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Improved energy production estimates by accounting for the wind shear

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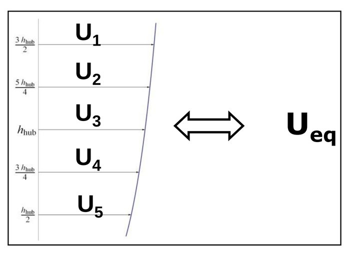
Motivation

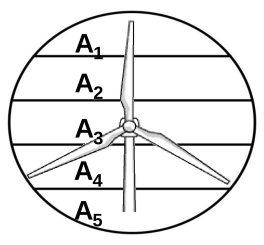
The estimation of the Annual Energy Production (AEP) estimate is obtained by combining the wind speed distribution measured at a proposed site with a wind turbine power curve, measured at the manufacturer's test site. Even if the wind speed is measured at (and below) hub height during the site assessment, the wind speed shear can significantly affect the AEP estimation, since the wind energy available actually depends on the kinetic energy contained in the whole wind speed profile. Given the large variation in speed profiles from one site to another and from one season to another, the kinetic energy estimated from the hub height wind speed is rarely truly representative of the total kinetic energy impinging the wind turbine.

Method and Objective

An equivalent wind speed concept has previously been introduced where the kinetic energy impinging the entire rotor disc is represented as a single, equivalent wind speed (ueq).



$$U_{KE} = \left(\frac{1}{A}\int_{-R}^{R} u(z)^3 c(z)\,dz\right)^{1/3} \approx \left(\sum_{i=1}^{N} u_i^3 \frac{A_i}{A}\right)^{1/3}$$



The use of this equivalent wind speed has been shown to improve the power curve measurements as it accounts for the variations of wind shear over the entire rotor disc. Clearly, this equivalent wind speed is a better representation of the available energy than the wind speed at hub height (uhub) when there is wind shear.

This method is now proposed in the revision of the IEC 61400-12-1, especially since wind speed profiles can now easily be measured over the whole rotor span of even large wind turbines by using lidars or sodars. Probably, in the foreseeable future, two power curves will be available for each wind turbine type: one traditional with the wind speed at hub height and one, independent of the shear, with the equivalent wind speed.

The novelty presented in this paper is the use the equivalent wind speed also in the site assessment.

Better AEP estimate

The wind speed profile has been measured in front of a wind turbine with a lidar. The dataset has been divided in two groups according to the shape of the wind speed profiles [2]. The two datasets resulted in two diffrent power curve due to the effect of the shear. The power curve from the first group was used to estimate the energy yield corresponding to the wind speeds of the second group. This was achieved first by considereing only the wind speed measured at hub height for each group (Figure 1, left) and secondely considering the equivalent wind speed (Figure 1. right).

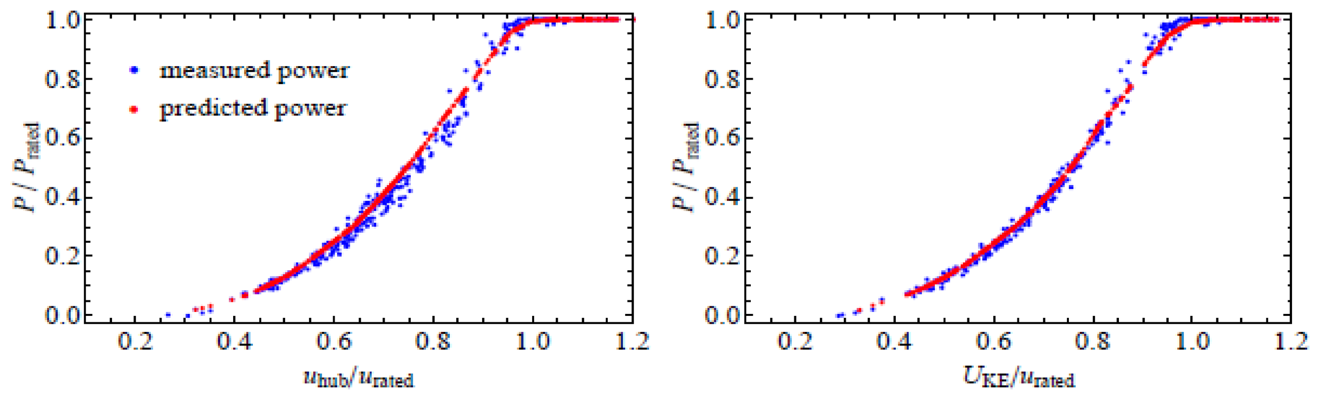


Figure 1 Predicted and measured power scatter plots for the data from group 2. with wind speed at hub height (left), with equivalent wind speed (right). Better agreement between prediction and measurements with the equivalent wind speed than with the wind speed at hub height.

	PC_{hub}	PC_{eq}
U_{hub} distribution	+1.76%	
U_{eq} distribution		0.005%

Table 1 Relative error in energy yield prediction. The wind speed at hub height results in an overestimation of the energy yield because the wind speed at hub height overestimated the kinetic energy flux of the wind speed profile during this power curve measurement.

Using the equivalent wind speed results in a much better energy estimate than the wind speed at hub height. However this requires to have measured the equivalent wind speed, therefore the wind speed profiles, both during the power curve measurement and the site assessment.

What if only the wind speed at hub height has been measured at the assessed site?

In the two following cases, both the wind speed at hub height and the equivalent wind speed was measured during the power curve, giving PC_{hub} and PC_{eq} resperctively, but only the wind speed at hub height (U_{hub}) was measured during the site assesssment. Is it then better, in terms on energy yield estimate, to combine the distribution of U_{hub} with PC_{eq} or to remain with the conventional combination of the distribution of U_{hub} with PChub? The answer depends on the wind speed profile distributions at the power curve site and at the assessed site, as shown with the two following test cases.

Case 1: the wind speed profiles are different at the two sites

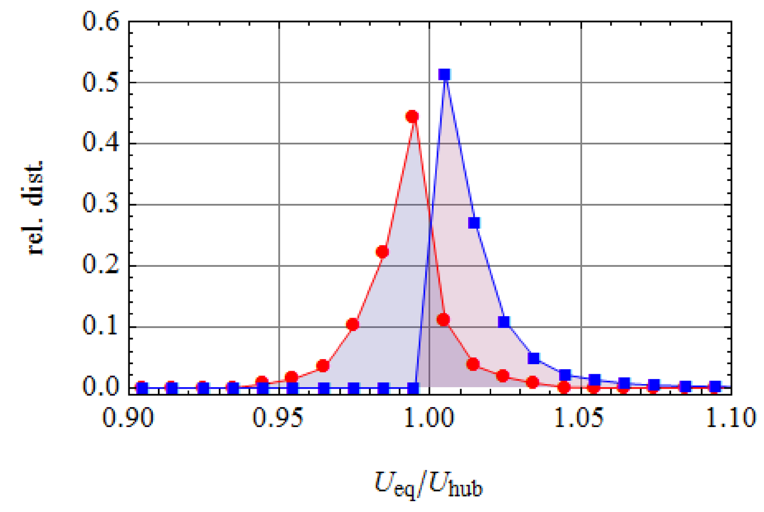


Figure 2 Distribution of U_{eq}/U_{hub} during the power curve measurement (red) and during the site assessment (blue). In this case, the kinetic energy flux of the profiles is overestimated by the wind speed at hub height during the power curve measurement while it is underestimated during the site assessment.

	PC_{hub}	PC_{eq}
U_{hub} distribution	-2.3%	-0.5%
U_{eq} distribution		ref

Table 2 Error in energy yield estimate relative to estimate obtained with the distribution of U_{eq} and PC_{eq} (ref). Using the power curve obtained with the equivalent wind speed (with U_{hub} distribution) results in a smaller error than using Pchub, since it accounts for the shear during the power curve measurement.

Case 2: the wind speed profiles are very simila,r on average, at the two sites

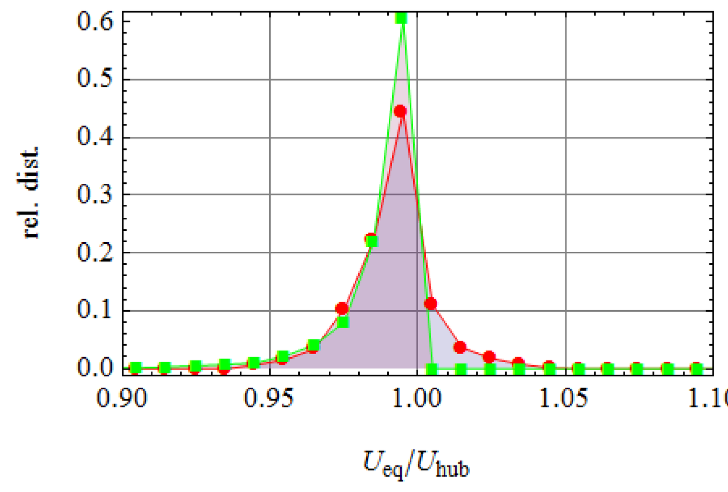


Figure 3 Distribution of U_{eq}/U_{hub} during the power curve measurement (red) and during the site assessment (green). In this case, the kinetic energy flux of the profiles is overestimated by the wind speed at hub height both during the power curve measurement and during the site assessment.

	PC_{hub}	PC_{eq}
U_{hub} distribution	-0.00%	+1.8%
U_{eq} distribution		ref

Table 3 Error in energy yield estimate relative to estimate obtained with the distribution of U_{eq} and PC_{eq} (ref). In this specific case, where the distributions of wind speed profiles must have been similar during th the power curve measurement an the site assessmnet, using PC_{hub} with U_{hub} distribution results in a smaller error than using PC_{eq}.

Conclusions

- It is necessary to measure the wind speed profile during the site assessment.
- Using the equivalent wind speed during the power curve measurement reduces the sensitivity of the power curve to the shear. Using the equivalent wind speed during the site assessement gives a better estimate of the available energy. Combining both results in a better AEP estimate.
- If only the wind speed at hub height has been measured during the site assessment, a better AEP estimate is obtained wth the standard power curve if the shear distcribution is similar at both sites; but a better AEP estimate is obtained with the equivalent wind speed power curve if the wind speed profile distributions at the two sites are very different.

References

1. Wagner R. et al., The influence of the wind speed profile on wind turbine performance measurement, Wind Energy 2009; 12:348--362.
2. Wagner R. et al., Accounting of for the wind speed shear in power performance measurement, Wind Energy 2011; 14:993—1004.

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