Influence of turbulence on wind turbine power curves

-Experimental evaluation of IEC 61400-12-1 CD1 Annex M

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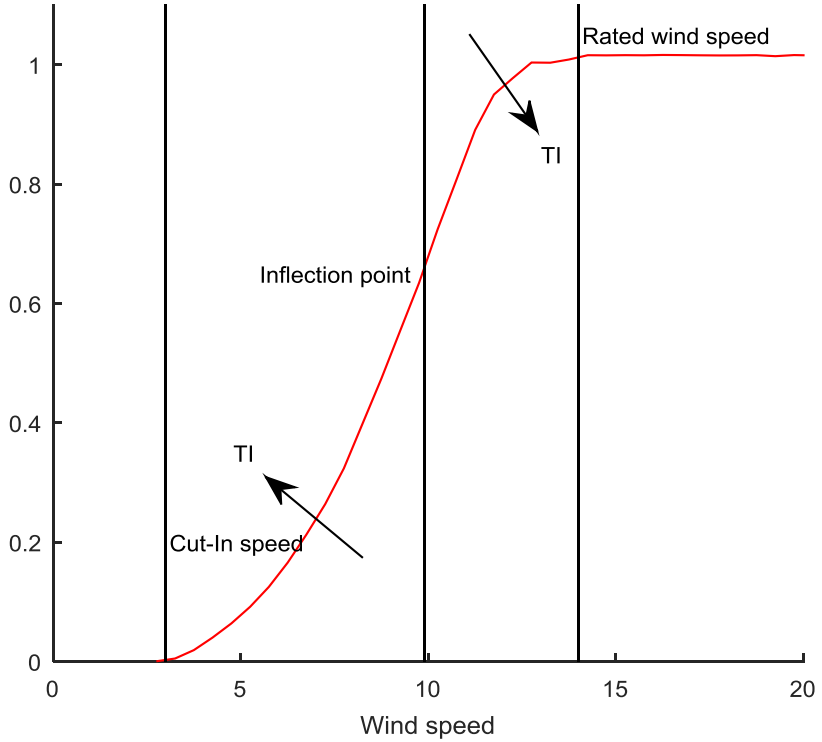
Outline

- Background
- Measurement site and methods
- Results
- Summary and conclusion

Turbulence influence on a power curve

- Time averaging of non-linear function
- Direct aerodynamic influence on rotor performance



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Taylor series expansion around $\bar{v}$

$$P(v) = P(\bar{v}) + \frac{1}{2}\frac{dP}{dv}\bigg|_{\bar{v}} (v - \bar{v}) + \frac{1}{2}\frac{d^2P}{dv^2}\bigg|_{\bar{v}} (v - \bar{v})^2 + \cdots$$

and averaging

$$\overline{P(v)} = P(\bar{v}) + \frac{1}{2}\frac{d^2P}{dv^2}\bigg|_{\bar{v}} {\sigma_v}^2 + \cdots$$

Standards for performance testing of wind turbines

- IEC 61400-12-1 1.ed (2005)
  - Site dependent
    - Wind shear
    - Wind veer
    - Turbulence intensity
  - 10 minute averaging period
- IEC 61400-12-1 2.ed (exp. Feb 2017)
  - Equivalent wind speed addresses wind shear and veer
  - Remote sensing wind speed measurement
  - Zero turbulence power curve normalization addresses turbulence and time averaging

Zero turbulence power curve

IEC 61400-12-1 2.ed CD Annex M

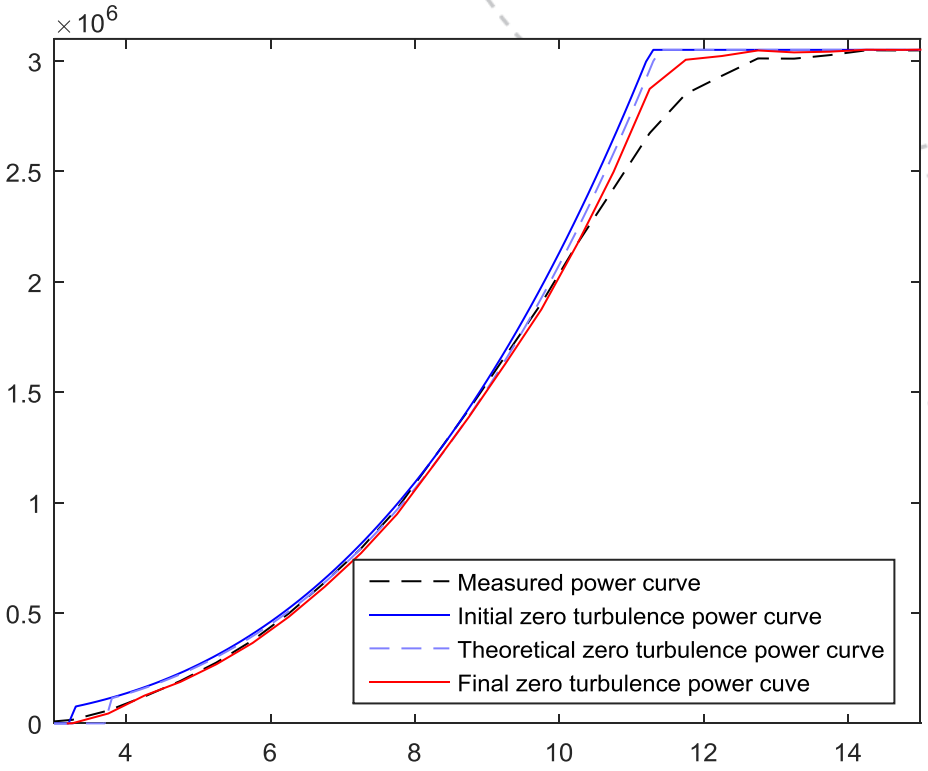
Normalize measured power curve to zero turbulence conditions

⇩

Simulate new power curve for different turbulence conditions assuming a gaussian wind speed distribution

$$\overline{P_{sim}(v)} = \int_{v=0}^{\infty} P_{TI=0}(v) f(v) dv$$

Mainly addresses effect of 10-minute averaging



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Valsneset wind turbine test site

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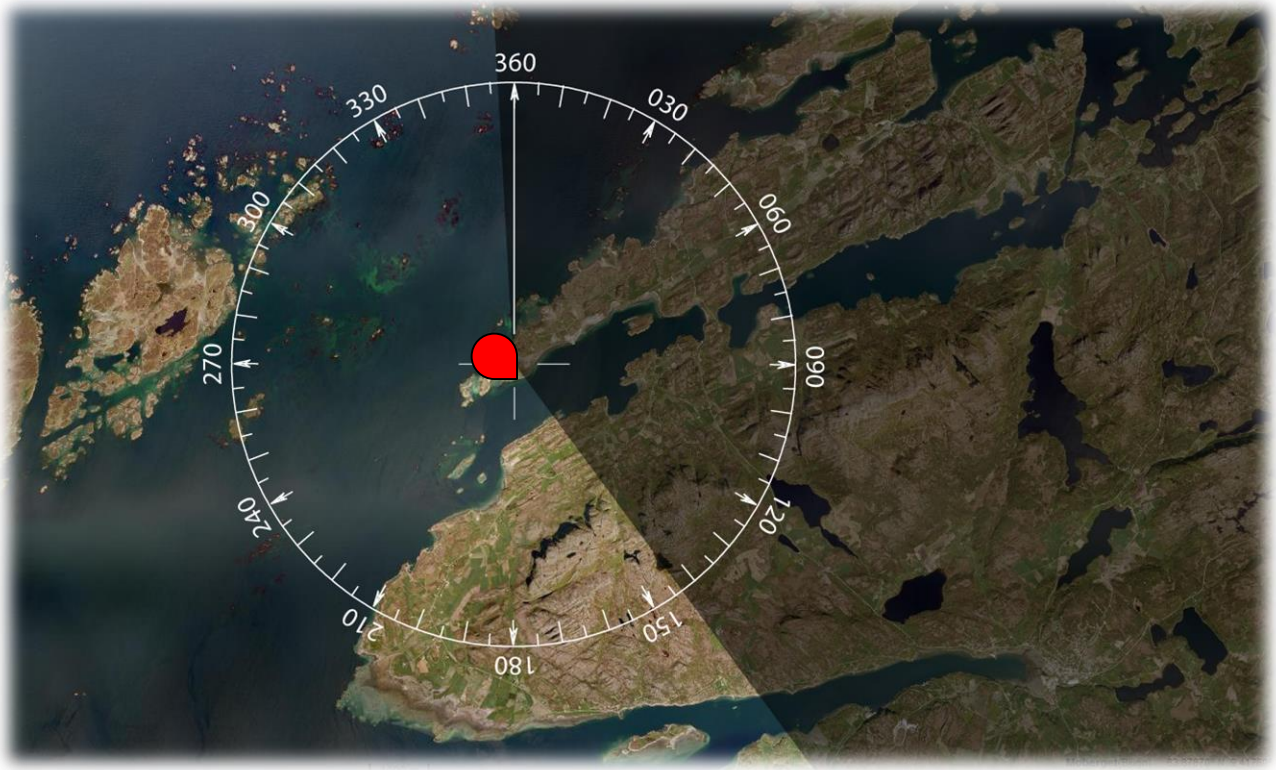

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Measurements

- IEC 61400-12-1 1.ed with modifications
- Leosphere Windcube v2 lidar
  - 3D from wind turbine
  - Wind speed, wind direction and turbulence intensity*
- 3MW wind turbine
  - Pitch regulated HAWT
  - Hub height: 92 meters
  - Rotor diameter: 100,6 meters
  - Direct drive
  - Net electrical power, status, air temperature
- Short met-mast
  - Air pressure
  - Verification of lidar measurements

*Turbulence measurement with a lidar involves high uncertainty for small time scales

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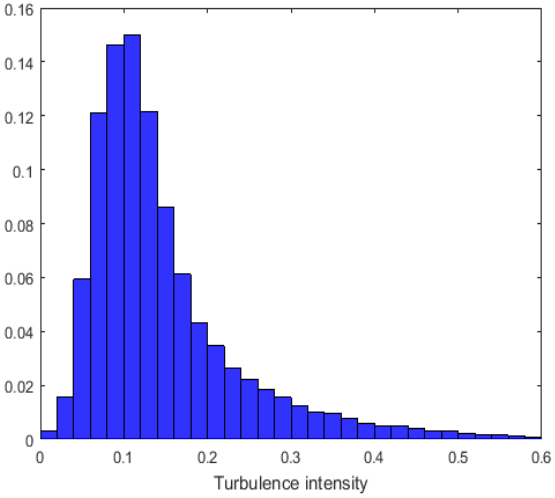

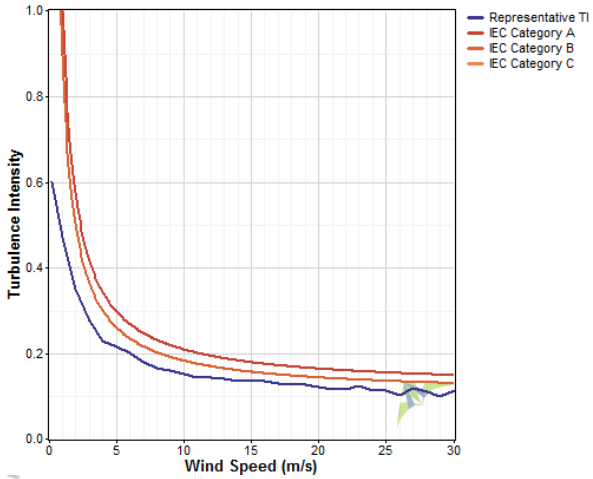

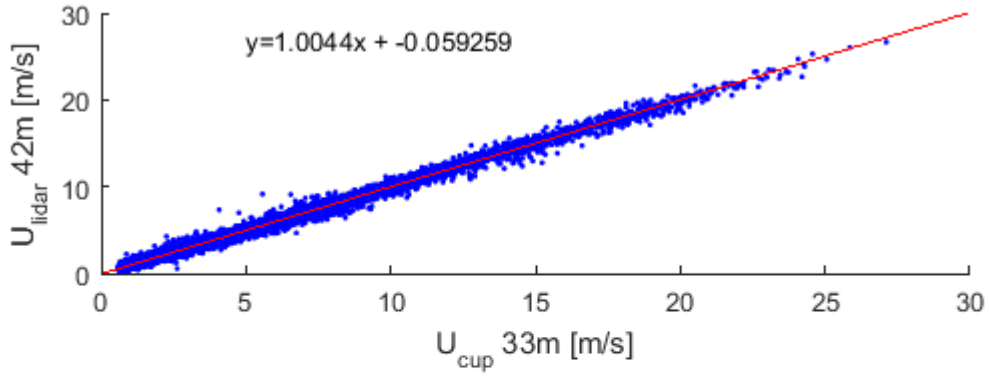

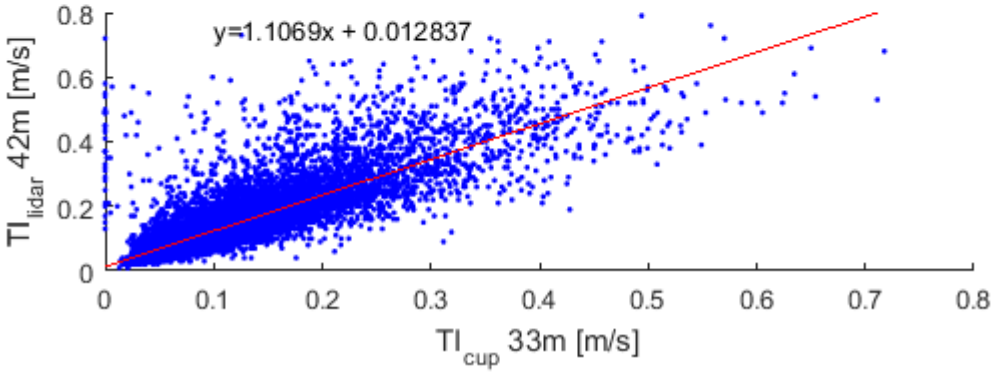

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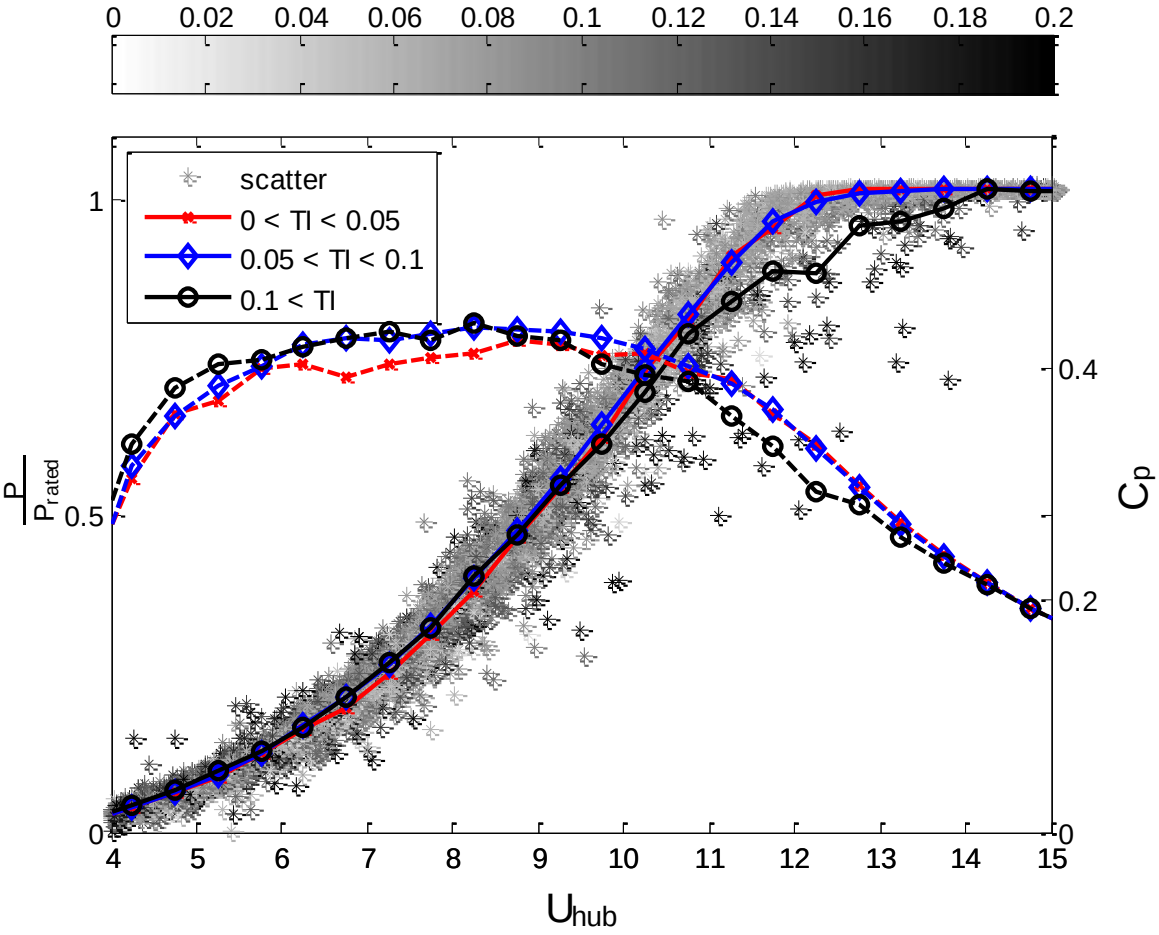
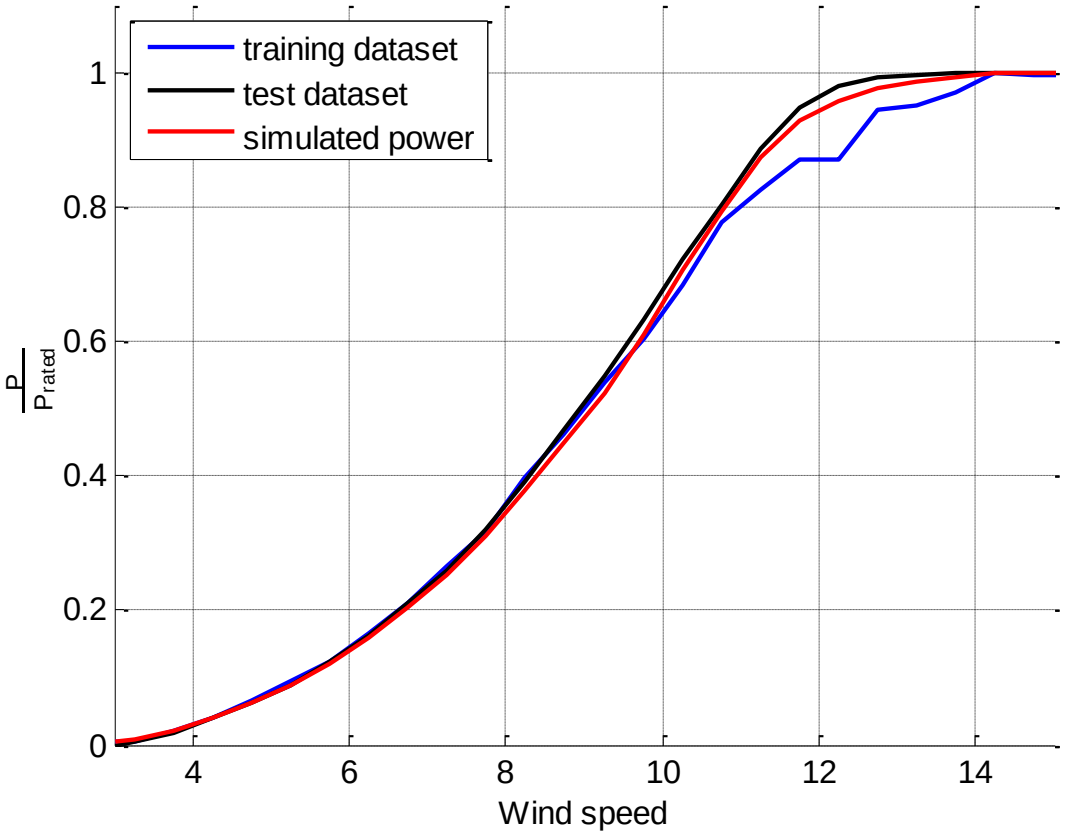
Results – TI and power



Results – Turbulence normalization: High TI to low TI



Training dataset: TI > 10%
Test dataset: TI < 10%

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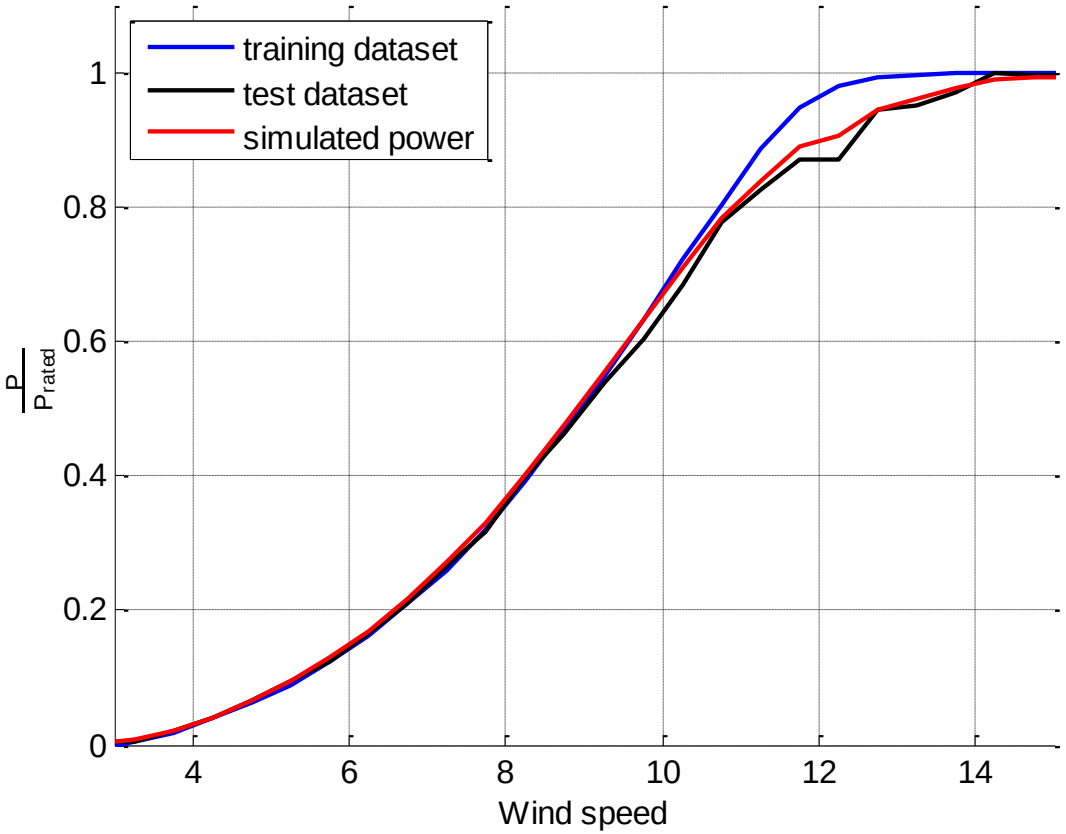
Results – Turbulence normalization: Low TI to high TI



Training dataset: TI < 10%
Test dataset: TI > 10%

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Results – Influence on AEP

	TI low->high	TI high ->low
AEP training data [MWh]	11774	11490
AEP test data [MWh]	11490	11774
AEP simulated [MWh]	11652	11619

ΔAEP ~ 2.5%

AEP difference reduced by ~ 50%

Summary & Conclusion

- Time averaging and turbulence causes a bias in the measured power curve depending on the curvature of the power curve and wind speed variance
- Using the zero turbulence power curve AEP difference between different datasets was reduced by ~50%. This in accordance to the estimate in the IEC standard
- Ground based lidar turbulence measurements involves increased uncertainty and scatter

Questions or comments?