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# Load Extrapolation during Operation for Wind Turbines

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## Introduction

Load on wind turbines during operation is among others dependent on:

- Mean wind speed.
- Turbulence intensity.
- Type and settings of the control system.

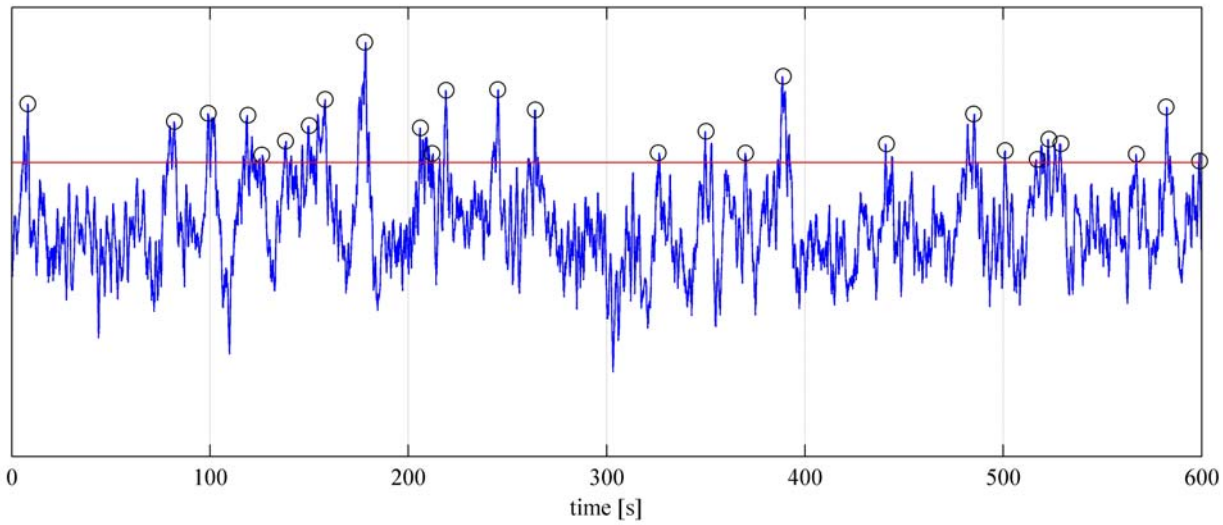
According to IEC 61400-1 3.edition 2005 the characteristic load is determined by statistical extrapolation of the response.

www.vestas.com

## Extraction of Local Extremes

Local extremes are extracted by the Peak-Over-Threshold method.

- Threshold – Mean plus a number of standard deviations.
- Independent extremes – Time separation.
- Individual 10 min time series are independent.



## Method for Load Extrapolation

Response is assumed Weibull distributed for local extremes:

$$F_{local}\left(l \mid T,U\right) = 1 - \exp\left(-\left(\frac{l-\gamma}{\beta}\right)^{\alpha}\right)$$

Statistical uncertainty in distribution parameters included.

Long-term distribution of the extremes for all wind speeds:

$$F_{long-term}\left(l \mid T\right) = \int_{U_{in}}^{U_{out}} F_{local}\left(l \mid T,U\right)^{n(U)} f_U\left(U\right) dU$$

Characteristic value for response with a 50 year return period:

$$F_{long-term}\left(L_c \mid T\right) = 1 - 3.8 \cdot 10^{-7}$$

## Flap Bending Moment – Simulation Time

- Limited number of simulations gives a large statistical uncertainty.
- Normally 6 – 10 min. simulations are performed at each wind speed.

| Simulations | Without statistical uncertainty | With statistical uncertainty | Statistical uncertainty |
|---|---|---|---|
| 5 | 1.114 | 1.450 | 30.2 % |
| 10 | 1.000 | 1.114 | 11.4 % |
| 25 | 1.000 | 1.045 | 4.5 % |
| 100 | 0.914 | 0.923 | 1.0 % |

## Flap Bending Moment – Threshold Value

- Decrease in characteristic response with higher threshold values.
- The statistical uncertainty increases with higher threshold values because the number of extremes are reduced.

| Threshold | Without statistical uncertainty | With statistical uncertainty | Statistical uncertainty |
|---|---|---|---|
| 1.4 | 1.000 | 1.045 | 4.5 % |
| 2.0 | 0.920 | 0.996 | 8.2 % |
| 2.5 | 0.773 | 0.845 | 9.3 % |

## Flap Bending Moment – Separation Time

- Small change in characteristic response for small variations of separation time.
- The statistical uncertainty increases with longer separation time because the number of extremes are reduced.

| Separation time | Without statistical uncertainty | With statistical uncertainty | Statistical uncertainty |
|---|---|---|---|
| 5 sec. | 1.017 | 1.053 | 3.5 % |
| 10 sec. | 1.000 | 1.045 | 4.5 % |
| 15 sec. | 1.002 | 1.057 | 5.4 % |
| 30 sec. | 0.923 | 0.992 | 7.5 % |

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