Concurrent Power Performance Measurements

Using an IEC mast, a Profiling Lidar, and a 4-beam Nacelle Lidar

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Abstract

AWS Truepower, a UL Company have developed and deployed a multi-sensor measurement program to accelerate the commercial application of lidar in wind turbine power performance measurement.

The significant cost, timing, and logistical requirements of conducting wind turbine power performance measurement according to the current IEC standards have fostered the development of alternate tools and methods. The technical efficacy of nascent techniques and sensors, including application of profiling and nacelle-mounted systems, have been demonstrated in a variety of environments; however, the public library of direct comparisons with traditional measurement technologies – upon which commercial acceptance is partly based – is still relatively limited.

This measurement campaign is uniquely scoped to characterize a single turbine's power curve using concurrent observations from multiple sensor platforms and analysis procedures. A new multi-megawatt turbine, installed at a simple terrain site in the Midwest USA, has been subject to power performance measurements according to the current IEC 61400-12-1 standards with a hub-height mast. The measurement site was also equipped with a Windcube V2 profiling lidar a commercial 4-beam Wind Iris nacelle-mounted lidar. This poster presents a summary of the project and initial results.

Test configuration

Site Characteristics

- Simple site in Midwest of US; Turbine passed IEC-compliant commercial test
- Valid IEC sectors reduced 15° to prevent nacelle lidar beam from measuring wakes of nearby turbines
- Data collection from October 16 – December 8, 2017; 2230 data points

Site Instrumentation

- IEC-compliant Met Tower
  - 80 m top sensor height, goal post
  - 3.8 RD from turbine
- Ground-based Profiling Lidar
  - Windcube V2 adjacent to Met Tower
  - Primary analysis on 80 m range gate
- Nacelle-based Lidar
  - 4-beam Wind Iris,
  - 1.5, 2.5, 3.6 RD gates @ 80 m
- Turbine
  - IEC-compliant power monitoring
  - SCADA power, wind & status

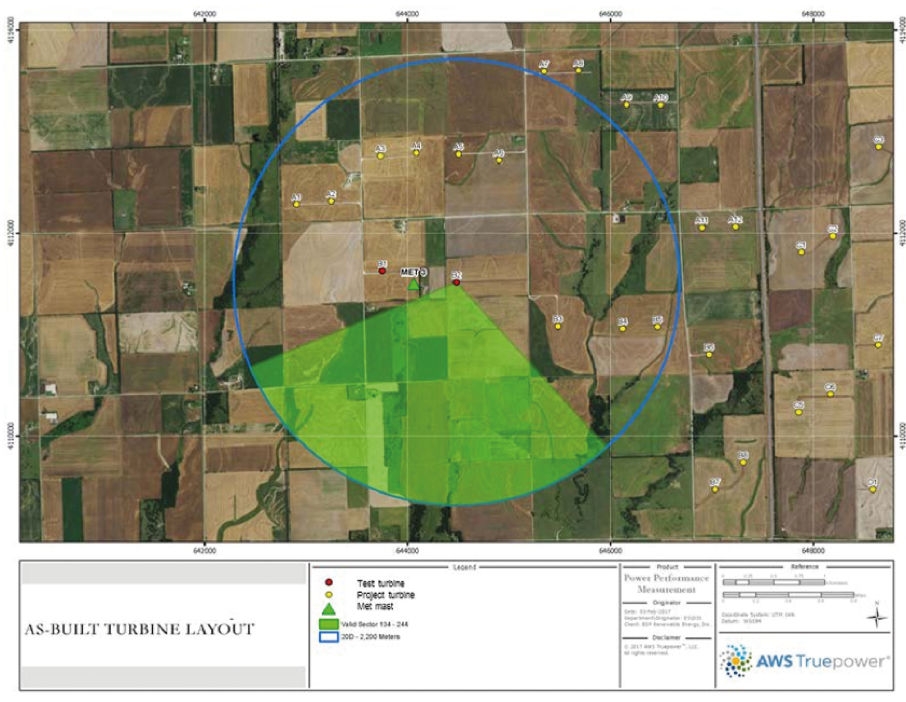

Figure 1: Site Map illustrating test turbine and valid IEC measurement sectors

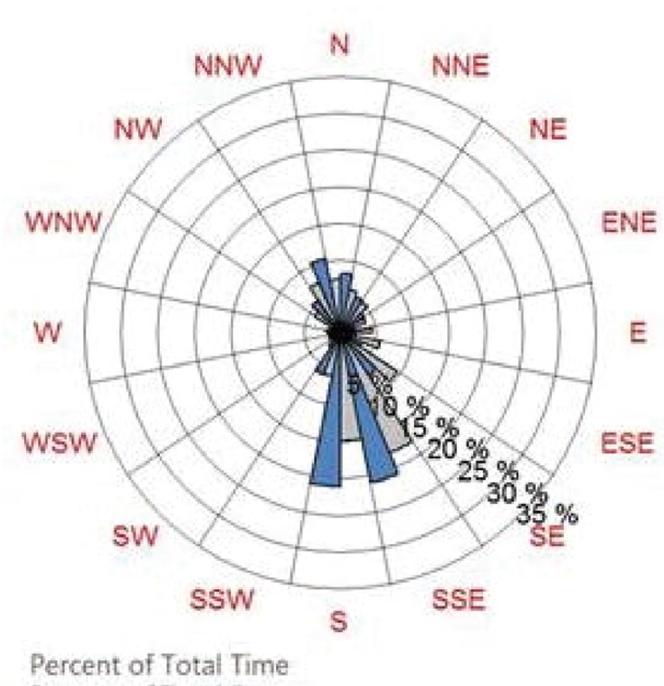

Figure 2: Site Wind Rose


Figure 3: View of IEC compliant met tower and Windcube V2 profiling lidar

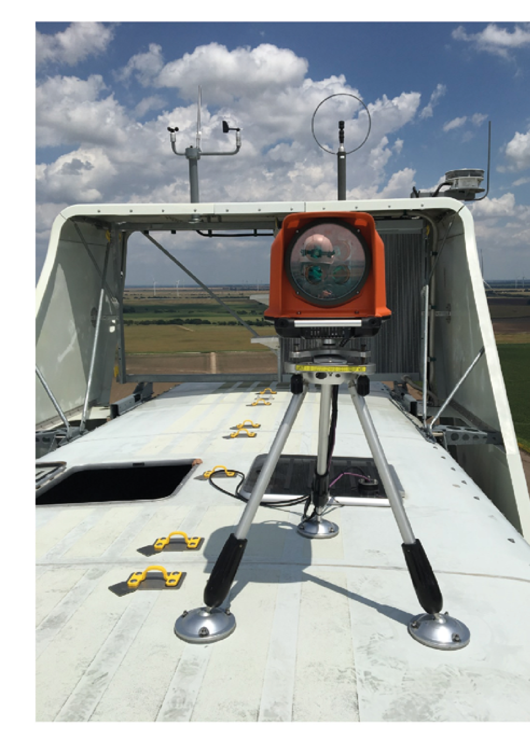
Figure 4: View of Wind Iris 4 beam lidar installed on the Project turbine

Results – Measurement Comparison

Primary Parameter Comparisons

- Primary wind parameters evaluated: wind speed & wind direction
- Lidar and tower wind speeds agree very well (Table 1)
- Single variable correlations also very good: Slope = 0.999 to 1.006; R^2 = 0.980 to 0.999
- Wind direction agreement excellent across all systems

Table 1: Campaign Average Wind Speed Comparison (density corrected)	Met Tower (3.8 RD)	Profiling LiDAR (3.8 RD)	Nacelle LiDAR (1.5 RD)	Nacelle LiDAR (2.5 RD)	Nacelle Cup
Average Speed (m/s)	9.42	9.49	9.40	9.43	9.82
Diff. from Met Tower (m/s)		0.07	-0.02	0.01	0.39
Diff. from Met Tower (%)		0.7	-0.2	0.1	4.2

Secondary Parameter Comparison

- Secondary parameters evaluated: Shear & Turbulence intensity (TI)
- Parameters commonly employed for commercial power curve test filtering or binning of results
- Wind Shear exponents agree very well between monitoring systems (Table 2)
- TI subject to further examination; unadjusted lidar values trended more conservative (i.e. higher) than anemometer values

Table 2: Power Law Wind Shear Comparison		**Mean Shear (α)**	**Day Shear (α)**	**Night Shear (α)**	**Monitoring heights**
Below hub height	Met Tower	0.327	0.183	0.461	80m & 53m
	Profiling LiDAR	0.324	0.175	0.460	80m & 53m
Across hub height	Profiling LiDAR	0.300	0.170	0.423	110m & 53m
	Nacelle LiDAR 2.5RD	0.287	0.160	0.410	~106m & 59m

Results - Power Curve Comparison

- Overall, lidar power curves agree very well with met tower (Table 3)
- Both profiling lidar and nacelle lidar power curve results had less scatter / lower standard deviations than that measured by the met tower

Table 3: Campaign AEP Comparison	**Met Tower AEP [MWh]**	**Measured AEP [MWh]**	**AEP Difference [%]**
Met Tower	10,557	10,557	**-**
Profiling LiDAR	10,557	10,402	**98.5**
Nacelle LiDAR 1.5RD	10,557	10,688	**101.2**
Nacelle LiDAR 2.5RD	10,557	10,572	**100.1**
Nacelle Cup	10,557	10,134	**96.0**

Conclusions and Next Steps

Based upon these results, AWS Truepower had the following conclusions:

- Nacelle and profiling lidar measurements provided accurate characterizations of a turbine power curve relative to concurrent IEC-compliant mast measurements.
- The results show good agreement between the met tower, the profiling lidar, and the nacelle lidar in terms of wind speed and direction measurements.
- The initial findings of this work present compelling technical and commercial cases to consider lidar for power curve testing in simple terrain.

Next Steps:

- Additional analyses on uncertainty, turbulence intensity, different turbine models, and wind climates.
- Engagement with various project stakeholders – developers, OEMs, and banks – to get input and facilitate commercial application of lidar power curve testing.

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