Offshore Power Curve Tests for Onshore Costs:

A Real World Case Study

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1 SUMMARY:

Testing the power performance of offshore wind turbines reduces project risk by establishing the compliance of those turbines with the power curves used when deriving pre-construction estimates of production. In addition, power curve tests can provide useful diagnostic information when undertaking preventative or reliability centred maintenance to minimise the downtime of offshore wind turbines.

The key impediment to offshore power curve tests has been the cost. Hitherto, it has been necessary to install an expensive offshore met mast to obtain the measurements necessary to characterise the incident wind resource with which the observed power production of the test turbine is compared.

The ability to install scanning lidar on the access walkway of the transition piece of an offshore wind farm provides a valuable opportunity to make highly cost-effective measurements. The lidar can be used to implement scan geometries that allow wind data to be acquired at hub height 2.5 rotor diameters upwind of the test turbine as recommended by the standard for power performance assessment of wind turbines, IEC 61400-12-1 [1].

The resulting cost of the power curve test is less than 1% of the cost of the equivalent met mast based test

1 INTRODUCTION

There is a need to make it easier to undertake power performance assessments of offshore wind turbines. This will allow more frequent compliance tests which in turn will contribute to a reduction in the risk that offshore wind power projects represent. Currently power performance assessments are most often undertaken using offshore met masts in accordance with [1]. Installation of a suitable met mast represents a significant cost, of the order of €10M, which can deter organisations from undertaking these tests. There is need for a significant reduction in the cost of offshore power curve tests so that these can be undertaken routinely during commissioning and subsequent operation on orders of magnitude more offshore wind turbines than is currently the case to secure a reduction in project risk.

The availability of lidar systems has provided new measurement opportunities which offer the possibility of lower cost power performance assessments (power curve tests). This has been acknowledged by the industry and the power curve test standard is currently being revised to include guidance for the use of lidars when conducting these tests [2]. This guidance restricts the use of lidar and “only ground based remote sensing devices are used (e.g. nacelle mountings are not included)”. The only locations that fulfil this requirement offshore are a fixed platform and the access walkway on the transition piece of the offshore turbine whose power curve is being tested. Given the need to reduce costs, the installation of a fixed platform may represent a prohibitive expense and the only remaining candidate location that corresponds sufficiently to ground based operations is the transition piece. The remaining deviation from [2] which requires suitable mitigation in the test procedure is the absence of a short met mast for *in situ* monitoring. The impact of this deviation on uncertainty must be assessed and documented in accordance with [1] and [2].

Figure 1: Alpha Ventus Offshore Wind Farm Wind Turbine #7 with scanning lidars installed

The cost of using lidar on the transition piece to perform a power curve test in the way described in this document is less than €100k, i.e. less than %1 of the cost of using a met mast. In addition this method has other advantages. The measurements made from the transition piece (as opposed to measurements from the nacelle) are fixed in the reference frame of the wind turbine array, i.e. adjacent wind turbines represent lidar fixed beam orientations with respect to the lidar. Therefore the lidar can also acquire wind inflow measurements suitable for testing adjacent assets as well as the asset on which it is installed. The viability of this is demonstrated below in Section 3 where the accuracy of the wind speed measurements obtained using the lidar installed on the test turbine is verified by measuring the wind at the location of the power performance reference mast for an adjacent asset. This capability will allow further cost reduction with respect to power curve tests. An additional advantage is the ability to measure wind shear from the transition piece, using an inclined beam as shown below in Section 2. This is more difficult from the nacelle where the nacelle itself represents an obstruction for the measurements. Wind shear measurements allow the adoption of the rotor equivalent wind speed methods described in [2].

Three Galion G4000 Offshore wind lidars were installed on Wind Turbine AV07 in Alpha Ventus Offshore Wind Farm on 18th February 2013. Two were installed on the nacelle and one on the transition piece, as shown in Figure 1. A detailed programme of research was undertaken over the course of over a year of successful data acquisition. One task achieved using the device on the transition piece was the demonstration of the power curve methodology described below in Section 2.

2 CAMPAIGN DESIGN

One of the tasks scheduled for the transition piece mounted lidar was the measurement of the wind turbine power curve using the scan geometry indicated below in Figure 2 and Figure 3 to acquire data characterising the incident wind resource.

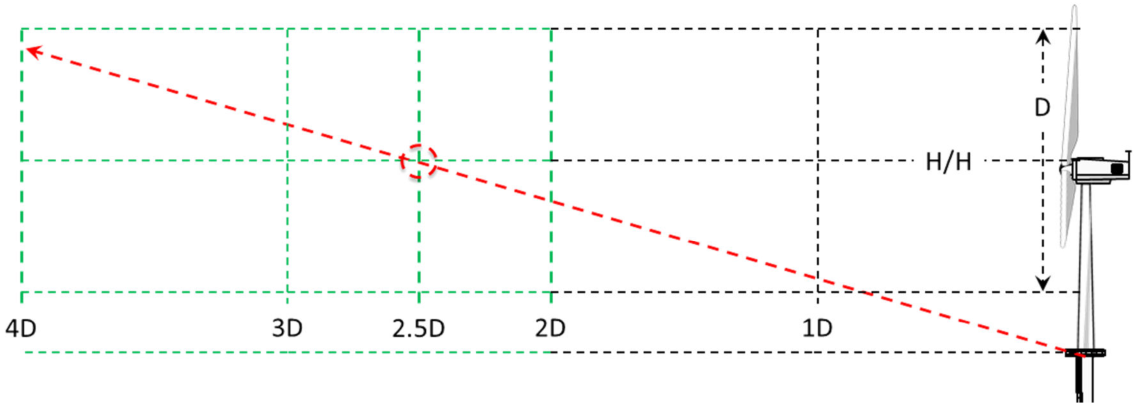

Figure 2: Side elevation of schematic arc scan geometry

The elevation angle of the beam was fixed so that the measurements at hub height corresponded to a distance upwind of the test turbine in the selected free stream wind direction sector of 2.5 rotor diameters, in accordance with the recommendations of [1]. This is shown in Figure 2. A schematic plan view of the scan geometry is shown in Figure 3. This shows that the beam is swept through a range of azimuth angles. This allows the variation in the radial wind velocity vector component along the line of sight to be observed, and this is fitted to a sinusoid in a manner identical to the wind data extraction algorithm adopted in VAD scans (Velocity Azimuth Display). As a consequence, wind speed and direction at hub height 2.5 rotor diameters upwind of the test turbine are measured as required by [1]. The azimuthal excursion used in practice for these measurements ranged from 180° to 340° in 20° increments, corresponding to free stream inflow.

The Galion G4000 Offshore wind lidar installed to undertake these measurements is shown in Figure 4. These methods have been described previously in [3] and [4]. The procedure is described in [5].

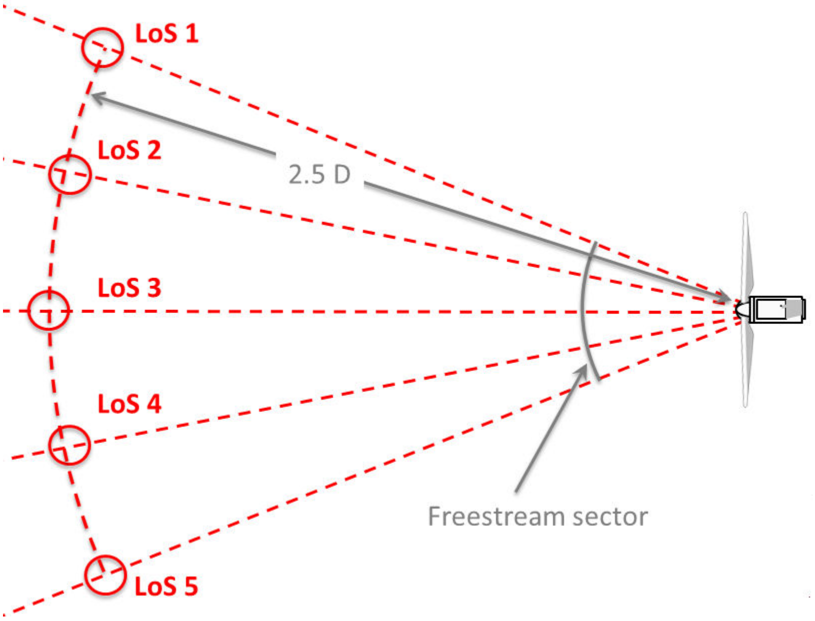

Figure 3: Plan view of schematic arc scan geometry

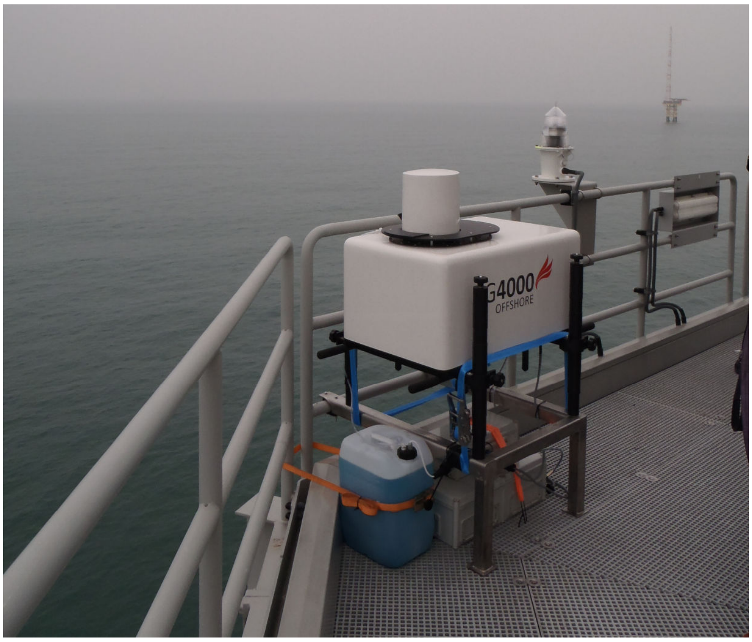

Figure 4: Galion G4000 Offshore scanning wind lidar installed on the transition piece access walkway on Alpha Ventus Offshore Wind Farm Wind Turbine AV07

Arc scan measurements are part of the standard lidar acceptance test that SgurrEnergy applies to every Galion at the Carrot Moor Test Facility south of Glasgow, Scotland, where comparison is made with the measurements obtained using an 80m IEC compliant met mast. In addition the technique has been used on multiple occasions in fully commercial applications and research projects over a number of years both onshore and offshore. As such, a significant degree of experience, expertise and confidence in this method has been developed over hundreds of measurement campaigns around the world. Indeed, arc scan techniques have been of interest for wind measurements for many years [6].

3 LIDAR PERFORMANCE VERIFICATION

It is essential when undertaking wind speed measurements using the methods described above to verify the accuracy of those methods under the circumstances in which they are used. This was achieved in this instance by comparing the lidar measurements with the measurements made using a conventional met mast. The FINO1 met mast was available as a suitable reference. The location of FINO1 relative to AV07 is shown in Figure 5. The met mast is approximately 900m away from the lidar.

The scan geometries adopted to acquire wind speed measurements using the lidar in the met mast location for comparison with the measurements obtained by the reference met mast are shown in Figure 5 and Figure 6. These shown the plan view and side elevation of the scan geometry respectively. The probe volumes in which the radial velocity measurements were made from which the wind speeds were derived are shown in green. The excursion in azimuth angle was only 30°.

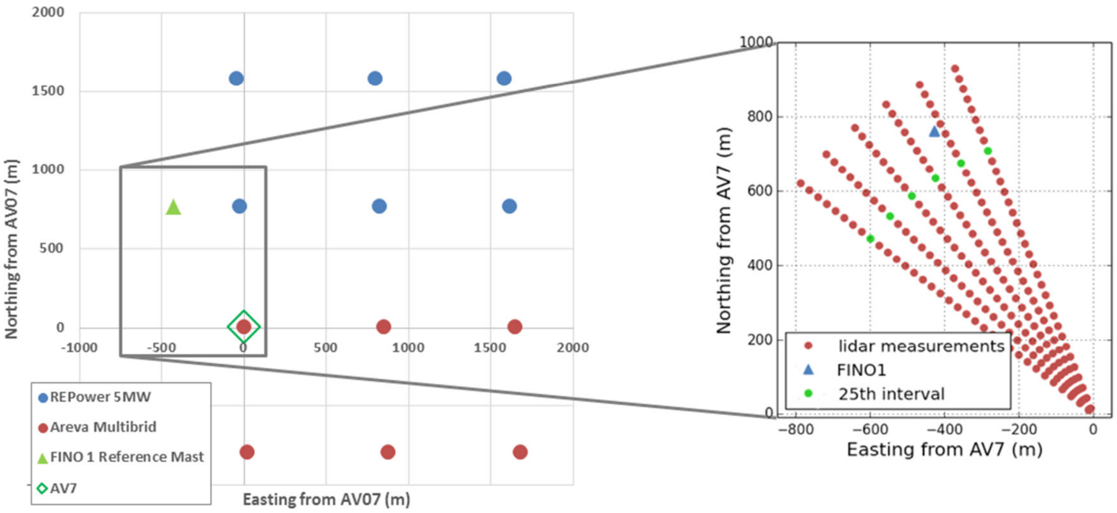

Figure 5: Plan view of scan geometry used for comparison with the FINO1 met mast. The probe volumes used for the wind speed measurement are shown in green

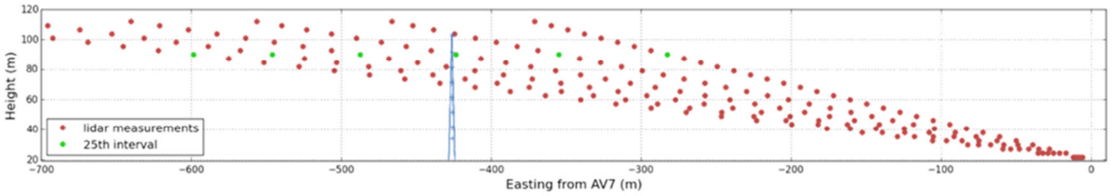

Figure 6: Side elevation of scan geometry used for comparison with the FINO1 met mast

The wind directions that were accepted on the basis that the wind in the measurement volume would not be perturbed by wind turbine wakes and that the reference met mast wind speed measurements would be relatively unaffected by mast effects are shown in Figure 7.

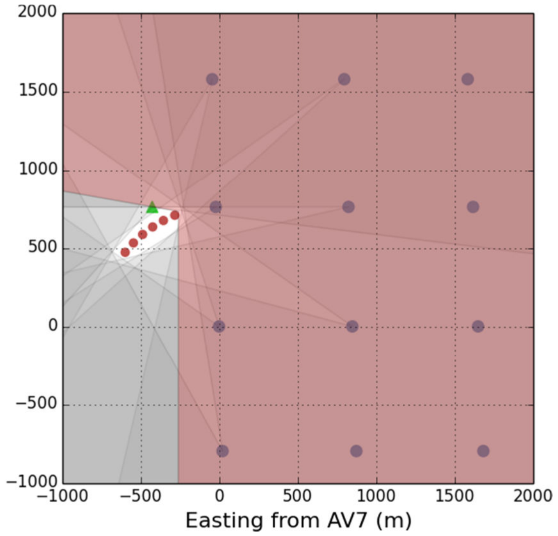

Figure 7: Direction sector selected for comparison, in which wind is unperturbed by wakes and reference mast measurements are relatively unaffected by mast effects

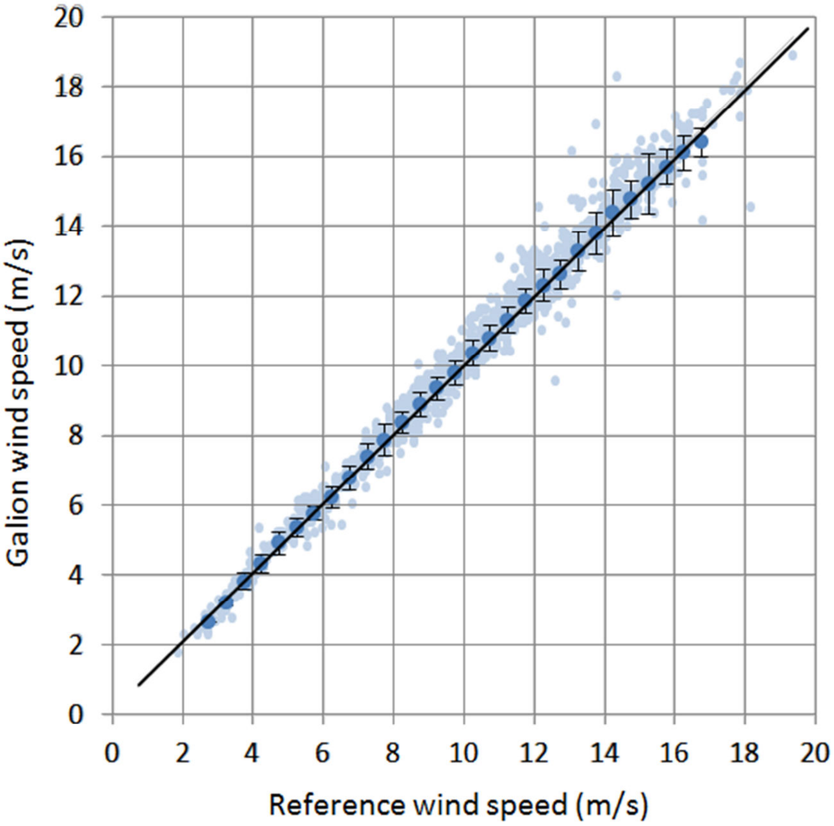

Figure 8: Comparison of lidar and met mast measurements

The Galion arc scan measurement methodology was verified against the FINO1 reference mast approximately 900m from AV07. The results shown in Figure 8 exhibit excellent agreement, consistent with onshore tests, with both correlation coefficient *R^2* and regression slope *m* exceeding conventional 0.98% acceptance criteria. These results are consistent with the performance of the device observed during onshore tests prior to installation offshore on AV07. These onshore results were independently verified [7]. That study concluded that the technique “may be recommended […] for a power performance assessment offshore with the Galion Lidar installed on the transition piece of the test turbine”.

4 RESULTS

The power curve for AV07 obtained using the wind speed and direction measurements acquired using the lidar on the transition piece is shown in Figure 9.

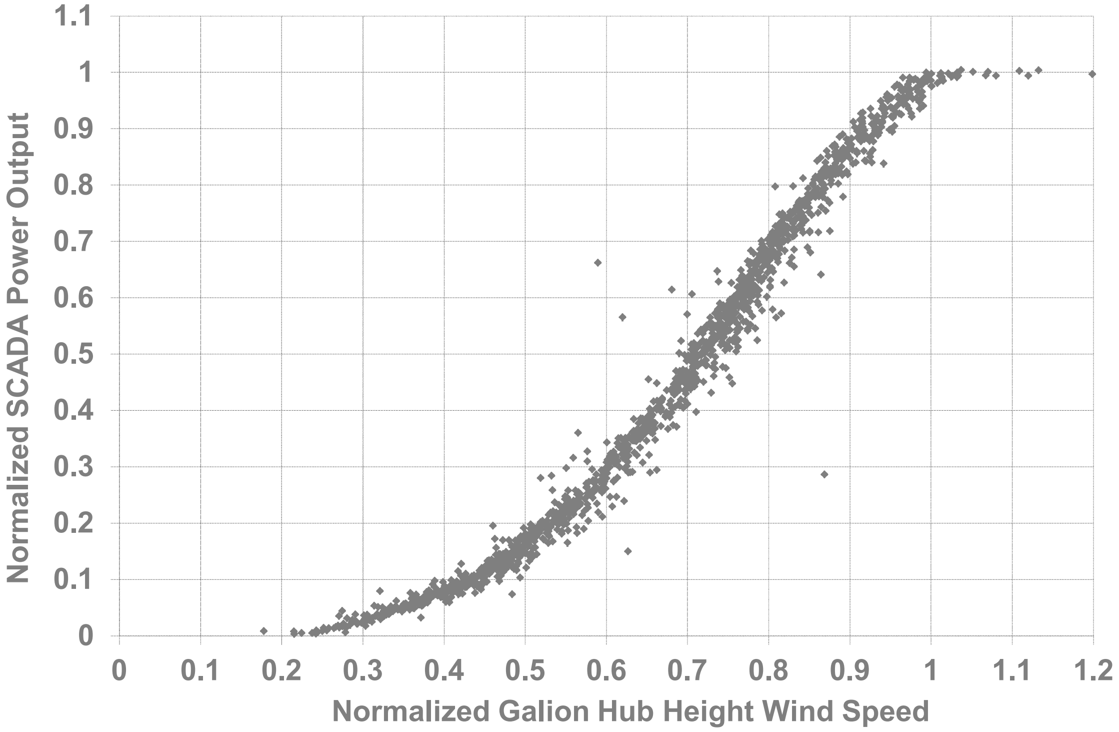

Figure 9: Power curve measured using lidar wind speed data

The results exhibited lower scatter than power curves obtained using the nacelle cup anemometry or the nearby FINO1 reference met mast. This means that of the available power curve test methods (using nacelle mounted cup anemometry, the nearby FINO1 met mast, and the lidar on the transition piece) the lidar method resulted in the lowest category A uncertainties. The corresponding power curves obtained using nacelle mounted cup anemometry and the nearby FINO1 met mast are shown in Figure 10 and Figure 11 respectively. The reference uncertainty that using the lidar entails can be obtained with reference to the result of the performance verification tests that have been undertaken both onshore and offshore.

The power curve obtained using the lidar was compared to the power curve obtained using the FINO1 measurements during the same period. This is shown in Figure 12. The power curves obtained using the wind speed as measured by the Galion and the wind speed as measured by the nearby reference mast FINO1 both show excellent agreement with each other, within the uncertainty of the met mast measurements. The difference in the AEP estimates obtained using each power curve in accordance with [1] is less that 0.5%.

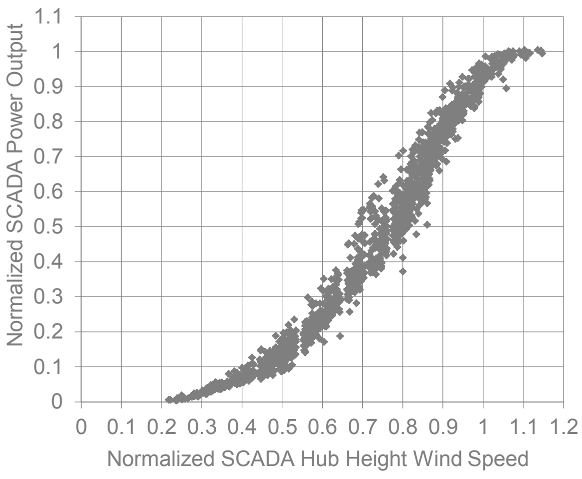

Figure 10: Nacelle cup anemometry power curve

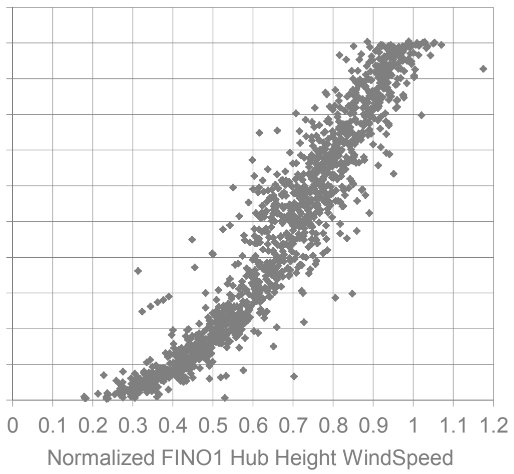

Figure 11: Met mast power curve

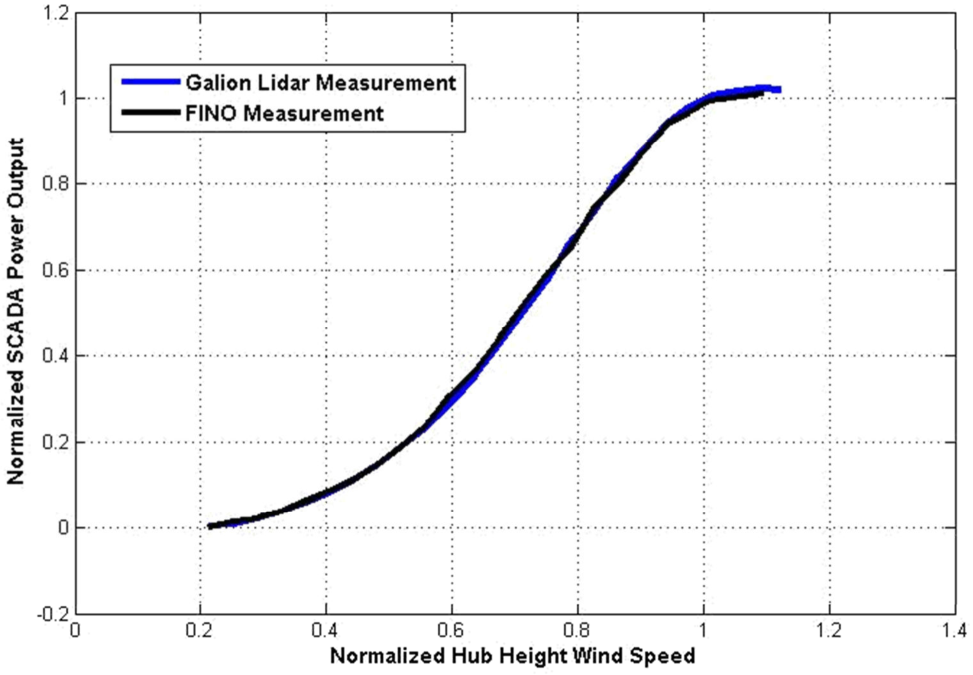

Figure 12: Comparison of power curves obtained using lidar and met mast wind speed data

Directions to other wind turbines in the array are constant in the reference frame of the measurements made by the lidar on the transition piece, but change with wind direction in the reference frame of a lidar installed on the nacelle. Therefore transition piece mounting allows the power curve tests of multiple offshore turbines during a single test campaign. This is illustrated in Figure 13. The viability of this technique, which will further reduce the cost of individual power curve tests, is confirmed by the verification test reported above, which compared measurements made using a device on the transition piece of one turbine (AV07) with the power performance assessment mast (FINO1) for an adjacent turbine (AV04).

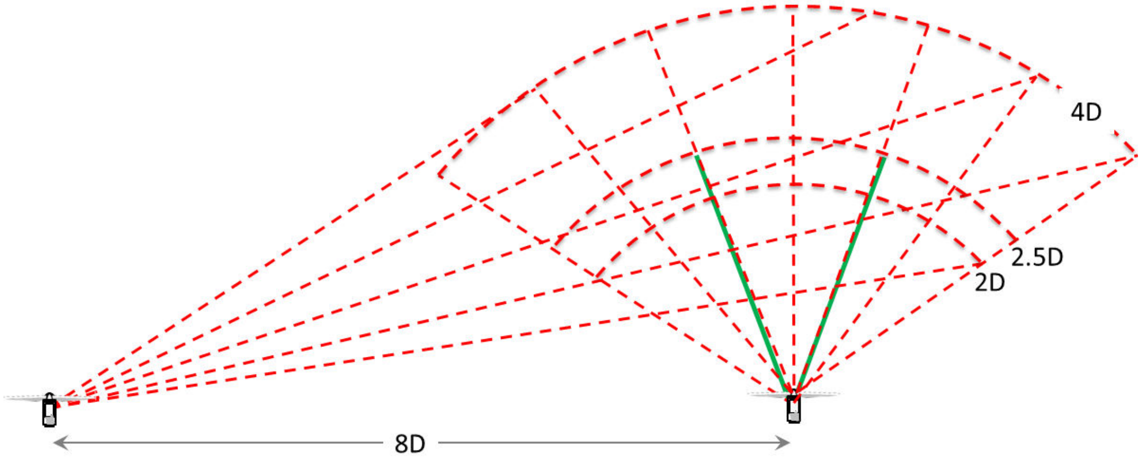

Figure 13: Power curve test of one offshore wind turbine from the transition piece of another

5 CONCLUSIONS

It is seen that transition piece mounted lidar acquires the wind speed data needed to undertake power curve tests offshore.

The transition piece is in effect "ground based", so guidance, standards and recommendations for ground based lidar can be used to support confidence in the results, such as the draft 2nd edition of the power curve test standard IEC 61400-12-1 [2]. This is not possible for nacelle mounted lidar which is explicitly excluded from the scope of this standard.

The costs of this technique, compared to met masts based techniques, are so low (less than 1%) that power curve tests offshore should become routine and be undertaken for purposes beyond the confirmation that warranted performance levels are achieved. For example, ongoing operations and maintenance efforts can benefit from scheduling an inexpensive power curve test on this basis. It is possible to track devaitions in the performance of wind turbines over their lifetime. Many more turbines can be tested than are currently tested.

6 ACKNOWLEDGEMENTS

The poster accompanying this paper won a EWEA 2014 Poster Award

7 REFERENCES

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