Power Performance Testing: Truly Useful of Just Box Ticking

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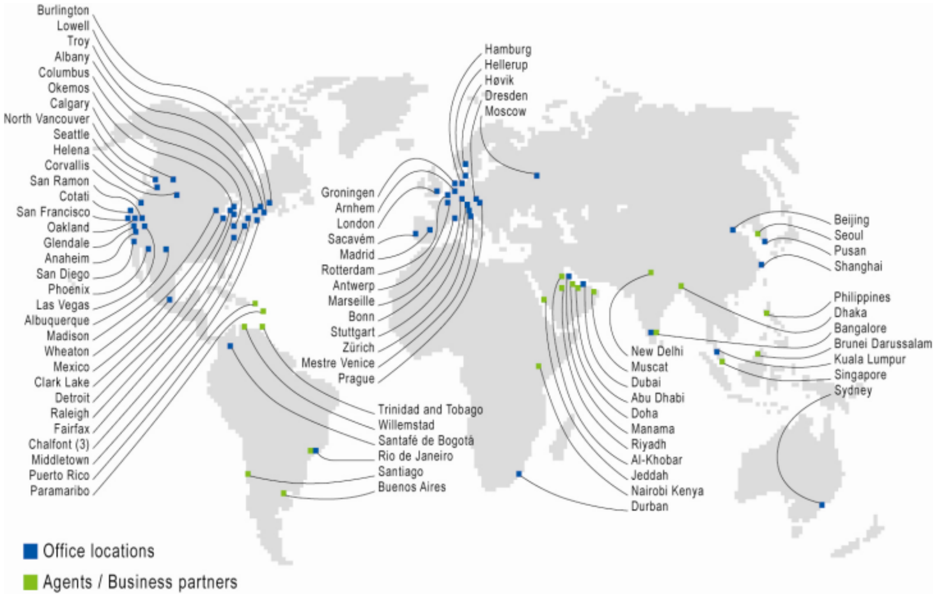
DNV KEMA Energy & Sustainability

- Part of DNV Group—an independent foundation with HQ in Norway founded in 1864—with 11,000 employees globally
- 200+ wind energy experts
- 30 GW+ energy assessments globally
- Testing, inspections, certification, consulting
- Risk, performance, and quality management
- Research & innovation
- Offices in over 30 countries



Why is power performance testing conducted?

- Regulatory compliance
- Warranty verification
  - Obtain liquidated damages if performance issues are observed
- Turbine performance verification (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

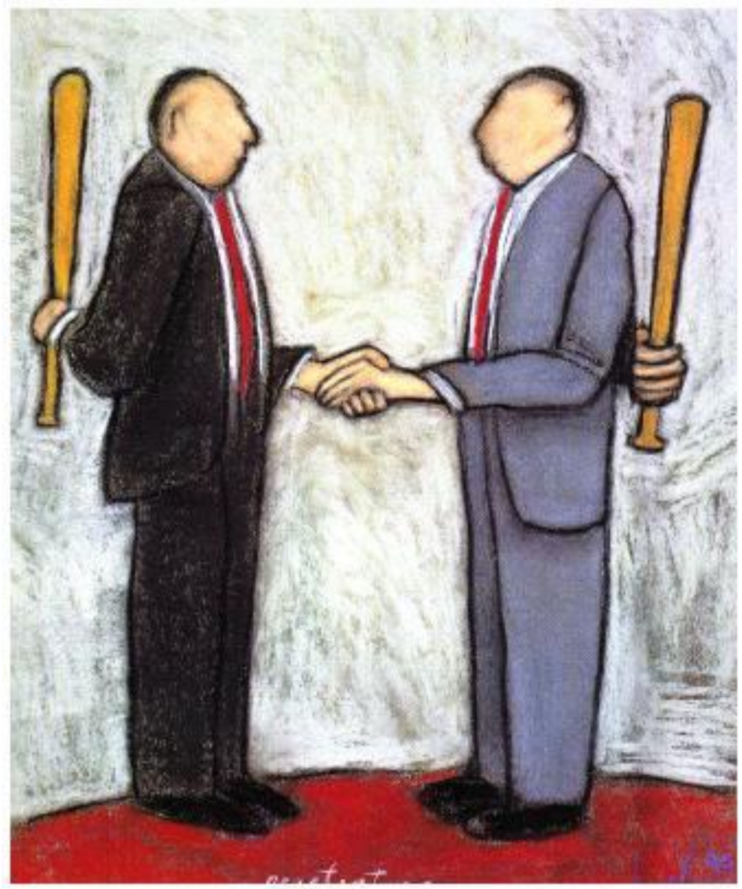
Perspectives on power performance testing

- OEM perspective:
  - Verify the power performance in conditions that are consistent with the published (type test) power curve
- Owner/operator perspective:
  - Verify the actual insitu power performance
- Conflict!
  - Consequences
- Range of philosophies with owner/operators

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



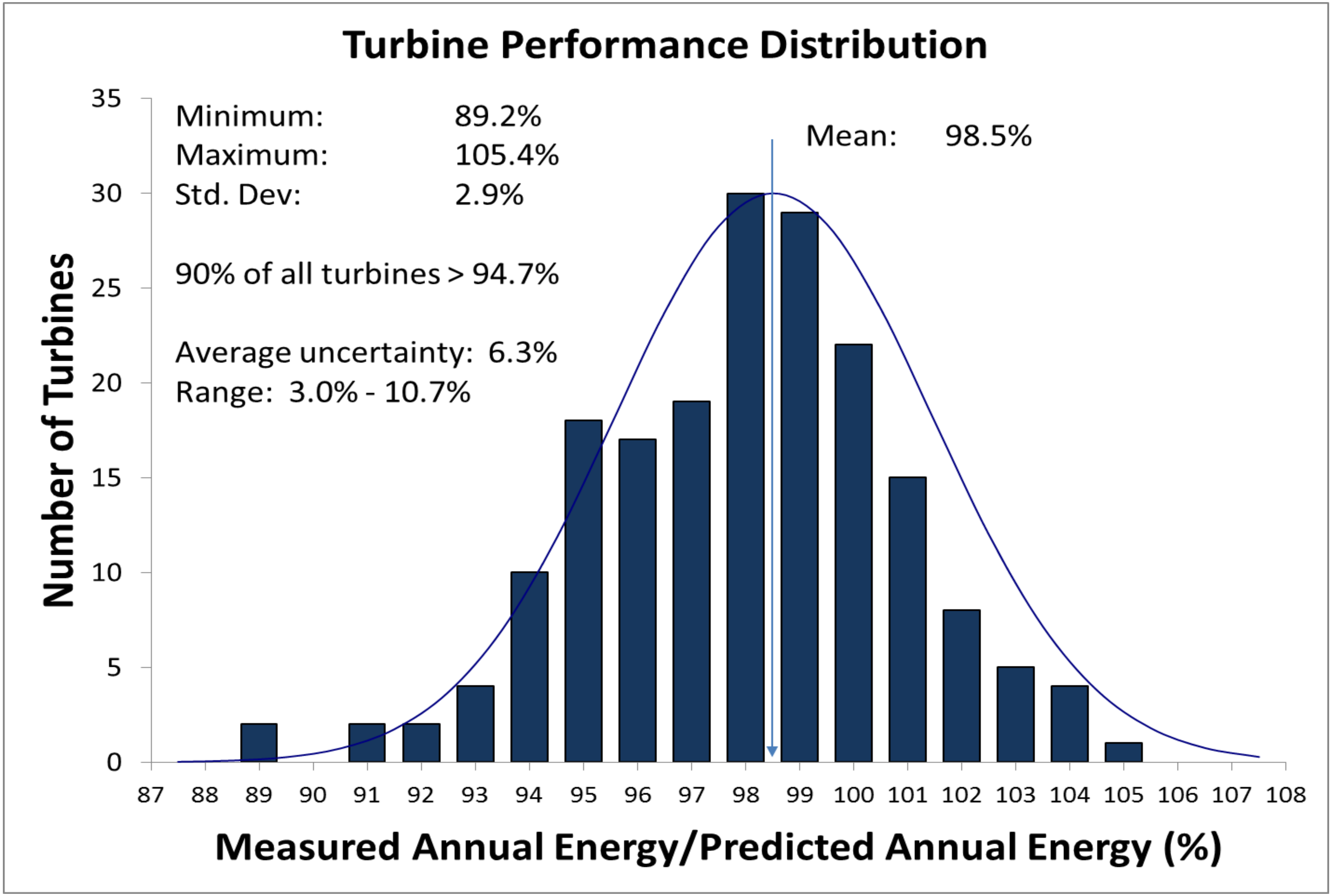
Uncertainty effects on warranty example

- Three turbines, complex terrain
- Warranty criteria based on average results of the three tests
- Warranty criteria:
  - Measured Annual Energy/Predicted Annual Energy + uncertainty > **97%**
- Results:
  - Measured Annual Energy/Predicted Annual Energy = **94%**
  - Uncertainty = **7.5%**
  - Result = **101.5%**
- Warranty is met, but **6%** of the expected energy is potentially missing!

Performance testing results from DNV KEMA database

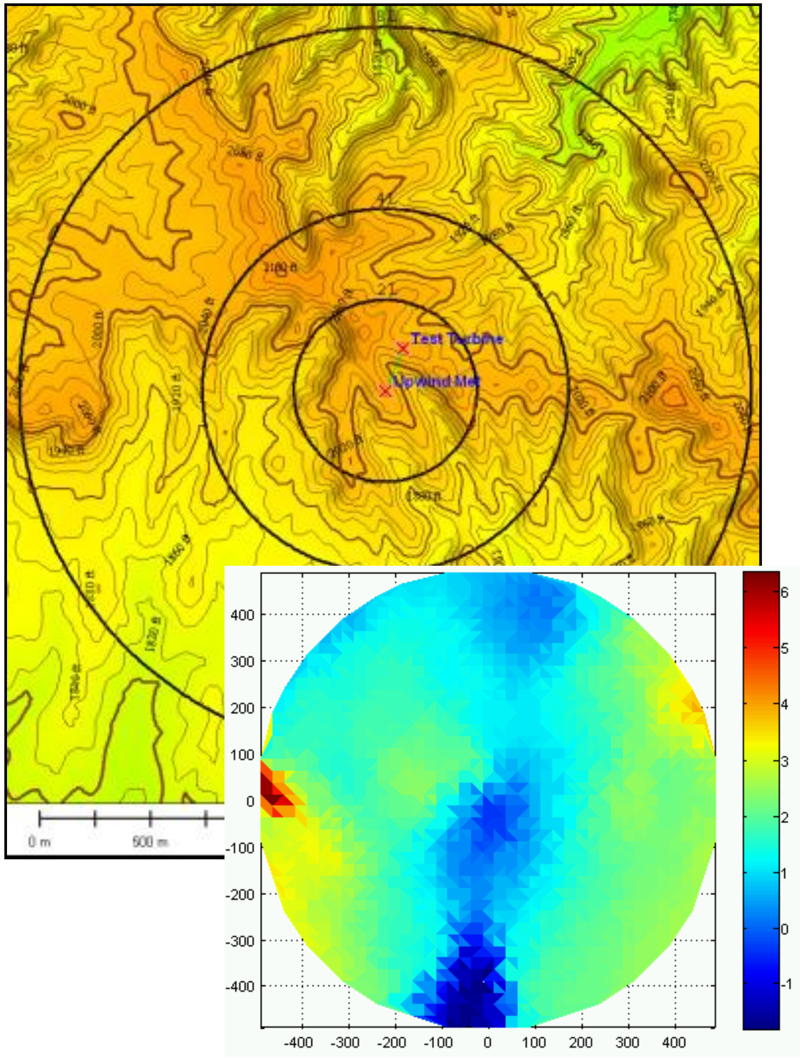
Data set encompasses:

- ~200 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
Minimum: 89.2%
Maximum: 105.4%
Std. Dev: 2.9%
90% of all turbines > 94.7%
Average uncertainty: 6.3%
Range: 3.0% - 10.7%
Mean: 98.5%
Number of Turbines
35
30
25
20
15
10
5
0
87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108
Measured Annual Energy/Predicted Annual Energy (%)

Variations in turbine performance

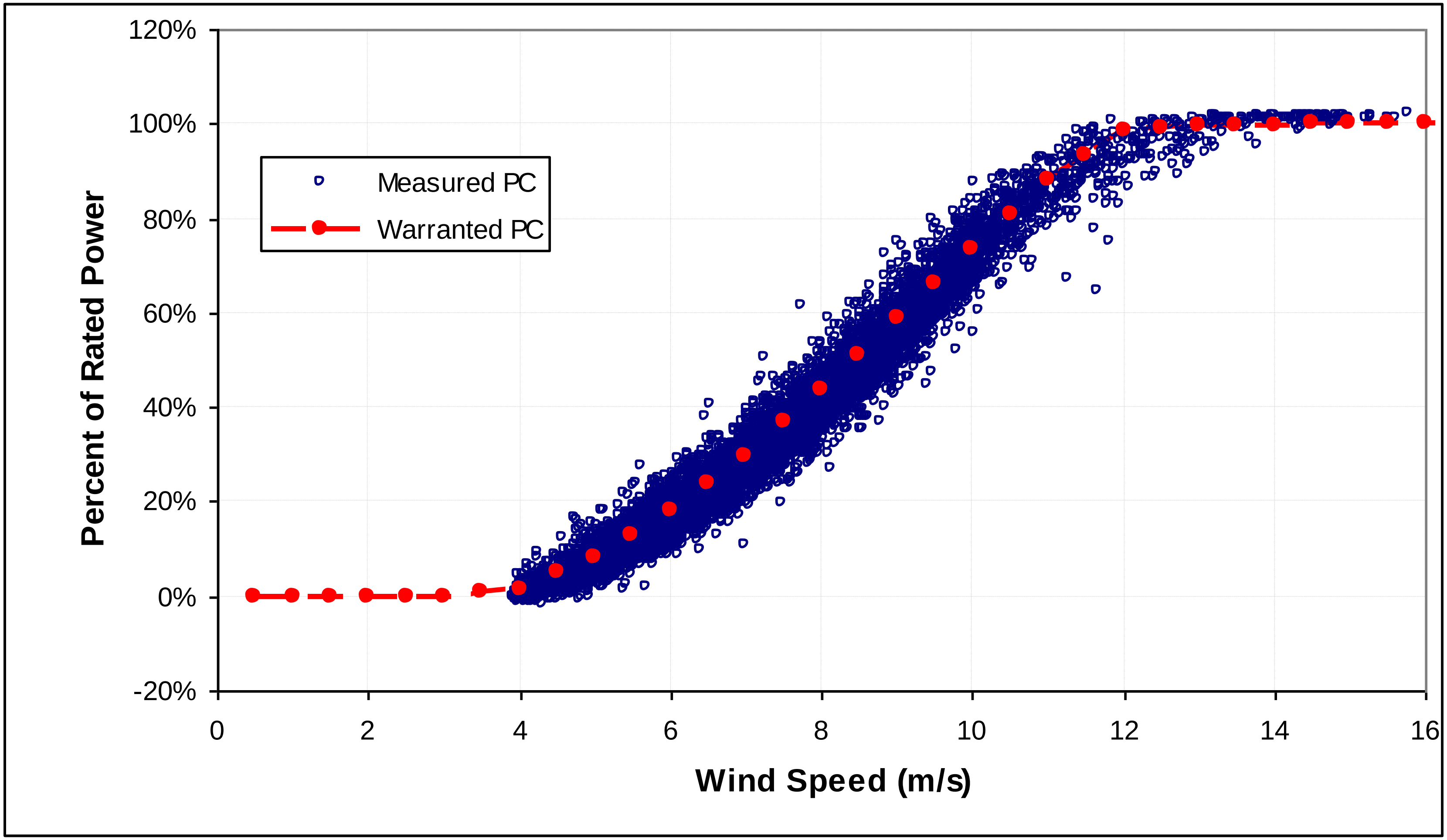
- Variation within turbine model
- Variation with site conditions
- Variation within single wind project
- Turbine issues
- Site conditions
- Reference curve measurement errors
- Anemometer and calibration differences



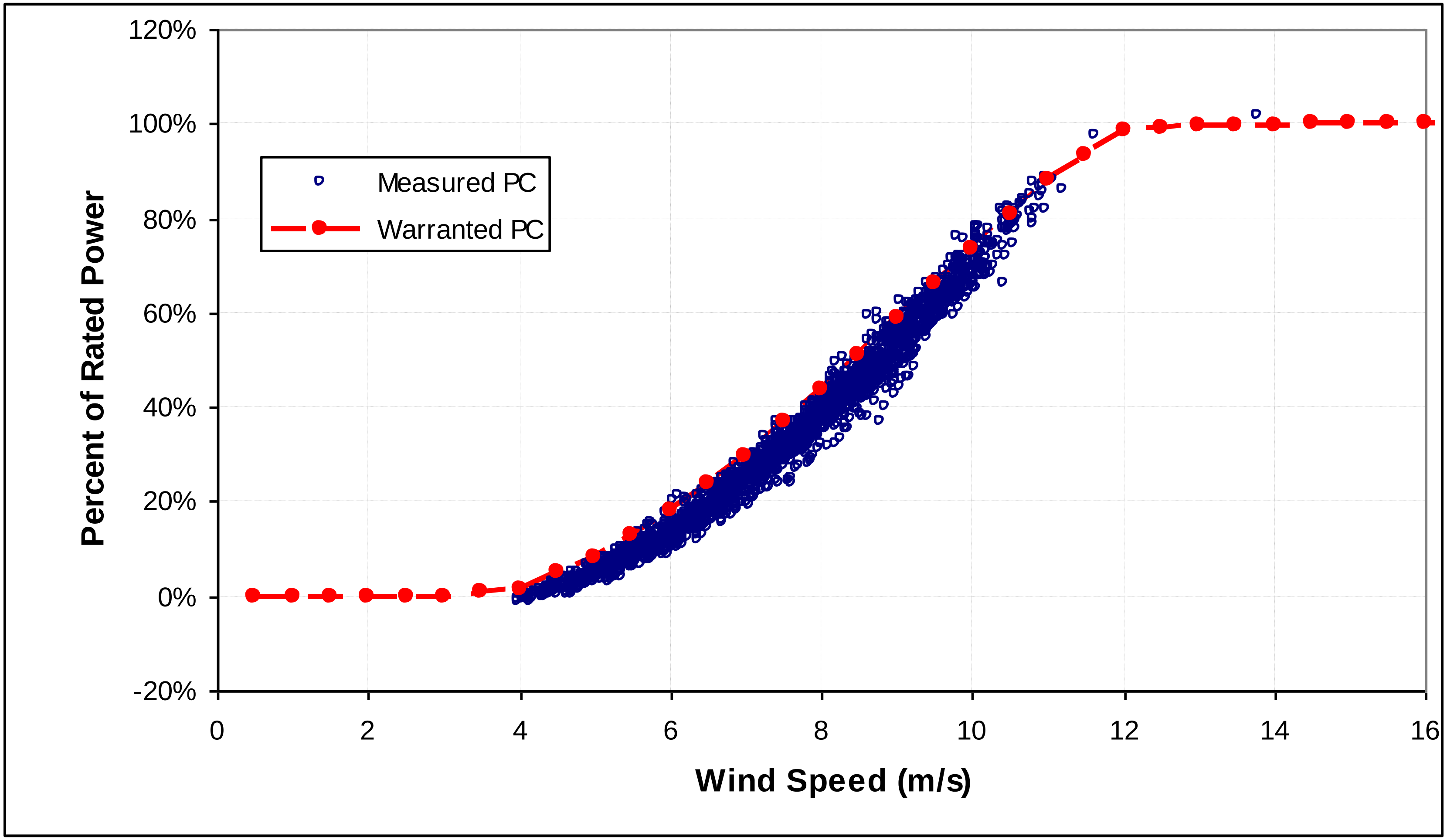
Case studies

- Stability
- Temperature/density/elevation
- Complex terrain and statistical (TI) effects
- Controls requiring optimisation
- 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!**

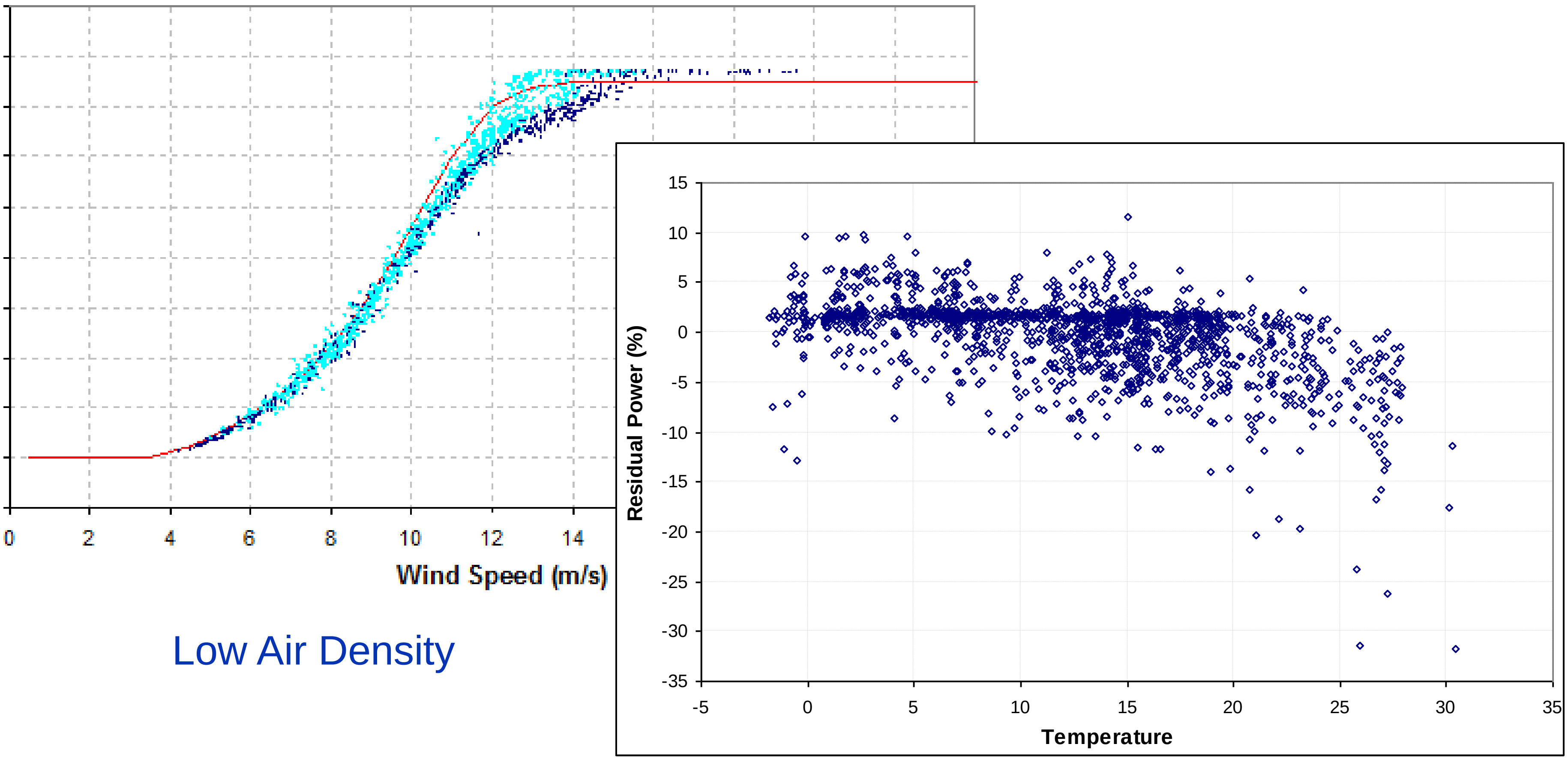
Measured power curve – all valid data from PPT



Measured power curve – valid data during stable conditions



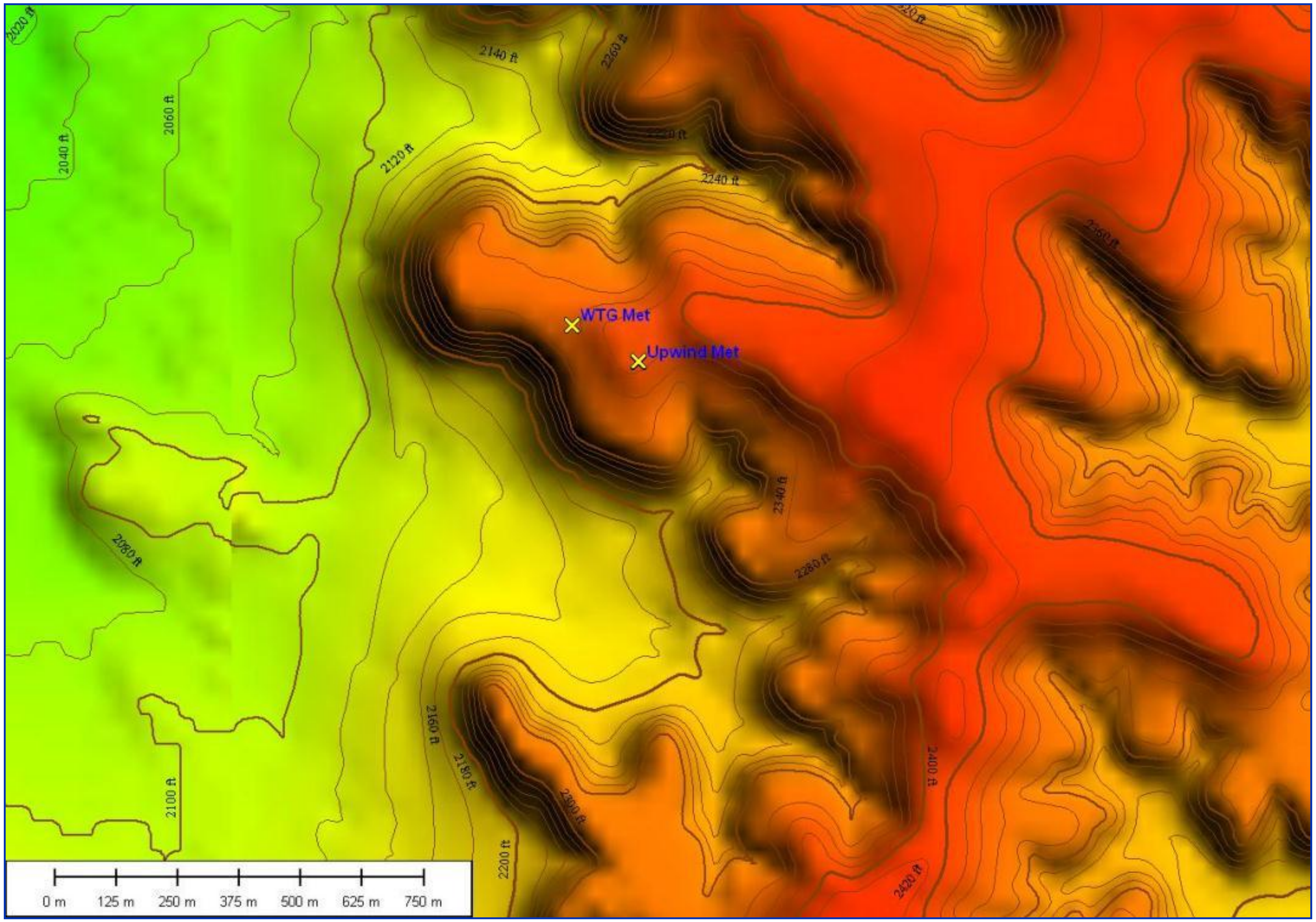
Density



Low Air Density

Density Correction Limitations

Complex terrain



Best practices – realising the most from your investment

- **Those that measure, understand…**
- Proper mast and instrument boom design
- Careful test site selection
- Traditional test combined with nacelle-based testing
  - Nacelle-based test standard IEC 61400-12-2 under development
- Long test periods to capture inter-seasonal effects and verify
- Negotiate fair (risk shared) and testable warranty terms with OEMs
- Consider anemometer differences between testing and wind resource measurement
- Use of SCADA tower for test
  - Practical for large projects
- Repeat test to identify performance degradation
- Gain experience with rotor-area average and other newer techniques
- Incorporate measurement results into project performance prediction
- Learn from results and incorporate into turbine procurement process

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