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Extreme Response for Wind Turbines

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ABSTRACT

The characteristic load on wind turbines during operation are among others dependent on the mean wind speed, the turbulence intensity and type and settings of the control system. The characteristic load during operation is normally estimated by statistical extrapolation of a limited number of simulated 10min time series of the response according to the wind turbine standard IEC 61400-1. However, this method assumes that the individual 10min time series and the extracted peaks from the time series are independent. In the present paper is this assumption investigated based on field measurements and a new method for estimating the characteristic load based on field measurements is proposed.

KEYWORDS

Wind Turbines, Load Extrapolation, Field Measurements.

1 INTRODUCTION

The methods for estimating the characteristic load on wind turbine during operation have been widely discussed within the wind turbine industry in the last years. In the wind turbine standard IEC 61400-1 3.edition 2005 [1] it is recommended that the characteristic load is determined by statistical extrapolation of simulated 10min time series of the wind turbine response during operation. This method is based on [2] and uses the Peak Over Threshold (POT) method for extracting the peaks from the simulated time series. Other methods for calculating the characteristic load and extracting the peaks are proposed in [3;4].

The load extrapolation method according to IEC 61400-1 is based on the assumption that the peaks extracted by the POT method and the individual 10 min time series are independent. The assumption about independence of the peaks has been studied in [4] and it was found that the correlation was weak. Since the extreme load is dependent on the mean wind speed, the turbulence intensity and the type and settings of the control system the correlation in the wind turbine response must be dependent on the correlation for these parameters.

In [5;6] has a correlation length in the range of 48-60 hours been used for the mean wind speed. Correlation in turbulence has been studied in [7] leading to a correlation length in the range of 10-20 seconds. For the control system the correlation will be dependent on how fast the wind turbine can e.g. pitch the blade or in other ways reduce the loads on the structural components. The correlation length for the control system will typically be in the range of a few seconds if the control system is active. The correlation length for the wind turbine response and thereby the extreme load is for this reason a combination of very different time scales.

2 STORM WIND SPEED

For normal civil engineering structures the extreme load occurs for the extreme wind speeds. However, for wind turbines the extreme load often occurs close to the nominal wind speed (typically U_{nom} = 15m/s) or the cut-out wind speed (typically U_{out} = 25m/s). In the following is a storm wind speed defined from which the extreme load can occur. In figure 1 is the mean wind speed and maximum flap bending moment for each 10min time series given for a pitch controlled wind turbine.

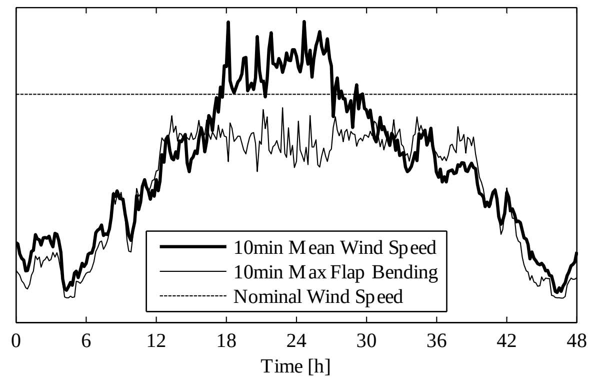

Figure 1: Mean wind speed and max flap bending for each 10min time series. Pitch controlled wind turbine.

From figure 1 it is seen that the maximum flap bending moment follows the mean wind speed closely for low wind speeds. However, at mean wind speeds close to the nominal wind speed the flap bending moment seems to reach a constant level. In order to avoid the non critical response at the small mean wind speeds in the extrapolation procedure is a storm wind speed defined. The storm wind speed is the smallest mean wind speed where the response can start to become critical. Based on figure 1 is the storm wind speed defined as the smallest mean wind speed where a gust can reach the nominal wind speed:

$$U_{storm} = U_{nom} - k_p \sigma_1 \tag{1}$$

where the turbulence is assumed to be a Gaussian process and the peak factor is assumed to be k_p = 3.5 as for the wind pressure. The standard deviation of the turbulence is given by [1]:

$$\sigma_1 = I_{ref}\left(0.75U_{storm} + c\right) \tag{2}$$

where I_{ref} is the reference turbulence intensity at 15 m/s and c = 3.8m/s is a constant. All wind speeds are specified at hub height.

3 LOAD EFFECT EXTRAPOLATION FOR FIELD MEASUREMENTS

Based on the definition of a storm wind speed given in the previous section a time series of field measurement can be reduced to a series of independent storms from which the extreme response can be extracted, see e.g. [8] where similar approach have been used for waves. From the extracted extremes a distribution for the extreme response can be obtained. In the present paper is a 3-parameter Weibull distribution fitted to the 25-30 largest extremes in order to ignore the smallest extremes and still have a representative dataset.

$$F_{response}\left(l \mid S\right) = 1 - \exp\left(-\left(\frac{l-\gamma}{\beta}\right)^{\alpha}\right) \qquad l \geq \gamma \tag{3}$$

where S indicates a storm and α, β, γ are parameters in the distribution function which is fitted using the Maximum-Likelihood Method in order to take the statistical uncertainty into account. The characteristic load during operation with a recurrence period on T_r years can then be calculated for the probability:

$$F_{response}\left(l_c \mid S\right) = 1 - \frac{1}{\lambda T_r} \tag{4}$$

where λ is the number of data per year used for fitting the distribution function. If the statistical uncertainty is taken into account the distribution function can be solved for the probability in (4) using FORM (First Order Reliability Method), see e.g. [9].

4 NUMERICAL EXAMPLE

In the present section is the characteristic load with and without statistical uncertainty calculated using the method in IEC 61400-1 and the method based on independent storms presented in the present paper. The dataset available for a stall controlled wind turbine contains 52 days of complete measurements and the results are given in table 1. A similar comparison should be performed for a pitch controlled wind turbine.

Table 1: Characteristic flap bending moment, with and without statistical uncertainty.

Method	Characteristic load	
	without stat. unc.	with stat. unc.
IEC 61400-1	1.000	1.037
Storms	1.106	1.348

It is seen from table 1 that the characteristic load calculated based on independent storms gives a higher characteristic load than obtained by the method used in IEC 61400-1. The limited dataset leads to a high statistical uncertainty.

5 CONCLUSIONS

In the present paper is a new method for estimating the characteristic loads on wind turbines proposed. The method is based on field measurements of the wind turbine response which is divided into independent storms. The characteristic load is determined by extrapolation of the largest response in each storm. In a numerical example is the characteristic load calculated for a stall controlled wind turbine using the method in IEC 61400-1 and the method based on independent storms. The difference between the characteristic loads could indicate that the local extremes and the individual 10min time series not are independent.

6 ACKNOWLEDGEMENT

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