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# TI influence on Power Curve Measurements

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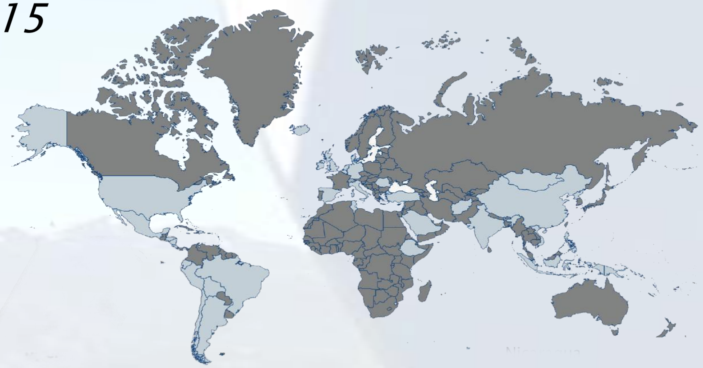
Measuring Network of Wind Energy Institutes · measnet

# ProfEC Ventus Group

- Founded in 2011
- **ISO 17025-accredited** for **IEC** and **MEASNET** conform wind sensor **calibrations** (**Calibration Laboratory**) and consultancy (**Testing Laboratory**)
  - ✓ *Accredited wind consulting services since 2014*
  - ✓ *Anemometer and Wind Vane Calibration since 2015*
  - ✓ *MEASNET member since 2016*
- Mission: supply of **bankable** wind energy services
- Staff professional expertise in > 30 countries



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DAkkS Deutsche Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

**Entrusted according to Section 8 subsection1 AkkStelleG in con[...]**
**subsection 1 AkkStelleGBV**
Signatory to the Multilateral Agreements of
EA, ILAC and IAF for Mutual Recognition

# Accreditation

The Deutsche Akkreditierungsstelle GmbH attests that the testin[...]

**ProfEC Ventus GmbH**
**Im Ofenerfeld 23, 26127 Oldenburg**

at the location:

**Marie-Curie-Straße 1, 26129 Oldenburg**

is competent under the terms of DIN EN ISO/IEC 17025:2005 to c[...]
following fields:

**Measurement of Wind Turbine Power Performance; Wind Reso[...]**
**Assessment of Wind Turbines and Wind Farms; Installation and[...]**
**Measurements with Anemometers; Site Classification of Wind T[...]**

The accreditation certificate shall only apply in connection with the notice [...]
with the accreditation number D-PL-19142-01 and is valid until 21.01.2020[...]
the reverse side of the cover sheet and the following annex with a total of [...]

Registration number of the certificate: **D-PL-19142-01-00**

Berlin, 30.01.2015

Dr. Heike Manke
Head of Division

See notes overleaf.

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EA, ILAC and IAF for Mutual Recognition

# Accreditation

The Deutsche Akkreditierungsstelle GmbH attests

**ProfEC Ventus GmbH**
**Im Ofenerfeld 23, 26127 Oldenburg, Germany**

that their calibration laboratory

**ProfEC Ventus GmbH**
**Marie-Curie-Straße 1, 26129 Oldenburg, Germany**

is competent under the terms of DIN EN ISO/IEC 17025:2005 to c[...]
following fields:

**Fluid quantities**
- **Velocity of gases**
- **Direction of flow**

The accreditation certificate shall only apply in connection with the notice [...]
with the accreditation number D-K-19142-01 and is valid until 2021-01-17. [...]
the reverse side of the cover sheet and the following annex with a total of [...]

Registration number of the certificate: **D-K-19142-01-00**

Braunschweig, 2016-01-18

Dr. Michael Wolf
Head of Division

See notes overleaf.

# Membership Document

The Council of Members confirms that the below listed measurements
performed by

MEASURING-NETWORK FOR WIND ENERGY measnet

## ProfEC Ventus GmbH

Im Ofenerfeld 23
26127-Oldenburg
Germany

fulfil the measurement quality criteria of MEASNET, stated in the respective
and actually valid MEASNET Measurement and Quality Evaluation Procedures for

## Anemometer Calibration

This document consists of 1 page and is valid until 27.06.2021 and only in
combination with a valid accreditation to ISO/IEC 17025

Madrid, 27.16.2016

Monika Krämer
Executive Chairwoman

Alejandro Martínez
Vice Chairman

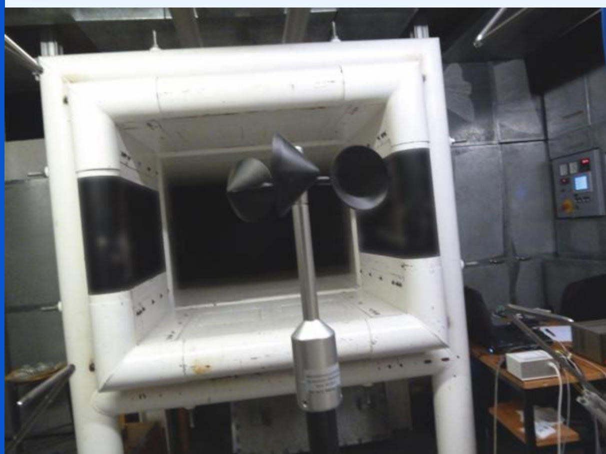
meas net

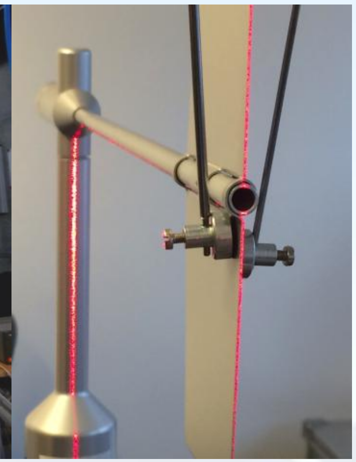
Measuring-Network for Wind Energy

# International Experience

# Services

Calibration services



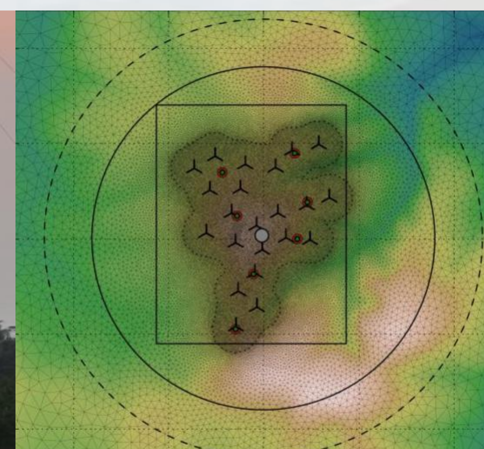


Installation and maintenance of measurement masts

Micrositing

Site Assessment

PPM



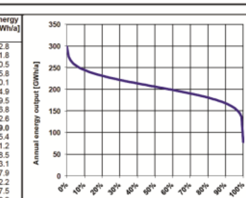
| | |
|---|---|
| Layout: | 1 |
| WT-type: | Vestas V100-2.0 |
| Rated power [kW]: | 2,000 |
| Rotor diameter [m]: | 100.0 |
| Hub height: | 100.0 |
| No. of WT: | 26 |
| Annual energy output [MWh/a]: | 205,789.0 |

**Estimation of uncertainty for main components**

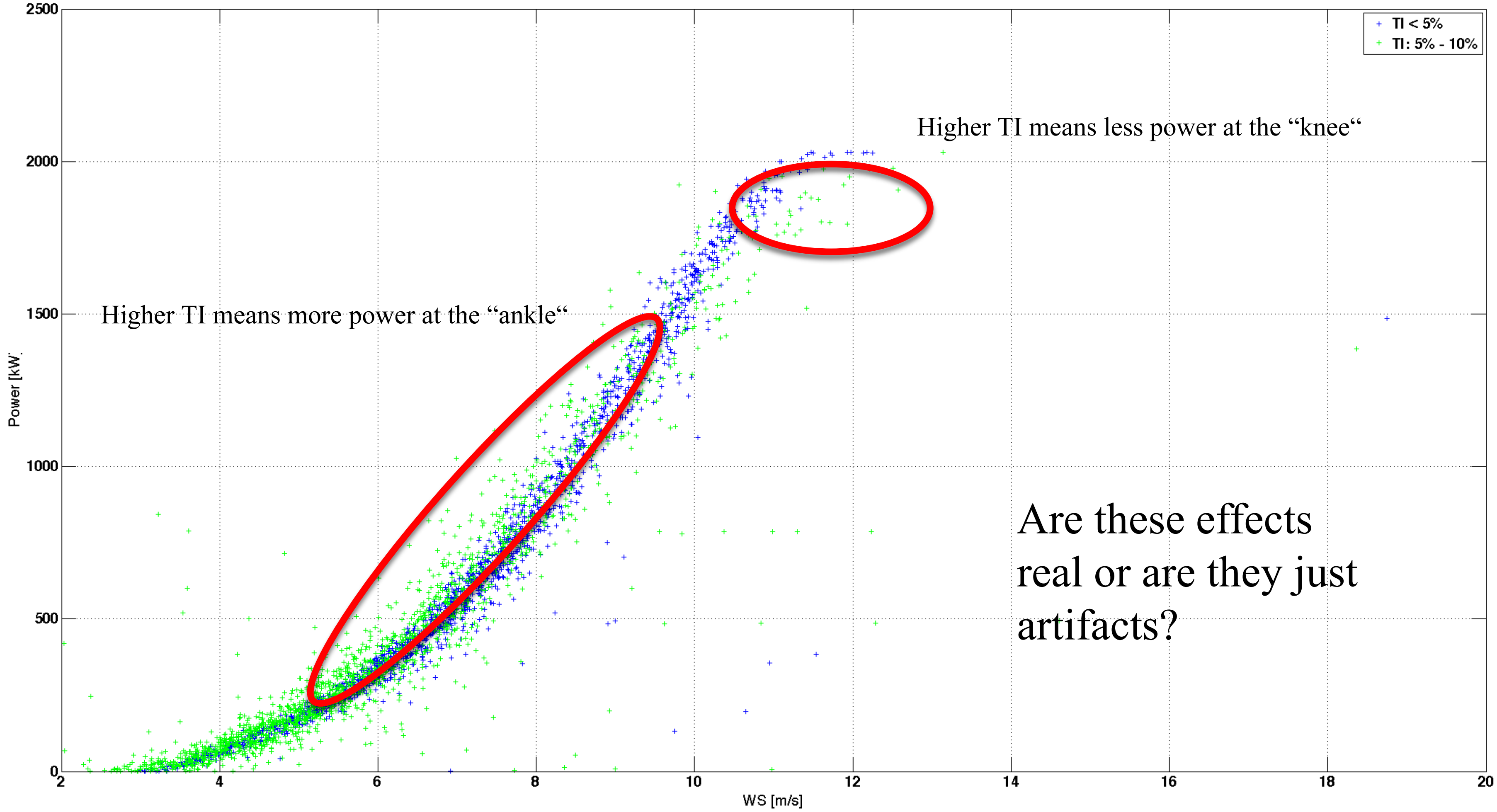
| Component | Desription | Uncertainty on energy output |
|---|---|---|
| *Meteorological input data* | *Uncertainty of wind resource* | 11.68% |
| *Modelling of wind conditions* | *Uncertainty of topographical input data (orography and roughness) as well as uncertainties related to the wind modeling* | 4.62% |
| *Modelling of wake losses* | *Uncertainties of modelling of wake losses* | 2.10% |
| *Input data related to wind turbine* | *Uncertainties related to the WT itself* | 7.04% |
| **Resulting overall uncertainty on energy output:** | | **14.55%** |

**Exceedance levels**

| Exceedance level [%] | Annual energy output [MWh/a] |
|---|---|
| 5% | 255,052.8 |
| 10% | 244,171.8 |
| 15% | 236,830.5 |
| 20% | 230,995.8 |
| 25% | 225,990.1 |
| 30% | 221,494.9 |
| 35% | 217,329.5 |
| 40% | 213,376.8 |
| 45% | 209,552.6 |
| **50%** | **205,789.0** |
| 55% | 202,025.4 |
| 60% | 198,201.2 |
| 65% | 194,248.5 |
| 70% | 190,083.1 |
| 75% | 185,587.9 |
| 80% | 180,582.2 |
| 85% | 174,747.5 |
| 90% | 167,406.2 |
| 95% | 156,525.2 |



# TI dependency of measured WT Power Curves




Are these effects real or are they just artifacts?

# TI dependency of measured WT Power Curves

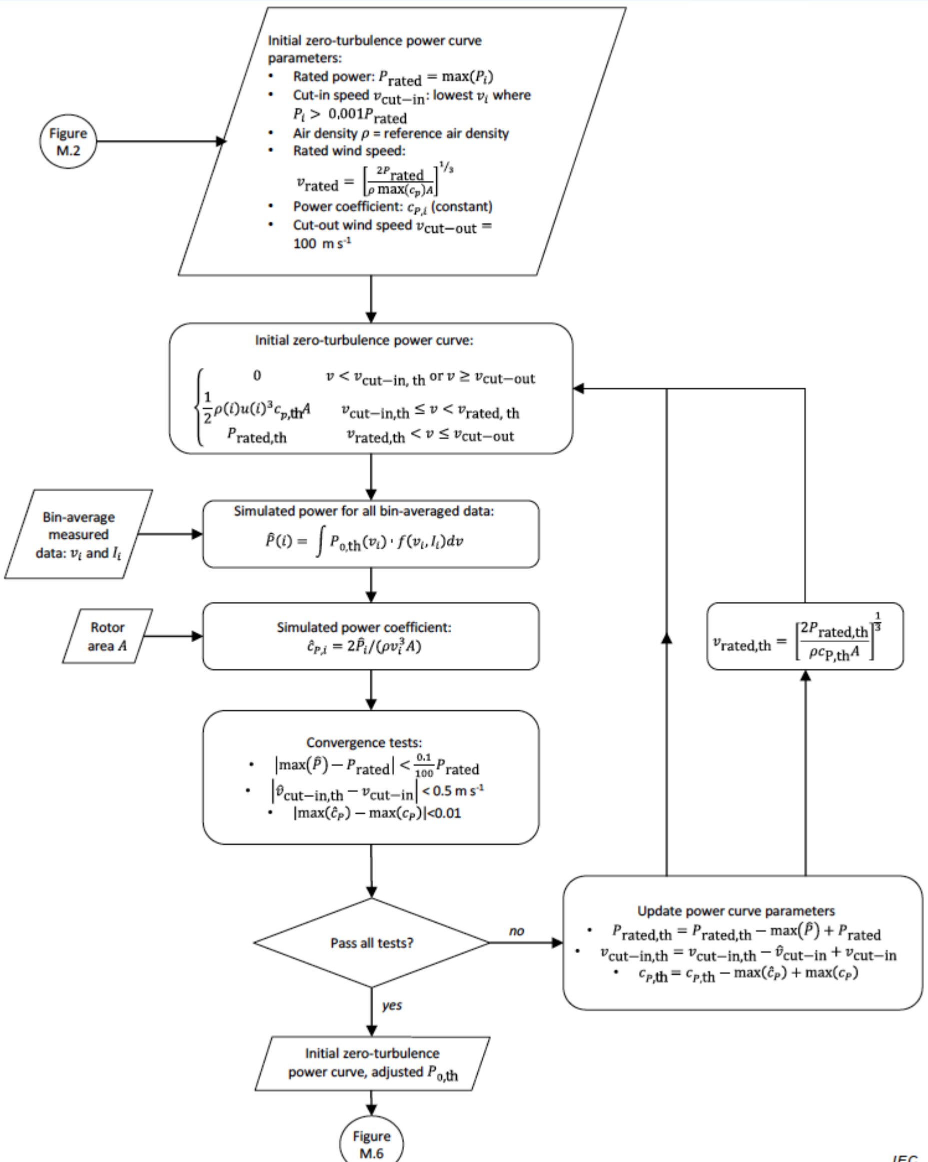
Most likely the effects seen on the previous plots are artifacts:

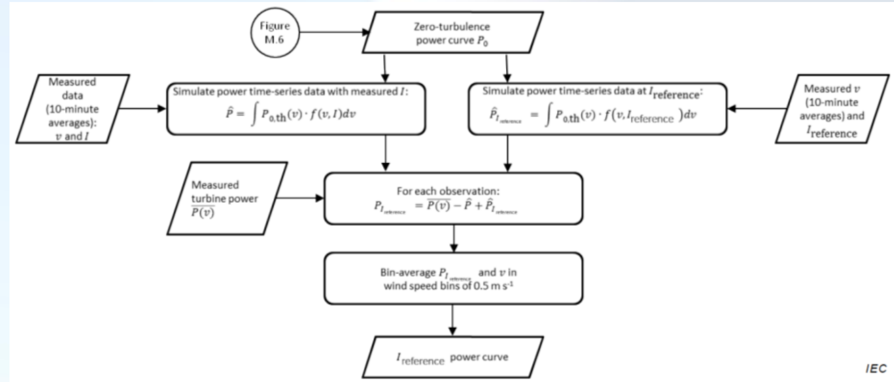
- *Measurements per IEC standard compute the 10 min mean of the Wind Speed and Power output*
- *Turbine control happens on time scales of a few seconds (depending on the event and the manufacturer)*
- *Dependency between Wind Speed and Power Output is highly non-linear, leading to "side-effects" while calculating the mean in each Wind Speed Bin*

# IEC 61400-12-1: 2017 TI corrected PPM

- Newly proposed procedure IEC 61400-12-1 standard
- Procedure:
    - *Establish a Zero Turbulence Power Curve via an iterative process from the measured PPM data*
    - *Zero Turbulence Power Curve used to determine Power Curves for different TI levels*

# Determination and application of Zero-Turbulence Power Curve



# IEC 61400-12-1: 2017 TI corrected PPM

- **Advantage:**
  - *Works quite well in most of the situations*
  - *Method without too much physics in it (advantage?)*
  - *Only informative part of the standard*
- **Disadvantage:**
  - *Complicated procedure*
  - *Questionable procedure*
  - *Only informative part of the standard*

# Alternatives

- "Langevin Power Curve"
  - *Gives accurate results in most situations*
  - *Needs high frequency data*
  - *Easy to understand, difficult to implement*
- Statistical method
  - *Uses the 10 min data recorded as per IEC standard*

# Langevin Power Curve – Basics

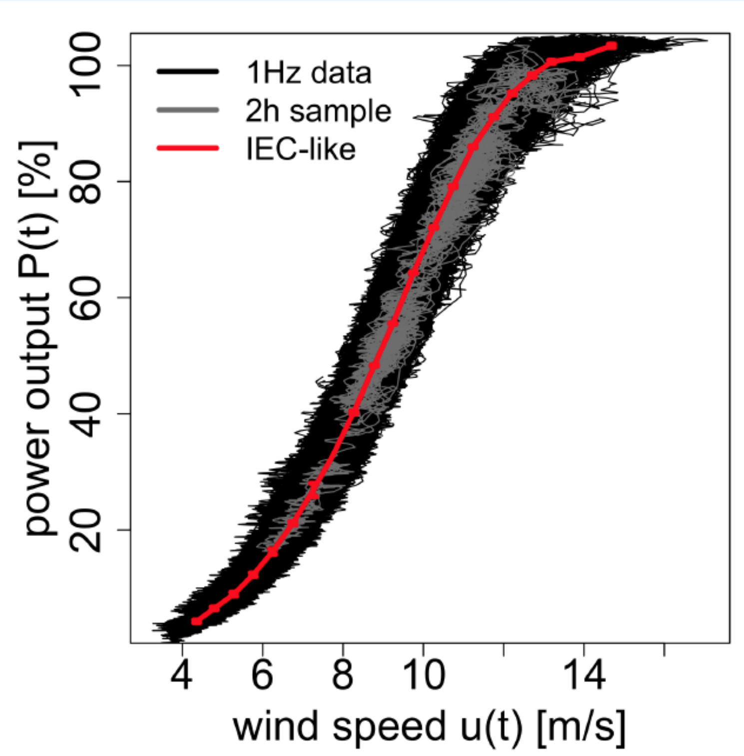
- Assumption: Markov process
- Dynamics described by Langevin equation:

$$\frac{du}{dt} = D^{(1)}(u) + \sqrt{D^{(2)}(u)} \cdot \Gamma(t)$$

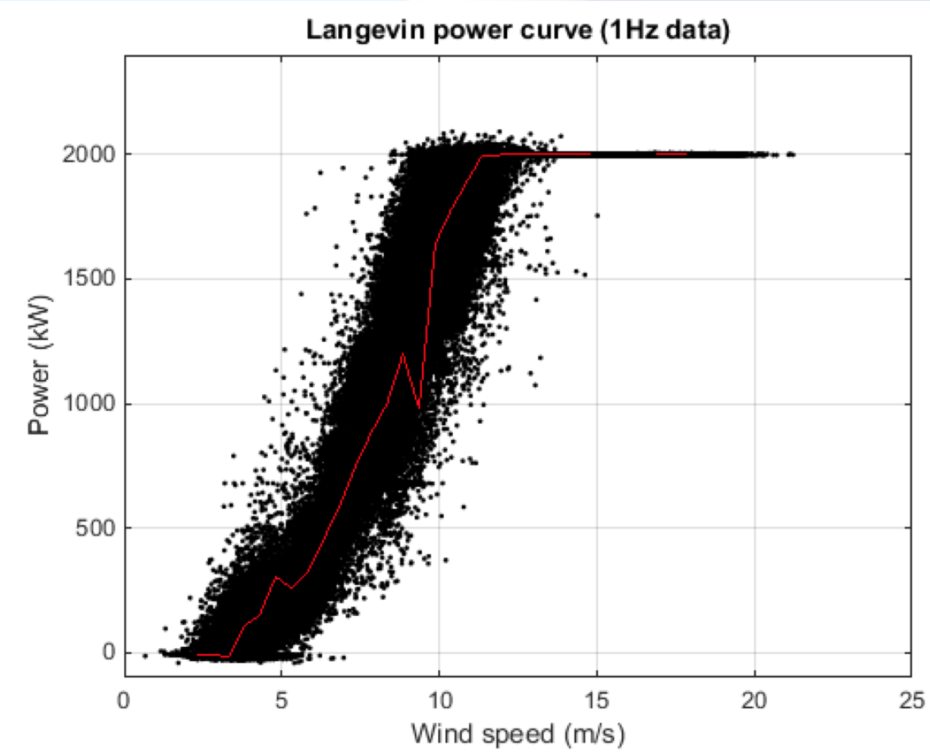
- Drift and Diffusion coefficients (Kramer–Moyal Coefficients) determine the dynamics of the system
- KM coefficients can be determined out of the n-order Moments
- Disadvantage: Continuous high Frequency data needed (faster than 1Hz)

# Langevin Power Curve – Results

- Might or might not give good results:




**Source:** The conversion dynamics of wind energy systems treated as a complex stochastic process, Milan (2014)




**Source:** Wind Turbine Performance Measurements by Means of Dyna mic Data Analysis, Friis Pedersen (2016)

→ Has the potential to be an alternative, but needs further investigation. Not in the IEC standard, thus not yet (?) accepted in the industry.

# Simplified statistical approach (1)

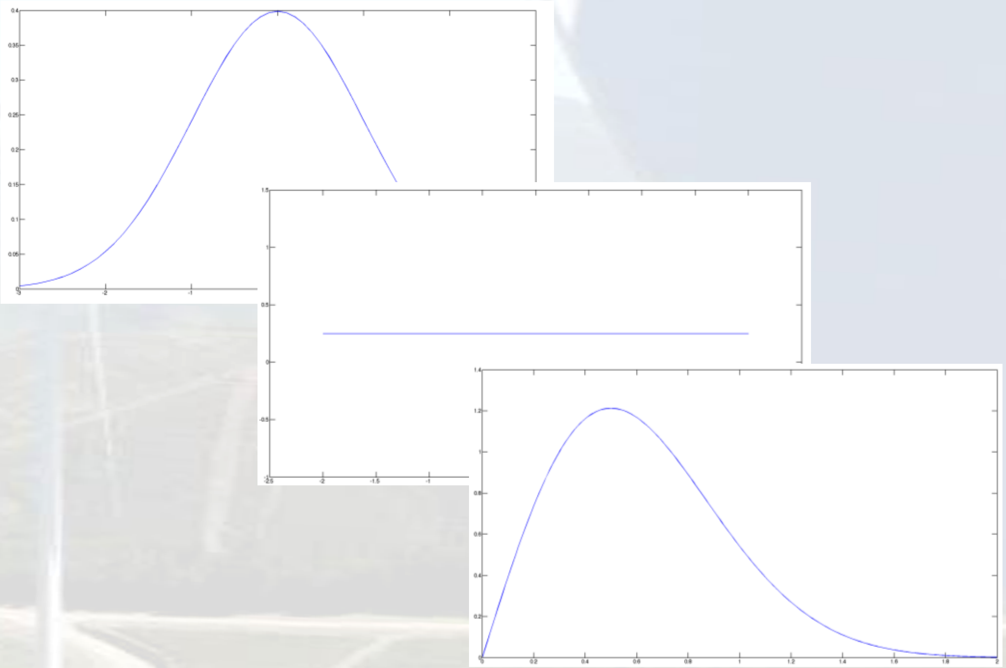
- For IEC measurements we are sticked to the 10 min averaging period

- We do not know what is happening inside the standard IEC 61400-12-1 Wind Speed and Power Signal BIN:

  - *Is the distribution Gaussian?*

  - *Is the distribution Uniform?*

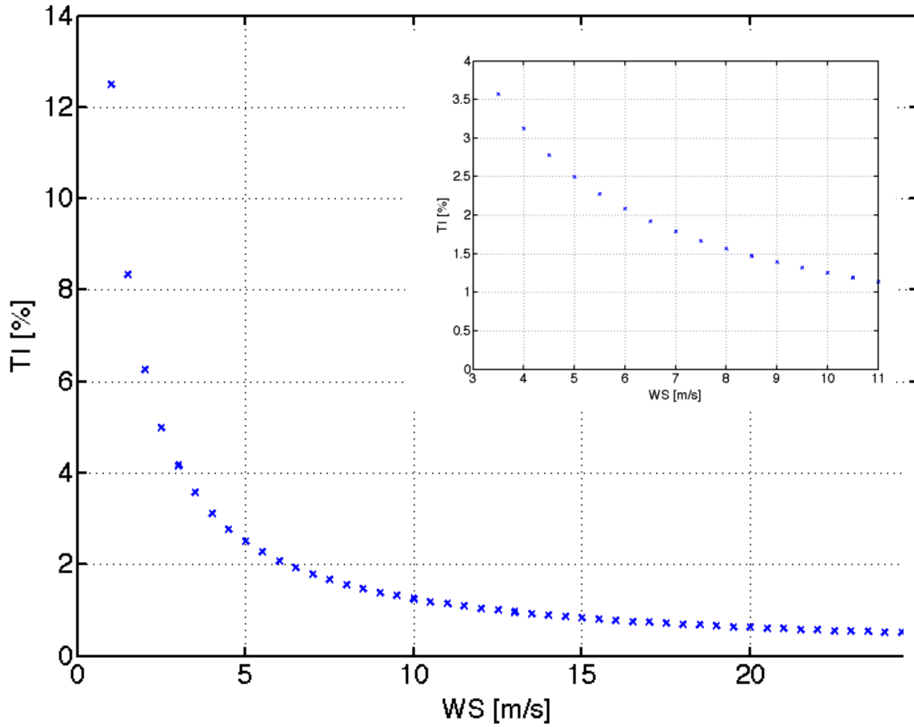
  - *What about the skewness?*



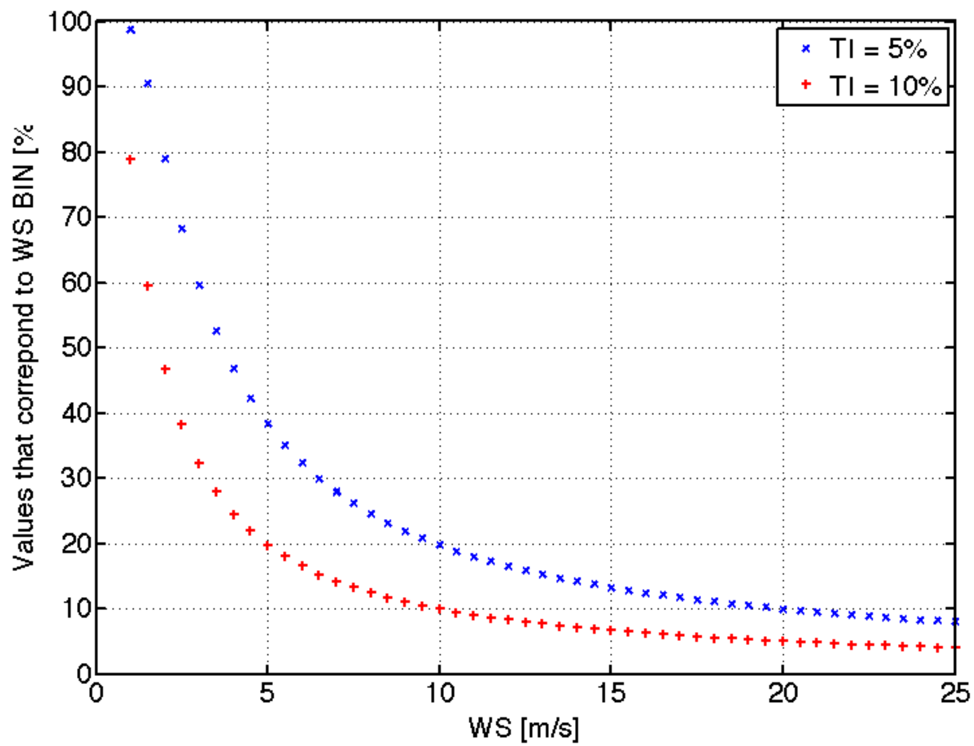
# Simplified statistical approach (2)

- Assumptions:
  - *Turbulence describes the wind speed change in a given time interval (here: 10 min)*
  - *Data within the 10 min averaging interval follows Gaussian Distribution*
  - *The turbine follows the same Power Curve for 0% TI as for higher turbulences up to the limit set by controller and WT dynamics. Effects seen on the Power Curve are only artifacts due to the BIN averaging*
  - *Shift in Power Curve due to „contamination“ of bins with data from neighboring bin*

# Simplified statistical approach (3)

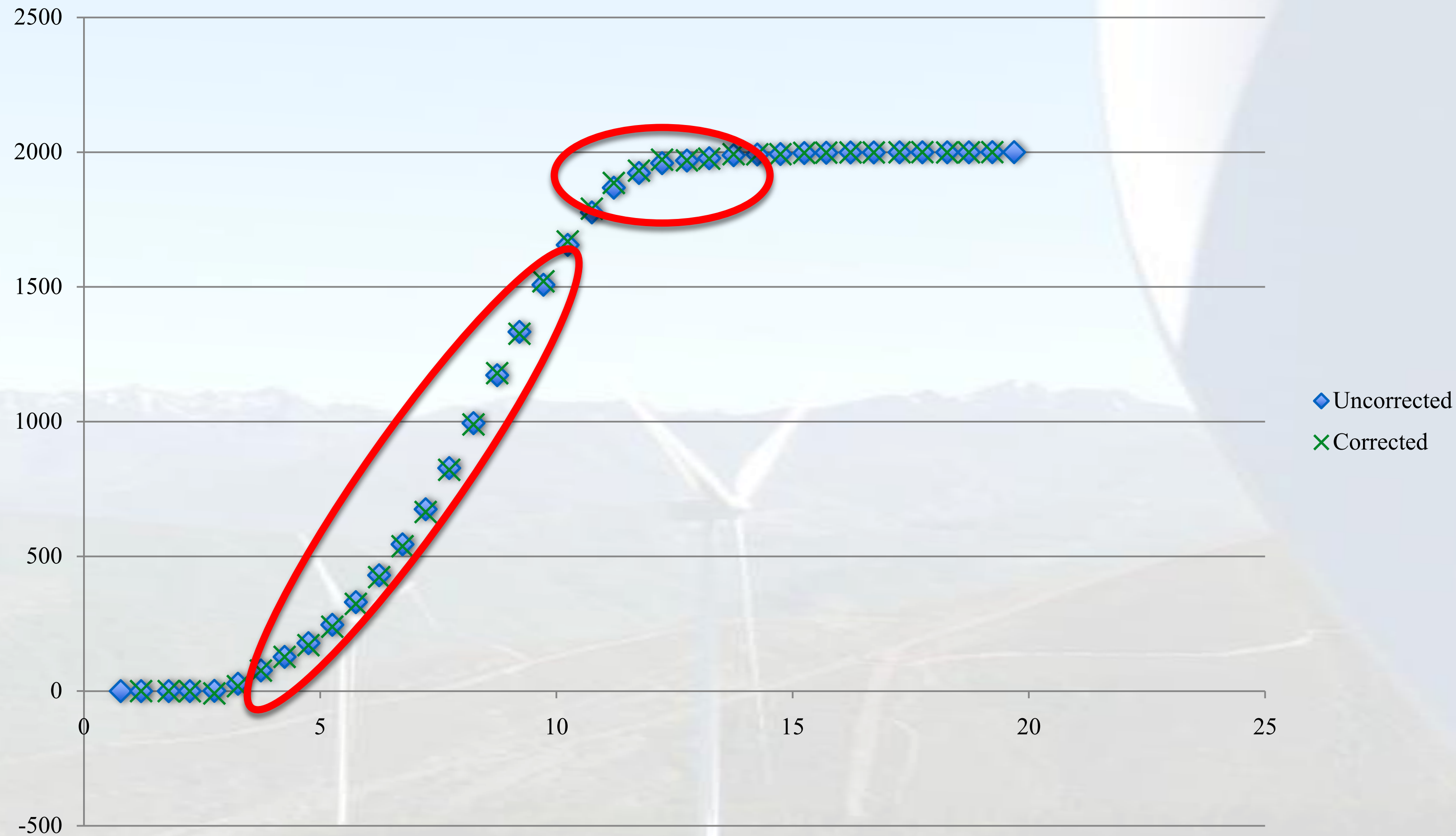



TI range with little contamination from neighboring BINs is very narrow (example: 95% of va lues within BIN)




Only very few data correspond to t he BIN they are recorded

# Simplified statistical approach (4)



# Method Comparison

| IEC Method | Langevin Power Curve | Simplified statistical approach |
|---|---|---|
| + Standard method<br>+ Well documented<br>+ Works with 10 min data | + Potentially very accurate Method<br>+ Very fast method | + Easy to use<br>+ Works with 10 min data |
| - Difficult to use | - Difficult to use<br>- Sensitive to assumptions and settings<br>- Non-standard method<br>- High-frequency data needed | - Cannot correct all errors due to 10 min averaging |

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# Thank you very much for your attention

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