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Wind gust factors in a coastal wind climate

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Abstract

Gust wind speeds in high wind speed conditions are important for load estimation on large structures in exposed locations, like a multi-megawatt wind turbine. Modern wind turbines operate at wind speeds up to 25 m/s so it is important to know the expected amplitude, acceleration and relevant scale of typical wind gusts under operating conditions.
The wind measurement station at Frøya is located near the village of Titran on the western tip of the island. The site (Fig. 1) is well suited for measuring coastal and marine wind conditions relevant for offshore and coastal wind farms. The database contains several hundred hours of wind data from high wind speed conditions (>15 m/s). A 100 meter high meteorological mast with 2D ultrasonic anemometers at 6 levels have been used to collect wind data over a time period of 5 years from 2009 to 2014.
Gust factors (G) measured at Frøya have been studied and correlated with height, wind speed, turbulence intensity (TI) and atmospheric stability, and compared to existing models.
The gust factor mainly depends on turbulence intensity and gust averaging time. This indicates that the "peak factor" (k_P) is a better measure for gustiness when turbulence values are available. k_P decreases with increasing turbulence intensity and averaging time, but is less dependent on atmospheric stability. Its pdf follows a Gumbel distribution. An asymmetry of the measured gusts could be observed , showing a higher fall time compared to rise time.

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1. 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 speed to be constant with no fluctuations, both from a design and operation point of view, but the reality is far from ideal. The atmospheric wind is 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

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control [1, 2]. The gust factor is a crude representation of the dynamic properties of the wind and is of limited value for dynamic analysis, but often this is the only available measure of turbulence from long term routine meteorological measurements. Average and maximum wind speed measurements are available from a large number of onshore meteorological stations and a few offshore stations, often as 10 minute or 1 hour values at 10 meter height. In order to estimate wind loads at these locations the ratio between maximum and average wind speed is useful. A common definition of the gust factor is

$$G_{T,\tau} = \frac{U_{max,\tau}}{\overline{U_T}} \tag{1}$$

where $u_{max,\tau}$ is the maximum τ-second moving average wind speed during a T-second averaging period and $\overline{U_T}$ is the T-second average wind speed[3]. Common values for T are 10 minutes – 1 hour and for τ 1-10 seconds. In a similar manner a normalized gust factor is defined as the ratio between the maximum wind speed fluctuation and the standard deviation of the longitudinal wind component (σ_u),

$$k_{P\,T,\tau} = \frac{U_{max,\tau} - \overline{U_T}}{\sigma_u} = \frac{G-1}{I_u} \tag{2}$$

where I_u is the longitudinal turbulence intensity. The gustiness parameter k_p, which we here denote “peak factor” is also sometimes referred to as “gust factor”.

Traditionally a 3-second gust has been used in standards for buildings as this was considered a typical averaging times for the anemometers used. It has however been shown that the averaging time of the gust should be related to the structural dimensions considered. Greenway [4] introduced the dependence of the gust scale for a given structure directly into an expression for the gust factor as the ratio between integral length scale and a structural dimension. Frandsen et al. [5] relates the moving average filter time, τ, to a spatial averaging of the wind speed equivalent to the effective spatial wind turbine rotor filtering and finds that the traditional 3-second averaging often used for buildings is too short for a modern large scale wind turbine. Using his formulation for a wind speed filter frequency based on rotor diameter, mean wind speed and integral length scale of turbulence we find an averaging time closer to 10 seconds for a multi megawatt wind turbine under typical conditions.

A number of models for the gust factor have been proposed in the literature. In [5] a model linking the peak factor to the scale of turbulence is presented. Greenway [4], continuing the work of Davenport [6], presented an analytical expression for the probability distribution of the gust factor based on a von Karman spectrum and a Gaussian wind speed distribution. This formulation however becomes quite complex and an empirical simplification was later added by Wood [7]. Wieringa [8] presented a simple expression for $G_{T,\tau}$ based on turbulence intensity or roughness length and height. In civil engineering standards we find different approaches to the wind gust factor. The ISO standard for Wind loading on structures [9] uses a mean k_P varying only with averaging time based on a 1 hour average wind speed while ESDU [10] uses the results of Greenway and Wood. Kristiansen et al. [11] discussed two different approaches to gust analysis, one based on a theory of the rate of exceedance of a normalized wind speed, and the other based on the Gumbel distribution.

The wind velocity gust factor treated here is related to the gust loading factor used in codes for structural load calculations for buildings [12, 13] and the formulation can be applied to a number of effects related to wind speed fluctuations [14]. In this paper we will study the main parameters influencing the wind velocity gust factor such as wind speed, height, turbulence intensity and atmospheric stability and compare measurements to some of the above mentioned models. Changes in wind direction are not treaded in this study.

2. Methods

Wind data have been collected from a meteorological station on the island Frøya on the western coast of Norway. The site shown in Figure 3 represents an exposed coastal wind climate with open sea-fetch, land fetch and mixed fetch from the various directions. The surrounding terrain is characterized by moor and bare rock in rolling