POWER CURVE MEASUREMENT EXPERIENCES, AND NEW APPROACHES

EWEA Resource Assessment Workshop 2013 - Dublin

Mark Young - Head of Department, Renewables
25 June 2013

Objectives

- Overview of reasons for power performance testing
- Drawing conclusions from 450+ power performance tests
- Real-world examples of performance variation (and improvement)
- Status of relevant standards and methods
- Translating testing experience into energy assessment process

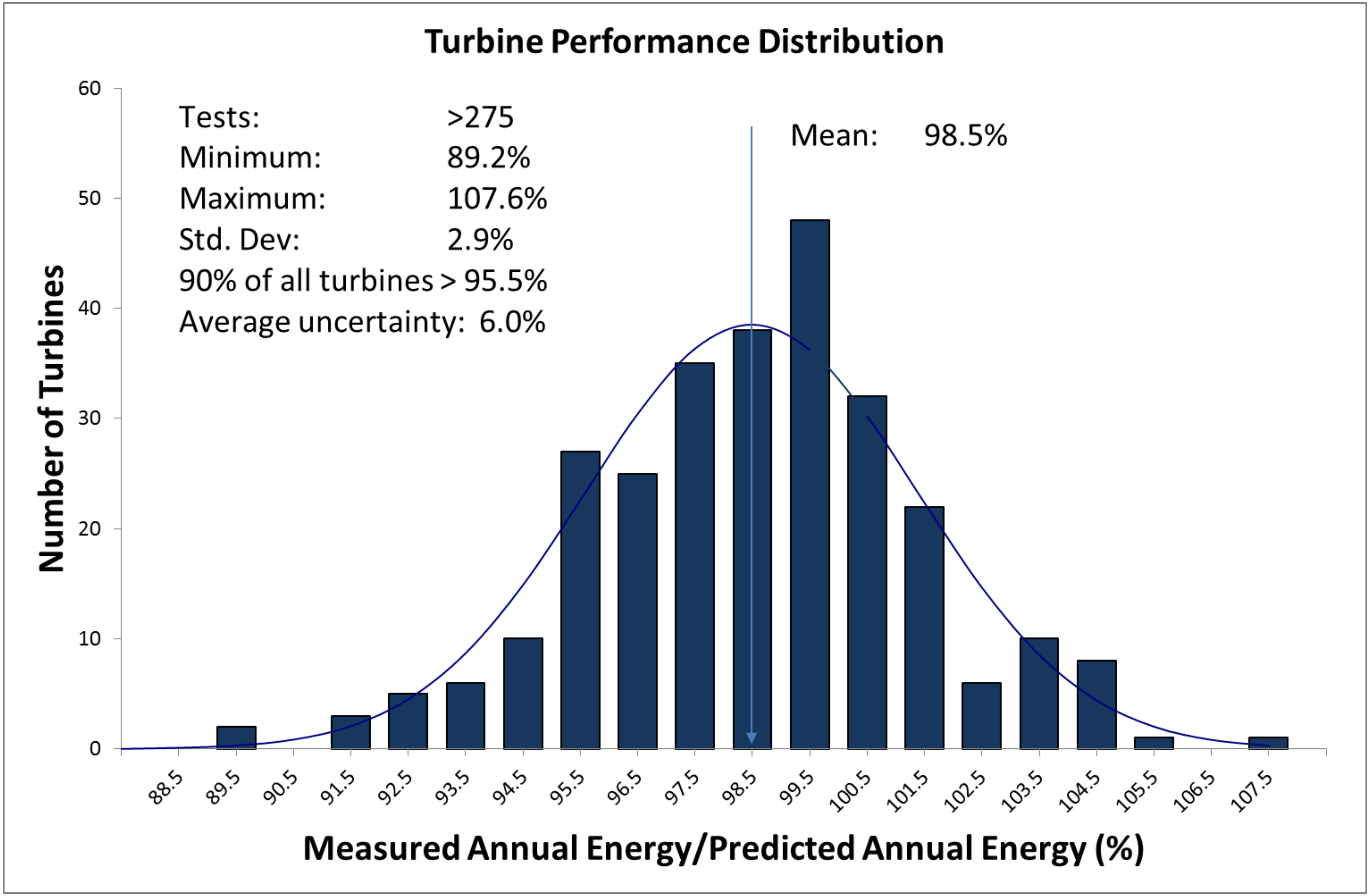
Why is power performance testing conducted?

- Regulatory compliance
- Warranty verification
  - Obtain liquidated damages if performance issues are observed
- Turbine performance verification and optimisation (asset risk management)
  - As-built baseline and life-cycle monitoring
- Characterise actual turbine performance in site-specific conditions
  - To be used to update yield forecasts and/or investigate shortfalls
  - Valuable input to OEMs
- Maintain balance in OEM/owner relationship
- Increased certainty -> increase asset value

Performance testing results from DNV KEMA database

Data set encompasses:

- >275 turbine tests (about half of DNV's experience)
- Dozens of different turbine types
- Flat and complex terrain ~ 50/50
- Troubled turbines, good performers, measurement issues
- Across all seasons
- Global results


Turbine Performance Distribution
Tests: >275
Minimum: 89.2%
Maximum: 107.6%
Std. Dev: 2.9%
90% of all turbines > 95.5%
Average uncertainty: 6.0%
Mean: 98.5%
Number of Turbines
0
10
20
30
40
50
60
88.5
89.5
90.5
91.5
92.5
93.5
94.5
95.5
96.5
97.5
98.5
99.5
100.5
101.5
102.5
103.5
104.5
105.5
106.5
107.5
Measured Annual Energy/Predicted Annual Energy (%)

Flat vs. Complex Terrain Results – database subset

- Turbines in flat terrain
  - Average: 98.4%
  - Standard Deviation: 2.6%
  - Average uncertainty: 5.1%
  - Sample size: ~100

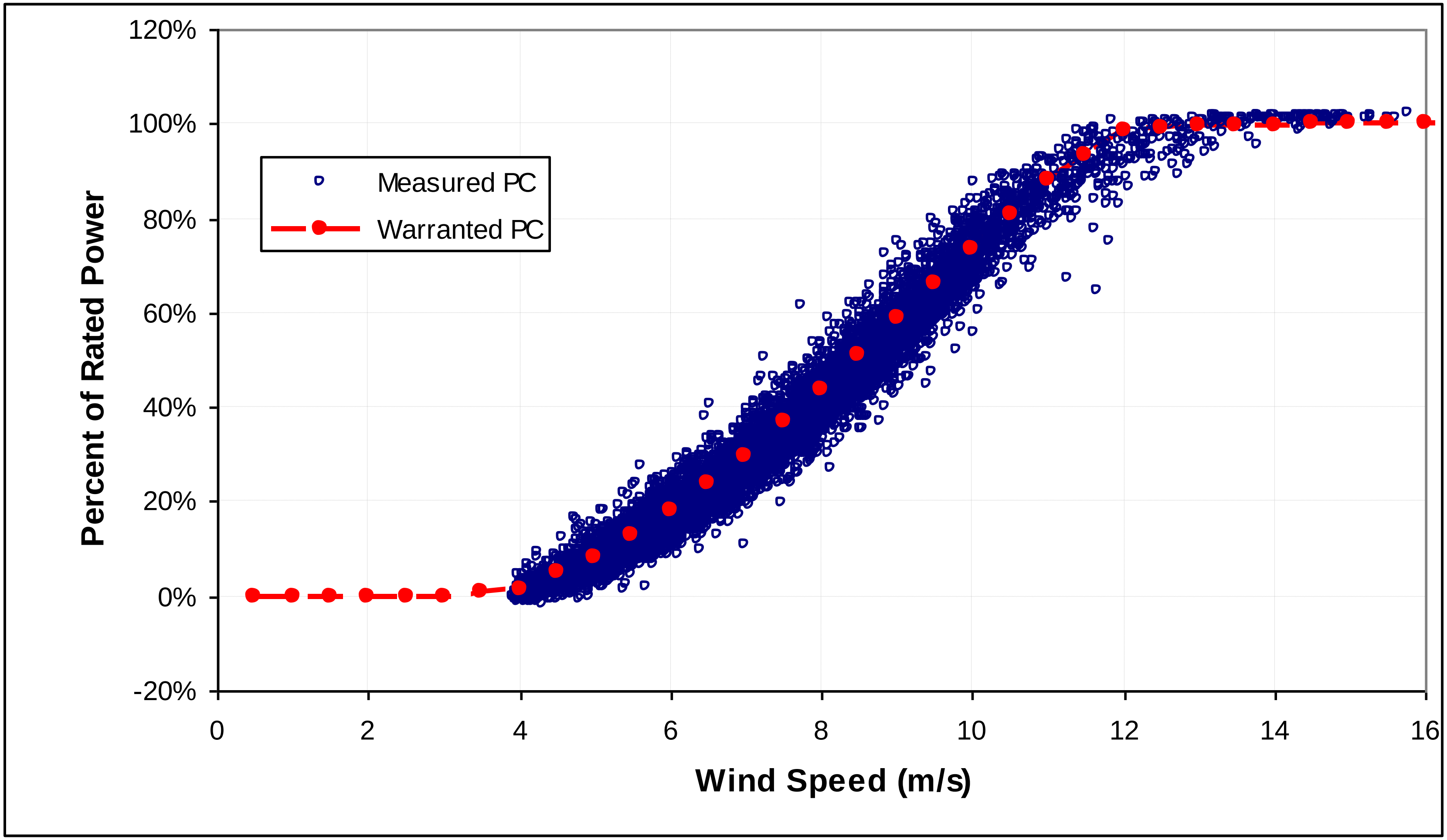
- Turbines in complex terrain
  - Average: 98.6%
  - Standard Deviation: 3.2%
  - Average uncertainty: 8.2%
  - Sample size: ~100

- More recent tests lower than database mean
- Variations within same model
- Variations model to model
- 5-10% of PPTs result in failures or at least re-testing

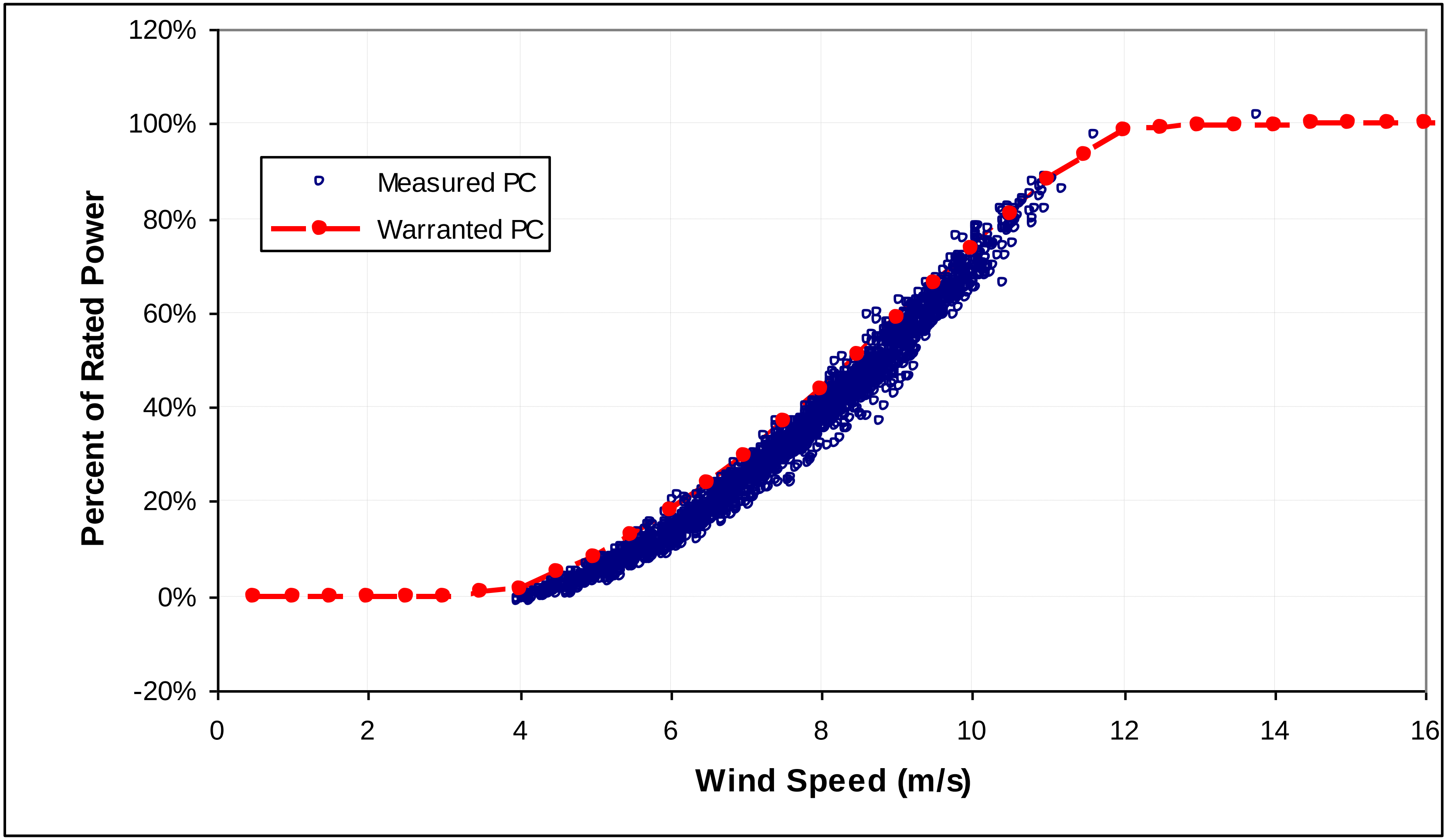
Case studies

- Stability
- Temperature/density/elevation
- Complex terrain and turbulence effects
- Controls requiring optimisation

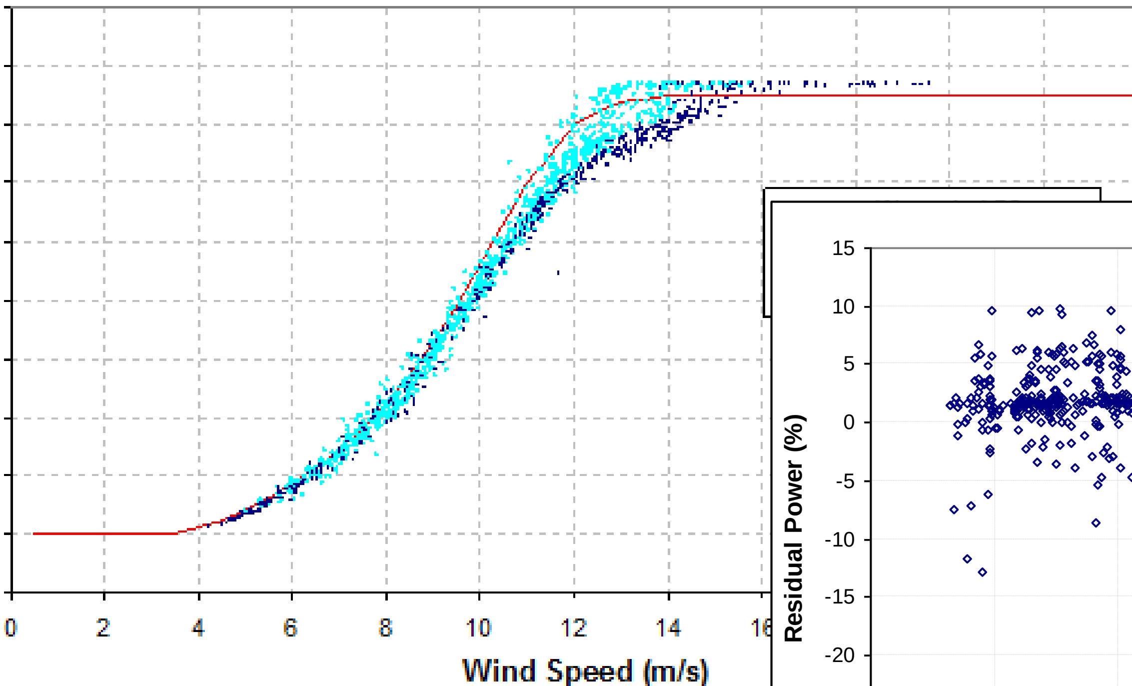
Measured power curve – all valid data from PPT



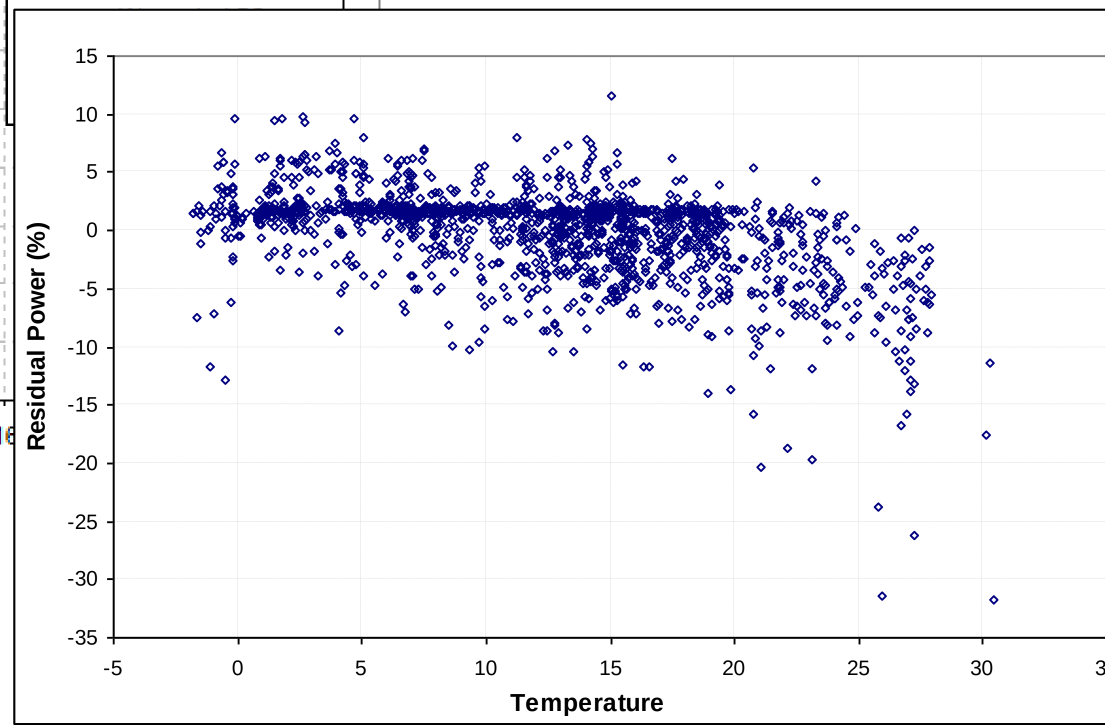
Measured power curve – valid data during stable conditions



Density

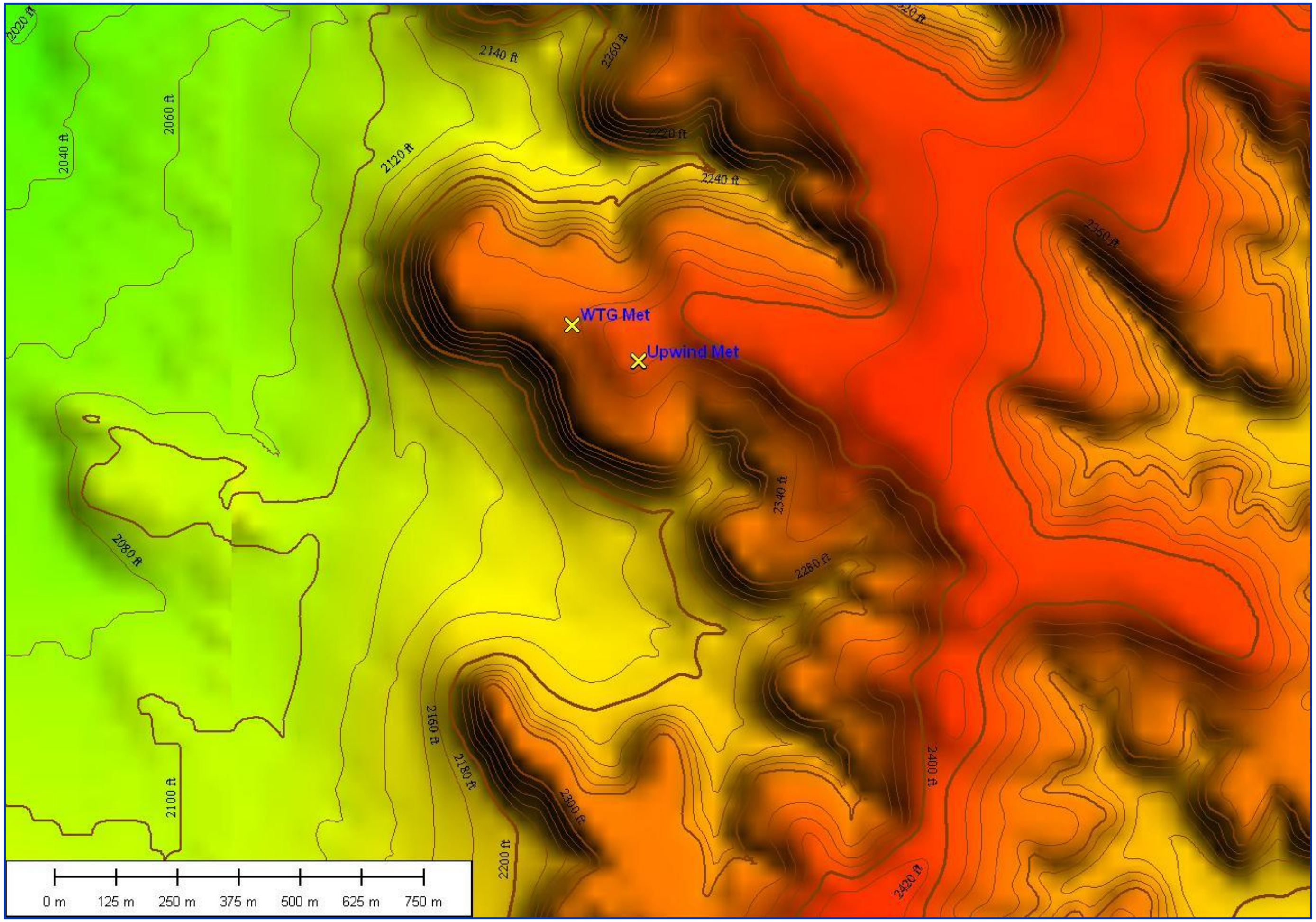


Low Air Density

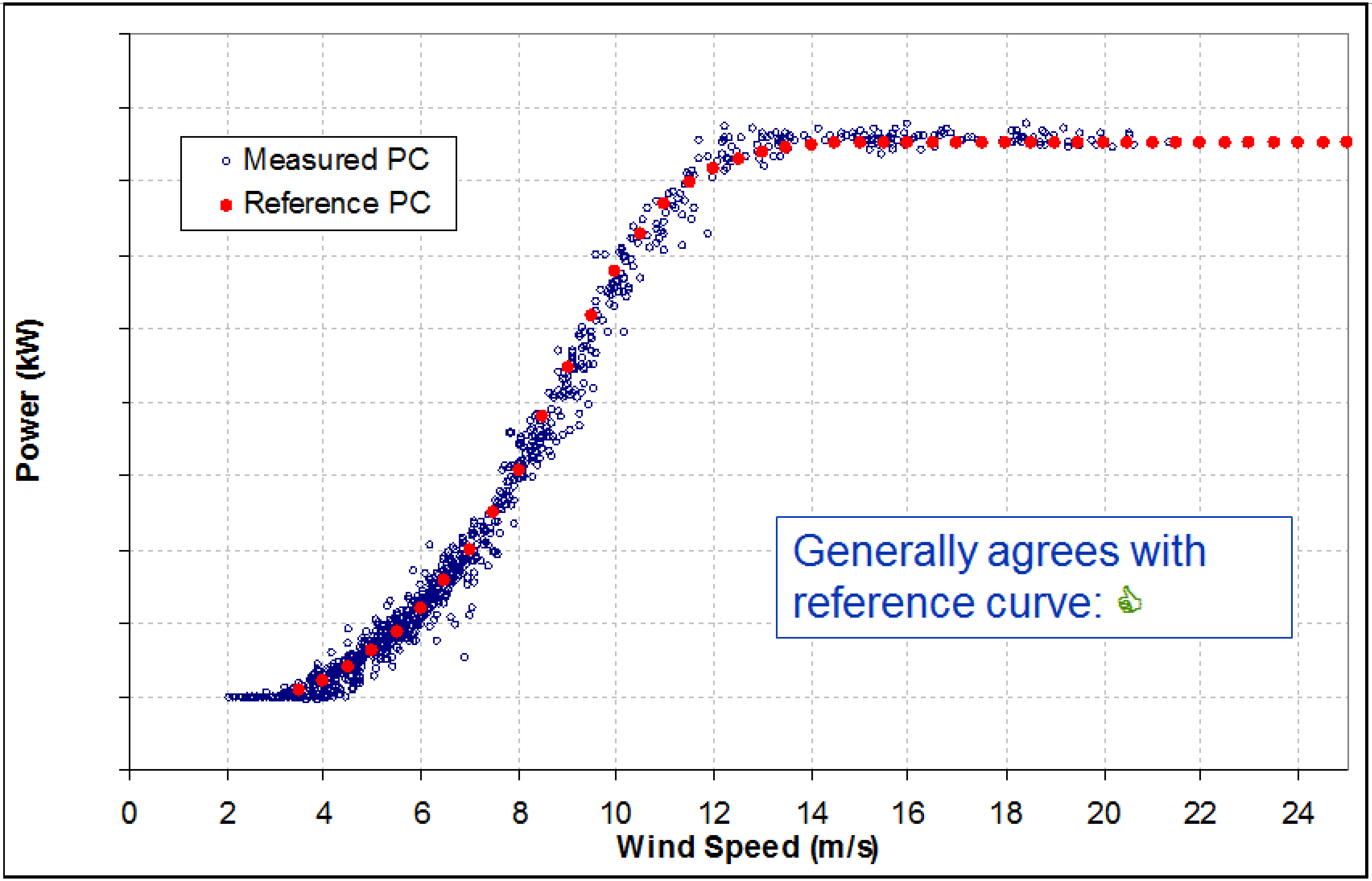


Density Correction Limitations

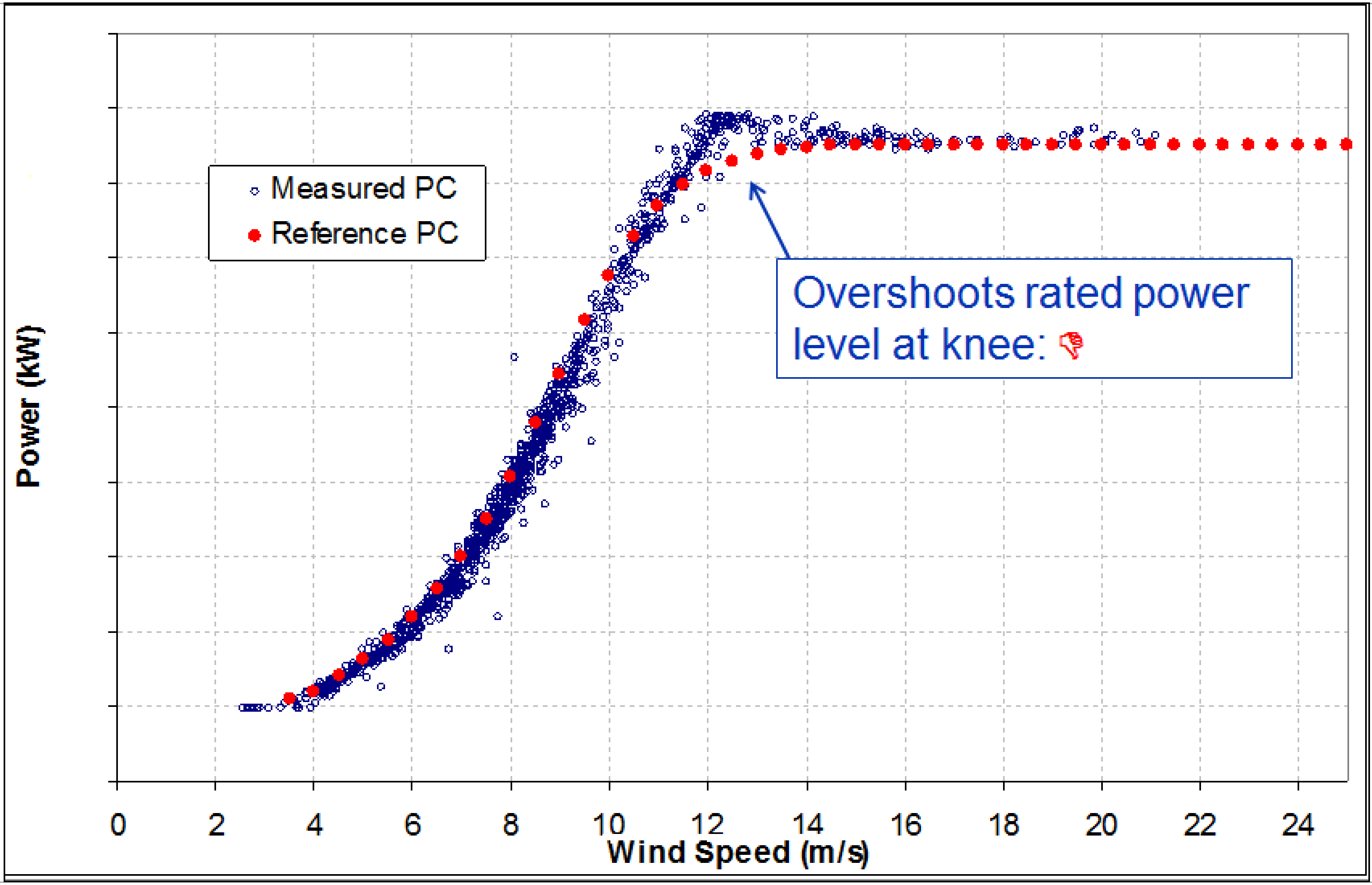
Complex terrain



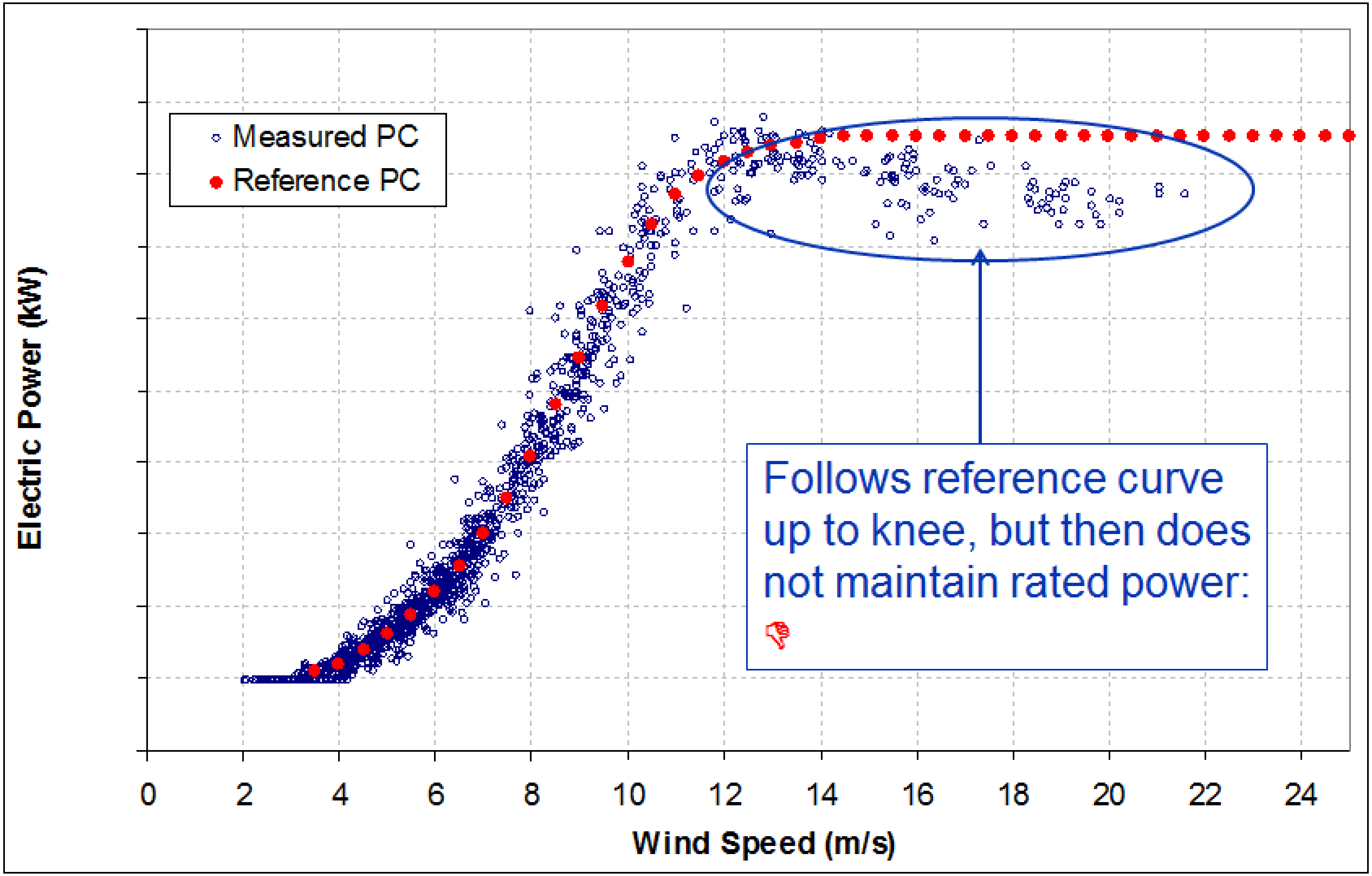
Type A turbine, high turbulence



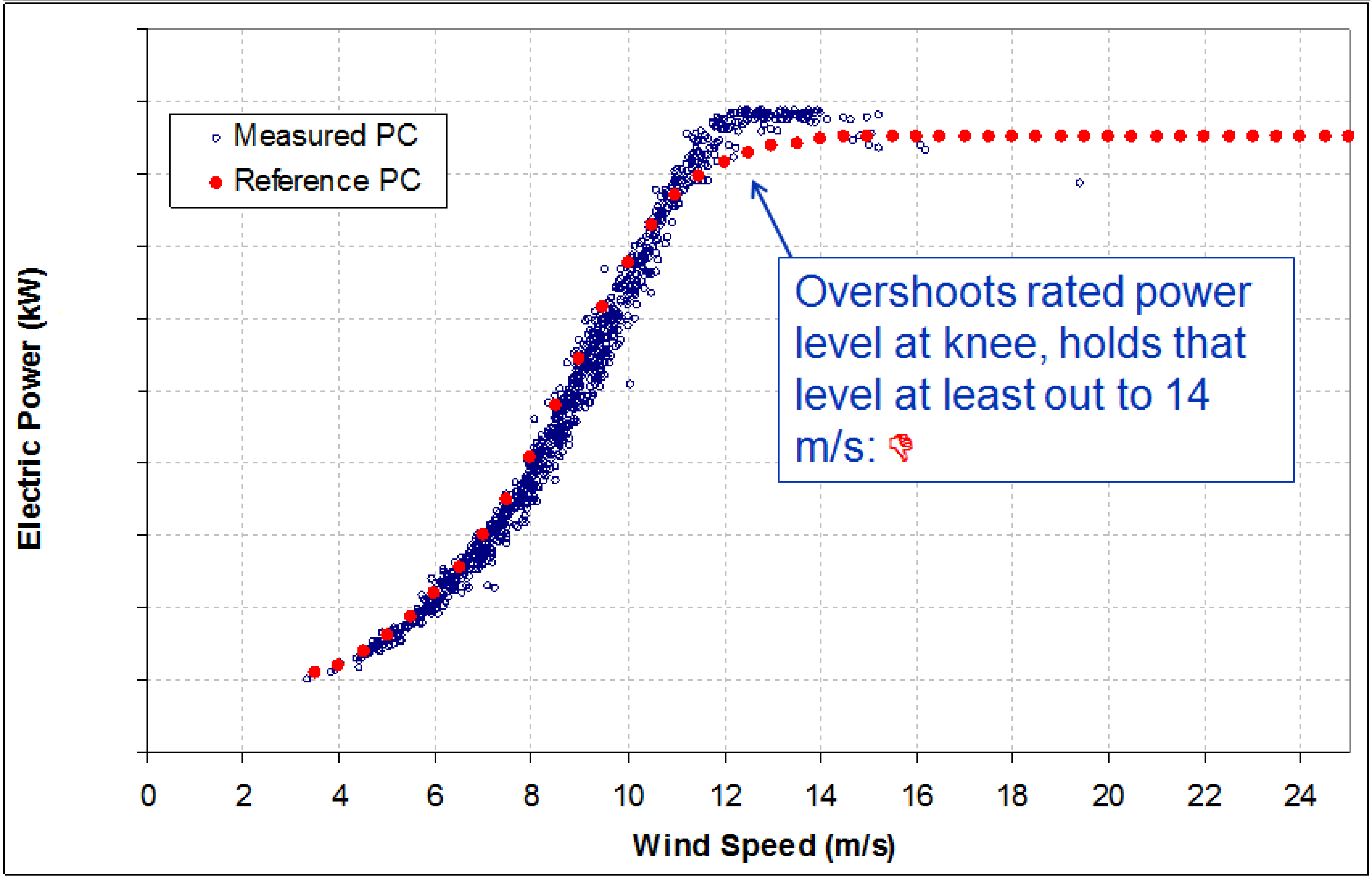
Type A turbine, low turbulence



Type A turbine #2, high turbulence



Type A turbine #2, low turbulence



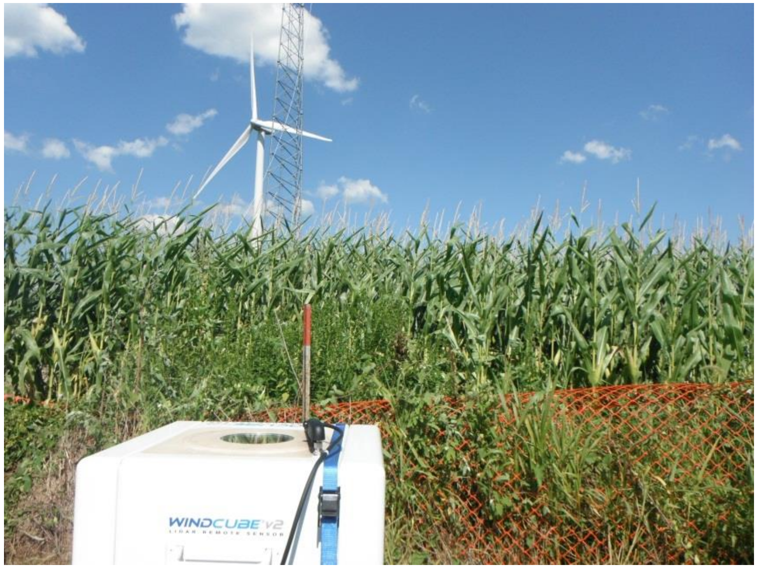
Other examples of underperformance

- New control algorithms – not fully validated
- High shear
- Intermittent pitching routines
- Blade surface degradation
- Curtailments – normal operation or not?
- In many cases, poor performers have been improved, even if turbines did not "fail"
- **An expensive way to find incorrect control parameter settings!**

Evolving methods

Power performance measurement methods development

- Ground-mounted remote sensing power perf and site calibration
  - Good field results, track record is improving
  - Slightly higher uncertainty
- Nacelle-mounted lidar
  - Encouraging results for measurements (Wagner-DTU)
  - Much more challenging to integrate into controls
- SCADA-measured power curve analysis

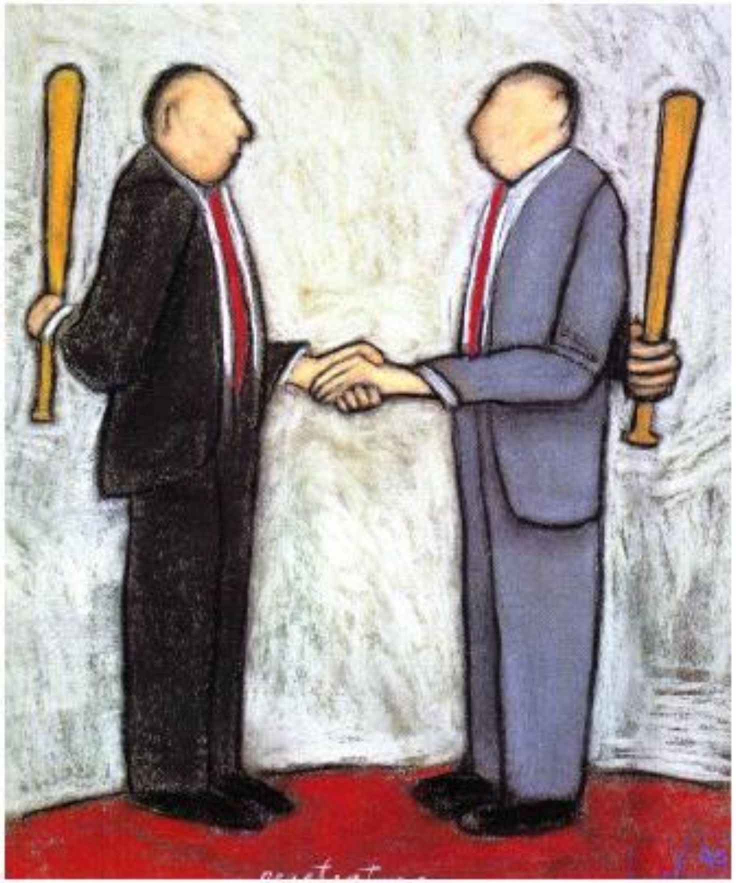


- Nacelle-mounted cup anemometer power curve measurement
- Areas of improvement/challenge
  - Site calibration – remote sensing and equivalent wind speed does not eliminate challenges
  - Cup anemometer calibration consistency (tunnel-to-tunnel) and sensor-to-sensor differences
  - Lessons *to be* learned with remote sensing for power performance measurement
    - What do we not know? What are we missing?
    - Should we expect issues with similar consequence than we have seen with cup anemometers?

Power performance warranty terms: typical examples

- Absolute warranty terms: 95%, 97%, 98%, 100%
- Lesser of (95%) or (100% - Uncertainty)
- Flat terrain 97%, complex terrain 100% – Uncertainty
- 98% minus uncertainties
- (Measured AEP/Warranted AEP)x100 – (Uncertainty% - 4)/2 > 95%
- Typical measurement uncertainty:

  - 3-5% in flat terrain and 4-8% in complex terrain
- Evolution of warranty terms:
  - Warranty levels have been increasing: e.g., 97-98% without significant limitations
  - Inverse, cyclic, relationship between turbine demand and warranty levels



Status of power performance standards

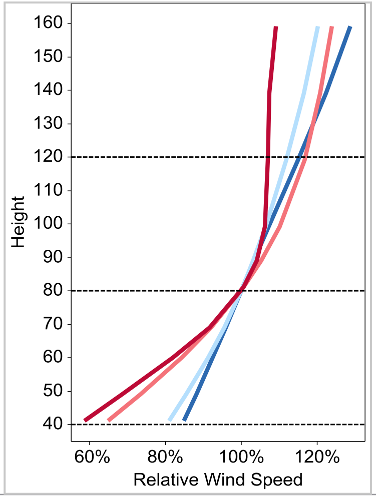
- IEC 61400-12-1
  - Back to CD stage, 2015 release?
- IEC 61400-12-2
  - Nacelle anemometer based testing
  - Not seeing much, if any uptake due to complexity and expense
  - Update for nacelle-mounted lidar?
- IEC 61400-12-3
  - Wind farm power curve
  - Work suspended to inactivity
  - Too difficult to standardise a method with so many site-to-site variations
  - End value is questionable given conflicts with stakeholders (OEMs, developers, consultants)
- MEASNET Version 5 (2009)
  - Additional requirements to IEC 61400-12-1:2005
    - Cup calibration by MEASNET
    - Measure and report shear, TI, pitch
    - Obstacle assessment, data filtering and reporting

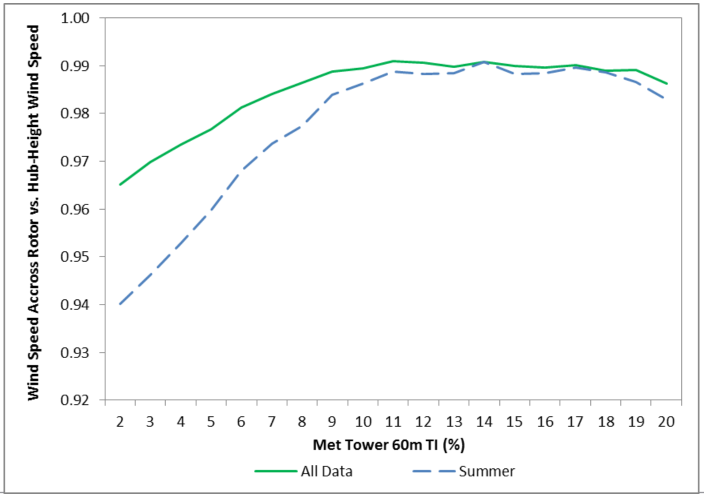
New methods and standards: implications on warranties

- Standard references in warranties are still to 61400-12-1:2005 with various limitations on filtering, process and instrumentation
- Equivalent wind speed and filtering based on cross-rotor measurements are likely to be introduced into warranties in the near future, before IEC 61400-12-1 v.3 is released
- OEMs are focused on limiting conditions—simulating a ‘wind tunnel’
- Multi-variant warranted power curves are needed although not expected anytime soon due to:
  - Challenges with field validation
  - Limitations of current models
- In time of lower turbine demand, buyers have more leverage on warranties
  - Owner/operators should be active in the development of better methods

Power curve experience, translating to energy estimation

- IEC focus is on reducing uncertainty of power performance measurements, reducing influence of inflow conditions. To reduce EA uncertainty (increase NPV), these methods need to be incorporated into EAs—layered analysis, equivalent wind speed analysis—using remote sensing and tall masts.
- Need to move beyond describing wind profile across the rotor with one or two numbers/parameters—large variations in energy flux are observed with similar shear, TI, stability, etc.
  - Ideal is a multi-variant power curve; only practical if modelled
  - Stop-gap is power or wind speed correction and measurements across the rotor





Concluding points

- Traditional power performance testing almost always works—don't discount value!
- Experience with lidar power performance testing is limited so far—we are still learning a lot about cup anemometers so caution must be used during this transition period.
- Value of warranty testing is oft debated, however, it provides:
  - Value beyond relying on damages—ability to improve and optimise performance
  - Important feedback loop!
  - Allows for institutional knowledge to build up for those that measure
- Realising the most from your investment:
  - Traditional test combined with nacelle-based testing
  - Use of remote sensing and equivalent wind speed
  - Long test periods to capture inter-seasonal effects and verify
  - Learn from results and incorporate into turbine procurement process

www.dnvkema.com