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# Improvement of power curve measurement with lidar wind speed profiles

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## Introduction

Power performance measurement is central to the wind industry since it forms the basis for the power production warranty of the wind turbine. For that reason it should be independent of the wind characteristics. A wind turbine power performance measurement consists of measuring simultaneous wind speed in front of the turbine and power output of the turbine. Ten minutes averages of these parameters are used to generate the power curve (power as a function of the wind speed) and the power coefficient ( $C_p$ , the ratio between the turbine power output and the kinetic energy flux).

The IEC 61400-12-1 standard for wind turbine power performance measurement [1] only requires measurements of the wind speed at hub height and the air density (derived from temperature and pressure measurements) to characterise the wind field surrounding the wind turbine. However it has been shown that other wind characteristics such as the variation of the wind speed with altitude (wind speed shear) and the fast variation of wind speed around the 10 minutes mean wind speed (turbulence) can also influence the power performance of a large turbine [2]. A few studies, focusing on the effect of the wind speed shear, showed that the power production decreased with increasing shear, [3], [4]. The assumption that the profile is constant over the rotor swept area (so that the wind speed at hub height is representative for the whole area) leads to inconsistencies in power curve measurements, [5] and [6]. It is therefore important to characterize the wind speed profile in front of the swept rotor area. As a simple extrapolation from below to above hub height may result in an erroneous estimation of the kinetic energy, it is preferable to actually measure the wind speed over the entire rotor disc. In this paper, we describe an experiment in which wind speed profiles were measured in front of a multi-megawatt turbine using a lidar. Those measurements were used to apply the equivalent wind speed method suggested in [7].

## 2 Measurements

The measurements were made in Risø DTU's Test Site for Large Wind Turbines in western Denmark in February/March 2009. A Windcube lidar [8,9,10] was installed in front of a multi-megawatt turbine measuring the wind speed at 9 heights within the swept rotor area range of heights.

## 3 Effect of the shear on power performance measurement

Firstly, the measured profiles were sorted into to groups according to their shape: on one hand the profiles with a shape close to a power law profile and on the other hand, the profiles very different from the power law. This was achieved by first fitting the 9 wind speeds constituting each profile to a power law function, so obtaining the shear exponent most representative of the profile. Then the profiles were grouped according to the residual sum of squares quantifying the goodness of fit.

These two groups of profiles resulted in different power and Cp curves (see figures a and b). This was shown to be due to the fact that the speed shear was ignored, ie the wind speed profile was assumed to be constant with a speed equal to the hub height wind speed. In the dataset analysed here, this assumption mainly results in an underestimation of the wind kinetic energy flux. A better approximation of the kinetic energy flux can be obtained by taking the wind speed shear into account:  $KE_{prof} = \sum_i \frac{1}{2} \rho u_i^3 A_i$ .

#### 4 Equivalent wind speed

Secondly, following the equivalent wind speed method suggested in [7], we defined an equivalent wind speed based on the kinetic energy flux definition given above:  $U_{eq} = \left( \sum_i u_i^3 \frac{A_i}{A} \right)^{1/3}$ . This equivalent wind speed was calculated for each profile measured by the lidar. The power (and Cp) curves for the two groups of profiles obtained with the equivalent wind speed were this time very similar (see figures c and d).

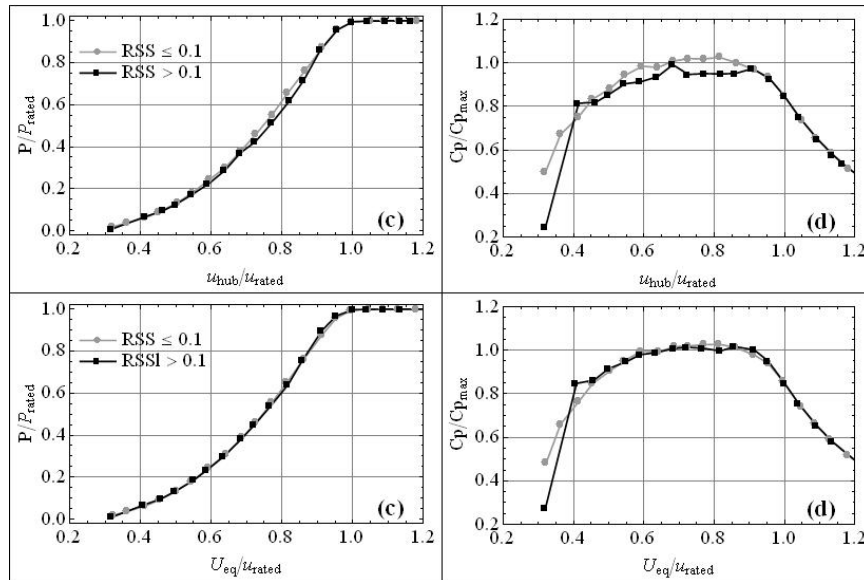


Figure 1 Gray: profiles with shape close to a power law profile, Black: Profiles different very different from a power law profile. (a): Power curve obtained with the wind speed at hub height; (b) Cp curves obtained with the wind speed at hub height; (c): Power curve obtained with the equivalent wind speed; (b) Cp curves obtained with the equivalent wind speed.

In a conventional power curve measurement the data would not be grouped according to the profile shape, but all the data would be considered together indifferently. The effect of assuming a constant wind speed over the whole swept rotor area in the kinetic energy flux estimation would then appear as a large scatter in the power and Cp curves. The use of the equivalent wind speed results in the reduction of this scatter and therefore contributes to reduce the uncertainty in power curve measurement.

#### 5 Conclusions

The wind speed shear has an influence on the measured power curve. What could be misinterpreted as an under-performance of the turbine was actually due to the fact the wind speed shear was ignored. Wind speed profiles possessing the same hub height wind speed but different kinetic energy fluxes likely give different power outputs. The equivalent wind speed method accounts for the wind speed shear in the power performance measurement. By applying this method to lidar profile measurements, we showed:

- The equivalent wind speed method enables us to reduce the scatter due to the speed shear;
- Therefore it reduces the type A uncertainty in the power curve.
- This definition of equivalent wind speed gives a more meaningful  $C_p$  than the single wind speed at hub height, therefore a better indication of the ability of the turbine to extract the energy actually available in the wind.
- Finally, a lidar can be successfully used to provide the profile information necessary for the equivalent wind speed method.

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