New IEC 61400-1 and Site Conditions in Reality

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ABSTRACT:

The second edition of IEC 61400-1 was finalized and voted in favour on the IEC level. The standard was intended to succeed national regulations in the EU and elsewhere. The new edition gives more flexibility to the designer to optimize his turbine in accordance with real site conditions. A missing item in the new edition is that no guidance is given how to include wind farm and/or complex terrain conditions in the calculations.

The wind conditions described in the standard are compared with those of two typical wind turbine locations in Germany, a coastal location and an inland one. Normal and extreme wind conditions appearing at the two sites are compared with those described in the standard. Fatigue loads are calculated for the wind conditions at the site and afterwards compared with the loads derived for the conditions given in the standard. The wind park influence is considered by using the approach presented in the EWTS II project.

The design loads derived by application of IEC 61400-1 result in an adequate safety level. The wind conditions described are conservative compared with the typical German sites considered. However, difficulties may occur in the site assessment and in the prediction of wake induced loading. The wind farm operation may lead to high fatigue and extreme loading, up to the level of the design loads.

1. GENERAL

The IEC 61400-1, 2nd Edition [1] is becoming a valid standard. In this standard the wind description is improved, as a result of reanalysis of wind measurements performed on many sites. Apart from the classification based on mean and extreme wind speed turbulence categories A (high) and B (low) are introduced. This gives the designer more flexibility, to optimize his turbine in accordance with real site conditions. A further innovation in comparison with the first edition of the standard is the introduction of a design value of the turbulence intensity at 15 m/s, defined as the mean plus one standard deviation of the turbulence intensity.

The intention of the standard is to produce design loads which cover a variety of sites. It is recommended that the wind conditions at the site shall be assessed according to the basic parameters, this is mean wind speed, reference wind speed and characteristical value of the turbulence intensity. Further the wake effects of neighbouring turbines has to be considered. The method how these tasks can be performed is unfortunately not described. In EU Joule project EWTS II [2], procedures were set up how to cope with hostile terrain, wind farm and extreme wind speed conditions.

Of interest for a certification society is to investigate these procedures in the way an usual certification procedure would take. It is assumed that the wind turbine is dimensioned to an IEC standard class. The wind conditions prevalent at the site are compared with the standard wind conditions. Loads are calculated for the site conditions and compared with the design basis.

2. SITE SELECTION

Two typical German wind turbine sites were selected. The wind conditions at hub height are shown in Table 2.1. The wind speed distribution is shown in Figure 2.1 the turbulence intensity in Figure 2.2. In both figures the values according to IEC class 2, the class used to certificate most wind turbines, is included for comparison.

.	.	COAST	INLAND	IEC 2A
Mean wind speed [m/s]	V_M	8.0	5.95	8.5
Weibull scale factor [m/s]	A	9.0	6.7	9.59
Weibull exponent	k	»2.15	»2.2	2.0
Mean turbulence intensity	I	11%	13%	18%
Hellmann exponent	a	0.21	0.16	0.2

Table 2.1: Wind conditions at site (Hub height 60 m)

Site in coastal area:

The site is situated near the North Sea coast of Schleswig-Holstein in the far north of Germany. The surrounding countryside is in agricultural use for the most part, while the surface roughness prevailing is of a corresponding roughness class 1. Apart from a dike in the west no further significant obstacles are in the immediate vicinity.

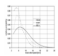
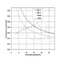


Figure 2.1: Wind speed distribution

Inland site:

The site is situated in the middle of Germany. The surrounding area is in use for opencast mining. The roughness is of a corresponding class 2-3 depending on the direction. The site does not meet the requirements as stated in the IEC standard 61400-12: Wind Turbine Power Performance Testing. This is due to significant slopes and terrain variation.



Figuere 2.2: Design turbulence intensity at hub height

3. NORMAL TURBULENCE MODEL

Fatigue calculations were performed with the given site wind data and the normal turbulence model as described in the IEC standard. For the calculation a representative, variable speed, pitch regulated turbine in the 600kW class was used.

3.1 Fatigue loads according to IEC standard

Fatigue calculations under variation of several parameters were performed, using wind conditions in accordance with the IEC standard. For most load components a high dependence from design turbulence intensity, mean wind speed and wind distribution was observed. A comparison of the calculation results with the scaling method for load spectra presented in IEC 61400-12 [2] (scaling of spectra as a function of turbulence intensity) showed a good agreement in most cases. This is only the case, when all other parameters (wind distribution, function of turbulence intensity over mean wind speed) do not change.

3.2 Fatigue loads for the Site

A typical approach was performed as a first step, using the estimated mean wind speed and turbulence intensity multiplied with a factor of 1.2 and standard parameters for the other values. The factor 1.2 was used as a safety factor and to gain commonality with the first edition of the standard. The results (Figure 3.1 and 3.2) show a much lower load level than reference load class 2a or the IEC class matching best the site conditions. Applying the procedure described in the standard (site assessment) to achieve a similar safety level results in much higher loading, similar to the IEC class matching best the site. The difficulty is that there is no opportunity to estimate the standard deviation of turbulence intensity, so long time and cost intensive, measurements have to be carried out. It is worth mentioning that for the inland site the high turbulence intensity at high wind speeds has no big influence on fatigue loads due to the practical absence of high wind speeds for longer periods.

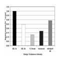


Figure 3.1: Fatigue loads for a coastal site.

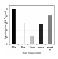


Figure 3.2: Fatigue loads for an inland site.

3.3 Wind farm influence

Reliable measurements in wind farms are difficult to obtain, since measurements of free stream wind and wake wind conditions as well as load measurements are needed. In the EU EWTS II project, the available measurements were compared to the methods available. This resulted to the proposal to use the method compiled by G.C. Larsen [2] which gives the best results. In day by day certification practice it showed that this method is difficult to handle so the method set up by S. Frendsen [2] is often used.

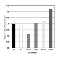


Figure 3.3: Extreme operating load.

It is assumed and shown in calculations that this method results in conservative loads compared to the proposed one. The increase in loading is essential but still below the design load.

3.4 Extreme operating load

In accordance with the standard, the extreme loads from the time series used for fatigue calculation have to be considered (Figure 3.3). Contrary to the fatigue calculation were the turbulence induced loads are weighted according to the wind distribution, in the extreme load case the influence of the high turbulence intensity of the inland site leads to loads higher than the design ones.

4. EXTREME WIND CONDITIONS

The installation of measurement equipment on a wind turbine and on a met-mast with the intention of data acquisition for an extreme environmental situation leading to extreme loads on a wind turbine is of engineers interest in order to get an impression of real environmental conditions in comparison with those required by national and international standards. These standards are often claimed to be too conservative and thus lead to safety margins in the structural design which is cost intensive. The problem is that these extreme environmental conditions have a probability of appearence with recurrence periods of several years. Therefore measured data of extreme wind situations are hard to find. Fortunately an extreme wind condition was recorded at a coastal site near the North See in Germany, in 1997. During this situation a wind turbine near the site location was damaged when a blade of the rotor hit the tower.

4.1 Available measurements on wind conditions

The wind data representing the environmental situation mentioned above were recorded by a long term mesurement system. The data are available as 10-minute-mean values of wind speed and wind direction including statistical information. For a time period of two days these data are schown in Fig. 4.1 and Fig. 4.2.

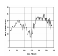


Figure 4.1: Measured 10-minute-mean values of the wind speed at the coastal site.

Regarding the wind direction in Fig. 4.2 the situations of interst can easily be figuered out and are identified as 10-minute time intervalls No. 161 and No. 162. These time intervalls, with the statistical data as given in Table 4.1, will be chosen for the following investigation.

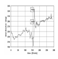


Figure 4.2: Measured 10-minute-mean values of the wind direction with indication of the data set numbers used for investigation.

time intervall	.	No.	161	162
mean wind speed	v_{mean}	m/s	14.4	18.1
std. deviation	s_v	m/s	2.26	3.05
turbulence Intensity	Iu	%	15.7	16.8
min. wind speed	v_{min}	m/s	9.8	11.3
max. wind speed	v_{max}	m/s	19.6	25.6
mean wind direction	Q_{mean}	deg	289	336
std. deviation	s_Q	deg	34.6	4.7
min. wind direction	Q_{min}	deg	240	315
max. wind direction	Q_{max}	deg	352	355

Table 4.1: Statistical values of the measured wind data during the extreme environmental conditions.

4.2 Analysis of measured data

4.2.1 Way of approach

Unfortunately, the data available do not allow an investigation of the short term transient change in wind conditions, as these data are averaged over 10 minutes, whereas the new IEC 61400-1 gives detailed information about these transient changes to be investigated. Due to the lack of information in the measured data, the worst transient was assumed. That is for the wind speed an amplitude change directly from the measured minimum value to the measured maximum value within the 10-minute data set. For the wind directional change the mean wind direction is assumed to be the starting value for the amplitude change to the measured minimum value as well as to the measured maximum value within the 10-minute data set. The comparison of the measurement results with the requirements of the IEC 61400-1 is carried out by applying the IEC equations for the 'extreme operating gust' (EOG) and the 'extreme direction change' (EDC) for both IEC categories A and B with respect to the one-year and the 50-year recurrence period. Additionally the IEC equations are applied by using the measured results for mean values and standard deviations.

4.2.2 Extreme operating gust

Following the procedure as mentioned above, the results are shown in Fig. 4.3 representing time intervall No. 162 for the gust amplitude. Thereafter it can be seen that the gust amplitudes according to IEC assuming a 50-year recurrence period 'e50(Std.)' for both categories A and B as well as the results of the IEC formula by application of the measured values 'e50(meas)' cover the measured gust amplitude change. Regarding the same comparison for the 1-year recurrence period, the measured gust amplitude exceeds those of the IEC results indicated as 'e1(Std.)' and 'e1(meas)' respectively. However, in this case one can conclude that the new IEC code accounts for extreme gust amplitude changes in the range measured for the site investigated, because of the defined extreme wind conditions with a 50-year recurrence period.

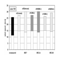


Figure 4.3: Comparison of the measured gust amplitude with the extreme operating gust according to IEC 61400-1.

4.2.3 Extreme change in wind direction

The investigation of the extreme wind direction change is shown in Fig. 4.4 using the measured data of the time intervall No. 161. The amplitude of the measured direction change is given with a value of Q=63deg and exceeds all values calculated according to IEC although the result of the IEC category A for the 50-year recurrence period 'e50(Std.)' with a value of Q=55deg is relatively close.

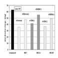


Figure 4.4: Comparison of the measured wind direction amplitude change with the extreme direction change according to IEC 61400-1.

Using the measured mean wind speed and the corresponding standard deviation for calculation of the extreme direction change acc. to IEC ('e1(meas), e50(meas)') leads to the lowest directional amplitude change compared to the standard category A and B. Regarding the mean wind speed of vmean=14.4m/s used for investigation, the extreme wind direction changes acc. to IEC might underestimate the environmental situations compared to what could happen in reality.

5. CONCLUSION

The IEC 61400-1 results in conservative loads when the normal turbulence model is applied. The different site conditions lead to big differences in load, to high safety margins when the stand alone turbine is considered. Even at the inland site with high turbulence intensity , the high Weibull exponent delivers low fatigue loading. Special care has to be taken in the estimation of the design values for the wind conditions. Wind farm influence may lead to high fatigue and extreme operating loads. The methods presented in EWTS II shall be applied for seizing wind farm effects and hostile terrain influence. For the investigation of the extreme environmental conditions measurement records of 10-minute-mean values, which represent such a situation, measured at a coastal site, are analysed and compared with the requirements of the new IEC 61400-1. The extreme operating gust with a 50-year recurrence period acc. to IEC covers the situation measured, whereas the extreme wind direction change measured is underestimated by the IEC requirements even for the same recurrence period. For a further judgement more measurements are necessary with high data solution so that the transient changes can be taken into consideration, too.

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