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Influence of turbulence intensity on wind turbine power curves

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Abstract

In this study the effect of turbulence on wind turbine performance measurements has been investigated, and the turbulence normalization method introduced in a draft for the second edition of the IEC 61400-12-1 standard has been evaluated. Experimental data has been collected from a wind turbine test site at the coast of Norway over a 10 month period from a Windcube v2 groundlidar, and a 3MW wind turbine, and the effect of turbulence intensity on power curves and annual energy production (AEP) has been studied. The range of turbulence conditions experienced at this coastal site has a significant influence on the power curve and calculated AEP. The measured dataset was split into two subsets featuring different turbulence conditions, and AEP was then calculated for each of these based on power curves from the opposite subset. Using the zero turbulence power curve method the difference in calculated AEP is reduced by 50% compared to using traditional power curves. The method only considers the effect of 10-minute averaging and not the direct influence of turbulence on rotor aerodynamics.

Keywords: Wind turbine power curve, Turbulence normalization, IEC 61400-12, lidar

1. Introduction

Wind turbine power curves are sensitive to site-specific conditions and are strictly speaking only valid for the conditions under which they are measured. In order to make the power curves supplied by the turbine manufacturers more universal applicable the effect of varying atmospheric conditions are studied. Turbulence intensity (TI) is one important inflow parameter which has been investigated in several studies [1–6].

The influence of turbulence on a standard power curve can be separated into two main components. First there is an effect of the standard 10 minute averaging of power and wind speed data. Considering the power curve as a transfer function between wind speed and power, the non-linearity of the power curve causes the produced power to depend on the variance of the wind speed as well as the mean. This imposes different effects on the different regions of the power curve shown in figure 1a depending on the second derivative. This is explained in more detail in [4]. In the lower part of the power curve where the power increases approximately following the cube of the wind speed, the power output increases with increasing TI, while in the transition region towards rated power the power decreases with increasing TI. This opposing influence on the different regions of the power curves implies that the net effect on energy production

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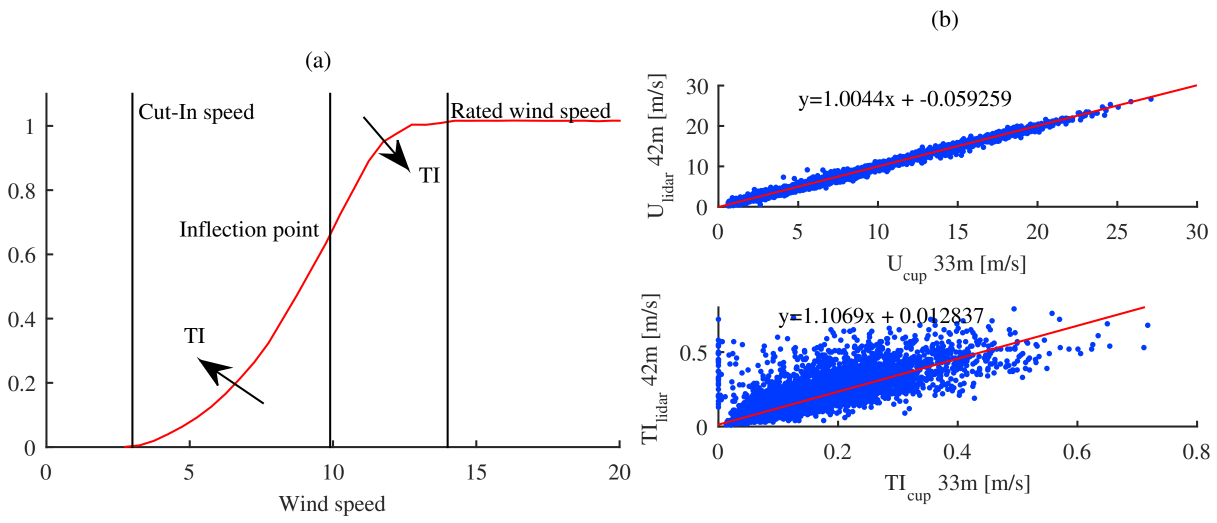

Fig. 1: (a) Schematic power curve (b) Correlation of lidar and mast mounted cup anemometer

is reduced. Tindal et al. [7] concludes that this cancelling behaviour makes the effect of turbulence on annual energy production (AEP) negligible for low and medium turbulence intensity sites. However this will largely depend on the wind speed distribution at the site and the rated wind speed of the wind turbine. A draft of the revised IEC 61400-12-1 standard for performance measurements of wind turbines [8] includes a turbulence normalization method for power curves which should reduce the time-averaging influence on the power curve. The basic idea behind the method is to derive a theoretical zero-turbulence power curve from the measured power, average wind speed and wind speed variance by assuming a Gaussian wind speed distribution in the 10-minute period as proposed by Albers et al. [5]. The method was described in detail and tested by Clifton and Wagner [1] using simulated data, and they found the method to overcompensate when adjusting the power output to different turbulence conditions.

The new standard will also include a possibility to use lidar measurements in conjunction with a short met mast for performance testing of large wind turbines. With the introduction of lidar technology the wind speed can be measured remotely from the ground at heights well above wind turbine hub heights. However the measurement principle involves both temporal and spatial averaging and homogeneous and stationary flow is therefore assumed for horizontal wind speed measurements. 10-minute average values from flat terrain show good agreement with traditional mast mounted cup anemometers [9], while lidar turbulence measurements involve higher uncertainty. Measurements from the Fino1 offshore mast show systematic overestimation of energy in the high frequency range of the spectrum [10]. Measurements and theoretical modelling by Sathe et al. [11] suggests an overestimation of horizontal variance for unstable atmospheric conditions and an underestimation for stable conditions for measurements using a Windcube lidar. The accuracy of lidar TI estimates is claimed to be improved by the introduction of a vertical beam in the Windcube v2 [12], but precision is still low and caution should be exercised when evaluating turbulence measured by a lidar. Because of the large volume averaging involved in the measurement principle, a lidar can not resolve the smaller scales of turbulence.

2. Measurements

2.1. *Valsneset test site*

Measurements were performed at a wind turbine test site on the coast of Mid-Norway. At the site there is currently a small wind farm consisting of five 2,3 MW wind turbines and a 3 MW pilot test turbine. The measurement sector was restricted to a 212 degree sector including both offshore and mixed fetch following the guidelines of Annex A in [8]. The surrounding terrain and resulting measurement sector is shown in figure 2. The upstream fetch in the