Performance test of a 3MW wind turbine

-Effects of shear and turbulence

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Introduction

Reliable power performance measurements of wind turbines are important for estimation of annual energy production (AEP) for planned wind farms. The power curve of a given wind turbine should ideally be independent of local conditions at the test site. The current standard for power performance measurements of wind turbines, IEC 61400-12-1, is based on hub height wind speed and does hence not account for wind shear or veer[1]. Neither does it correct for turbulence intensity. The potential variations caused by these wind field parameters will increase with rotor diameter. The statistics of these parameters might be site specific and variations will increase the scatter of the power curve. The IEC standard is currently being revised to meet with these issues and remote sensing technology such as the wind lidar will be included for measurements of vertical shear and veer[2]. A definition of equivalent wind speed summing up the normal kinetic energy contributions from the rotor subdivided into horizontal segments is used:

$$U_{eq} = \sqrt[3]{\sum_{i=1}^{N} (U_i \cos \varphi_i)^3 \frac{A_i}{A}}$$

The purpose of this study is to indentify the influence of wind field parameters commonly experienced at a coastal site in Norway on the measured power curve of a 3MW wind turbine. Experiences with using a ground lidar for power performance measurements have also been gathered.

Measurements

Wind data from a Leosphere Windcube v2 ground lidar and net power output to the grid from a 3MW variable speed wind turbine was collected over a 10 month period from the turbine test site at Valsneset on the coast of Mid-Norway. The tested turbine has a hub height of 92 meters and a rotor diameter of 100,6 meters. The IEC 61400-12-1 standard [1] was used as a guideline for the measurement campaign. The lidar was installed on top of a container at a distance 3D and a direction of 290 degrees from the turbine. Meteorological data was also collected from a 33 meter high mast located 350 meters from the turbine. Prior to analysis the raw lidar data was filtered by wind direction from disturbed sectors and data availability. The quality criterion was a data availability ≥ 99% in each 10 minute interval for all heights.

Valsneset test site

The test site at Valsneset is located on the coastline of mid-Norway with mixed surrounding terrain as shown in Fig.1.

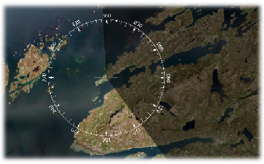

Fig. 1 Surrounding terrain of test site with valid test sector

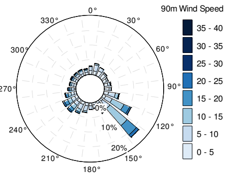

Fig. 2 Valsneset wind rose for hub height based on unfiltered lidar data

The sector from south-west via west to north-east has a sea fetch only disturbed by a group of flat islands 5-13 km west of the test site. Winds from this sector generally have low vertical shear, directional shear and turbulence. The south to east winds are influenced by a small mountain ridge rising 300 to 500 meters asl. giving turbulent, high shear winds. This is also the typical case for north-eastern winds having a mixed land and sea fetch.

Results

Lidar data availability proved to depend on wind direction on this coastal test site (Fig. 2). The highest availability is clearly found in the offshore sector, and corresponds to the valid test sector for the turbine (Fig. 1). This will be a more critical issue when a lidar is used for site assessment.

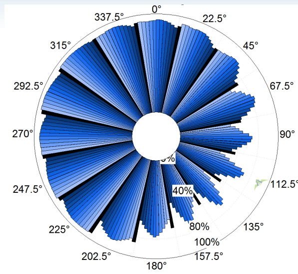

Fig. 3 Lidar data availability by wind direction

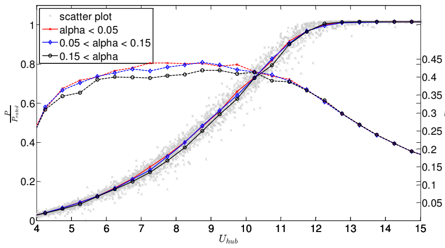

Fig. 4 Power curve and power coefficient binned by shear coefficient α

The influence from wind shear is identified as a reduction of power in the region around the inflection point of the power curve for increasing shear. This is also apparent using the equivalent wind speed.

Wind veer causes a partial yaw error over the rotor plane reducing power output in the entire partial load domain. Influence on AEP is relatively low, ~0,5%, and is marginally reduced by introducing U_{eq} considering only the normal component of the incoming wind vector.

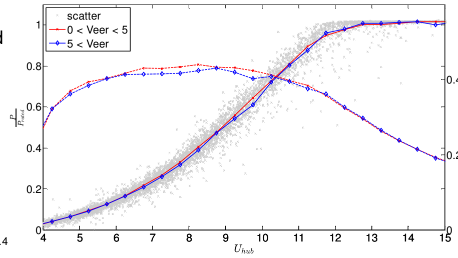

Fig. 5 Power curve and power coefficient binned by absolute veer

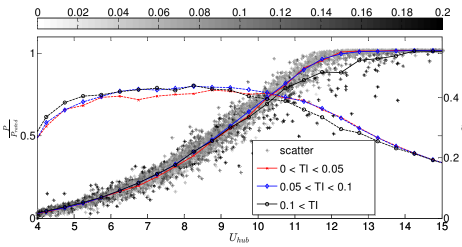

Fig. 6 Power curve and power coefficient binned by turbulence intensity

The influence of turbulence and 10-minute averaging on the power curve is more complex. High turbulence intensity (TI) increases power output below the inflection point and decreases power output above the inflection point , also above the rated wind speed.

Δ AEP (Annual Energy Production) is the percentage difference between the mean AEP from the complete dataset and the AEP calculated from the binned power curves. The highest deviations are found for high turbulence conditions (-2%) and low shear conditions (+1,1%).

Table 1 ΔAEP calculated from prower curves derived for the typical turbulence, shear and veer conditions experienced at Valsneset

	Turbulence intensity			Shear Coefficient (α)			Absolute veer [°]	
	0 - 0,05	0,05 - 0,1	> 0,1	0 - 0,05	0,05 - 0,15	> 0,15	0 - 5	> 5
ΔAEP_{eq}	-0,05 %	0,55 %	-1,99 %	1,16 %	0,73 %	-0,69 %	0,27 %	-0,45 %
ΔAEP_{hub}	-0,39 %	0,62 %	-2,00 %	1,10 %	0,58 %	-0,71 %	0,32 %	-0,52 %

Conclusion

○The power curves derived for different, commonly occurring wind shear, and turbulence conditions experienced at Valsneset influences the AEP of the 3MW wind turbine by up to 2% compared to the measured average AEP at the test site. The largest influence is found for low shear (α<0,05) and high turbulence conditions (TI<0,05).

○Using an equivalent wind speed definition instead of the hub height wind speed should in theory reduce the scatter and site dependency of the power curve and this is also reported in several studies [3, 4, 5]. In the Valsneset dataset it appears that other variables than wind shear are more responsible for the scatter, and introduction of the equivalent wind speed only gives a marginal convergence of the binned power curves.

○ Low lidar data availability at this site causes biased wind statistics and a prolonged data collection period.

References

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