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Detection and statistics of gusts

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Abstract - In this project, a more realistic representation of gusts, based on statistical analysis, will account for the variability observed in real-world gusts. The gust representation will focus on temporal, spatial, and velocity scales that are relevant for modern wind turbines and which possibly affect the loads. Emphasis will be put on gust rise time and velocity jump, within the context of extreme as well as normal turbulence.

Keywords – Gusts, Rotational sampling, Filtered wind speed, Joint distribution

I. INTRODUCTION

The IEC international standards for wind turbines **[1]**prescribe a set of design requirements to ensure that wind turbines are properly engineered. These standards take into consideration extreme wind conditions and various operational turbine load regimes, and specify the damage a wind turbine may withstand over its lifetime. The characterization of loads in the IEC standards is limited, and does not adequately represent the variability in the atmospheric flow parameters used as input in load simulations.

Deterministic 'gust shapes' are used for several types of load cases, which do not take into account a large number of expected gust scenarios.

II. METHODOLOGY

To achieve a statistical representation of gusts, long time series of high-resolution wind speed measurements from cup anemometers are analyzed. To process such long time series, an automated gust detection algorithm has been developed. The algorithm includes a band-pass filter function. In addition, the effect of rotational sampling of turbulence has been accounted for by means of a model for power spectra of a rotating wind turbine blade [1].

III. DATA

The analysis is made from measurements from Høvsøre, a coastal site in Western Jutland in Denmark[1]. The data consist of 10 Hz cupanemometer wind speed measurements at three different heights, 80m, 100m and 116.5m. The cups are mounted on a meteorological mast, where the highest cup is at the top of the mast and the lower cups are installed at booms on the south side of the mast. Measurements where the wind is from north are excluded from the analysis. This is done because of flow distortion of the mast itself and the presence of four wind turbines on the north side of the mast, resulting in the mast being in the wake of the turbines.

IV. THE EFFECT OF ROTATIONAL SAMPLING

Turbulent wind speed fluctuations encountered in a rotating frame of reference are different from those observed in a fixed reference frame. Certain periods of the rotationally sampled turbulence are seen to be more compressed in time, when compared with fixed-point turbulence. The spectrum of rotationally sampled wind speed fluctuations is distorted in certain frequency sub ranges. This distortion resulting in narrow areas/concentrations of high turbulence energies in the frequency ranges corresponding to multiples of the rotational frequency of the reference frame. Possibly influencing detection and statistics of gusts…

L. Kristensen and S. Frandsen[1] derived a model that describes the power spectrum of rotationally sampled turbulent wind fluctuations. The turbulence is assumed to be stationary and isotropic and the autocorrelation function is based on the Von Kármán energy spectrum:

$$\rho(s) = \frac{2}{\Gamma(1/3)}\{\alpha^2 \sin^2 s + \beta^2 s^2\}^{1/6} \left\{K_{1/3}\left(2\{\alpha^2 \sin^2 s + \beta^2 s^2\}^{1/2}\right) - \frac{\alpha^2 \sin^2 s}{\{\alpha^2 \sin^2 s + \beta^2 s^2\}^{1/2}} K_{2/3}\left(2\{\alpha^2 \sin^2 s + \beta^2 s^2\}^{1/2}\right)\right\}$$

Here, Γ is the Gamma function and $K_{1/3}$ and $K_{2/3}$ are modified Bessel functions of the second kind. The expression is given as a function of s, a normalized time lag,

$$s = \omega_0 \tau / 2$$

where τ is the time lag and ω_0 is the rotational frequency. The parameters α and β are given by:

$$\alpha = r/L$$
$$\beta = \mathrm{U}/(L\omega_0)$$

Where r is the radius of the rotation and L is the length scale of turbulence. The parameters, α and β, are chosen from the operational conditions of the NREL 5MW reference wind turbine [1], operating between the rated- and the cut out wind speed (11.4 m/s - 25 m/s).

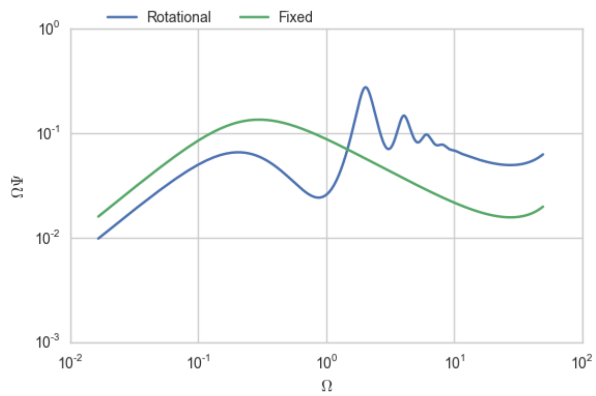

Fig. (1)The normalized rotationally sampled power spectrum (blue) and the fixed point von Kármán spectrum (green).

The power spectrum of rotationally sampled wind speed is found by applying the discrete Fourier transform to the autocorrelation function. The spectrum, $\psi(\Omega)$, is given as a function of the normalized frequency $\Omega = 2\omega/\omega_0$ (Fig. (1)).

In order to apply the effect of rotational sampling to the measured wind speed, a shaping filter is defined:

$$H_{shape}^2 = \frac{\psi_{rot}(\Omega)}{\psi_{fixed}(\Omega)}$$

Where $\psi_{fixed}(\Omega)$ is the spectrum of fixed-point turbulence. The filter is multiplied with the Fourier transform of the measured wind speed:

$$\hat{u}_{rot} = \hat{u}\, H_{shape}$$

While similar shaping filters have previously been derived in order to simulate a wind speed signal [1], the filter applied in this project is much simpler. Also the shaping filter here is applied to measured wind speed.

V. Gust Detection

The wind speed signal is filtered with a shaping filter, described above, to include the effect of rotational sampling. Additionally the signal is filtered with a first-order, band-pass Butterworth filter. The purpose of the band-pass filtering is to eliminate slow wind speed variations, that the wind turbine can react and adapt to, and eliminate the fast variations that are not expected to have influence on the wind turbine loads.

After the wind speed signal is filtered in the frequency domain, it is transformed back to the time domain. Gusts are then detected as high peaks above a threshold in the signal. An example of the a filtered wind speed signal is showed in Fig.(2)

VI. Gust Characterization

The peaks are identified from the filtered wind speed signal, while the gusts are characterized from the original wind speed measurements. The time of the peaks in the filtered wind speed signal correspond to local maxima in the original wind signal, u_{peak}. The gusts are characterized by a velocity jump, Δu, and rise time, Δt. The Δu and Δt are found by looking at a period of 30 seconds preceding u_{peak}. The mean wind speed of the period is calculated, u_{mean}, and all u values below the mean, $u_{bm}(t)$, are used to calculate the maximum slope of the wind speed:

$$\frac{\Delta u}{\Delta t} = max\left(\frac{u_{peak} - u_{bm}(t)}{t - t_{peak}}\right)$$

The maximum slope between u_{peak} and the preceding $u_{bm}(t)$ indicates the velocity jump, Δu. The time between, $t - t_{peak}$, indicates the rise time Δt.

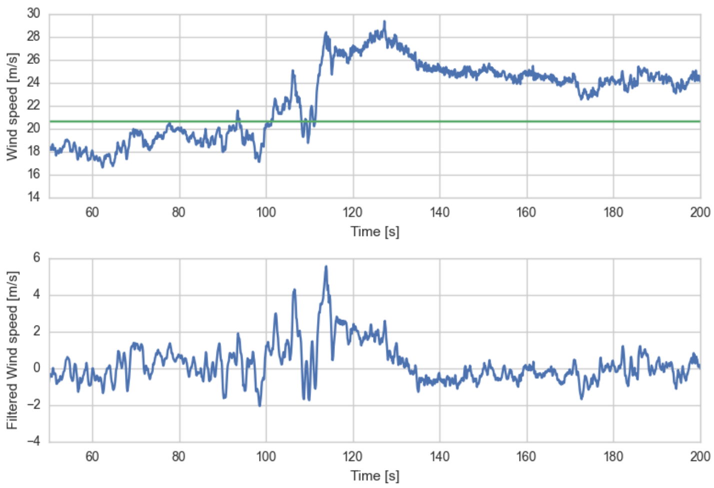

Fig. (2)Above: The measured wind speed at 100 m height (blue) and the 30 s-mean wind speed preceding the peak (green). Below: The corresponding filtered wind speed signal, including the effect of rotational sampling.

VII. Results

The gust detection was applied to 10 years of data. The filtering and peak detection was done on all three measuring heights (80 m, 100 m and 116.5 m), while the gust characterization was performed on the 100 m height measurements only, both with and without rotational shaping filter.

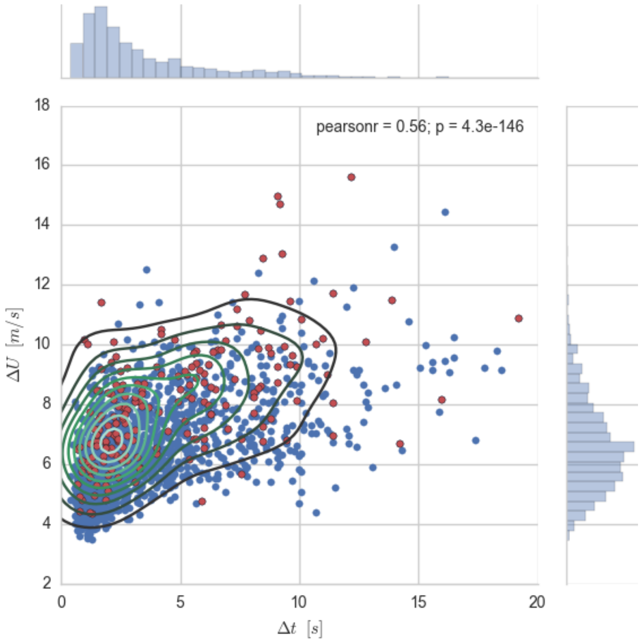

Fig. (3)The joint distribution of rise times and velocity jumps of the detected gusts.

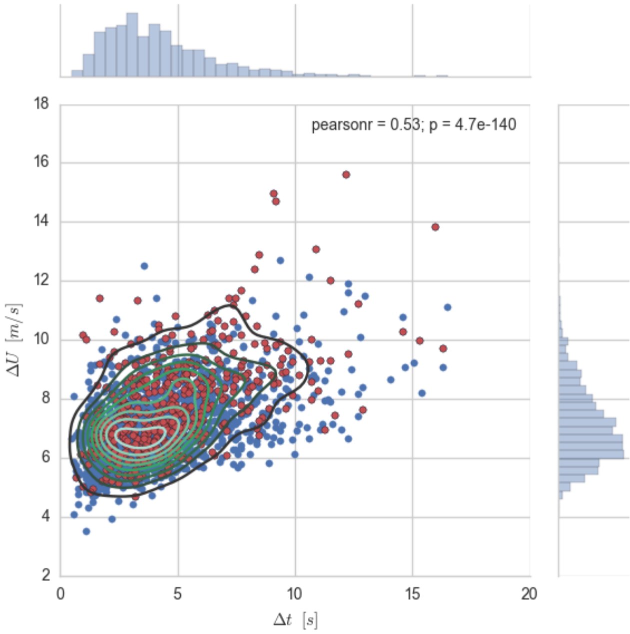

Fig. (4) The joint distribution of rise times and velocity jumps of the detected gusts.

Fig. (3) shows the distribution of the found velocity jumps and rise times, detected from the filtered signal (Butterworth- and shaping filter). The threshold on the peak detection was set to 4.5 m/s. The red dots indicate gusts that are detected at all three heights within 10 s. The blue dots show the gusts that are detected at either one or two heights.

In Fig. (4) the distribution of Δu and Δt is shows, where the peaks are detected from the filtered signal, filtered with the Butterworth filter only.

It is seen from the figures that the distributions for both Δu and Δt have higher mean values, when the rotational shaping filter is not applied. When the rotational shaping filter is applied:

$$\Delta u_{mean} = 6.64\, m/s$$
$$\Delta t_{mean} = 3.56\, s$$

Butterworth filter only:

$$\Delta u_{mean} = 7.15\, m/s$$
$$\Delta t_{mean} = 4.31\, s$$

VIII. CONCLUSION AND OUTLOOK

The results from the analyses indicate that the application of a rotational shaping filter on wind speed measurements has an effect on the gust statistics. The detected rise times and velocity jumps have lower mean values when the effect of rotation is included.

The gusts that are detected at all three measuring heights simultaneously are expected to result in higher loads on the wind turbine. Though this has to be verified with load simulations with an aeroelastic code for wind turbine response.

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