PEER REVIEWED

Load Duration Distribution based on SCADA history

Alexander Werkmeister[1]

Björn Roscher[1*], Ralf Schelenz[1], Georg Jacobs[1]

[1]Center for Wind Power Drives

Campus-Boulevard 61, 52074 Aachen, Deutschland

Contents

1 Introduction

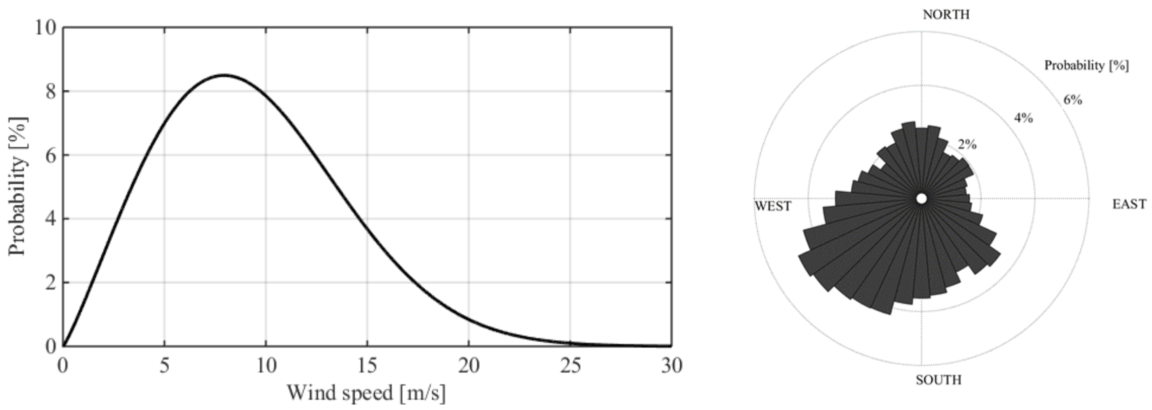
Nowadays, profitability is a key element in wind energy. The profitability can be raised by reducing unexpected downtime and improved maintenance schedules. These schedules are mainly based on a specific time period, e.g. every 6 months. However, if the loading history of a component is known the maintenance interval can be adjusted and therefore reduced.

Since 2006, wind turbines are equipped with a standardized supervisory control and data acquisition (SCADA) system, allowing to obtain data of turbine behavior and experienced loads. At that time data storage was limited, therefore SCADA-data of various channels are stored by a 10 min based average, maximum and minimum. Therefore the historical data neglect any dynamic in the system.

In this publication, the authors present a possibility to estimate a 1 Hz sampling distribution. Their aim is to include the wind turbine dynamic into the loading history. As wind turbines are situated in a wind farm, the effects of the surrounding wind turbines have to be introduced as well. In [ROS17] the authors introduced the effect of wakes on the damage equivalent loads. Their approach will be used to add the effect into the SCADA estimation.

2 Site Assessment

To inspect the effect of the SCADA data estimation, it was decided to use the wind resource of Alpha Ventus [BAR17]. The location is a well-known research wind farm, with a nearby located wind measurement station FINO-1 [BSH18]. In [BAR17] the wind resource at Alpha Ventus is displayed. It can be seen that average wind speed is around 9 m/s with a preferred direction of south west.



(b)

(a)

Figure 1: Weibull distribution (A = 10.61 and k = 2.15) and (b) wind direction distribution at FINO-1 in 80 m height [BSH18]

While inspecting the wind farm setup, shown in Figure 2, it becomes clear that the wind turbine number 5 and 8 (specification given in Table 1) are located most of the time in the wake of the other turbines. As a result of the wake, the turbines will experience a reduced wind speed and a resulting increased turbulence (TI).

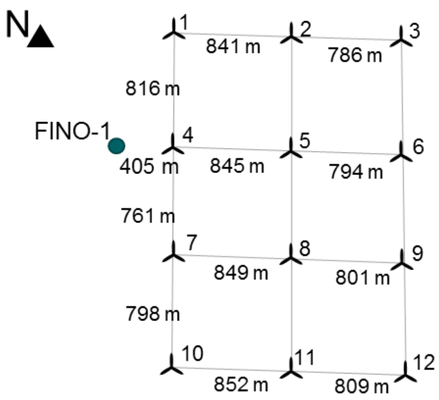


Figure 2: Spacing of WT inside Alpha Ventus, including location of FINO-1 [BAR17]

		Repower 5M	Areva Multibrid M5000
Wind turbine number		1-6	7-12
Rated power	[MW]	5.0	5.0
Hub height	[m]	92.0	90.0
Rotor diameter	[m]	126.0	116.0
Cut-in wind speed	[m/s]	3.5	3.5
Cut-out wind speed	[m/s]	30.0	25

Table 1: Wind turbine configurations inside Alpha Ventus [BAR17]

The resulting increased TI can be determined using the model suggest by Frandsen given in Eq. 1, where D represents the normalized distance between the wind turbines, I_{ref} the environmental turbulence intensity (5 %) and C_T the thrust coefficient of the wake shedding wind turbine. Below rated power the thrust coefficient is approximately constant. After reaching the rated power, the thrust coefficient is reduced as more wind is allowed to flow through.

$$TI_{Frandsen} = \sqrt{\frac{1}{\left(1.5 + \frac{0.8D}{C_T}\right)^2} + I_{ref}^2}$$ **Eq. 1**

Based on the location of the wind turbines an inflowing TI can be determined relative to the wind speed. In Figure 3 the inflow TI for 3 different wind turbines is shown. As expected, wind turbine number 5 (indicated in Figure 2) experiences an increased TI the majority of time.

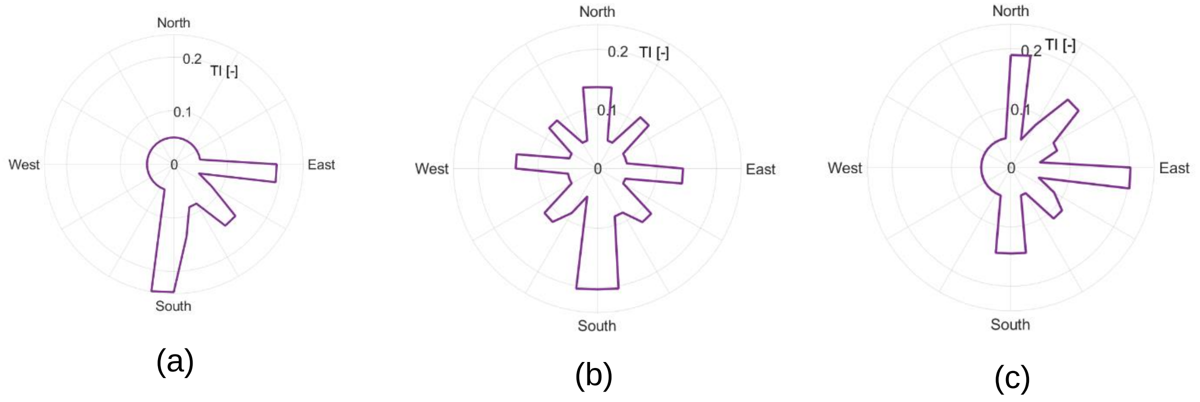


Figure 3: Incoming TI per wind direction at 10 m/s at
(a) wind turbine 1; (b) wind turbine 5; (c) wind turbine 7

3 From SCADA data to a 1Hz distribution

With the SCADA data the mean, max, min and standard deviation within 10min is available. To calculate a distribution from this data and to validate that the interpolation is correct, data with at least 1 Hz is needed. Therefore, simulation data from a design load calculation with a multi body simulation software is used.

For the simulation a 5 MW wind turbine model with a rotor diameter of 126 m is used. Compared to the paper from 2017 [ROS17] the generator torque characteristic is changed so that the wind turbine operates at 5 MW. The simulation data is sampled with 50 Hz because of the eigenfrequencies of the simulation model. To use the data a low-pass Butterworth filter is used to reduce the frequency to 1 Hz. With this 1 Hz data the mean, max, min and standard deviation is calculated and a load duration distribution is determined. With this information a normal distribution is assumed to fit to the data set.

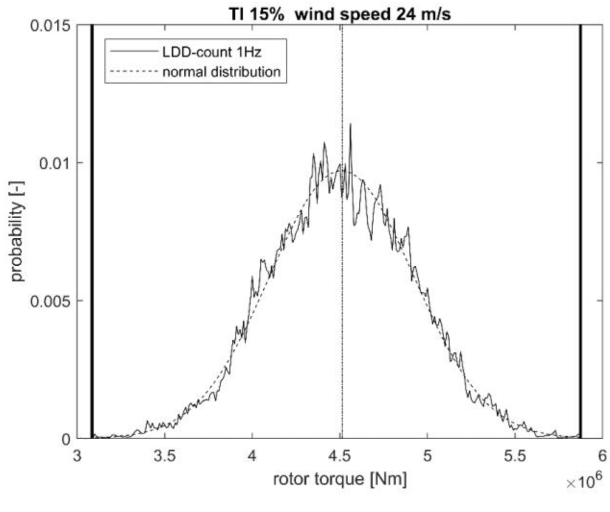


Figure 4: Comparison of the load duration distribution of 1Hz Data to Mean/Min/Max – Values and a normal distribution.

Figure 4 shows the normal distribution compared to the real LDD, additionally are the mean, max and min values indicated as vertical lines. This figure shows that the normal distribution fits nearly perfectly to the real data. This shows that the method of the normal distribution fits for the majority of all normal operations to the real data, with only 4 data points, which are available for nearly all turbines since 2006, compared to 600 data points of the 1 Hz data. An exception are the distributions close to rated conditions, as shown by [ROS18].

4 Influence of the Turbulence Intensity

The site assessment in combination with the Frandsen model shows that the TI varies between 5% and 20% with the wind direction and of course the TI varies depending on the wind speed as defined in the standard DIN EN 61400-1 [IEC15].

That the normal distribution is also valid for several TIs shows Figure **5**. The figure at the top shows the LDD of the 1Hz simulation data for a wind speed of 24 m/s with 5 TIs, 1 %, 5 %, 10 %, 15 % and 20 % TI. The figure below shows the normal distribution which is calculated as described in the chapter before. The normal distribution seems to fit for all kinds of TIs.

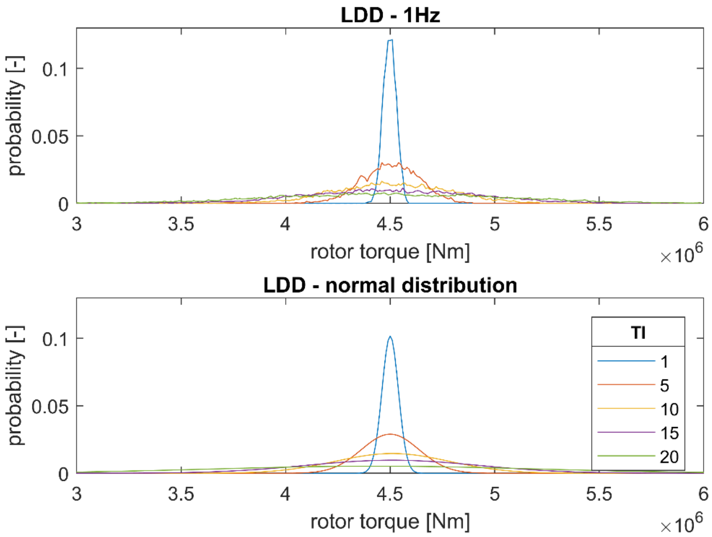


Figure 5: Influence of the TI to the normal distribution algorithm, with a wind speed of 24m/s

Normally, TIs are not just pure integers. Additionally, it is not feasible to do simulation for all TIs and all wind speeds, therefore an interpolation between two LDDs of two TIs is used to cover all TIs. Figure 6 shows the linear interpolation between a TI of 10 % and 15 % at a wind speed of 7 m/s. The linear interpolation at 11,791 % fits between the two known distributions. The interpolation is not accurate at the minimum point and maximum point, but the distribution in between is good enough, as the majority of the distribution lies between the given points.

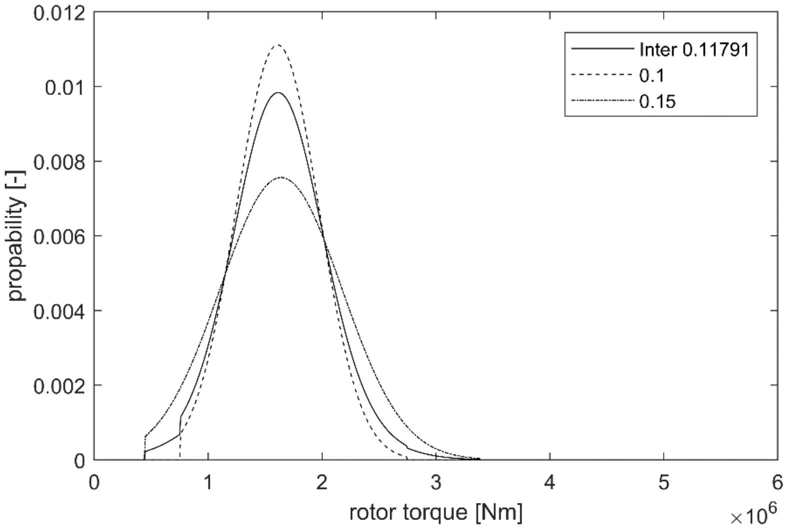


Figure 6: Interpolation of the distribution between two TIs with a wind speed of 7m/s

5 Combination of the distribution

The distribution of the TI in Figure 3 is a combination of all wind speeds. In order to calculate the complete LDD distribution for WT5 the distribution for all wind speeds, TIs and wind directions is needed and calculated. The wind direction has a distribution from 0° to 350° in 10° steps. The wind speeds have a distribution between 3 m/s and 25 m/s with 1 m/s steps. Both vectors define a matrix with a TI per wind speed and wind direction. Simulations are done for TIs of 1 %, 5 %, 10 %, 15 % and 20 with wind speeds between 3 and 25m/s with a simulation time of 10 min. The wind fields are calculated with TURBSIM with a single random number. This leads to a total of 115 simulations.

From Figure 3 WT5 is selected because of the higher disturbances it experiences compared to the other turbines in the wind park. To classify WT5 with a turbulence class, the TI for each wind speed and wind direction is multiplied with their probability, based on the previous done load calculation. For all other TIs, the interpolation method from Figure 6 is used. For the classification the TI classes from the standard [IEC15] are shown in Figure 7. The TI of WT5 is always lower than any TI-class defined in the standard.

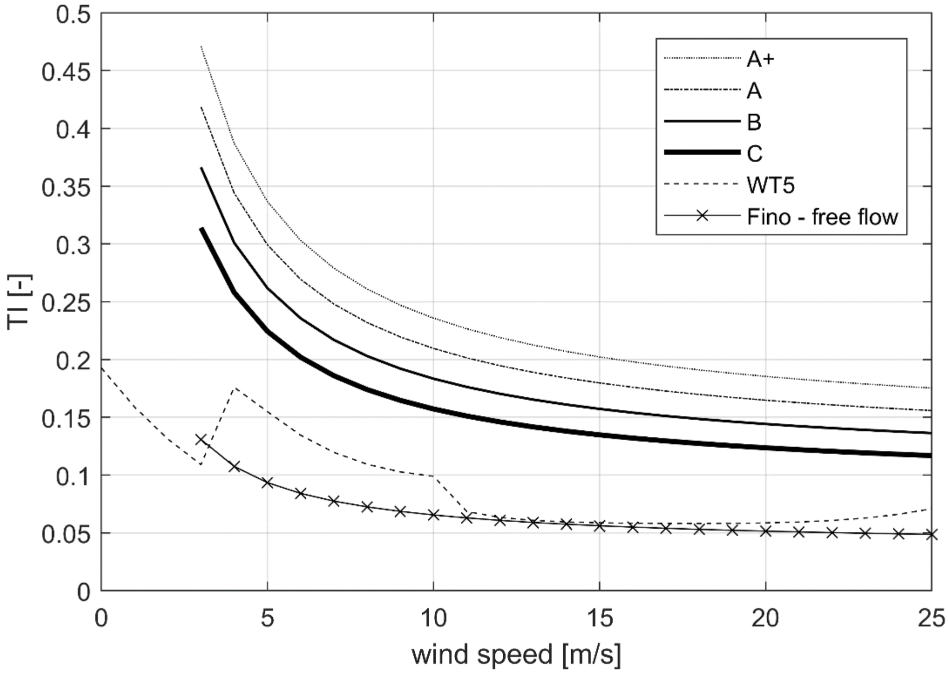


Figure 7: TI plotted against the windspeed for 4 TI classes defined according to DIN EN 61400-1 and for the WT5

To calculate the complete LDD, at first the LDD per angle is calculated and then multiplied with the probability per angle. The combined LDD represents the LDD for WT5 over the life time with the real park influence with an ambient TI of 5%. The comparison between the LDD with the correct calculated TI, the Class IC and the site conditions at FINO-1 is shown in Figure 8.

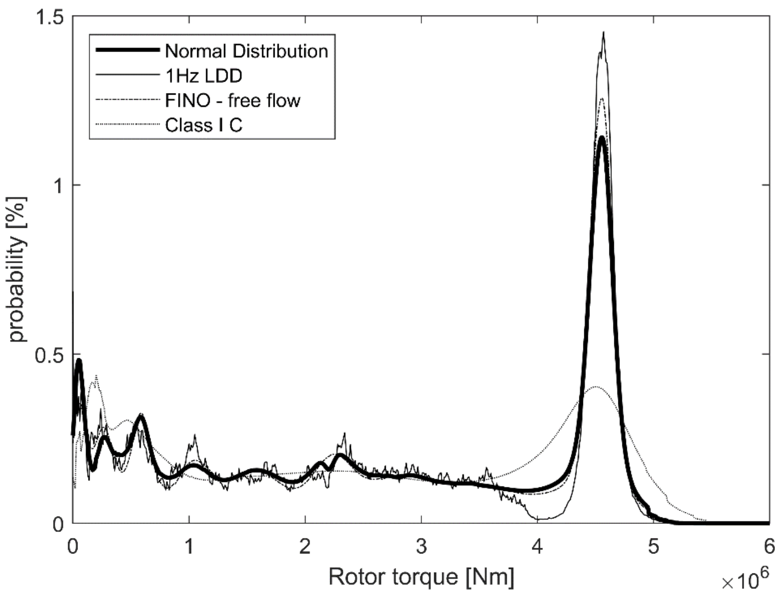


Figure 8: LDD- Distribution of WT5 compared to IEC class and FINO-1

At rated rotor torque (4.7 MNm) class C has a wider distribution because of the higher TI. The 1 Hz LDD distribution and the normal distribution which is generated from

SCADA based data is quite similar. Only close to rated torque the distribution differs. This is because of the change in the wind turbine controller. Close to rated conditions the wind turbine controller changes between a pitch and generator torque control and because of this there are two peak in the LDD distribution for the 10min data (see Figure 9).The FINO-1 free flow shows a change in the LDD curve at low wind speeds, which means rotor torques from 0 MNm up to 2.5 MNm, which is clear because the TI also changes between 3 m/s and 11 m/s.

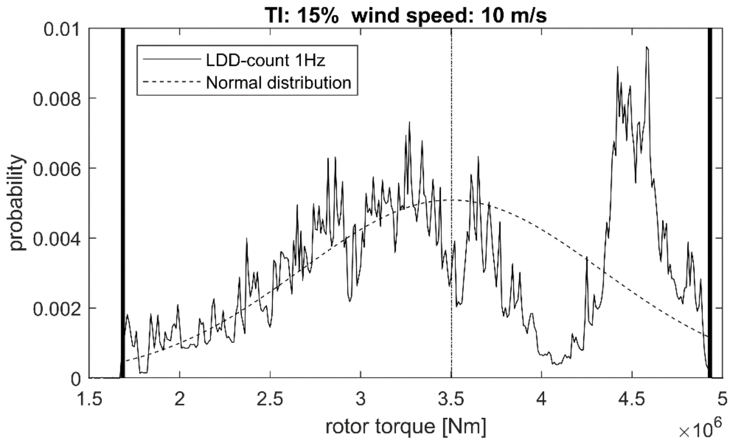


Figure 9: LDD- Distribution of WT5 compared to IEC class and FINO 1

6 Conclusion

The approach described in this paper shows that SCADA data can be up-scaled to 1 Hz distributions for all TIs between 1 % and 20 %. This approach can be used to get a more detailed load distribution of the torque over the life time of a wind turbine.

The site assessment with a detailed calculated TI over each wind direction and wind speed can easily be used to calculate a more detailed load distribution of the torque of a wind turbine before the wind turbine is build.

This approach also shows that the turbulence classes in the IEC are a good reference for the real conditions but at a realistic site condition the wind turbine can be exposed to complete different wind conditions which might lead to a change in the life time.

7 Bibliography

[ROS17] Roscher, Bjoern; Werkmeister, Alexander; Jacobs, Georg; Schelenz, Ralf: Modelling of Wind Turbine Loads nearby a Wind Farm

In: IOP Conf. Series: Journal of Physics: Conf. Series 854 (2017) 012038

IOP Publishing, Visby (Sweden),2017

[BSH18] Federal Maritime and Hydrographic Agency: FINO-1 Research Platform database,

(http://www.fino1.de/en/)
(accessed 20-08-2018)

[BAR17] Bartsch, Christian: FACT-SHEET alpha ventus (12/2017)

Alpha-ventus.de, Oldenburg, 2017

[FRA07] Frandsen S: Turbulence and Turbulence-generated structural loading in wind turbine cluster (Riso-R-1188)

Riso, Roskilde, 2007

[IEC15] DIN EN ISO 61400-1: Windenergieanlagen – Teil1: Auslegungsanforderungen (Entwurf), 2015.

[ROS18] Roscher, Bjoern; Werkmeister, Alexander; Schelenz, Ralf; Jacobs, Georg: Estimation of 1 Hz Distribution based on 10.min SCADA Data

Offshore Wind R&D Conference 2018 (14-16.11.2018, Bremerhaven)