October 2017

Minutes
of the IEA Wind Task 32 Workshop #6 on

Power Performance Measurement Using Nacelle Lidars

Date: 27th September 2017
Venue: DONG Energy, Gentofte (5 km North of Copenhagen), Denmark
Workshop leader: Rozenn Wagner (DTU)
Minutes by Rozenn Wagner, Nicolai Gayle Nygaard, David Schlipf

Agenda

8:45	**Registration**
9:00	**Introduction** Welcome to DONG Energy – Nicolai G. Nygaard – DONG Energy Purpose of the workshop and agenda – Rozenn Wagner – DTU Wind Energy Presentation round
9:30 to 12:00	**Nacelle lidar calibration & measurement uncertainty estimation**
9:30	**Presentations** Nacelle lidar calibration – how we do it at DTU Wind Energy (Antoine Borraccino) Calibration of Nacelle-based LiDAR systems – Best practice at DNV GL (Jens Riechert) Nacelle lidar calibration - best practice at ECN (Jan Willem Wagenaar) Nacelle lidar calibration - best practice at COWI (Flemming Langhans) Flyweel calibration of lidars (Mike Courtney - DTU)
10:45	**Break**
11:00	**Group discussions** Systems that have been calibrated and/or have a procedure Common practices and differences in nacelle lidar calibration; what are the main barriers in nacelle lidar calibration identified by the industry? What (critical) points need to be addressed in a standard (e.g. IEC -50-3)? What are the proposed solutions?
11:45	**Groups discussions conclusions** Presentation of posters and short plenum discussion
12:15	**Lunch Break**
13:15 – 16:15	**Nacelle lidar applied to power curve measurement**
13:15	**Presentations** • Performance verification using a nacelle mounted LIDAR: The perspective of SGRE (Ioannis Antoniou - Siemens) • Nacelle lidar power curves – Challenges Ahead (Nicolai G. Nygaard - DONG Energy)

	• Nacelle lidar for power perf. – the UniTTe approach to retrieve V∞(A. Borraccino - DTU) • Assessment of nacelle lidar measurements in the induction zone for power performance assessment (Samuel Davoust - GE) • Power Curve measurement On floating wind turbines (Bruno Declercq – Engie Lab)
14:15	Break
14:30	**Presentations by nacelle lidar manufacturers** • Some challenges when using nacelle lidars for power curve measurements (Chris Slinger - ZephIR) • Retrieving wind speed at constant height above ground level in complex terrain with a 4-beam nacelle Lidar(Paul Mazoyer - Avent) • IEC compliant Power Performance Measurement with Nine-beam Nacelle Lidar (Shumpei Kameyama - Mitsubishi Electric)
15:30	**Group discussions** What are the main barriers in using nacelle lidars for power performance measurements? What (critical) points need to be addressed in a standard (e.g. IEC -50-3)? What are the proposed solutions?
16:15	**Groups discussions conclusions** Presentation of posters and short plenum discussion
16:45	**Conclusion of the day**
17:00	**End of Workshop**
18:30	**Dinner in Copenhagen**

Minutes

9:00	**Start of workshop – Introductions**

- Welcome and Safety information from Nicolai
- Overview from Rozenn Wagner
- Participants' introductions
  - Combination of lidar manufacturers, consultants, and data users.
  - General interest in knowing how to get the best information from lidar measurements
  - Would like to see best practices and community consensus documents
- Thanks to DONG Energy for hosting the workshop!

9:45	**Nacelle lidar calibration & measurement uncertainty estimation** **Presentations**

- Antoine Borraccino (DTU Wind Energy)
  - White-box calibration is a well-proven method (calibrate all inputs to wind field reconstruction model)
  - DTU set-up: lidar on the ground, reference instruments at 8.9m a.g.l., only one mast (compare one LOS at a time)
  - Available for different types of commercial systems (results shown for Avent 5 Beam Demonstrator and ZephIR Dual Mode)
  - Consider the binned fit as the calibration outcome

- Barriers:
  - Better reference anemometers
  - Propagation of lidar V_los uncertainty to reconstructed wind field characteristics
  - Shorter calibration procedure
- Jens Riechert (DNV GL)
  - Calibration from DTU can be adapted with adjustments (results shown for ZephIR Dual Mode and Wind Iris 4 Beam)
  - Presentation of Janneby site
  - DNV GL set up: nacelle lidar on a platform at 30 m a.g.l., reference cup anemometer at 30 m a.g.l., 2 reference masts (can compare 2 LOS simultaneously)
  - Uncertainty assessment under development – main challenge: deriving uncertainty for relevant ouput parameters (e.g. HWS)
  - Many clients prefer a simpler black-box calibration
  - Barriers:
    - Further development of uncertainty assessment procedures
    - Define reliability and data quality related KPIs and Acceptance Criteria for maturity judgement and repeatability
    - Quantify benefits of the white-box vs. black-box approach
- Jan Willem Wagenaar (ECN)
  - ECN set up: lidar on the ground and reference cup anemometer at 23.3m a.g.l (boom mounted), only one mast (compare one LOS at a time)
  - Compared white-box and black-box approach (sequentially) with the same 2-Beam Wind iris unit → white-box LOS wind speed compared better to the reference wind speed than the black-box horizontal wind speed (lower R^2).
  - White box approach similar to DTU and DNV GL
  - Uncertainty assessment following recommendations of IEC 61400-12-1 Ed.2, Annex L, regarding calibration uncertainty of ground-based lidars.
  - Barrier:
    - White box approach is different from black box approach commonly used for ground based lidar calibration
    - White box approach should be further detailed and standardized.
- Flemming Langhans (COWI)
  - Presented Tårs calibration site
  - COWI set up: lidar on the ground and reference cup anemometers at 20 m a.g.l., 2 reference masts (can compare 2 LOS simultaneously), and up to 3 lidars simultaneously
  - Adapted DTU approach
  - Compared to guidelines for uncertainty assessment: DTU 2013 and another anonymous one which, showing the terms and their relative contribution to the lidar LOS speed measurement uncertainty were not the same.
  - Barriers:
    - Use another reference than the cup (or sonic) anemometer (Measnet criteria of +/-1% is too weak)
    - Improve the accuracy of the beam position relative to cup
    - Use higher masts (less sensitive to height differences between cup and Lidar beam)
    - There is a need for harmonization (a standard) for uncertainty estimation

- Mike Courtney (DTU)
  - Calibration of short range cw lidar with a fly wheel
  - Alternative to cup anemometer
  - Controlled reference speed, LOS wind speed calibration only takes a few hours
  - Barriers:
    - The LOS speed estimator may not provide the same results for a distribution of LOS speeds as in turbulence air as for a unique LOS speed as provided by the wheel.
    - Not completely clear whether such a method could be applied to pulsed lidar as well (never tested). This would make different calibration approach for different types of lidars.

11:45	**Group discussion: what are the main barriers in nacelle lidar calibration identified by the industry?** **What (critical) points need to be addressed in a standard (e.g. IEC -50-3)?** **What are the proposed solutions?**

Outcome from the 3 groups:

- Barriers:
  - Time duration of multi-beam lidars with the White-Box calibration approach.
    - ➔ It could be mitigated with alternative approach like calibration with a golden lidar or using a flywheel or a moving belt instead of the cup anemometer as reference or using pipe wind tunnels for each LOS or with a lab-based method.
  - Large uncertainty of cup used as reference in current calibration methods
    - ➔ It could be mitigated by using alternatives to cup anemometer for the reference wind speed (see above)
  - Gap between LOS speed and horizontal speed uncertainties (in whitebox calibration approach)
    - ➔ The standard could have pragmatic WFR model with uncertainty to capture physical uncertainty of model
  - Lack of experience to assess the required frequency of calibration
  - Lidar transportation (more fragile than cups)
    - ➔ could the calibration be carried out by the manufacturer at the factory?
  - Lack of nacelle lidar classification, need more studies, understanding of sensitivities
  - Need common understanding of uncertainties and consensus
    - ➔ need more discussion and collaboration (meetings, workshops)
  - Calibration is performed in flat terrain, how is it applied for complex terrain measurements?

- Critical points for the IEC 50-3 standard:
  - Different lidars
  - Common calibration missing
  - Ensure repeatability of the calibration
  - The standard should clearly define the calibration,
  - But should also allow for technology evolution
    - ➔ General scientific calibration (described the requirements without specifying the lidar design)
  - Standard should allow for cup anemometer free calibration, should be flexible to evolving calibration techniques

- Clarify link to other standards in terms of e.g. power curve verification, wind field reconstruction, controls.
- Need to include an uncertainty for nacelle lidar motion

- Message brought to PT61400-50-3:

The new standard needs to:

- address the gap between LOS speed and horizontal speed uncertainties in white-box calibration approach
- Remain open to reference instruments alternative to cup anemometer (define measurement requirements and not required instruments)
- Propose a clear recommendation on the calibration uncertainty assessment
- Clarify what should be included in the nacelle lidar classification/operational uncertainties
- Give a recommendation regarding the frequency of calibration

13:15	**Nacelle lidar applied to power curve measurement** **Presentations**

- Ioannis Antoniou, Siemens
  - Nacelle lidars present obvious benefits over met mast: faster and flexible deployment, lower cost, can also be used to detect yaw misalignment
  - Already used offshore and in flat terrain, some tests in semi-complex terrain showed promising results
  - Barriers:
    - Limited measurement range of nacelle lidars compared to coming turbine rotor diameters
    - Lidars price too high
    - Lidars weight and size should be downscaled to make easier deployment
- Nicolai G. Nygaard, DONG Energy
  - Problem of induction zone: 2.5D is not in the free wind yet (not far enough)
  - Whose responsibility is it to account for this: developer of turbine OEM?
  - What do we want warrantied:
    - Actual site conditions and free stream wind speed
    - Or Restricted conditions at a fixed upstream distance, but then need to model AEP correction
  - Barriers:
    - Limited measurement range of nacelle lidars compared to coming turbine rotor diameters
    - At long ranges: De-correlation due to time lag and Inhomogeneity as beam separation grows
- Antoine Borraccino, DTU
  - One possible solution to issues related to large measurement ranges (>300m) – see above – is to use shorter range measurement with model fitting reconstruction
  - Presented combined wind induction model (UniTTe & PhD projects)
  - Results with 5 beam Avent demonstrator and ZephIR Dual Mode show promising results (within 1% of top mounted cup anemometer)

  - Barriers:
    - Need recommendations/guidelines on wind characteristics reconstruction methods
    - Application of REWS with this approach has not been implemented nor tested yet
    - Application in complex terrain
    - Mounting: could turbine manufacturers integrate brackets in the nacelle design?
- Samuel Davoust, GE Research
  - investigation of nacelle lidar measurements in the induction zone (shorter range)
  - used a wind-induction model similar to A. Borraccino (DTU)
  - results for a 4-Beam Wind Iris in flat terrain
  - Encouraging results (reconstructed wind speed at 2.5D at hub height compare well to mast mounted cup), maybe except at low wind speeds
  - Promising and generic technique
  - Barriers:
    - The turbine considered in this analysis belongs to a row a turbines – this may affect the induction (not accounted for in wind-induction model)
    - Not sure the fitting solution is unique
- Bruno Declercq, Engie Lab
  - Two floating wind farm projects under development (Portugal and South France)
  - Nacelle lidar seems to be the only possibility of floating turbine power performance testing
  - The challenge is to separate the turbine performance from the floater performance (tilt, roll and yaw)
  - For a floating turbine it is more important to separate the inner/outer ranges
  - IEC 61400-50-3 should include the possibility to test floating turbines

14:30	Presentations by nacelle lidar manufacturers

- Chris Slinger (ZephIR Lidar)
  - Some challenges when using nacelle lidars for power curve measurements:
    - Economical (time, cost) and precise (low uncertainty) calibration techniques
    - Deployment
    - Terrain effects
    - Data selection
    - Long ranges, as turbine rotors continue to increase in diameter
    - Lack of nacelle lidar guidelines/standards to help inform ourselves and clients of best practice
    - Match lidar to turbine model to avoid beam clipping and interference with nacelle anemometry

- Paul Mazoyer (Leosphere/Avent)
  - Retrieving wind speed at constant height above ground level in complex terrain with a Wind Iris 4-beam nacelle Lidar
  - When measuring exactly at the same height, 2-beam Wind Iris reconstructed wind speed compares well with anemometers, Wind flow associated with complex terrain are slightly inhomogeneous, it does not seem to impact the accuracy
  - Different with 4-beam Wind Iris: need indicate at which height the speed has to be evaluated
  - This depends on the ground elevation and therefore on the wind sector.

- Comparison to mast from two campaigns in complex terrain show small deviations
- The wind flow over complex terrain seems not to prevent good measurement -> only valid to a certain extend!

- Hirokazu Kawabata (AIST) -> Shumpei Kameyama (Mitsubishi Electric) introduced on behalf of him
  - Presentation of Nine-beam Nacelle Lidar
  - Comparison of wind speed reconstructed from 2 external middle beams and central beam → good
  - Possibility to measure wind speed at 3 heights, shear and REWS

15:30	**Group discussions** **What are the main barriers in using nacelle lidars for power performance measurements?** **What (critical) points need to be addressed in a standard (e.g. IEC -50-3)?** **What are the proposed solutions?**

Outcome from the 3 groups:

- Lack of standard
  - ➔ Should provide clear guidance in required wind field quantities, heights and frequencies, distances, etc
  - ➔ Most of those are probably already provided by application standards (12-1, 13, 15, …)
- Scope of IEC -50-3 is not clear (re-organisation of standards and scope of IEC -50-3 should be clarified in kick off meeting (4-6 oct 2017)
- Standard must be technology agnostic but still provide minimum requirement on the turbine lidar technology
  - ➔ Should change the name from “nacelle mounted lidar” to “turbine mounted lidar” which would then include lidars mounted in the spinner, on the hub or on the blade - but is it really the same (same requirements/recommendations)
  - ➔ IEC -50-3 should allow possible future nacelle lidar configurations
  - ➔ It could specify the lidar requirements (e.g. aspect of sampling frequency but independent horizontal measurements?)
- Homogeneous flow violated in complex terrain
  - ➔ Short range measurement can reduce the terrain uncertainty
  - ➔ Adopt different approaches depending on terrain complexity (similar to what is done now with met mast measurements); when can homogenous flow assumption be used?
  - ➔ Should the standard focus on offshore application (for now)?
- Mounting criteria/Integration with turbines
  - ➔ lidar should not disturb anemometer
  - ➔ need standard mounting place on nacelle (need help from turbine manufacturers)
- Range limitations, capabilities to measure up to 2.5D
  - ➔ This will implicitly be required by the application if we follow the current standards requirements (-12-1, 15, 13, …)
- Lack of common flow model
- Need measurements of TI and shear – to which accuracy? (defined in -12-1?)

- Quantification of uncertainty of wind field characteristics
- Lack of experience and confidence in technology
    - ➔ Need more case studies
    - ➔ Could provide example datasets with standard
- Pressure, Temperature and humidity measurements need to be addressed in the standard as well
    - ➔ It can probably be adapted from existing IEC-12-2
- Need a standard procedure for alignment of lidar on nacelle (e.g. a reference in the nacelle)
- Price of lidars

Messages brought to PT61400-50-3:

- Clarifications are needed on
    - the re-organisation of the 61400-12-1 and -12-2 document and place of -50-3 in this organization (what should be the content of this new measurement standard).
    - the application to be addressed by this standard (power curve measurement)
    - whether this standard (first version) will address the application in complex terrain or not.

- The new standard needs to:
    - define what is included in the term "Nacelle mounted" lidars (is spinner lidar included as well?)
    - provide lidar performance requirements instead of design requirements in order to be technology agnostic.
    - Provide some mounting requirements/recommendations
    - provide recommendation regarding the measurements or temperature pressure and humidity (without mast)

Participant List

Name	Country	Institution
Adrian How	UK	SSE
Andrew Henderson	UK	DONG Energy
Antoine Borraccino	Denmark	DTU Wind Energy
Apostolos Tentolouris Piperas	Denmark	DONG Energy
Beatriz Cañadillas	Germany	DEWI
Bernd Meyerer	Germany	Opticsense
Bruno Declercq	Belgium	Engie Lab
Chris Slinger	UK	ZephIR Lidar
Christophe Lepaysan	France	Epsiline
Christos Tsouknidas	Denmark	Siemens
David Schlipf	Germany	SWE University Stuttgart
Detlef Stein	Germany	Multiversum
Dominique Philipp Held	Denmark	Windar Photonics
Eloise Burnett	UK	Carbon Trust
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