

Minutes of the IEA WIND Task 32 Workshop #8: Certification of Lidar-Assisted Control Applications

Date: 30. – 31. January 2018

Venue: DNV GL, Hamburg, Germany

Workshop leader: Nikolai Hille, DNV GL

Minutes by Holger Fürst, Steffen Raach, Tim Hagemann, David Schlipf

Version: 9. February 2018

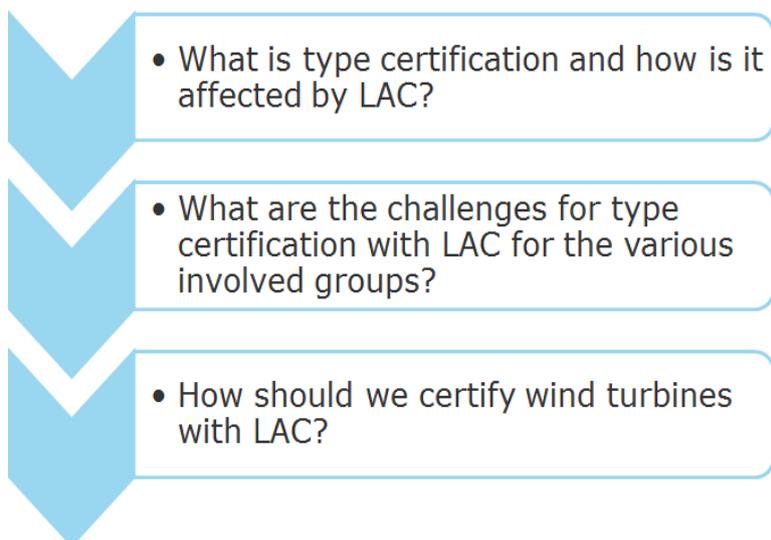
Minutes

Day 1

Welcome and Introduction

10:30	Start of workshop - welcome and introduction round
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- Nikolai welcomed everybody
- David introduced the IEA Wind Task 32 to the participants
- Nikolai presented the main objectives of the workshop and the program of the two days



	David Schlipf, SWE Introduction to Lidar-Assisted Control
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- Lidar-assisted control is very inter- and multi-disciplinary!
 - We need to combine knowledge from control, meteorology, remote sensing technology, signal processing, aerodynamics and mechanics
- Application requires tailored data processing techniques!
 - nacelle-based lidar needs new model-based wind field reconstruction
 - lidar data needs to be filtered according to its the correlation
- Load reduction is possible, more energy more difficult!
 - nonlinear feedforward controller as add-on to conventional feedback
 - design assuming perfect wind preview and then adding adaptive filter
- *Question by Theodore Holtom:* We shouldn't close the door. With certification and standards we should be careful how we write them to avoid to prevent future developments. David agrees.

What is type certification and how is it affected by LAC?

11:45	Mike Woebbeking, DNV GL: Overview of certification
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- confirmation of requirements to authorities, financiers, insurers, etc.
- building of trust in the design and construction (confidence in technical integrity)
- assisting in satisfying health & safety requirements
- greater confidence of reliability and energy output
- aids securing investment, eases buying decision
- helps or allows for market entries
- independent expertise by a third party
- (four-eyes-principle)
- support of internal quality management
- early feedback in design
- *Question by Theodore Holtom:* What are the benefits of collecting data in lifetime extension assessment?
 - For lifetime extension applications, it is important to know the availability data of the lidar data to assess the possible lifetime extension.

12:15	Nikolai Hille, DNV GL: Implications of LAC on the certification of Wind Turbines
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- Introduction on standard deliverables of required documentation to the Certification Body for assessment
- Identification of requirements for documentation on the LiDAR system by the LiDAR manufacturer
- Identification of extended requirements for documentation by the wind turbine manufacturer as well as assessment for Type Certification by DNV GL for a wind turbine with LiDAR assisted control. This manly concerns the Control & Protection System, the Design Loads as well as Prototype Measurements.

- Even without specific standards on LiDAR assisted control being available yet DNV GL already today offers Type Certification of wind turbines with LiDAR assisted control based on individualised interpretation of the standards and assessment of the specific Lidar and turbine type.

12:45	Reinhard Schleeßelmann, DNV GL: Introduction to ISO 13849: Safety-related parts of control systems
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- Definitions of *Control Function* and *Protection Function*
- Does LIDAR contribute to Control Functions or Protection Functions?
- Basic principles of the design of Protection Functions

What are the challenges for type certification with LAC for lidar manufacturers?

14:00	Chris Slinger, ZephIR: Practical matters affecting the utility of nacelle mounted lidars for turbine loads measurements and control
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- Lidar sensitivity in clear air conditions, including analysis of data from several sites around the world
- The effect of lidar beam blocking due to nacelle, hub and blades
- The use of lidars, operating inside the turbine inductions zone, for wind speed and TI measurements for load certification
- New lidar TI algorithms based on Doppler signal analysis which are range independent and agree very closely (within 3%) with cup measured TI.

14:20	Shumpei Kameyama, Mitsubishi Electric: Description of realistic lidar modelling and lessons learned from field tests for lidar-assisted turbine control
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- experience on their LAC experience, and lessons-learned from their field test
- necessity of the lidar simulation model including the blade blocking, atmospheric conditions, and so on
- necessity of considering on the not-ideal information of turbine power performance (for example, fast-based)
- *Question by Jesús Arellano* : Control correction: Adaptation of pitch angle based on FAST - may interfere with WTC stability;

14:30	Paul Mazoyer, Leosphere: The necessity of a representative Lidar simulator
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- Leosphere introduced Simulid®, a representative Lidar simulator based on optical, electronics, signal processing and atmospheric modeling.
- Simulid® has been developed for years and is regularly used by Leosphere to support the design of its Lidars.
- For Lidar-assisted control application, Simulid® can be coupled with modeled wind fields or aero-elastic tools to enable the design and performance assessment of wind turbines integrating Lidar-assisted control.
- Real-time Lidar wind measurement accuracy and availability are realistically modeled to offer a full evaluation of Lidar-assisted control and mitigate risks.

- For example, Leosphere presented the impact of blade passing: it shows that Simulid® could reproduce well experimental observations, it thereby allows considering this effect in the control design.
- Many other uses cases of Simulid® could be performed such as modeling of extreme turbulences, atmospheric content or fog conditions.
- *Question by Nikolai Hille:* Is there a proposal for standard atmospheric conditions?
 - It should be typical conditions to challenge a lidar.
- *Question:* Is there an interface with Bladed?
 - Not at the moment, but this could be further investigated.

What are the challenges for type certification with LAC for turbine manufacturers?

15:25	Liu Lei, Goldwind: Goldwind EFarm - Lidar Assisted Control Application
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- The presentation shows LiDAR Assisted Control application and field testing in Goldwind;
- For evolving turbulence effect, by simulation in Bladed v4.6, evolving turbulence has little influence on wind turbine load result using LiDAR Assisted Control;
- Field testing results show that, the LAC control technology implemented by Goldwind could show positive effects on load reduction and stability improvement,
- the on-site testing results are similar with the design based on load simulation.
- *Question by David Schlipf:* Which model for wind evolution did you use within Bladed?
 - The Kristensen model.

15:40	Eric Simley, Envision: An industrial perspective on LAC at Envision Energy
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- LAC combined with modified feedback control can reduce tower and blade fatigue loads.
- Large turbines designed for low wind speeds are increasingly ultimate load dimensioned. Extreme load and blade tip deflection reduction are important design objectives.
- Although more challenging, by detecting extreme wind events LAC can be optimized for extreme load reduction.
- The lidar system and scan pattern have a big impact on the load reduction with LAC.
- It is important to verify lidar measurement quality in the field prior to using LAC.
- Simulating turbulent wind design load cases for turbines with LAC is expected to be relatively straightforward for fatigue loads.
- Clear definitions of how lidars can measure the extreme deterministic wind fields are needed to fully understand the value creation of LAC for extreme load reduction.
- *Question by Francesco Perrone:* Does the structural load reduction come for free or is lifetime of other components also reduced?
 - Lifetime of other components is not affected. But there is a slight impact on AEP.
- *Question by Ashim Giyanani:* How much does the induction zone impact the coherence?
 - The preview time will change and this is very important to consider.

What are the challenges for type certification with LAC for consultants?

16:18	Oscar Hugues Salas, DNV GL: Considerations in Design Load Cases when using LIDAR Assisted Control
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- The inclusion of LIDAR-Assisted Control (LAC) in the wind turbine controller would require additional Design Load Cases (DLCs) to be considered in the wind turbine design standards
- The control performance improvement due to LAC requires to be proved in the standards, where a combination of different environmental scenarios, including faults, need to be taken into account
- LAC should be first designed, in order to do this, aeroelastic modelling softwares are needed, which have to take some assumptions when resolving line-of-sight wind speed measurements; blade blockage; tower inclination; nacelle acceleration and its direction; effect of rotor induced velocity; rotor swept area covered by the LIDAR sampling; turbulence evolution; use of weighting function. Therefore a standardisation of the assumptions should be required
- In order to facilitate the simulations and controller design, LIDAR manufacturers should supply a DLL file which processes raw data to signals ready to be fed to the controller
- DLCs to be added to the standards could be:
 - change the convecting time at which the LIDAR measurement hits the rotor
 - correlation between LIDAR measurements and rotor average wind speed reconstruction (when using a wind speed estimator), this will increase the loading
 - modify the measurement quality (noise) and simulate a faulty LIDAR, which will have an effect in the loading
 - when detecting extreme gusts, to vary the approaching time to the turbine and change of direction
- *Comment by Theodore Holtom:* Maybe it is not helpful to go into too much detail.
 - Therefore feedback from this workshop is highly appreciated.

16:43	Mike Lüdde, DNV GL: Prototype measurements on Wind Turbines - Considering LiDAR Assisted Control
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Recommendations for measurements

- Certification:
 - Additional tests for switching operations and LiDAR control functionality
 - Additional verification of fatigue loads for both operational modes (e.g. toggle test)
 - Metmast always required for independent meteorological measurements
- Experimental:
 - Applicability of LAC under varying conditions
 - Optimization of LAC and load reduction
 - Verification of LiDAR data with independent meteorological data

17:02	Steffen Raach, sowento: Cross-tool realistic lidar simulations
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- Realistic lidar simulator independent of simulation model
- Frequency based approach
- Workflow:
 - Define your input data (lidar scan config, turbine properties, wind spectra, seed number)
 - Insert the wind field
 - Receive the lidar signal
 - Perform load simulation
- Applications: standardized load calculations, system engineering
- *Question by Eric Simley:* How do you include lidar availability?
 - By decreasing correlation.

What are the challenges for type certification with LAC for researchers?

17:18	Andrew Scholbrock, NREL: Lessons learned from field testing experience on using lidars with wind turbine controls research
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- Lidars have shown from field tests that they can be used to reject the wind disturbance to improve rotor speed regulation with feed-forward control such that the feedback controller can be optimized to reduce tower loading
- Lidars have also been shown from field testing that they can be used to improve the yaw control of a wind turbine
- Field testing has shown many practical issues that arise and are not accounted for in modelling

17:36	Eric Simley, Envision: Overview of traditional lidar modeling and wind evolution modeling methods
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- Probe volume averaging and line-of-sight velocity modeling for continuous-wave and pulsed lidars is well-understood and straightforward to implement in simulation.
- Wind evolution can be quantified using longitudinal spatial coherence.
- Several longitudinal coherence wind evolution models exist, including theoretical, empirical, and simulation-based models.
- Wind evolution can be added to stochastic turbulent wind fields used for simulation by adding additional planes of wind speeds correlated with each other according to a longitudinal spatial coherence model.
- Lidar and wind evolution models are both important for simulating preview measurements with realistic measurement error.
- *Question by Ashim Giyanani:* How does induction effects the wind evolution?
 - Correction gains are needed, but impact is small.
- *Question by Torben Mikkelsen:* Why is correlation so poor in stable conditions? Maybe LES is not sufficient because length scales are smaller?
 - That's probably true.

18:00	Tim Hagemann, SWE: Turbulent extreme event simulations for LAC
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- coherent wind fields for deterministic load cases are not valid anymore if used with LAC
- optimising algorithm can be used to shape rotor-effective quantities of wind fields
- results: fully turbulent wind fields containing extreme events (e.g. EOG and EWS)
- algorithm can be used to shape 10 minute turbulent wind field
- possible usage in hybrid simulations: real lidar measurements & wind field shaped to field measurements
- advantage: re-simulate real situation accurately and retrieve loads not measured in the field testing

Day 2

9:00	How should we certify wind turbines with LAC? 4 floating working groups rotating every 45 min with a 10 min break in between
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14:00	Moderators: Steffen Raach (sowento), Reinhard Schleeßelmann (DNV GL), Johan Olaison (DNV GL), Andrew Scholbrock (NREL): Presentation/discussion of workshop's results
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The summaries of the discussion groups are provided by the group moderators and can be found in the appended documents.

15:00	David Schlipf, SWE: Presentation/discussion of next steps
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Following next steps have been proposed by David Schlipf:

1. Compilation of Minutes and publication of presentations on workshop homepage (<https://www.ieawindtask32.org/workshop-8/>) (timeframe: one week).
2. Compilation of an IEA Wind document (most likely a "Best practices document") led by SWE. SWE will contact Nikolai Hille and Eric Simley (workshop organisation) as well as the group moderators and possibly some workshop participants to form an author team and a review team (timeframe: months).
3. Based on the workshop material and further material, DNV GL aims to publish a DNV GL document (timeframe: possible end of the year).

No objection for these steps.

Nikolai Hille mentioned that DNV GL offers already Type Certification under current standards.

Nikolai thanks all workshop participants for their valuable confirmation and especially the moderators for their effort. Torben Mikkelsen as one being involved in the initiation of the Task 32 thanks the workshop organization team and the operation agent for further developing the Task. David Schlipf thanks DNV GL for hosting the event, sponsoring lunch and coffee breaks and part of the dinner. Nikolai Hille and Eric Simley get honored for their high personal dedication to the workshop.

15:30	End of Workshop (as planned!)
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15:30	Optional event: Visit of Elbphilharmonie (sponsored by sowento)
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Participants

Name	Country	Institute
Aksel Benlevi	Netherlands	Lagerwey Wind
Andrew Scholbrock	USA	NREL
Antoine Larvol	Denmark	Windar photonics
Ashim Giyanani	Netherlands	TU Delft
Chris Slinger	UK	ZephIR Lidar
Christophe Lepaysan	France	Epsiline
Claudia Meyer	Germany	DNV GL
David Schlipf	Germany	SWE University Stuttgart
Dennis de Bot	Netherlands	Lagerwey Wind
Detlef Stein	Germany	Multiversum
Dominique Philipp Held	Denmark	Windar Photonics
Dong Liang	China	Envision Energy
Eric Simley	USA	Envision Energy
Ervin Bossanyi	UK	DNV GL
Fabian Anstock	Germany	HAW Hamburg
Fabrice Guillemin	France	IFP Energie Nouvelles
Fan Qu	China	Goldwind
Francesco Perrone	Germany	GE
Frank Scheurich	Denmark	DNV GL
Gerhard Peters	Germany	Metek
Hans-Juergen Kirtzel	Germany	Metek
Holger Fürst	Germany	SWE University Stuttgart
Iñaki Lezaun Mas	Spain	Gamesa
Inga Reinwardt	Germany	HAW Hamburg
Jesper Bonding	Denmark	Envision Energy
Jesús Arellano Aguado	Spain	Gamesa
Johan Olaison	Germany	DNV GL
Jörn Jacobsen	Germany	Enercon
Julian Hieronimus	Germany	M.O.E. GmbH
Lei Liu	China	Goldwind
Linpeng Wang	China	Envision Energy
Martijn Zijlstra	Netherlands	Lagerwey Wind
Matthieu Boquet	France	Leosphere
Mike Lüdde	Germany	DNV GL
Mike Woebbeking	Germany	DNV GL
Nikolai Hille	Germany	DNV GL
Nils Gerke	Germany	HAW Hamburg
Oscar Hugues Salas	UK	DNV GL
Paul Mazoyer	France	Leosphere
Reinhard Schleeßelmann	Germany	DNV GL
Shumpei Kameyama	Japan	Mitsubishi Electric Corporation
Stefan Löw	Germany	Siemens
Steffen Raach	Germany	sowento
Theodore Holtom	UK	Wind Farm Analytics
Tim Hagemann	Germany	SWE University Stuttgart
Torben Mikkelsen	Denmark	DTU Wind Energy
Ulf Schaper	Germany	Enercon

Minutes of meeting to:

Organiser of Workshop

IEA Wind Task 32 Workshop #8

Copied to:

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MoM. No.:

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From:

DNV GL

Date:

2018-02-01

Prep. By:

Reinhard Schleeßelmann

Certification of Lidar-Assisted Control Applications

Time/Place: 2018-01-31, 9:00 ... 12:40

Participants: Participants on the workshop in four groups 'Red', 'Blue', 'Green' and 'Yellow'

Absent: -

Workshop sessions on content of upcoming IEA Best Practice on Lidar-assisted control of wind turbines (WT)

Topic: Control and Protection System

1 GENERAL

Propose of this MoM is to comment on the key words given on the flip charts and notes from the workshop session meetings.

2 GROUP 'RED'

Brainstorm session was made to create headlines of upcoming Best Practice.

A picture of the flip chart is in the appendix.

2.1 Prevision of wind

The novelty of the Lidar on the wind turbine is information on the wind some seconds before it hits the rotor plane.

2.2 Control functions vs Protection functions, definition needed

Does the Lidar contribute to control as well as protection functions? How to distinguish the two? How to find out whether a given function is a Control Function or a Protection Function?

2.3 Redundancy

What is needed as back up on the signal from Lidar?

2.4 Reference to baseline control (sanity check), coherence check (γ^2_{RL})

What can be done to cross check the plausibility of the Lidar signal?

[Aerodynamics, inflow physics]

This item is important but does not belong the scope of discussion inside group 'Control + Protection'.

2.5 Control design: Robust, Adaptive

Along which principal shall the controller be designed?

2.6 Failure modes, quality signals

What information need the Lidar supplier to submit to the WT manufacturer in terms of quality of the signals?

2.7 Different wind characteristics

How can information – other than common values as wind speed, shear, ... – that the Lidar presents be used in WT control?

Weighting

Participants were asked to state their personnel weighting of these 7 items in terms of importance for the Best Practice.

		Topic						
		1	2	3	4	5	6	7
		Prevision of wind	Control vs Protection	Redundancy	Sanity check	Control design: Robust, ...	Failure modes	Defferent wind characteristics
Participants	A	4	5	1	6	3	2	7
	B	7	2	4	3	5	1	6
	C	5	2	6	1	3	7	4
	D	7	1	6	2	3	4	5
	E	5	4	1	6	3	2	7
	F	7	1	7	2	3	4	7
	G	5	6	7	4	2	3	1
	H	7	1	2	4	5	3	6
	I	1	5	4	2	7	7	3
	J	7	4	5	1	3	2	6
	K	7	5	4	2	3	1	6
	L	5	1	2	3	6	4	7
Average		5,58	3,08	4,08	3,00	3,83	3,33	5,42
St-Deviation		1,832	1,929	2,193	1,706	1,528	2,015	1,881

Rating: 1 = most important
7 = least important

Group Rating:	7	2	5	1	4	3	6
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Topic no. 4 (Reference to baseline control (sanity check), coherence check (γ^2_{RL})) was rated most important.

3 GROUP 'BLUE'

The list of the topics from the previous group was presented. Participants were asked on which topic work shall be done in this session.

Discussion took place on item 2.2 "Control functions vs Protection functions, definition needed".

A picture of the side notes is in the appendix.

- "Protection Function can exceed the 'Protection System'."
Components, which take part in performing Protection Functions sometimes are not direct components of the Protection System. E.g. sensors or even the control system might in cases be part of the group of components performing a Protection Function.
- "Lidar will contribute more to protection in future. First application will be control improvements."
In systems coming up now the Lidar will probably mainly improve control functions. However, in near future it is expected, that Lidar assistance will be used to e.g. reduce extreme load cases and by that the function of the Lidar may directly influence designs limits. This would bring the Lidar in being a component contributing to a Protection Function.
- "Define different layers of safety?"
It is felt a grey zone between Control Functions and Protection Functions. E.g. an 8 MW turbine might be operated at 9 MW, if external conditions and turbine's conditions allow for (operational mode 'extra power'). Turbine would leave this mode 'extra power' as soon as the Lidar detects a larger gust on its way towards the turbine. Is the function of leaving this mode a *Control Function* or *Protections Function*?
- "Baseline controller is always needed."
It is common understanding, that the WT must be able to operate without signals from the Lidar. It shall be possible to continue operation in case the Lidar health signal ceases.

4 GROUP 'GREEN'

We discussed the list of topics from group 'Red'. Two areas were chosen to work on:

- a) Items 4. Sanity check / 6. Signal quality
- b) Protection functions

A picture of the flip chart notes is in the appendix.

Discussion was made on option a) as the previous group had discussed the topic 'Protection Function' already.

- "Lidar should give 'quality signal'."
It was discussed that it would be helpful to define a quality signal (QuaSi) given constantly from Lidar to WT's controller. The signal should be defined uniquely over Lidar and WT manufacturers. It should be either a value (e.g. 1 10) or a status (e.g. bad/medium/good or green/yellow/red).
- "Common understanding on this quality signal"

- "Trustability"
QuaSi should reflect how large the confidence in the signal is at the moment.
"Trustability" could e.g. contain the Signal-to-noise ration.
- "Precision"
Also possible shortfalls in the accurateness of the signal should be reflected by QuaSi.
- "per measured category ..."
QuaSi should be given separately for each of the measured values like e.g. wind speed, wind direction, turbulence intensity, ...
- "Difficult, because dependent on Lidar principal"
The different functional principles of Lidar systems (pulsed, constant, ...) function differently. Also, the possible outcome is different. Therefore, a uniform definition of QuaSi will be difficult, maybe impossible.
- "Reliability of the quality signal"
For risk assessments on wind turbines it will be important to know how reliable the QuaSi and the health signal of the Lidar are. One of the failure scenarios will be: Lidar reports good quality of the signal, but signal is corrupt. What is probability of occurrence of this scenario?

5 GROUP 'YELLOW'

We discussed the list of topics from group 'Red'. Three areas were chosen to work on:

- a) Item 3. Redundance
- b) Items 4./6. Failure modes, failure probability
- c) Maintenance plan

The topic of option c) is not on the list from group 'Red'. It was brought up from participants.

A picture of the flip chart notes is in the appendix.

Discussion was made on option c) "Maintenance plan":

- "is needed. No special requirements for application on wind turbine."
It was concluded that for Lidar application at a wind turbine no special requirements on a maintenance plan are necessary. Standard operation and maintenance manuals including maintenance plan would be sufficient.

Discussion was held on option b) "Items 4./6. Failure modes, failure probability":

- "Health signal from LIDAR"
In the communication from the Lidar to the WT, a health signal should be present. The WT controller should ignore the data from the Lidar, if not the health signal is in status 'healthy'.
- "Sanity check in turbine controller"
The WT control system should always include a sanity check in its procedures to verify constantly the plausibility of Lidar data.
 - "Comparison Lidar wind speed with wind speed estimation"
Signals from the Lidar can e.g. be time shifted into the rotor plane and then compared to

the wind speed calculated from turbine's operational data (rotor speed, pitch angle, generator torque).

- "Threshold value to be found in simulation"
Suitable threshold values for this comparison can be derived e.g, by simulation during load simulation.
- "Sanity check for each signal used"
Each measured signal from the Lidar should undergo such a sanity check in the WT control system. Suitable check procedures should be derived.
- "Too much / too low back scatter signal from Lidar → WT controller. Or equivalent"
Lidar should also convey a signal on the momentary data quality to WT controller. This signal can e.g. be on the amount of back scatter. Other quality related values also can be used as well, like e.g. signal to noise ratio (SNR).

End of MoM. One appendix follows.

6 APPENDIX: PICTURES OF THE FLIP CHARTS AND NOTES

1. Revision of Wind

2. { Control functions vs Protection functions } Definition needed!

3. Redundancy

4. { Reference to baseline control (Sanity check) Coherence check (γ_{RL}^2)

[Aerodynamics, Inflow-Physics]

5. Control Design: Robust, Adaptive

6. Signal quality Failure modes, Quality signals

7. Different wind characteristics

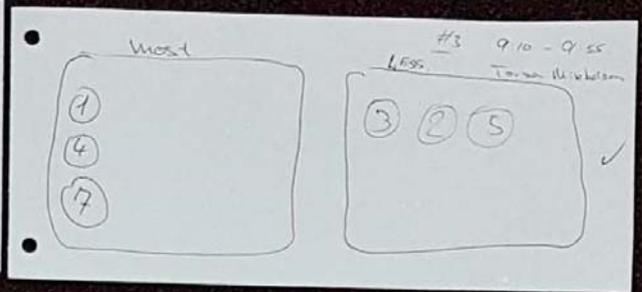
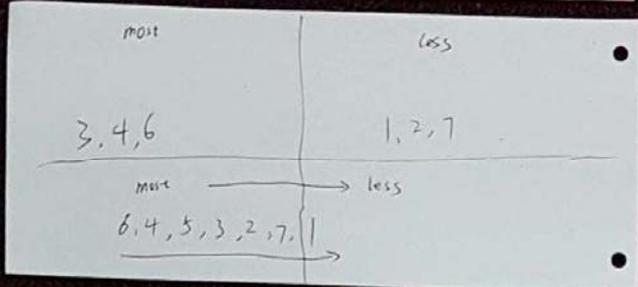
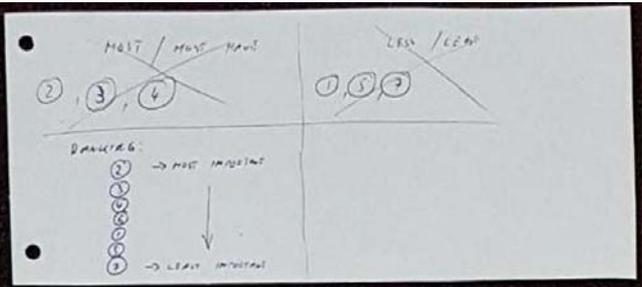
Group red

Most	less
$\gamma_1 \gamma_2 \gamma_3$	$\gamma_1 \gamma_2 \gamma_3$

PRG/OFFICE



• ~~Most~~ important 4
 6
 5
 2
 3
 7
 • ~~Less~~ important 1



- | | |
|--|--|
| Most important
7 Wind parameters ✓
3 Control Design ✓
7 Quality checks ✓
4 Clearance ✓
4 Position ✓
2 Definition ✓
3 Redundancy ✓ | Less important ✓ |
|--|--|

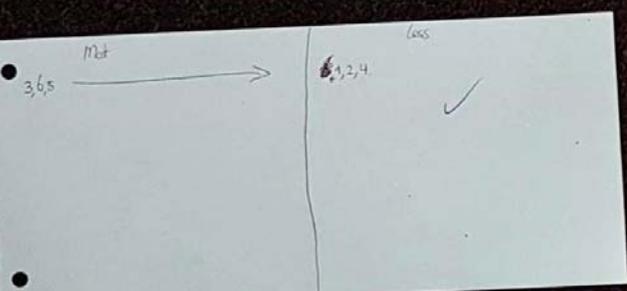
- RANKING (MOST IMPORTANT - OTHERS)
- 3
4
5
6
7
3
1
- ✓

- 2
3
6
4
5
7
1
- Less important ↓

Must: 2 ← Most important
 4 5 ← Second most important
 6 ← Third most important
 Less important: 1 7 ✓
 3 → Should not be part of a grade line.

3. Most important ✓
 6.
 5.
 2.
 1.
 4.
 7. less

Ranking
 6 4 2 4 3 4 7 ✓

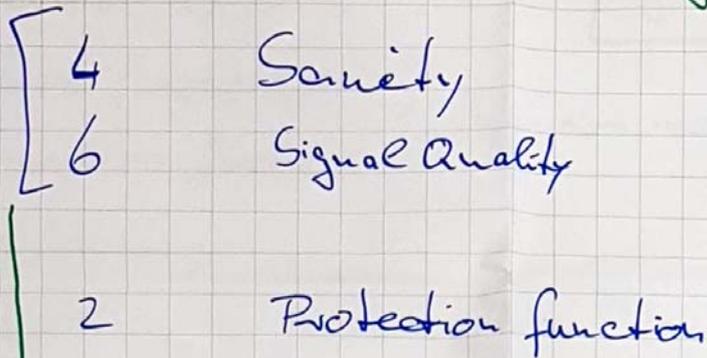


- RANKING (most to least important)
- 4
2
5
7
1
3
6
- ✓

Group blue

- Protection function can create the a protection system
- LTOIR will contribute more to protection in future. First application will be control improvement.
- Define different layers of safety?
- Baseline controller is always needed.

Group green



- LIDAR should give "quality signal"
- Common understanding on this quality signal
 - trustability
 - precision
 - per measured category (speed, direction, TI...)
- difficult because ~~def~~ dependent on LIDAR principal
- reliability of the quality signal.

yellow group

3 Redundancy

[6 Failure modes, failure probability
4

Maintenance plan

↳ is needed. No special requirements for application on wind turbines.

- ↳ - health signal from LIDAR
- sanity check in turbine controller
 - o comparison LIDAR wind speed with wind speed estimator
 - o threshold value to be found in simulation
- sanity check for each signal used
- too much / too low back scatter signal from LIDAR → WT controller are equivalent

Summary of the group discussion of lidar requirements

Steffen Raach (sowento) – 01/31/2018

General perspective

Wind turbine is a machinery designed under ISO13849. The lidar must be considered as part of the safety and control component and therefore quantifications on mean time to failure, probability of failure, probability of failure on demand (safety chain) need to be provided for the lidar sensor. Everything with respect to the lidar within the lidar-assisted control framework need to be considered under the requirements of the norm.

Measurement uncertainty

- Guidelines are needed for uncertainty analysis (standardization of methods and models)
- Guidelines are needed how to perform in certification
- Lidar manufacturer are responsible for the quantification
- Uncertainty measure on each delivered signal.
- More meaningful measures like measurement noise/process noise, variance info

Data Processing

- Raw signal should be provided (Definition is needed)
- If the processed data is used, a binary (dll) needs to be provided to for the certification to have the full simulation chain
- Specs on real-time capability (also approximations of the processing)
- Common data format might be needed, however not possible because of a missing reference and comparability
- Metric of standard signals

Data availability

- Everything can be summarized in standardization is needed.
- Standard for definition
- Standard for condition classification / site classification
 - o Problem: conditions are not reproducible in field-testing
- Suggestion of delivered measures: 1 s availability, 60 s availability
- -> link to measurement uncertainty
- Meaningful measure for every provided signal
- Link to uncertainty

FMEA

- Implementation & installation are crucial for preventing higher impact of failures. General intension: failure should not lead to a worse situation than without lidar.
- FMEA needs to be done on a probabilistic basis, ranked by impact and detectability (detection coverage)
- Self-monitoring of the lidar system can help to prevent to consider main failures on turbine level, not everything is covered.
- Treat lidar as normal sensor and learn/adapt from the requirements on normal sensors
- Analysis of the failures of the lidar. The prevention procedures might be redundant to existing features, also test cases are perhaps already considered (like pitch runaway)

Lightning protection / EMC

- Nikolai will collect the standards and procedures the lidar manufacturer already perform to standardize/align the minimum requirements.

Personal safety

- Eye safety
 - o Documentation
 - o Certification
 - o Guidance
- Safety procedures
 - o Documentation
 - o Guidance
- Need of clear separation on responsibilities

Minutes of the meeting - 31.01.2018

Working group: Simulation models and load simulations

Moderator: Johan Olaison and Claudia Meyer

DLC – Design Load Cases

- Check each DLC if the lidar can see it / preview is possible or not (depends also on the lidar)
 - o e.g. extreme horizontal shear hits the turbine and cannot be detected by the lidar: DLC 1.4
- Define visibility classes or specify assumptions on the visibility
- DNV GL asked the industry for conservative data about Lidar ration visibility/aerosol content (can be defined ranges as well)
- Safety factor
 - o Can safety factors be reduced due to good lidar preview of the event? => probabilistic approach (be careful in reducing safety factors, especially in new features)
- Extreme loads
 - o Visibility / backscatter (define an additional class in the standard...)
 - o Consider lidar failure as a sensor failure
 - o Include the EOG in a turbulent wind? => more realistic for the controller
 - o Proposal to use turbulent rotor averaged wind characteristics matching the deterministic load cases
 - o Assure the “correct” consideration of all extreme events (e.g. thunder storm...)
 - o Propagation time of the wind / controller interface
 - o (Consider delay on preview time?)
 - o Interesting aspect: Extrapolation of DLC 1.1 and comparison with DLC 1.3 – lidar behavior
- Fatigue loads
 - o Specify the lidar availability (consider good / not good signals) – availability of 99%?
 - o Hybrid simulations with lidar switched on and off (see also prototype testing)
 - o Consider a scatter diagram of the visibility to be able to reduce the fatigue loads?
- Safe mode
 - o Specify transition modes (add number and time and criteria for going into the safe mode)
 - o Define the amount of time for the safe mode
- Complex terrain
 - o high vertical inclinations (...cannot be detected by the lidar)

Lidar modelling

- Include wind evolution (different are available => which are acceptable?), consider different lidar types
- Include beam blocking

- Interface between lidar device and controller
- Amount of preview time (10 seconds?)
- Line of sight measurements should be modelled realistic
- Include nacelle motions considered in the modelling for e.g. changing beam inclination
- Include scan pattern and scan dynamics
- Quality flag

Wind modelling

- Wind evolution (different are available => which are acceptable?)
- Dynamic inflow and response of the turbine
- Grid size
- CFD
- Frequency domain

General aspects

- Provide an exchange and interface between lidar manufacturers and controller society
-

Minutes of the meeting - 31.01.2018

Working group: Prototype Measurements

Moderator: Andrew Scholbrock

Group 4:

- a. Electrical Installation:
 - i. Lightning Protection
 - 1. Need to have lidar system safe from lightning
- b. Prototype Measurements:
 - i. Met Mast/Ground Based Lidar as a secondary measurement to the nacelle lidar
 - ii. 10 Minute data recorded when everything is working nominally (lidar and turbine)
 - iii. Need to record both baseline control and LAC control?
 - iv. Need to fill test matrix of baseline/LAC:
 - 1. What wind speed bins need to be filled?
 - 2. Even though below rated wind speed might not have LAC active, the wind speed bins should be tested anyway to satisfy certification requirements?
 - 3. Need to address different turbulence intensities. LAC looks to reject wind turbulence, so it will look more beneficial in higher turbulence intensities
 - 4. Only measure LAC, measure fatigue loads
 - 5. What to do when the lidar does not work, run the turbine in a faulted case, revert to a fall back solution/baseline only control
 - 6. Environmental considerations
 - a. Type certification would only be valid in certain terrain (flat)
 - b. Type certification only valid in certain weather conditions?
 - 7. Extreme Loads:
 - a. Lidar needs to have a reliability requirement
 - b. The turbine needs to be able to react properly to extreme gust cases detected by lidar
 - c. Reduce gust thresholds during prototype measurement to demonstrate system's response's effectiveness
 - 8. Controller robustness?
 - v. For prototype measurements, de-rate the turbine to test baseline vs. LAC so that turbine is not subjected to excessive loading during prototype measurement period. However, if it is going to run at full rated, then the prototype measurement should cover full operational envelop of the wind turbine controller.

Group 3:

1. From yesterday: “need to use a met mast since it is in the standard” – not the case for prototype measurements
2. What instrumentation do we need? Do we assume that the lidar has been shown to be reliable?
3. For prototype measurements:
 - a. Record loads data, blade root strain gauges, tower base strain gauges, tower top acceleration; lidar to possibly record shear exponents/veer, other atmospheric quantities
 - b. Fill a test matrix
 - i. Wind Speed bins
 - ii. Turbulence intensities
 - iii. Bin for various backscatter coefficients
 - iv. Do we de-rate the turbine to get more region 3 winds? Uncertainty of what will happen when the turbine runs at full rated?
 - v. De-rate thresholds for extreme loads
 - vi. Test matrix should include tests that show LAC and non-LAC control
 - vii. Test matrix should include test where LAC is on, and lidar signal is lost (and what if lidar data is corrupted?)
 - viii. Need to record more atmospheric conditions for large rotors possibly?
 - c. Need a separate lidar/met mast to measure the wind conditions during prototype measurement test?
 - i. Is a separate measurement needed? Or, is the lidar on the turbine good enough?
 - ii. Are these measurements allowed inside the induction zone? Could it be a possibility?
 - d. Need to assess lidar availability
 - i. Weather conditions:
 1. Need to record lidar backscatter
 2. Need to have visibility/backscatter (independent of Lidar)
 3. Or, only have certification valid for certain conditions (have a class of lidar valid for certain sites)
 - ii. Measurement coherence
 1. Collect enough data to get an idea of coherence performance?
 2. Unstable/stable atmosphere? – Perhaps too detailed for prototype measurements
 3. Not a requirement
 - e. Lidar needs to be calibrated ahead of certification test
 - f. How detailed to the prototype measurements need to get?
 - i. Are you just showing that the measured loads match the simulated loads
 - g. Complex terrain
 - i. Only consider simple terrain
 - ii. However, should there be a workaround? There are many, many complex terrain sites where turbines are installed.
 - h. Complex wind flow (wakes for example)

- i. Is it handled just by modeling?
- ii. Or do you only have the certification cover turbines when flow is simple/not waked?

Group 2:

1. Test matrix
 - a. Need to have turbine load measurements
 - b. Guaranty control stability
 - c. Need to test failure modes
 - i. Pull plug of lidar during LAC
 - ii. What happens large noise in signal
 - iii. Degradation of lidar (gets old)
 - iv. If lidar is part of mitigating extreme loads, then should it be part of the safety system? If the lidar is lost, then do we need to shut down the lidar (probably meant turbine)?
 - v. Test low SNR (or maybe just lower coherence, or other ways; which way to introduce noise into the signal) to fool the controller to verify that the controller works as intended
 - vi. Are vibrations, temperatures, other operating conditions in turbine mounting location in agreement with what the lidar is designed for
 - vii. Should we have a test that time of arrival agrees with what is expected
 - viii. Test if lidar has been installed/aligned correctly?
 - ix. Test if designed beam blockage methods match what happens in reality
 - d. Fatigue Loads
 - i. Toggle between LAC on/off or have two turbines
 - ii. Half hour on/off
 - iii. Maybe not a step 0/1 off/on; Maybe go from 0 to 0.1 to 0.5 to... to 1 (a static gain), maybe should not be mandatory
 - e. Extreme Loads
 - i. Recommendation of reducing extreme loading case to see how turbine reacts to the same level of turbine activity
 - f. Need to test extreme yaw misalignment?
 - g. Have field tests designed to create artificial extreme events like yaw misalignment
 - h. Collect lidar data and turbine data (without LAC) and then run a hybrid simulation where the recorded field test data is fed into the simulation
 - i. Backscatter measurement
 - j. Trigger sanity checks
 - i. Pull plug of lidar
 - k. Weather conditions
 - i. Need to show that the lidar works in all weather conditions
 - l. Yaw the turbine in an idle case (blades might block lidar while idle), or operating (turbine manufacturer might not be happy)
2. Need to have an independent measurement system from the turbine/lidar system to verify against
3. Site Compliance
 - a. Should certification only be valid for certain terrain conditions? Only at the best sites? Test sites?

Group 1:

1. Validation of systems (including lidar system within LAC) against an independent met mast, or use a lidar, but perhaps only in simple terrain
2. Terrain considerations
 - a. Exclude complex terrain for prototype measurements
3. For prototype measurements:
 - a. Need to know about the wind field
 - b. When you include a lidar does anything need to be different from a prototype certification of a wind turbine?
4. Has the lidar been certified on its own? – Possibly a requirement;
5. IEC 61400-50-3 tests cover the lidar assisted control?
6. Two types of certification: Are we talking about certifying a turbine system including LAC within the turbine control, or a lidar system product for LAC application to turbine manufacturers/owners?
 - a. Component certification – perhaps for the second case, then a component certification process is all that is needed.
 - b. For the first case, follow existing prototype certification processes, and verify that the lidar can be used to measure a wind field.
7. Test if lidar signal is lost
 - a. Test if the wind turbine can ride through the temporary loss of LAC
 - b. It must be acceptable that the turbine can function with loss of lidar signal
 - i. How long of a duration of signal loss should occur before fall back plan goes into effect?
 - c. Loss of LAC does not fail certification test, but shows that a fall back plan exists
 - d. Also, test that when signal is regained, then LAC resumes
 - i. How long lidar okay before LAC resumes
 - e. Overall, the turbine should show to respond okay to a loss of lidar signal event
8. Controller should show that it can detect loss of lidar signal, or bad lidar signal
9. Test on/off behavior for validation purposes
 - a. Important thing is that the experienced loads don't exceed the design loads for both control modes
10. Test weather conditions that could impact lidar performance
 - a. Foggy conditions – perhaps not necessary, or certification does not cover foggy conditions
 - b. Clear atmosphere – perhaps not necessary, or certification does not cover clear conditions
 - c. Perhaps prototype measurements should show its performance with limited availability – this could be done in simulation after the fact
 - d. Side note: Perhaps lidar should have a “signal strength” instead of an okay/bad signal
 - e. Group 1 questions the need of the weather condition item being necessary in LAC certification. Should the lidar be simply producing a signal or not? Or, should there be a gray area of consideration in between where signal might be okay.
11. Loads measurements
 - a. Collect the same measurements that is typically done
 - b. Perhaps, no need for any additional loads measurements

- c. Need to record weather conditions to understand in how lidar could have been performing when simulations are done later for comparison
 - d. Need to understand how the lidar mounting was done, how well oriented is the unit to the turbine
 - e. Loads measurements should cover operation of the turbine with LAC, and with turbine in “safe mode”
12. Assume that a test matrix for normal prototype test covers wind speed, turbulence intensities
13. Certification of turbine should not be more onerous than normal turbine prototype test
- a. Lidar as additional sensor needs to be tested, and to be rigorous, test matrix should be complete with and without LAC, but is that overkill?

Transition between control of LAC on/off should show a bumpless transfer

Process should not be written to exclude certain technologies.