KINETIC ENERGY FLUX MEASURED BY LIDAR AND ITS IMPACT ON WIND TURBINES POWER PERFORMANCE.

Antoine Bégué*, Beatriz Canadillas, Thomas Neumann, Harald Mellinghoff
DEWI GmbH – Deutsches Windenergie-Institut, Wilhelmshaven, Germany
*E-Mail address: A.Begue@dewi.de

Summary

In the scope of the RAVE (*Research at Alpha Ventus*) – LIDAR project, wind profile measurements from LIDAR (Leosphere - WindCube) are collected at the offshore platform FINO1. In the present work, some atmospheric parameters, such as the wind shear and the turbulence intensity, are investigated. The kinetic energy flux passing through the rotor area is also calculated by using LIDAR wind speed measurements at different heights. It is compared to the kinetic energy flux resulting only from the wind speed at hub height, as established in the IEC 61400-12-1 [1]. A new wind speed concept, the so-called "equivalent wind speed", is defined as proposed by Risø DTU [2]. This wind speed takes into account the wind shear and the turbulence intensity. Then, this study highlights the impact of the equivalent wind speed on the power performance calculation of the wind turbine M5000 from AREVA Wind GmbH for offshore atmospheric conditions. Finally, the power curves are also calculated for different wind shear classes in order to check the consistency of the defined equivalent wind speed.

1. Introduction

The LIDAR is a very promising tool for offshore wind energy applications. It is a good alternative to replace the classical met masts, in order to assess the power performance of offshore wind turbines. Besides its practical aspect, it also enables a better estimation of the kinetic energy flux passing through the rotor, and then a better definition of the representative wind speed used for the power curve.

In order to come to a more complete understanding of the wind a new definition of the wind speed named equivalent wind speed had been proposed by Risø DTU [2]. This approach is based on the caluclation of the kinetic energy flux considering several measuring points over the rotor area.

Within the framework RAVE – LIDAR, we had the opportunity to assess the power performance of the turbine M5000 in offshore conditions in combination with wind profile measurements gained with LIDAR (Leosphere - WindCube) over the full rotor height.

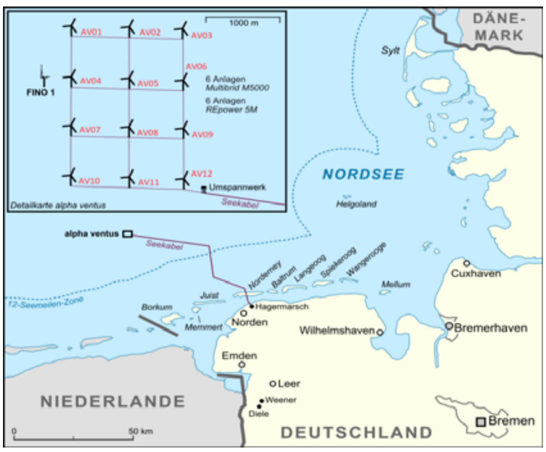

Fig. 1: Layout of Alpha Ventus.

2. Measurements: Experimental setup

The measurement campaign has been performed at the german offshore wind park Alpha-Ventus. The wind turbine AV07 of type M5000 has been assessed (see Fig. 2). The hub height is 91 m and the rotor diameter 116 m. The WindCube LIDAR is located on the research offshore platform FINO1 (see Fig. 3), which is about 870 m away from the wind turbine. This is exceeding the IEC 61400-12-1 requirements for the maximum distance Mast-WT [1]. The LIDAR is set up to measure at 6 heights over the rotor area: 71.5m, 81.5m, 91.5m, 101.5m, 121.5m and 141.5m (above LAT). The LIDAR measurements were continuously collected and checked by DEWI [3].

Fig. 2: Assessed wind turbine of type M5000 at the Alpha-Ventus offshore wind farm.

The lowest available measurement is already at 71.5 m, because the location of the WindCube is 23 m above the sea level and for technical reasons the lowest measuring height is 40 m above the device. Therefore, the cup anemometer measurement at 33.5 m (lower blade tip height of the AV07) from the FINO1 met mast has also been used.

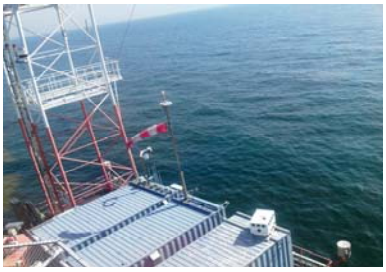

Fig. 3: Location of the LIDAR on the offshore platform FINO1.

The measurement campaign extends from December 2009 to April 2010 and covers a period of about 600 hours.

3. Equivalent wind speed

According to IEC 61400-12-1, the wind speed at hub height is supposed to be representative of the whole rotor area. Given the bigger and bigger size of rotors, this assumption becomes unsufficient. Thus, a new wind speed definition was introduced called equivalent wind speed [2]:

$$P_{wind,eq\_KE\_turb} = \frac{1}{2}.\rho.\sum_i \langle U_i \rangle^3.(1+3.TI_{hub}{}^2).A_i$$

$$V_{eq} = \left(\frac{2.P_{eq}}{\rho.A_{total}} \right)^{\frac{1}{3}}$$

This wind speed is based on the estimation of the kinetic energy flux crossing the rotor swept area. It aims at defining a wind speed, for which a flat profile without shear would give the same energy flux as the real measured profile. This definition considers several wind speed measurements from the LIDAR at different heights over the rotor area. It also takes into account the turbulence intensity at hub height in each 10min sample.

4. Wind profiles

The LIDAR measurements enable to observe all the wind profiles during the measurement campaign. The mean turbulence intensity is calculated from the LIDAR measured turbulence intensity at hub height. The wind shear exponent is estimated by fitting the LIDAR measurements with a power-law profile. During the offsore measurement campaign the mean turbulence intensity was 5.9% and the mean wind shear 0.095.

The mean kinetic energy fluxes during the campaign $\langle P_{hub} \rangle$ (based on a single point measurement at hub height) and $\langle P_{eq\_KE\_turb} \rangle$ can be compared in order to estimate the deviation caused by the IEC simplifications.

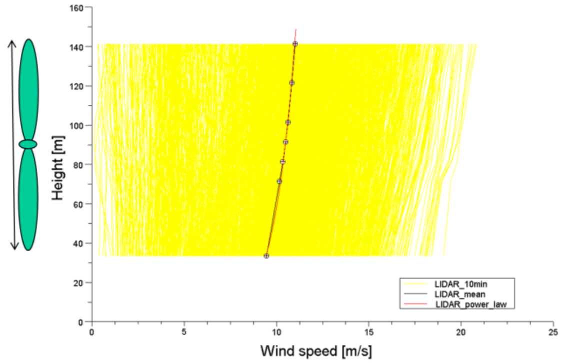

Fig. 4: 10 min and mean wind profiles during the whole offshore measurement campaign.

The offshore site is characterized by a mostly neutral atmospheric boundary layer; it means low turbulence intensity and a low shear exponent. In this case, the deviation between $\langle P_{hub} \rangle$ and $\langle P_{eq\_KE\_turb} \rangle$ is really a small one (0.3 % more for $\langle P_{hub} \rangle$). Similar results have been calculated from *Large Eddy Simulations* under offshore conditions, where the atmospheric boundary layer was mostly neutral [4].

5. Power curves

The power curve is calculated with 2 different methods. At first, the classical power curve according to IEC 61400-12-1 is assessed, using a single LIDAR wind speed measurement at hub height. It is then compared with the power curve based on the equivalent wind speed.
The effect of the equivalent wind speed on the offshore power curve is negligible (see Fig. 5).

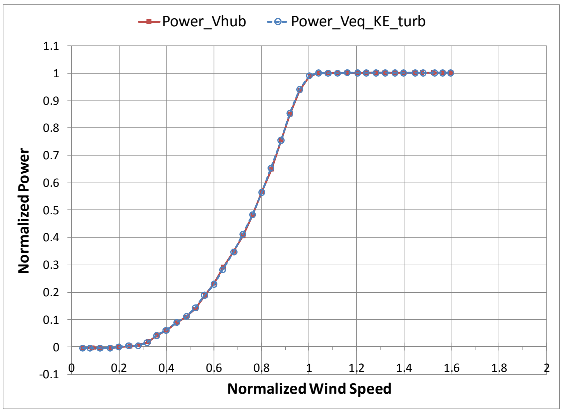

Fig. 5: Power curves using V_{hub} (red line) and $V_{eq\_KE\_turb}$ (blue line).

It can be concluded that In this case, for this offshore atmospheric conditions, a single point measurement at hub height is sufficient to represent the full rotor area.

6. Influence of the wind shear on the power curves

6.1 Shear classes

In order to investigate if the wind shear still have an influence on the power curves in offshore conditions, the whole database has been divided into 2 classes according to the wind shear exponent:

- Low wind shear: $|\alpha|<0.079$ (median value)
- High wind shear: $|\alpha|\geq 0.079$

Then, the power curves have been calculated and compared for the both databases

6.2 Power curves using V_{hub}

The difference between the power curves using V_{hub} for low and high wind shear is not negligible (see Fig. 6), especially in the partial load domain, which is of high importance for the annual energy yield assessment.

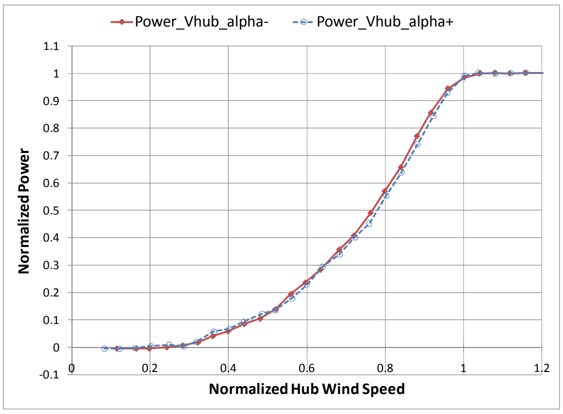

Fig. 6: Power curves using V_{hub} for $|\alpha|<0.079$ (red line) and $|\alpha|\geq 0.079$ (blue line).

6.3 Power curves using $V_{eq\_KE\_turb}$

The deviation between the both power curves are strongly reduced when the equivalent wind speed is used (see Fig. 7).

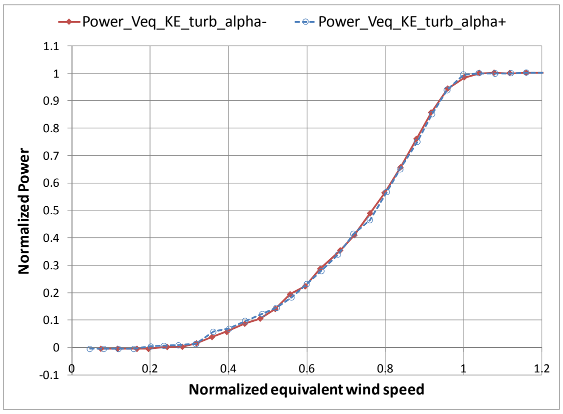

Fig. 7: Power curves using $V_{eq\_KE\_turb}$ for $|\alpha|<0.079$ (red line) and $|\alpha|\geq 0.079$ (blue line).

It means that the observed differences in the power curves based on V_{hub} are mainly due to an unsufficient description of the kinetic energy flux on the rotor and do not originate from different performances of the turbine at the first place.

7. Conclusion

The differences in the power curves using V_{hub} and $V_{eq\_KE\_turb}$ are rather small for this offshore campaign. These results suggest that the use of a single point measurement at hub height would be sufficient in offshore conditions to represent the whole rotor area. Thus, offshore power curves should be better comparable and less influenced by the location.

However, it has also been shown that outstanding wind shear conditions can still occur offshore and have an impact on measured power curves. But the differences in the calculated power curves using V_{hub} for different shear classes are reduced when the equivalent wind speed methodology is used. Therefore, considerations of wind profiles are still of importance in offshore conditions.

Since the effect does not primarily relate to the turbine model, it should be checked if it can be observed for other offshore turbines and sites as well. This requires measurement programs with the use of remote sensing technologies comparable to the setup of the RAVE experiment.

Acknowledgements

We would like to thank the Project Management Jülich (PTJ), the project coordinator Fraunhofer IWES, and our project partners for the measurement campaigns: the Endowed Chair of Wind Energy (SWE), University of Stuttgart, the joint Center for Wind Energy Research of the University of Oldenburg (ForWind) and AREVA Wind GmbH.

This work has been carried out within the joint research project RAVE (Research at Alpha Ventus), RAVE-LIDAR work package [5]. It is funded by the German Environment Ministry.

References

[1] IEC 61400-12-1 Ed.1: Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines, December 2005.

[2] Antoniou, I. and al.: Influence of the wind characteristics on the turbine performance. In Proc. EWEC, Milan (Italy), 2007.

[3] A. Westerhellweg, A. Beeken, T. Neumann, B. Cañadillas, DEWI GmbH: One Year of Lidar Measurements at FINO1-Platform: Comparison and Verification to Met-Mast Data and a View to the Vertical Wind Profile above the Mast. DEWEK2010, Bremen (Germany).

[4] B. Cañadillas, T. Neumann, DEWI GmbH: Uncertainties in Wind Power Measurements Under Offshore Conditions. A Large Eddy Simulation Study. DEWEK2010, Bremen (Germany).

[5] Rettenmeier, A., et al. „Development of LiDAR measurements for the German Offshore Test Site.“ 14th International Symposium for the Advancement of Boundary Layer Remote Sensing.