De-Trending Turbulence Measurements
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Identification of Trends and Their Suppression

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The traditional turbulence definition indicates the variation intensity of the wind speed around a mean value and is based on the simple ratio of the wind speed standard deviation and the mean wind speed. Slow variations in wind speed over longer time periods referred to as trends (s.a. slow gust, diurnal wind behaviour) may result in non-representatively high turbulence. The traditional turbulence parameter does not distinguish between these trends and the "real" turbulence. To interpret measured wind speed data in the appropriate way, especially when comparing measured data with simulated data, it is important to cautiously take care of this effect. The question arises: What is the appropriate way to deal with "trendy" turbulence?

1 Introduction

The urgency to find a way to handle trends was detected in different fields. For example during the wind turbine prototype testing it is important to identify measured trend data. The measured turbulence is used as a classification parameter of the capture matrix as given in IEC61400-13. The purpose of this classification is to arrange the measured data into comparable data container on which fatigue loads are calculated. Especially when comparing measured load data with simulated load data it is important to take care of trend effects.
A complete different field is the wind farm micro-siting process. Here it is absolutely necessary to know the real turbulence without trend effects. "Trendy" data can decide if it is authorised to erect a class A, B or C turbine according to IEC 61400-1.

2 Definition of *Trend*

It is difficult to distinguish between trend and real turbulence. The guidelines give no clear definition. Discussions with different experts and correlation between measured and simulated wind data revealed the different views and concepts.
The following figure gives an example to illustrate the complicate situation.

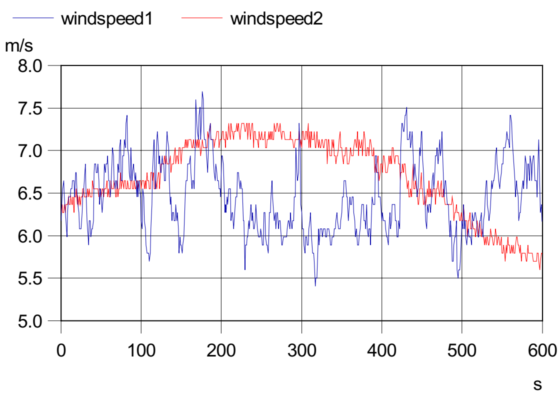

Fig. 1 Example for a Trend

Calculation of the turbulence intensity by the traditional way gives for both signals a turbulence intensity of 6.5%. The high-resolution data demonstrate clear the differences between both wind speed signals and the inadequacy in attaching the same turbulence label to both situations.

Figure 1 shows clear a trend situation. But not all data show such clear behaviour. The difficulty is to find a criterion to distinguish between trend data and real turbulence data and to find a way to handle such trendy data.

3 Methods of Identification and Suppression

The following evaluations show the different methods to handle trends. It must be distinguished between high resolution data (1 Hz / 50Hz) and statistic data (10-minute-average-data).

3.1 High Resolution Wind Speed Data

During load measurement campaign normally high resolution data are recorded. These data can be used to indicate and work with trends. There are different methods to handle trends.

3.1.1 "IEC-Method"

The Technical Specification IEC TS 61400-13: "Wind Turbine Generator Systems, part 13: Measurement of the Mechanical Loads" [1] suggests for high-resolution wind speed data to use a high-pass filtering to correct the wind speed data. The parameters of this filter are not described in the guideline. This method is difficult to use and is not applicable in practical work because of the oscillation which is normally created by the filter function at the beginning of each data file.

3.1.2 "DEWI-Method"

DEWI uses a procedure which is based on a calculation of a de-trended standard deviation of the wind speed. The following procedure is used:

- Subdivide a 10-minute-data-set into a consecutive smaller periods
- Subtract the mean values of each subinterval from the original wind speed signal
- Compute the standard deviation for the derived zero-mean wind speed signal
- Compute turbulence intensity using de-trending standard deviation and original 10-minute mean value

This method detects the unrealistic high turbulence. The “corrected” turbulence intensity is used to make a new classification of the data base into the capture matrix. The following figures show the capture matrix of a typical measurement before and after de-trending.

Capture matrix

data base 1 - before de-trending

Wind speed bin size (x-axis): 1 m/s

Turbulence bin size (y-axis) : 2%

V(m/s) I(%)	0 3.5	3.5 4.5	4.5 5.5	5.5 6.5	6.5 7.5	7.5 8.5	8.5 9.5	9.5 10.5	10.5 11.5	11.5 12.5	12.5 13.5	13.5 14.5	14.5 15.5	15.5 16.5	16.5 17.5	17.5 18.5	18.5 19.5	19.5 20.5	20.5 21.5	>21.5 Vout
0- <3																				
3- 5			1	7	5	4	1	2												
5- 7			8	10	13	22	16	21	8	9	1	1	1							
7- 9			7	12	38	65	56	67	42	52	28	15	7	1						
9- 11			5	12	38	78	141	172	163	142	95	53	21	5	3					
11- 13		1	2	14	54	109	201	230	245	180	143	64	22	2	1					
13- 15			4	16	34	99	139	145	161	139	86	33	11	2						
15- 17		1	5	19	35	51	68	88	79	53	30	5	2							
17- 19			5	10	15	20	36	36	33	20	7	2	1							
19- 21			1	4	8	13	20	11	11	5	2									
21- 23				3	4	7	5	2	3	3	1									
23- 25				1	2	3	3													
25- 27			1		3	1	4													
27- 29						2														
>29																				
	0	2	39	108	249	474	690	774	745	603	393	173	65	10	4	0	0	0	0	0

Datasets : 4329

mean Turbulence: 12.35

Fig. 2 Capture matrix: before de-trending

Capture matrix

data base 2 - de-trendet (DEWI-method)

Wind speed bin size (x-axis): 1 m/s

Turbulence bin size (y-axis) : 2%

V(m/s) I(%)	0 3.5	3.5 4.5	4.5 5.5	5.5 6.5	6.5 7.5	7.5 8.5	8.5 9.5	9.5 10.5	10.5 11.5	11.5 12.5	12.5 13.5	13.5 14.5	14.5 15.5	15.5 16.5	16.5 17.5	17.5 18.5	18.5 19.5	19.5 20.5	20.5 21.5	>21.5 Vout
0- <3			1	2	2	1														
3- 5			11	17	15	17	8	12	2	1										
5- 7			8	16	40	69	73	78	35	52	20	13	8	3	2					
7- 9			6	17	72	156	234	269	299	260	184	93	35	5	2					
9- 11		1	4	26	73	142	248	297	312	225	155	58	21	1						
11- 13		1	5	24	35	65	97	100	86	58	31	9	1	1						
13- 15			1	5	11	20	21	16	10	6	2									
15- 17			3	1		2	8	2	1	1	1									
17- 19					1	2	1													
19- 21																				
21- 23																				
23- 25																				
25- 27																				
27- 29																				
>29																				
	0	2	39	108	249	474	690	774	745	603	393	173	65	10	4	0	0	0	0	0

Datasets : 4329

mean Turbulence: 9.09

Fig. 3 Capture matrix: after de-trending

The following frequency distribution histogram illustrates the de-trending effect in a more graphic way.

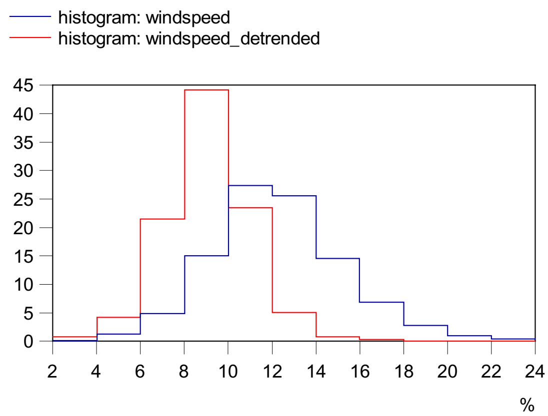

Fig. 4 Frequency distribution
(y-axis = no. of data files)

By examination of a voluminous data base recorded during several load measurement campaigns the de-trending techniques are applied and significant reductions of the turbulence parameter of as much as 25 - 30% were found. An influence of the site could not be found. Several measurements in coastal sites, flat terrain, hilly terrain, mountainous terrain all show a reduction of the turbulence through de-trending in the same order.

The de-trended wind speed signals were validated with data of different simulation programs. The simulated wind speeds show no slow variations over longer time periods. The result of the comparison shows that the (DEWI-)de-trended wind speed signal fits very well with the simulated time series. The following figures show an example of the comparable results.

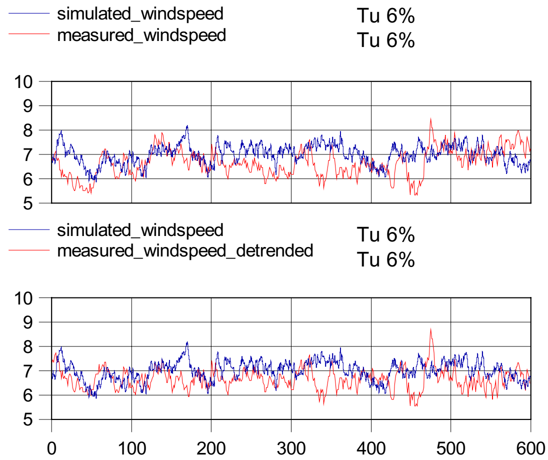

Fig. 5 Data file without trend effect
The measured turbulence before and after de-trending is similar.

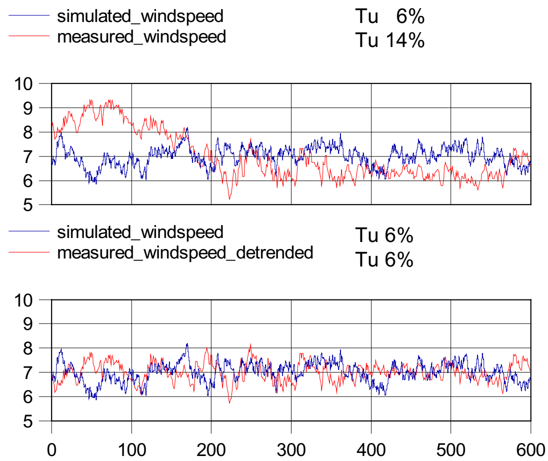

Fig. 6 Data file with trend effect
The measured turbulence before de-trending is 14%. After de-trending the turbulence is 6% like the simulation.

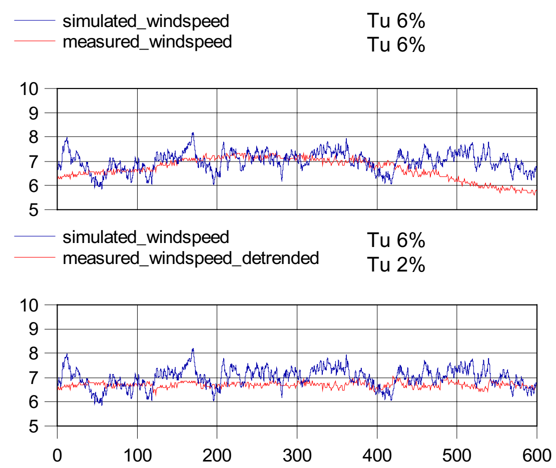

Fig. 7 Data file with trend effect
The measured turbulence before de-trending is 6% like the simulation. After de-trending the turbulence is 2%.

3.1.3 Method “Polynomial Regression”

A further method is to use a polynomial function to approximate the slow moving mean value of the wind speed signal. The procedure to calculate a de-trended standard deviation of the wind speed is similar to the DEWI method. The results of this method show a reduction of the turbulence in the same order like the DEWI method does.

3.1.4 Comparison

The following figure illustrates the results of the different de-trending methods. Note, the high pass filtering data file shows no oscillations at the beginning because the beginning of the data file was cut to get useful results.

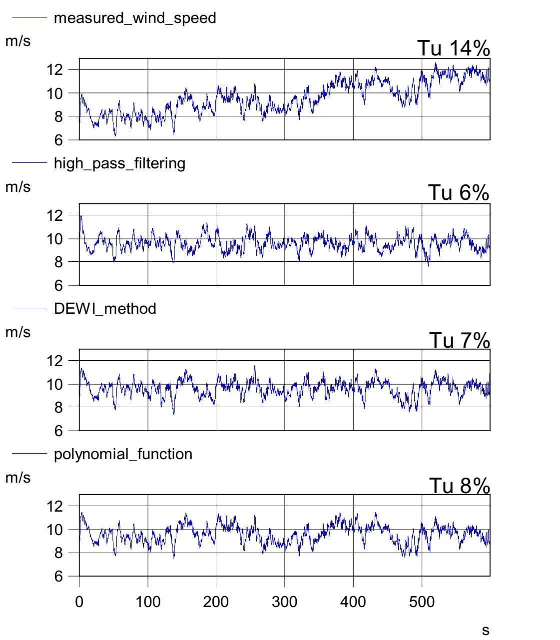

Fig. 8 Comparison of the results of different de-trending methods

4 Method of Identification and Exclusion

The described methods in chapter 3.1.1 – 3.1.3 were used to calculate a *new* turbulence which corresponds to a turbulence according to the traditional definition of turbulence. A different way to deal with “trendy” data is to select the data which show a trend and exclude these data from the evaluations. As described before the difficulty is to decide which wind speed signal shows a true turbulence and which shows slow variations. Also here different methods are conceivable.

After examination of simulation wind speed data DEWI found a criterion to exclude the trend data files from the whole data base. DEWI uses the method which was described before to de-trend the data (chapter 3.1.2) and together with the definition: all files with a corrected turbulence class of more than 4%-points different from the original turbulence class indicate trend effects. These data are excluded from further evaluation
Example:
During a typical measurement period of 2 months a data base from undisturbed direction of 5413 data files were recorded. The de-trending method indicates 777 data files as trendy. This means a reduction of the data base of approx. 15% when all trendy data are discarded. Other measurements show reduction of up to 25 or 30%. This means, however, to arrive at the same data base it will be necessary to extend the campaign by 25 or 30% in time.

4.1.1 Result

To find the trends and exclude the data files from further evaluations is the most exact way to handle with trends. Nevertheless sometimes the data base does not allow renouncing of a part of the measured data. In such cases it will be necessary to correct the measured turbulence.

There are different methods which are used in practice. They lead to different results! For example some methods detect only trends which show a steady increase or decrease of the wind speed. Other methods are able to detect trends, but they are unable to “correct” the data. This results in a big “waste-data-base” and leads to a longer measurement period and to higher costs

5 10-Minute Average Data

For the determination of the average turbulence at the site, at least a one-year time series of wind speed and standard deviation is needed to avoid having seasonal effects in the calculation.
Such wind measurements are normally performed with a temporal resolution of 10 minutes, what means that no high resolution data were available to perform a de-trending of the data. But to be consistent with the approach from the load measurements view, and according to the IEC 61400-1, edition 3 [2], the assessment of the wind turbines' suitability for the site should preferably be based on de-trended data.
For this reason Hansen und Larsen of RIS∅ [3] suggested the use of an empirical model for

performing a de-trending of the data. Slightly modified it may be expressed the following way:

$$\sigma_{\text{detrend}} = \sqrt{\sigma^2 - \frac{\Delta v^2}{12}} \quad \text{mit} \quad \Delta v = v_{i+10\min} - v_i$$

Formula 1 empirical model for de-trending

Table 1 presents the differences between turbulence intensities as determined by using the raw 10-minute data, de-trended 10-minute data using expression 1 and the de-trending on basis of the high resolution data.

Position	Raw 10min Data	De-trending on 10min Data	De-trending on High Resolution Data
Average Turbulence all wind speeds	12.2%	12.0%	9.2%
Characteristic Turbulence I_{15} for v >10m/s	14.9%	14.6%	10.7%
Difference Average Turbulence		-0.3%	-3.1%
Difference I_{15}		-0.2%	-4.2%

Table 1 Differences between the turbulence intensities as determined by different methods

Presented are the average turbulence intensities over all wind speeds, the characteristic turbulence intensity for wind speeds larger 10 m/s, i.e. turbulence intensity + standard deviation. Generally, this value is taken as a measure for the suitability of the wind turbine for the site. It must be lower than 18% (IEC class A) or 16% (IEC class B).

The effect of the de-trending according formula 1 is very small and lies in the range of the overall uncertainties of the turbulence intensity assessment. The effect of de-trending the high-resolution data is - on the opposite - with 3-4% reduction in turbulence intensity, of a highly significant magnitude, and could be the criterion whether a wind turbine can in theory stand the site conditions or not.

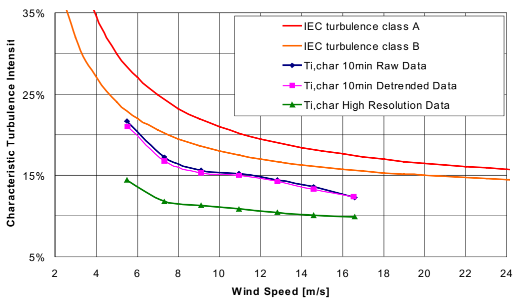

Fig. 9 Ambient characteristic turbulence intensity over wind speed. Presented are IEC-classes A and B and the site turbulences based on raw data, de-trended 10-minute values, and de-trended high resolution data.

Figure 9 shows the turbulence intensities for the site and the IEC-turbulence classes for the individual wind speed bins.

6 Consequences of Trend-Effects

6.1 Fatigue Evaluation

Back to high resolution load measurement data the “new” capture matrix after de-trending is used to choose a data base for the fatigue evaluations. The results of the fatigue evaluation are used to validate the simulation tools. Generally, it is instinctively assumed that application of “de-trending” will give conservative fatigue results. To check this statement different evaluations are performed on a de-trended data base and the same non-de-trended data base. The results show that de-trending does not always come out conservative because the fatigue loads are not only influenced by the turbulence intensity. The fatigue loads are influenced as well by some other factors, for example: the mean wind speed, the parameter of the turbine controller, the kind of trend and so on…

Therefore a de-trending method must be used which fits to the simulation. In case of “special trend effects” the best method is to find the trends and exclude the data files from further evaluations.

The de-trending methods are only used in load measurement campaigns to “produce” a new classification of the data base. But one has got to be aware that the mechanical loads on the components are mainly dependent on the wind characteristics: A trend in the wind speed results in a trend in the loads. The de-trending methods ignore this effect. To get results with the best correlation to real-turbulence-data a de-trending of the load quantities will be necessary. The following figure shows the 1Hz-EQL of each 10-minute-data-file of “trendy” and “not-trendy” data of the flatwise blade bending moment. The below graph shows the EQL after de-trending the load signal by the same DEWI-routine as used for de-trending the wind speed: The scatter of the de-trended loads seem to tune in with the non-trendy data base.

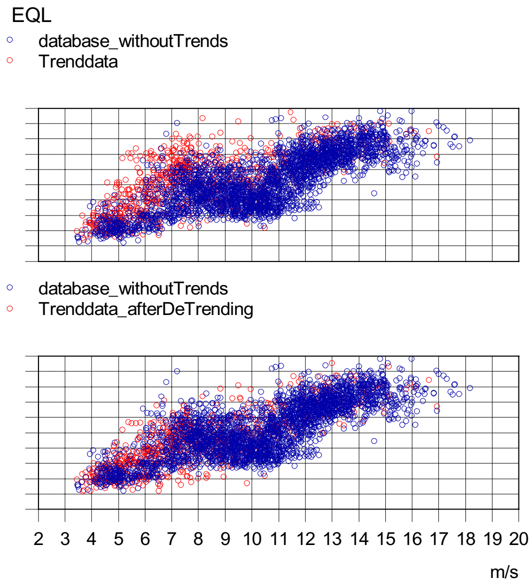

Fig. 10 EQL of the flatwise blade bending moment after de-trending the load quantity

Nevertheless, DEWI is still working at the assessment of how de-trending and associate filtering of data sets affects the evaluation of fatigue loading.

6.2 Site-Specific Condition

It is very simple to explain the consequences of de-trending regarding to the micro-siting process:
De-trending can “decide” if it is allowed to erect a class “A”, “B” or “C” turbine!

7 Conclusion

The measured turbulence is influenced by trend effects. To get an unadulterated data base it is absolutely necessary to take care about this.

For high resolution wind speed data there are different ways to deal with trends. All methods come to different results. Therefore it is important to find a clear definition for a trend and a standardised method to handle these data.

For 10-min-statistic data a method to handle trends was suggested. This method leads only partially to a satisfactory result.

8 Perspective

The guidelines show no clear definition for a trend. A useful recommendation is missing. Therefore it is important to find a definition and a standardized method to handle trends.

The existing methods to consider trend effects for the assessment of the site turbulence should be revised.

[1] IEC 61400-13

[2] IEC 61400-1, edition 3

[3] Hansen, Kurt S. (DTU); Larsen, Gunnar Chr. (RIS∅): De-Trending of turbulence measurements. Presented at OMEMES 2006, Civitavecchia 20-22 April, 2006