ENERGY

LiDAR – Application to resource assessment and turbine control

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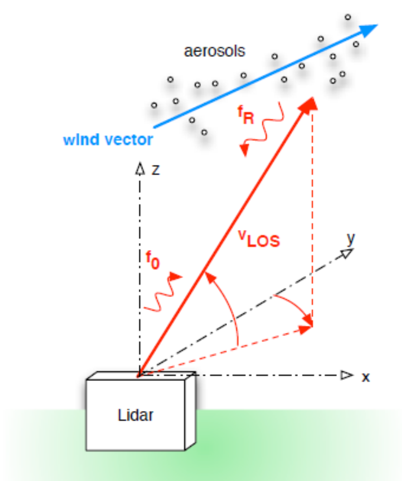
Agenda

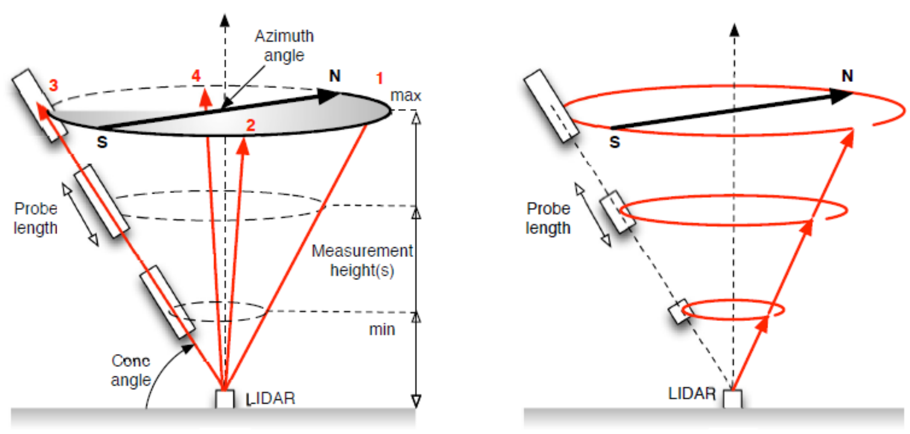
- What is LiDAR?
- Remote Sensing in IEC 61400-12-1 Ed.2
- Remote Sensing beyond IEC 61400-12-1 Ed.2
- LiDAR Assisted Turbine Control

What is LiDAR?

Background: What is LIDAR?

- LIDAR (Light Detection and Ranging) systems probe the atmosphere with a pulsed or continuous stream of electromagnetic radiation at a known frequency/wavelength (different ways of probing)
- Laser radiation scatter from collisions with atmospheric aerosols (dust, pollen, particulates) at shifted frequencies.
- Return signal is analysed for its intensity and frequency to determine the wind speed - Doppler phenomenon





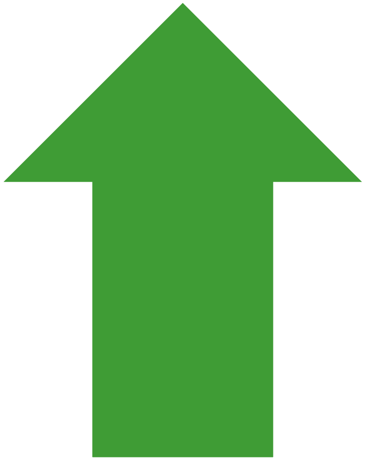
(a) Pulsed DBS lidar

(b) Continuous Wave VAD lidar

Figure A.3 Different possible lidar scanning techniques.

Background: What are the advantages of LIDARs?

- Reduce installation time and campaign duration
- More measurement points across an area
- No Permission for installation is required
- Measurement Location can chosen flexibly
- Invisible from the distance
- No noise
- Measurement heights up to 200m are possible and can be chosen freely
- No Icing
- Installation on nacelle possible
- Measures valid data in light to moderate precipitation events
- High data recovery



Background: What are the challenges with LIDARs?

- Costly (approximately $200k – perhaps less?)
- High power consumption (some units incorporate heating elements)
- Stable power supply required
- Sensitivity to ambient conditions (fog, cloud cover, precipitation)
- Maintenance intensive
- Fragile
- Not suitable for complex terrain (?)
- Not suitable for sites with high frequency of stable atmospheric conditions (?)
- Need some particulate in the atmosphere
- LIDARs measure over a volume rather than a point and therefore there are disparities between measurements done by a LIDAR and a cup anemometers.
- For this and other reasons (frequency of sample for example) there are substantial differences in what comes to:
  - Turbulence
  - Extreme wind speeds

Power curve assessment

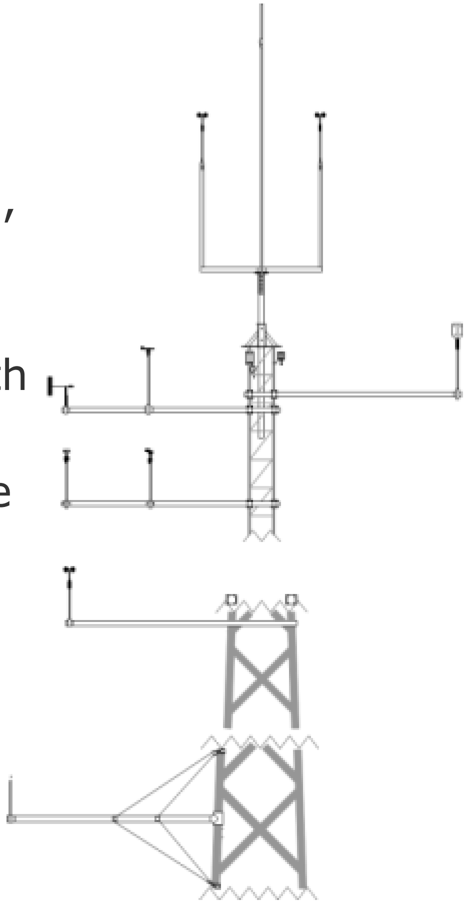
Why Undertake Power Performance Measurements on Wind Turbines?

- Certification requirement
- Prediction of energy output
- Optimisation of turbine performance
- Warranty Measurements
- Basis for feed-in-tariff (e.g. in Germany)
- R&D

Wind Measurement for Power Performance Measurement on Wind Turbines – Status

- Current Status of the IEC Standard:

  Following the IEC 61400-12-1, Edition One, 2005-12, wind speed and direction measurement is only valid with a reference met mast in a distance of 2D-4D to the to be measured turbine.



Wind Measurement for Power Performance Measurement on Wind Turbines – Status

- Near Future Status of the IEC Standard:
  The new version of the IEC 61400-12-1, Edition Two, will presumably allow the wind speed and direction measurement with ground base Lidar systems (in non-complex terrain).

Remote Sensing in IEC 61400-12-1 Ed.2

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Remote Sensing in IEC 61400-12-1 Ed.2: Major changes in the Standard

Wind speed measurement	HH	HH	REWS	REWS
Terrain type	**Non-Complex**	**Complex**	**Non-Complex**	**Complex**
Hub height meteorological mast	X	X		
Hub height meteorological mast + RSD	X	X	X	
RSD + non-hub height meteorological mast	X		X	
Meteorological Mast significantly above Hub Height	X	X	X	X

- Two wind speed definitions:
  - HH: Hub Height Wind Speed
  - REWS: Rotor Equivalent Wind Speed
- Four setups
- Note: "remote sensing" applies to ground-based measurements only

Remote Sensing in IEC 61400-12-1 Ed.2: Rotor-equivalent wind speed

Definition:

"The rotor-equivalent wind speed is the wind speed corresponding to the kinetic energy flux through the swept rotor area, when accounting for the vertical shear."

$$v_{eq} = \left(\sum_{i=1}^{n_h} v_i^3 \frac{A_i}{A} \right)^{1/3}$$

where

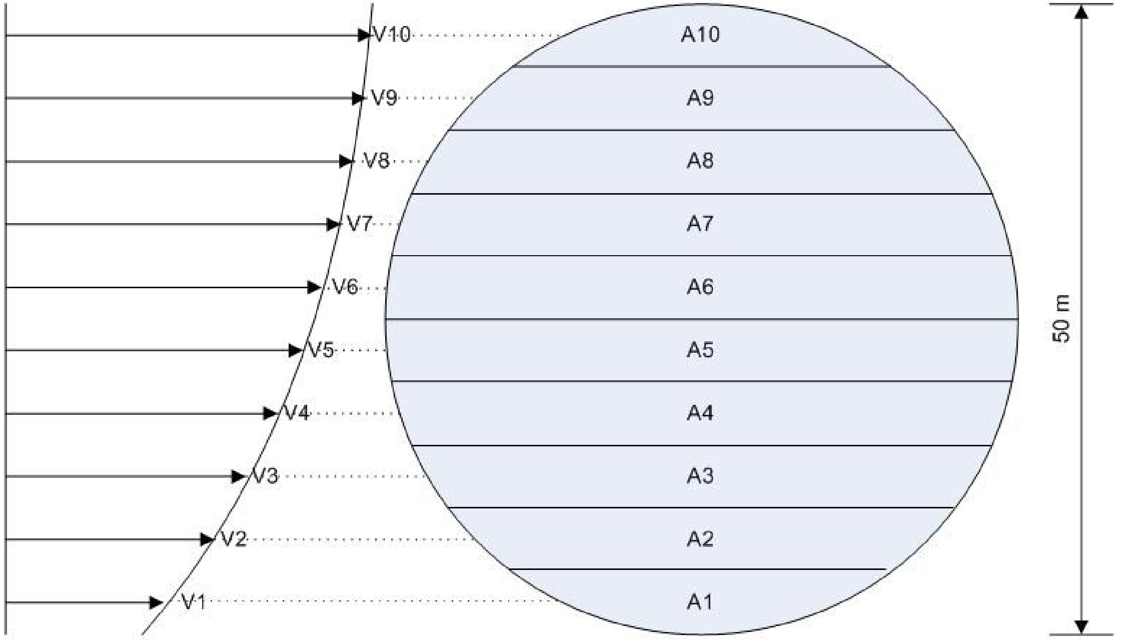
n_h *is the number of available measurement heights* ($n_h \geq 3$)*;*

v_i *is the wind speed measured at height i;*

A *is the complete area swept by the rotor (i.e. πR² with Radius R);*

A_i *is the area of the* i^{th} *segment, i.e. the segment the wind speed*

v_i *is representative for, derived from Equation*

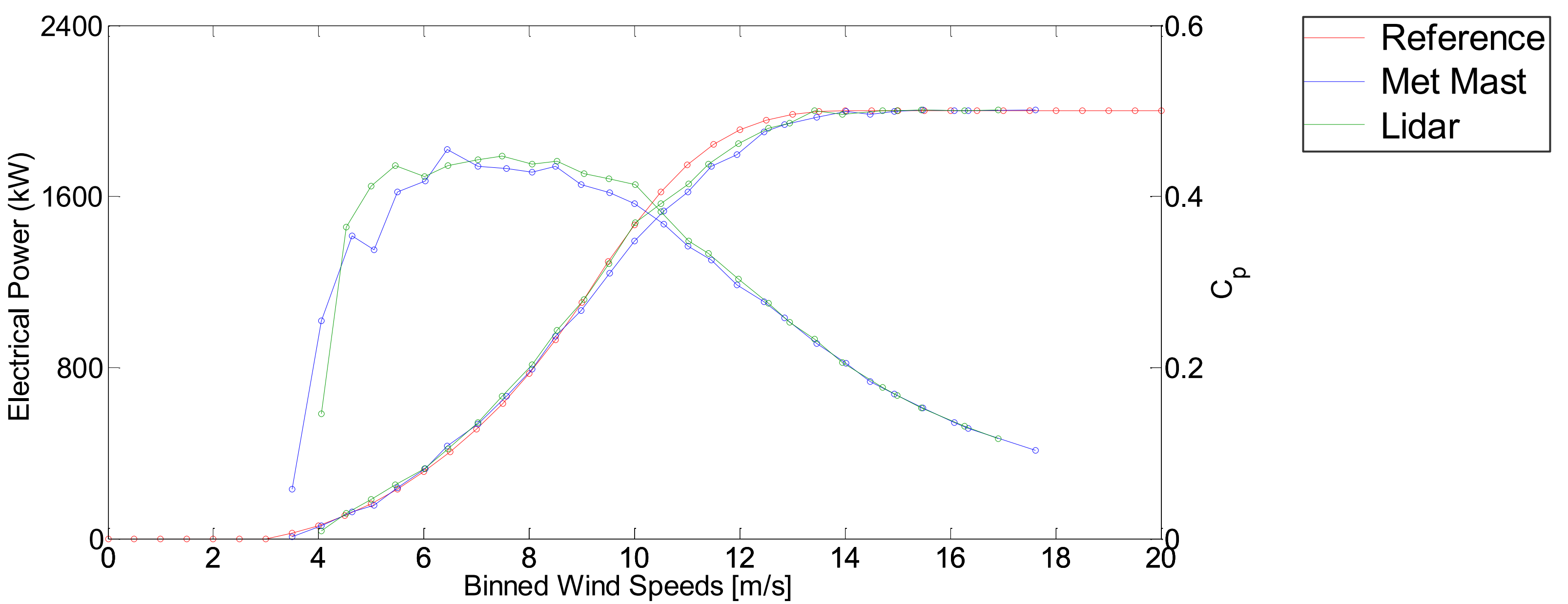


Relevant points of the standard...

- Only flat terrain
- Each RSD must be verified before each measurement – a short mast is still required at each measurement point!
- RSD can be used to calculate the REWS, wind shear and wind veer but not the turbulence
- IEC has given a method to calculate uncertainty
- Ground based LiDAR only

Remote Sensing in IEC 61400-12-1 Ed.2: Non-compliant Measurements

- Aim to be pragmatic:
  - Restrictions on mast installation?
  - Follow procedure as closely as possible
  - Quantify uncertainty due to non-compliant methods
  - All parties must agree



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Remote Sensing in IEC 61400-12-1 Ed.2: Non-compliant Measurements – Offshore

- Floating LIDAR?

- Currently Status:
- Floating Lidar System (FLS) technology has significant potential to drive down costs for Offshore Wind Measurement campaigns.
- Mounting proven Lidar technology on buoys creates challenges for
  - reliability,
  - maintainability and
  - power management;
  - and also introduces additional uncertainties in the data produced.

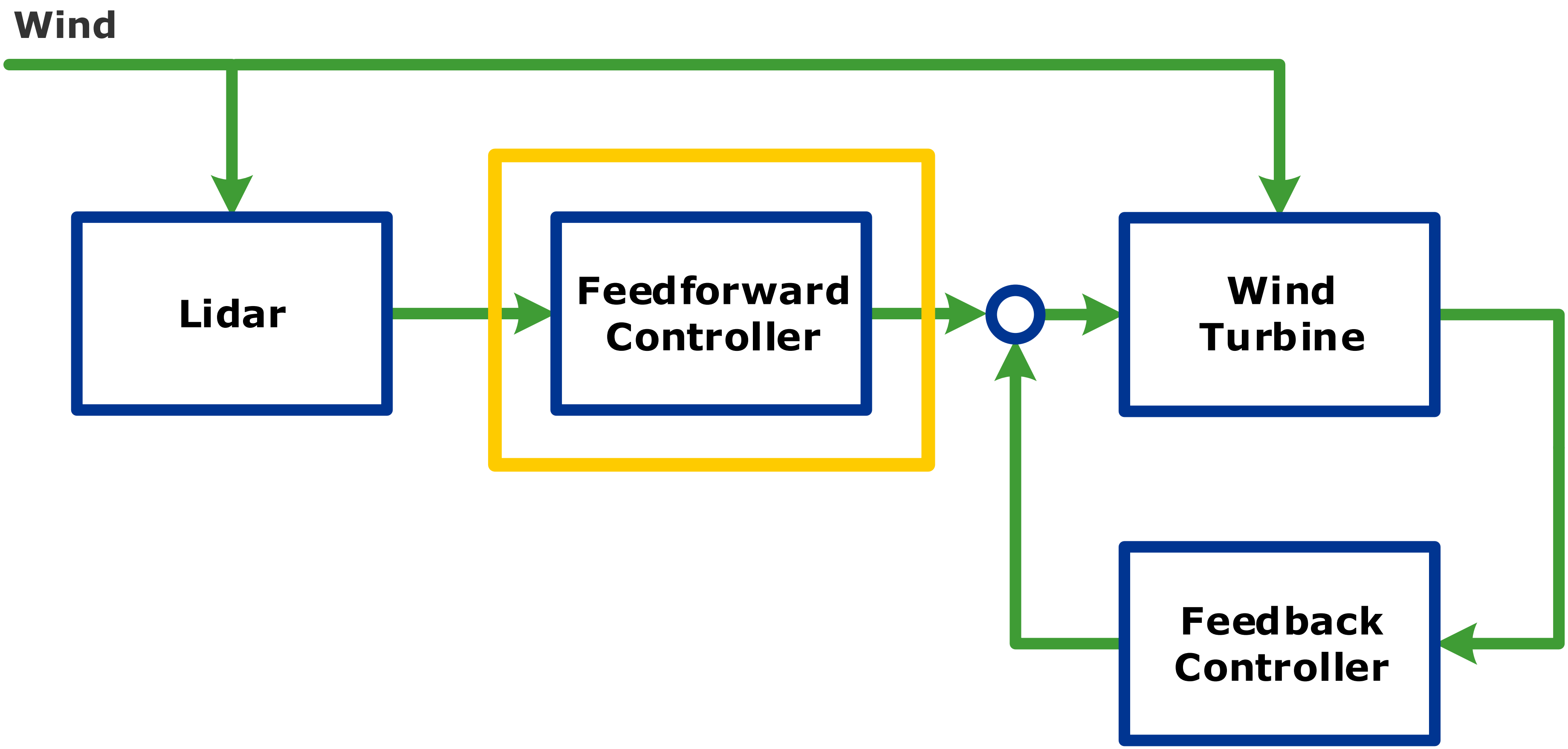
LiDAR Assisted Turbine Control

Where are we now?

Generation from wind is odd:

- No control over “fuel”
- No knowledge of “fuel” characteristics until after it is used

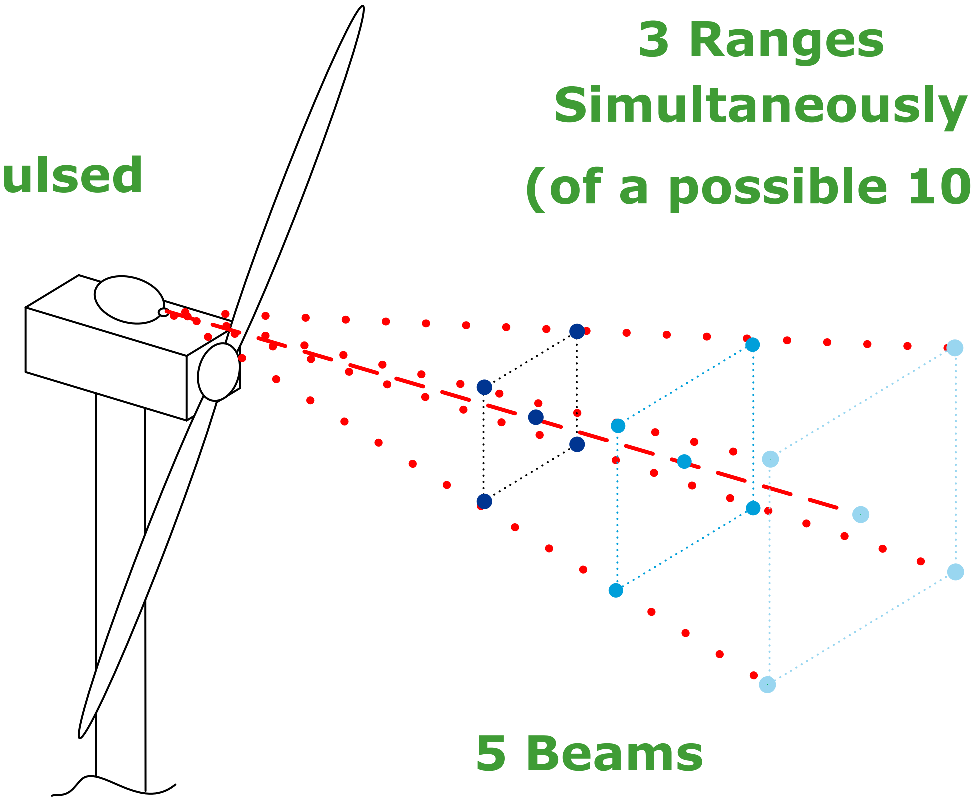
Lidar Assisted Control



Avent five-beam LIDAR

Pulsed

3 Ranges Simultaneously (of a possible 10)



5 Beams

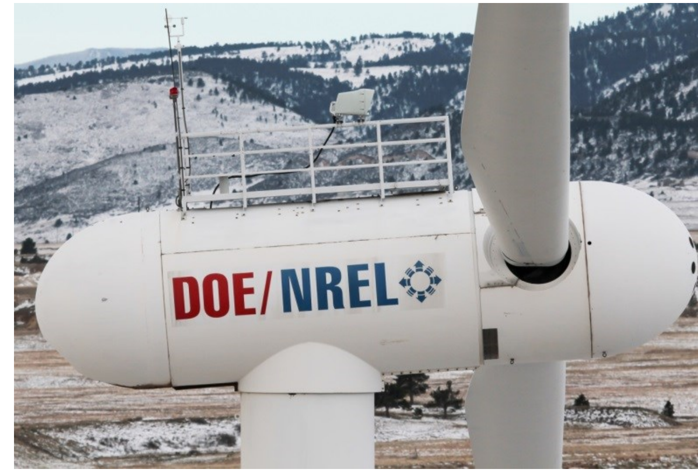
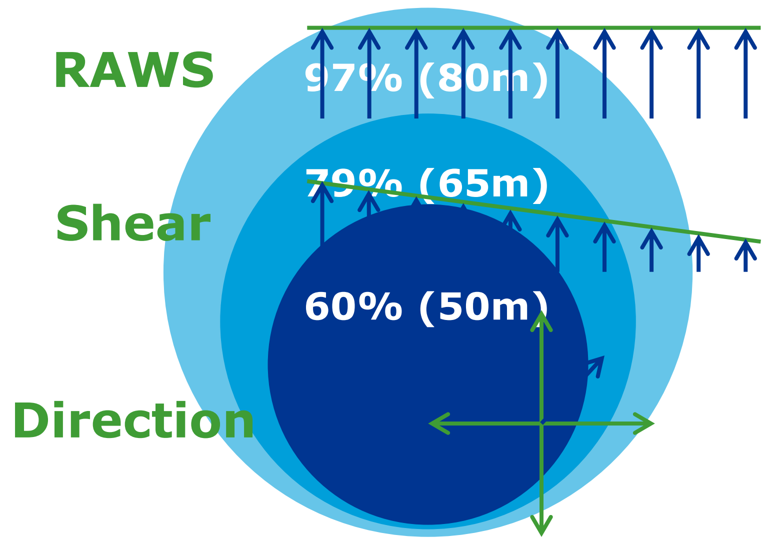
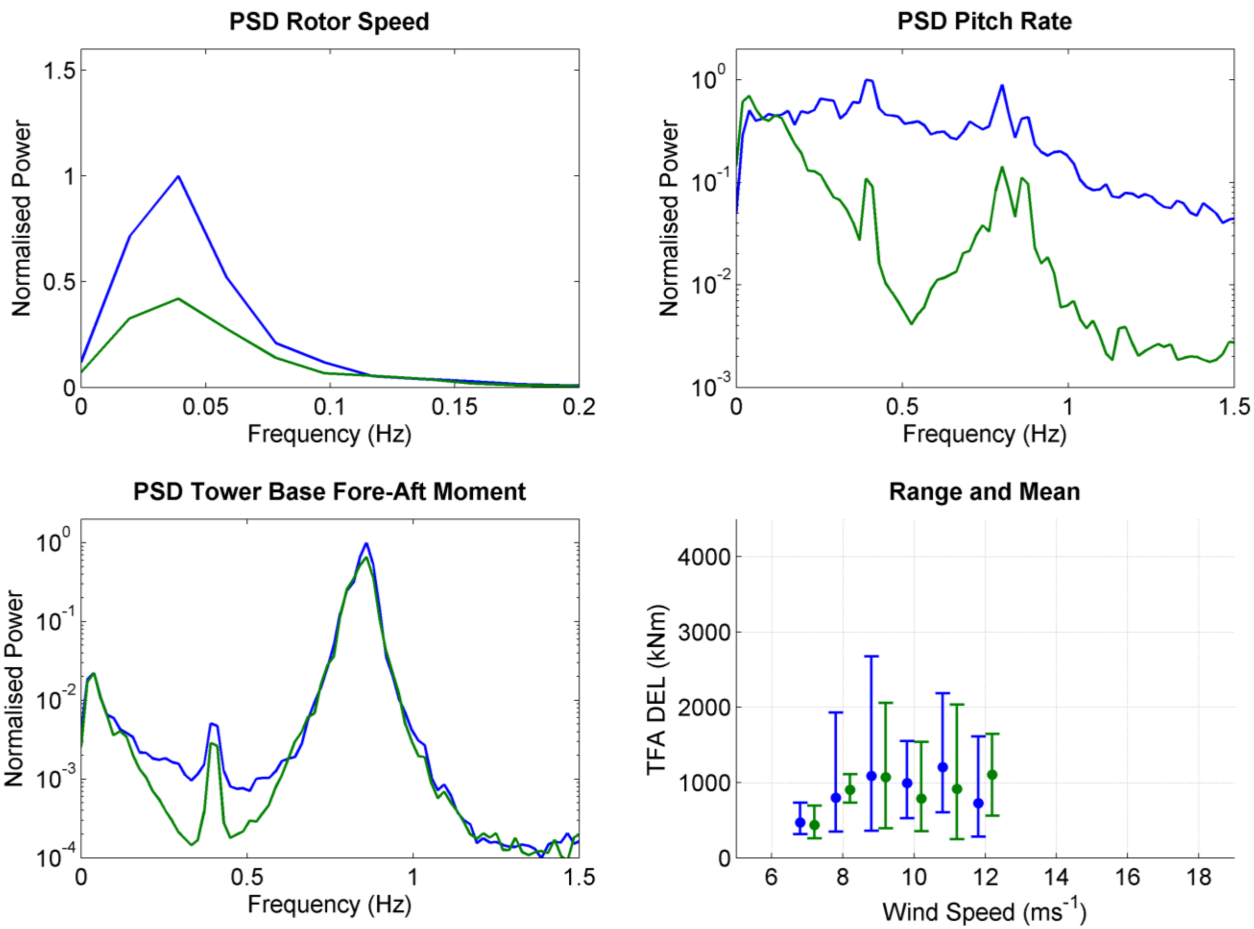


Photo Credit: Lee Jay Fingersh, NREL 33621



LAC 38



Further speed control improvement

Reduced pitching above 0.2Hz

Reduced tower spectral response

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Conclusions

- LAC easily added to existing controllers
  - Relatively low levels of tuning for immediate performance increase
  - No impact on stability
- LAC achieved better speed regulation than feedback only
- Significant detuning before speed regulation suffered
- Detuning resulted in:
  - Reduced pitch activity
  - Reduced tower spectral response
- Tower spectral response likely to reduce much further with no harmonic/structural clash

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