Abstract

Tall hub heights which reach 100 m and more pose a challenge for wind resource assessment: Conventional measurements seldom cover these heights and common industry flow models are technically not valid in those levels of the atmospheric boundary layer (ABL).

Theory

Tall hub heights reach into the so-called Ekman layer, where the common scaling assumptions of the surface layer are not valid anymore. With increasing height the flow will differ from the well-known relations of the surface layer. The demonstration of consequent modelling errors of common industry flow models and some immediate remedies conclude this analysis.

Measurements

Practical measurements of wind conditions at tall hub heights in different terrain:

<table>
<thead>
<tr>
<th>Sites in simple terrain</th>
<th>Site in complex terrain</th>
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<tbody>
<tr>
<td>Wind speed</td>
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<td>Wind shear</td>
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<td>Wind veer</td>
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Fig. 1: ABL with its characteristic diurnal features [1].

Fig. 2: Common power law fits tend to underestimate the wind speed at heights above 100 meter.

Fig. 3: Orogaphy induces low shear, so wind speed at high heights is overestimated with power law fit.

Fig. 4: Measurements show how the wind shear varies – and increases – over height.

Fig. 5: The shear decreases with height at this site, and the extent depends strongly on the wind direction.

Fig. 6: Variation of wind veer between top and lowest measurement height (average and max values).

Fig. 7: Wind vector plotted over height reveals the typical Ekman spiral for this 10-min sample.

Fig. 8: Six different model results compared to remote sensing measurements. The measured data has been filtered for neutral atmospheric conditions.

Fig. 9: CFD model results and analytical profiles according to [3] for two estimates of the ABL height. The measured data has been filtered for neutral atmospheric conditions.

Fig. 10: Vertical extrapolations based on lower measurement heights compared to actual measurements.

Fig. 11: Comparison of flow model setups (standard adopted for higher measurements).

Results from six different flow models compared to remote sensing measurements at a site in simple terrain demonstrate modelling errors (Fig. 8).

High measurements can serve as an immediate remedy:

In Fig. 10 it can be observed that measurements within the surface layer do not suffice for a reliable extrapolation to high hub heights. If conversely measurements up to or even above hub height are available, the uncertainty of model based vertical extrapolation for tall turbines can be reduced significantly.

Furthermore high measurements can help in a proper model setup. Fig. 11 shows a standard CFD model which roughly matches measurements below 80 m, but performs poorly above. Using available high measurements the model settings can be adjusted so to achieve satisfying results even above 100 m.

Conclusions

Tall hub heights reach into the Ekman layer, where the common scaling assumptions of the surface layer are not valid anymore. Attempts to describe the wind profile above the surface layer require meteorological parameters which are not available from standard mast measurements. Thus, assumptions have to be made which are hard to verify for practical cases. Depending on the site specific conditions, these facts may lead to (severely) false estimates of the wind conditions at tall hub heights.

When using flow models which have been validated well in the surface layer to estimate the wind conditions for tall hub heights, remote sensing measurements reaching heights above are essential in reducing extrapolation errors to acceptable levels. They can also aid in the model setup, thus achieving a better overall “model fit”.

High measurements are finally a prerequisite for developing and validating new parameterizations for ABL flow, specifically for areas above the surface layer.

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References


