Analysis of gust factors from Frøya

Lars Morten Bardal[1], Lars Roar Sætran[1]

[1]Norwegian University of Science and Technology, Dept. Energy and Process Engineering, 7491 Trondheim, Norway

Introduction

A wind turbine is harvesting the energy in the wind, but must also withstand the large dynamic forces imposed by the turbulent wind field. Ideally we would like the wind to be stable with no fluctuations, both from a design and operation point of view, but the reality is far from ideal. The atmospheric wind is very turbulent over a large range of scales and wind gusts of the scale of a wind turbine become important for load calculation and wind turbine control. The wind velocity gust factor is a parameter used for extreme load calculations and is defined as the ratio between maximum and mean wind speed:

$$G_{T,\tau} = \frac{U_{\max,\tau}}{\bar{U}_T}$$

where $U_{max,\tau}$ is the maximum τ second moving average wind speed during a T-second averaging period. Another gust parameter often used is the "peak factor" which is defined as the relative gust amplitude divided by the standard deviation of the longitudinal wind speed:

$$k_{pT,\tau} = \frac{U_{\max,\tau} - \bar{U}_T}{\sigma_U} = \frac{G-1}{I_U}$$

Many models and standards exist for gust factor for engineering applications. In this study measurements will be compared to an analytical model by Greenway [1] based on a Von Karman turbulence spectrum and a Gaussian wind speed distribution and a simple formulation for peak factor by Wieringa [2]:

$$G_{T,\tau} = 1 + I_U\left(1.42 + 0.3013\ln\left(\frac{T}{\tau} - 4\right)\right)$$

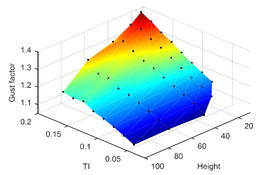

Fig. 1 Measured mean gust factor vs. Turbulence intensity and height

The Frøya site

- Location: Skipheia, near the village Titran at the island Frøya on the coast of Mid-Norway. (Fig. 2)

Fig. 2 The measurement site and mast at Frøya

- Facilities: 2 100m masts, 1 45m mast and house for instrumentation and accommodation
- Instrumentation:
  - 16 Gill WindObserver ultrasonic 2D anemometers
  - 1 Gill WindMaster 3D ultrasonic anemometer
  - 6 PT100 temperature sensors
  - pressure and humidity sensor
- Wind climate:
  - Mean wind speed at 10m: 6.5m/s
  - Mean power law exponent α: 0.108
  - Roughness length: 0.0005-0.02

Methods

Gust factor and peak factor have been calculated for 6 heights between 10 and 100 meters from 100000 10-min time series. A running average filter with a time window τ of 1, 3 and 10 seconds was applied to the time series. In order to remove low frequency trends and reduce influence of non-stationarity, linear de-trending was applied prior to analysis. The horizontal wind speed and wind direction were measured at a sampling rate of 1Hz using Gill WindObserver 2D ultrasonic anemometers. The Obukhov length have been estimated from the measured bulk Richarson number.

Results

The gust factor increases with turbulence intensity and deceases with gust averaging time. A linear model by Wieringa based on these two parameters is compared with measurements in Fig. 3 and shows a good fit for low and moderate turbulence intensities, but not $I_U > \sim 0.2$. The reason for this might be that the high turbulence intensity conditions are associated with low wind speeds and therefore the assumption of a Gaussian wind speed distribution is broken.

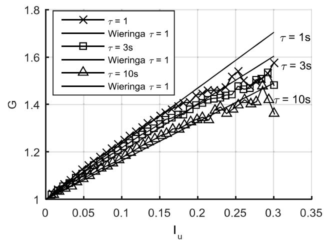

Fig. 3 Gust factor $G_{600,\tau}$ as a function of turbulence intensity I_U and gust averaging time τ.

Comparing the measured gust factors to the model of Greenway [1] we use only data from narrow bins for wind speed and turbulence intensity. For a detailed derivation of the model see [1]. The results shown in Figure 4 shows a discrepancy between the measurements and the model, the model giving a mode value 1.24 compared to a mode of 1.20 from the data. A length scale of 300 meters is used, but it could be noted that the analytical model is not very sensitive to the integral length scale used. The error increases with increasing turbulence intensity and systematically overestimates the gust factors from the Frøya .

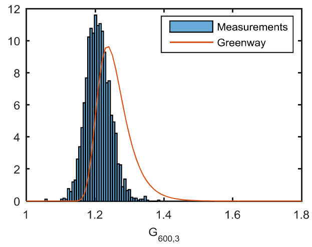

Fig. 4 Measurements of G600,3 compared to the analytical model from [1] for U=10m/s, I_U=0.1 and L_U=300. Measurements include 14m/s < U < 16m/s and 0.09 < I_U < 0.11.

The mean peak factor measured at Frøya is independent of wind speed and height, but decreases with increasing turbulence intensity (Fig. 5) . The ISO 4352 standard for wind action on structures recommends a constant peak factor of 3.9, 3.0 and 2.4 for 1, 3 and 10 second gust averaging respectively. Compared to the measured data (Fig. 5 and Fig. 6) this appears very conservative.

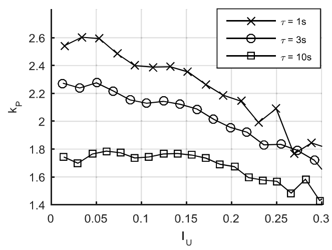

Fig. 5 Peak factor k_P vs. Turbulence intensity and gust averaging time, τ

The peak factor (Fig. 6) is less sensitive to atmospheric stability, but shows a slightly deceasing trend with increased stability. This variation might be due to the larger scale and intensity of turbulence associated with unstable conditions[13].

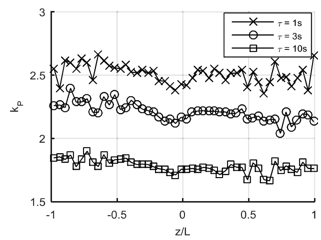

Fig. 6 Peak factor k_P vs. atmospheric stability z/L

Conclusion

The dependence of measured gust factors on various parameters of the atmospheric wind field is presented based on a 5 year dataset from Frøya.

- The gust factor mainly depends on turbulence intensity, height and gust averaging time
- The simple linear model by Wieringa [2] fits the measurements well for low and intermediate turbulence.
- The model from Greenway [1] for the distribution of gust factors shows an overall overestimations compared to the measured data., but a good fit of the scale parameter.
- The peak factor which includes the turbulence intensity has a small dependence on turbulence intensity and atmospheric stability.

References

[1] M.E. Greenway, An analytical approach to wind velocity gust factors, Journal of Wind Engineering and Industrial Aerodynamics, 5 (1979) 61-91.

[2] J. Wieringa, Gust factors over open water and built-up country, Boundary-Layer Meteorol, 3 (1973) 424-441.

[3] S. Frandsen, H.E. Jørgensen, J.D. Sørensen, Relevant criteria for testing the quality of turbulence models, in: The European Wind Energy Conference and Exhibition, EWEC 2007, Milan, 2007.

NTNU
Norwegian University of Science and Technology