | edge max | edge min | deflection max |
|-------|----------|-----------|----------|----------------|
| 2.0   | 1.01     | 0.79      | 0.97     | 1.04           |
| 3.0   | 1.07     | 0.86      | 1.02     | 1.12           |

### Table 8. – Turbine 2 ETM loads as fraction of IEC 61400-1:1999 loads

| \( c \) | flap max | edge max | edge min | deflection max |
|-------|----------|-----------|----------|----------------|
| 2.0   | 1.08     | 1.08      | 0.89     | 1.13           |
| 2.5   | 1.11     | 1.17      | 0.97     | 1.16           |
| 3.0   | 1.21     | 1.18      | 1.06     | 1.25           |
| 3.5   | 1.30     | 1.29      | 1.21     | 1.35           |
Table 9. – Turbine 3 ETM loads as fraction of IEC 61400-1:1999 loads

| c   | flap max | edge max | edge min | deflection max |
|-----|----------|----------|----------|----------------|
| 2.0 | 1.12     | 0.87     | 1.06     | 1.05           |
| 2.5 | 1.17     | 0.94     | 1.09     | 1.08           |
| 3.0 | 1.21     | 1.05     | 1.13     | 1.15           |
| 3.5 | 1.28     | 1.16     | 1.16     | 1.23           |
| 4.0 | 1.32     | 1.16     | 1.20     | 1.30           |

For increasing c resp. turbulence intensities, the DLC1.3 loads increase as well. The flapwise components bending moment and tip deflection are more influenced by turbulent wind variations. Turbine 1 (with collective pitch and active vibration damping) shows the smallest load increase compared to the IEC 61400-1:1999 loads, followed by turbine 3 (with individual pitch, but without load measurements as control input) and turbine 2 (collective pitch). For every load component one simulated value is highlighted. This is the one which comes closest to the extrapolated load value based on the Log-Normal distribution without tail fitting, compare Tables 7 to 9 with Tables 2 to 4. The Log-Normal method without tail fitting was chosen to be the most reliable one. For all turbines the tip deflection requires the highest value for c. By linear inter/extrapolation, the exactly required values for c for all three turbines is determined to 3.27 ≤ c ≤ 3.43. The DLC1.3 time series for this c value and ETM turbulence level shall then be analysed to determine the characteristic DLC1.3 loads for all load components. Table 10 shows the finally obtained blade loads of this case study. Turbine 2 with its relatively simple control strategy requires the highest ETM turbulence level to match the extrapolated loads. This results in the highest load increase compared to IEC 61400-1:1999, ranging from 19% to 34% for turbine 2 compared to 3% to 15% for turbine 1. Please note that the value of only 88% for the minimum edgewise load of turbine 1 will probably be increased by load case groups not considered within this study.

Table 10. – Final ETM loads as fraction of IEC 61400-1:1999 loads

| Turbine | c   | flap max | edge max | edge min | deflection max |
|---------|-----|----------|----------|----------|----------------|
| 1       | 3.27| 1.09     | 0.88     | 1.03     | 1.15           |
| 2       | 3.43| 1.29     | 1.28     | 1.19     | 1.34           |
| 3       | 3.32| 1.25     | 1.12     | 1.15     | 1.19           |

5. Conclusions
For the first time the standard IEC 61400-1:2005 introduces stochastic and statistical analyses to the determination of extreme loads. This includes the wind distribution and spatial variability in the analysis of operational loads, being the basis for load extrapolation. From a case study of four state-of-the-art multi-megawatt turbines with different design and control concepts the following main conclusions can be drawn:

- For the extrapolation of loads the fittings methods of Log-Normal (best) and 3-parameter Weibull provide more reliable results than GEV and Gumbel, which may lead to too conservative results.
- Control strategies can introduce non-linearities in the data distribution. Different data populations may occur, to be fitted separately. For the present case optical tail fitting did not
result in significantly improved fits. Tail fitting needs to be carried out with care and can lead to arbitrary loads.

- Compared to the IEC 61400-1:1999 loads the extrapolated maximum tip deflection increased by 12% to 38% for Log-Normal and Weibull, the flapwise moment by 7% to 32%. The extrapolated edgewise bending moments do not exceed the IEC 61400-1:1999 load level for all turbines.
- Advanced control strategies (active vibration damping and individual pitch) seem to cause smaller load increases due to extrapolation than a regular collective pitch strategy.
- To match the Log-Normal extrapolated load level the scaling factor $c$ in the Extreme Turbulence Model was set to 3.27 and 3.32 (advanced control) resp. 3.43 (regular control). The tip deflection was the ‘design driver’.
- The final load level (DLC1.3 loads based on these $c$ values) exceed the IEC 61400-1:1999 level for the tip deflection and flapwise moment by 9% to 25% (advanced control) resp. 34% and 29% (regular control).
- Contemporaneous loads to extrapolated loads can be obtained by scaling DLC1.3 time series.
- A significantly increased amount of computation time and pre/postprocessing is required to achieve realistic and reliable results. The judgement of the goodness of fit requires visual inspection
- Although the presented methods are mathematically correct, the variability and interpretability of the results require a detailed analysis for any application case.

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