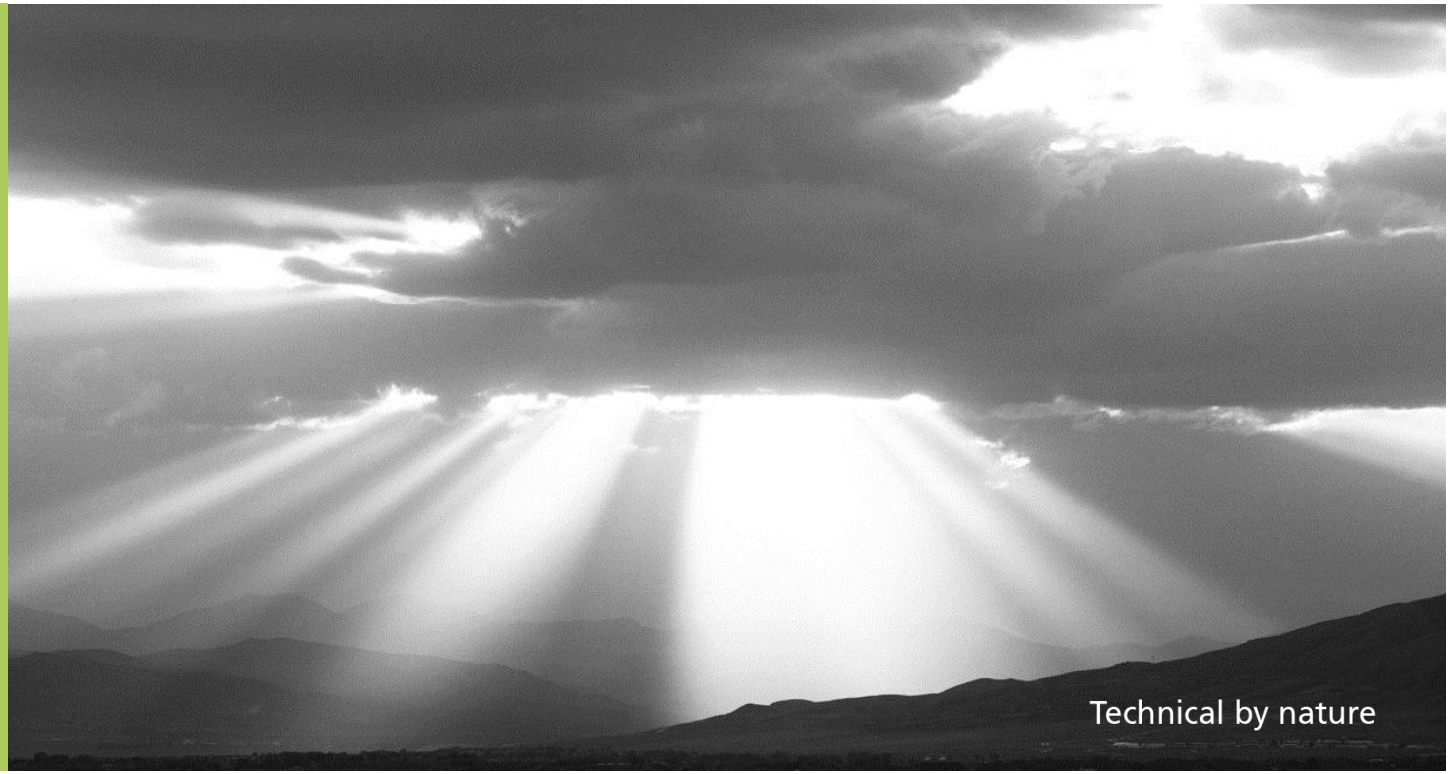
How does the real world performance of wind turbines compare with sales power curves?

EWEA: Lyon, July 2012 – Keir Harman



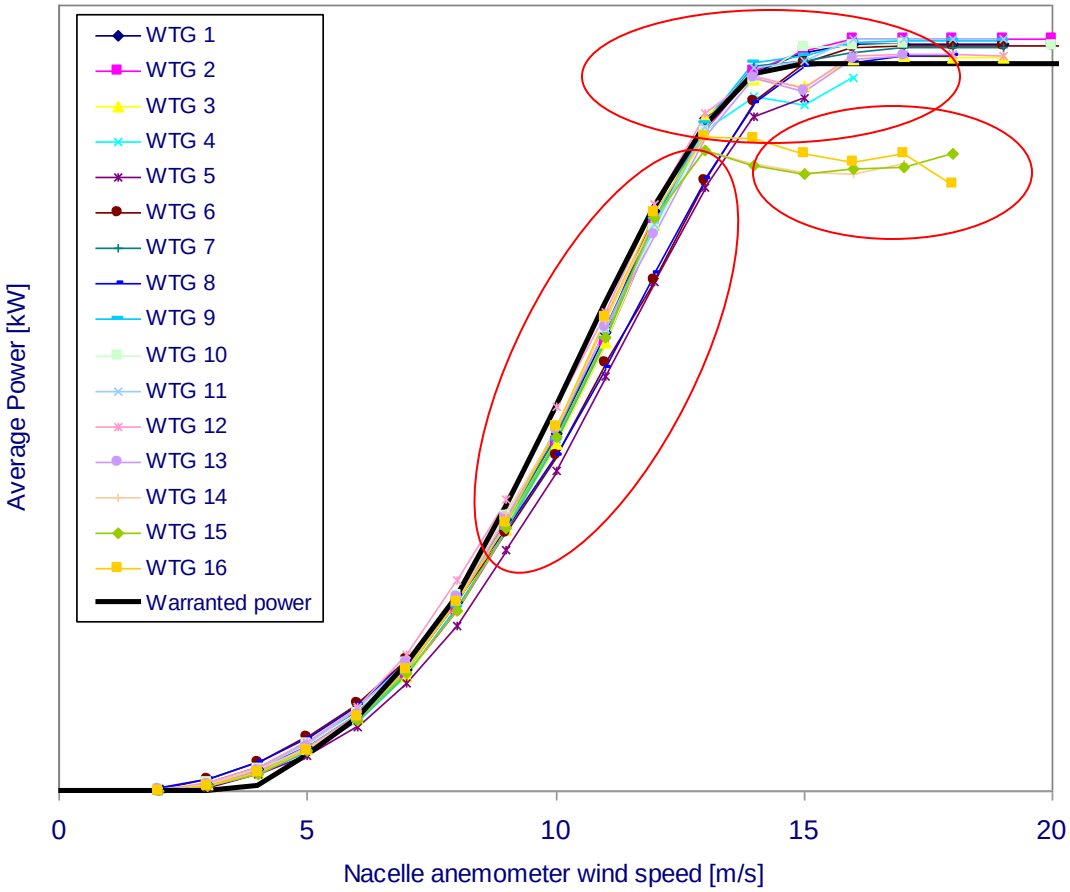
Asset Management and Optimisation Services (AMOS)

- Turbine performance monitoring
- SCADA-based condition monitoring
- Fault diagnosis and forensic analysis of SCADA data
- Post-construction energy forecasts
- Warranty calculations
- End of warranty inspection analyses
- O&M advice
- Reliability profiling and benchmarking

Over 30 GW of operating wind farms assessed to date

What do we typically see in operating data?

- Power curves rarely lie on the sales power curve

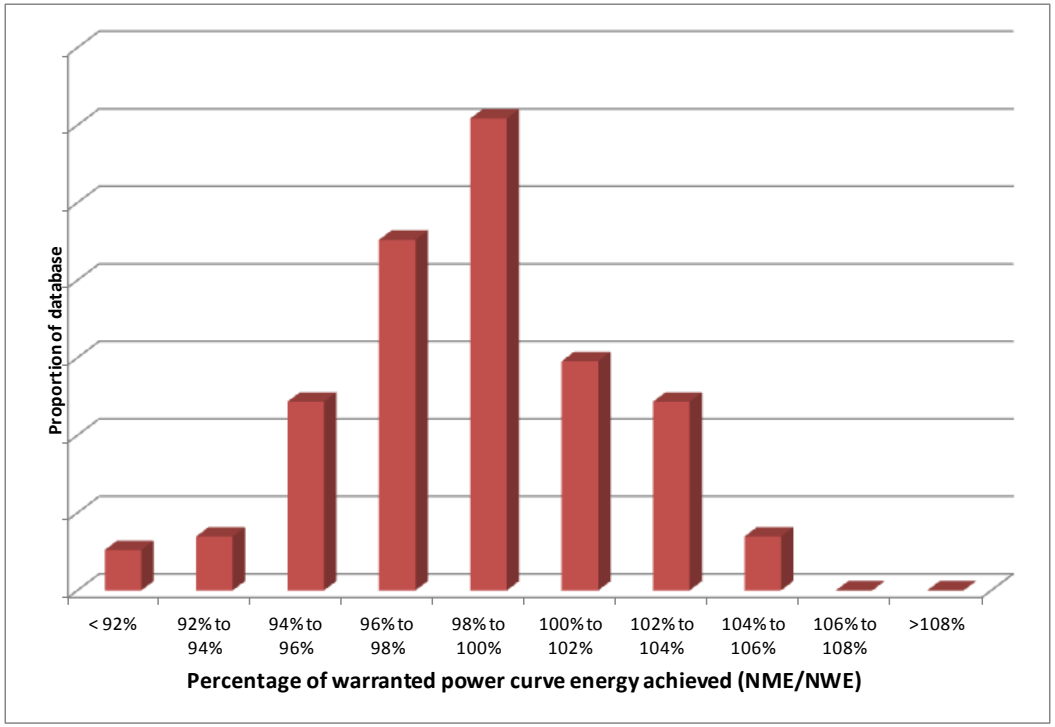


Real world power curve losses/gains categorised

Category	Typical range of loss/gain (nominal energy %)	Most likely (nominal energy %)
1) Generic power curve performance		
2) Mechanical sub-optimal performance	???	
3) Environmental: icing and dirty blades		
4) Wind conditions: turbulence intensity, shear and flow inclination		

Category 1: Generic power curve performance

- 115 project power curve tests using IEC guidelines [61400 pt 12-1]



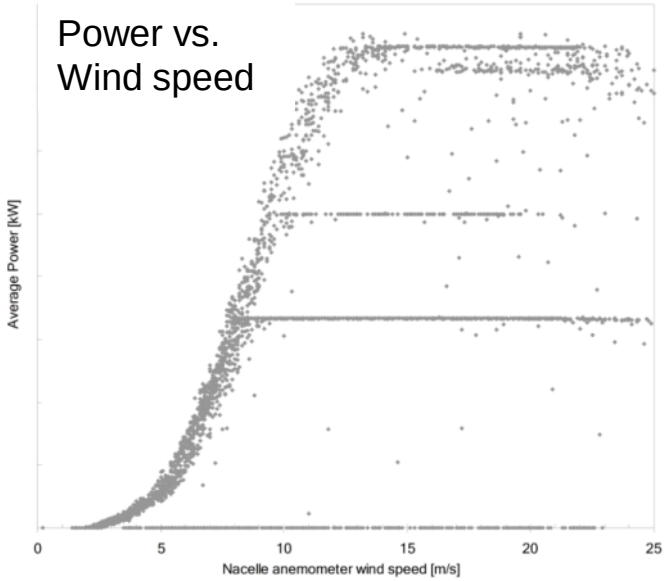
- Average of results = 99%
- IEC measurement uncertainty typically 5%

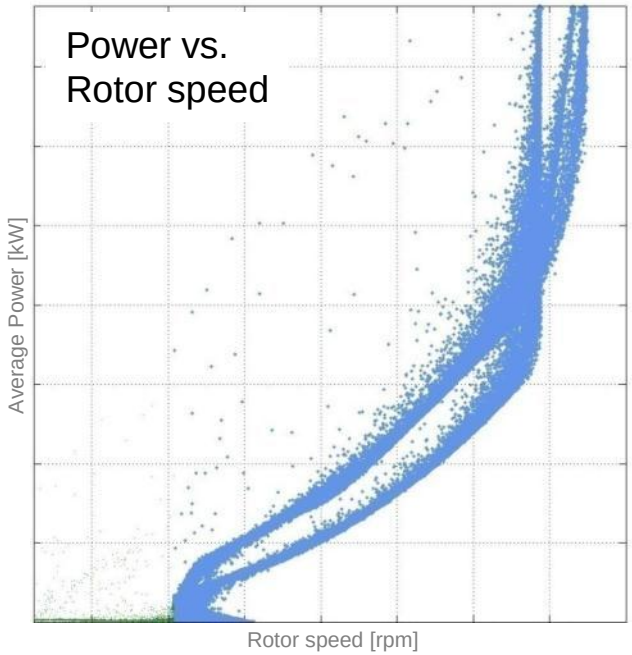
Category 2: Mechanical sub-optimal performance – common causes

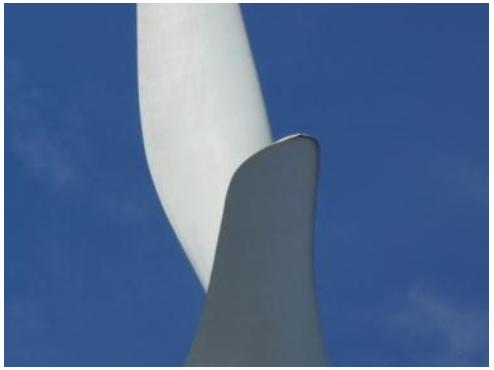
1) De-rating

2) Non-optimal controller settings

3) Component misalignment / Sensor error





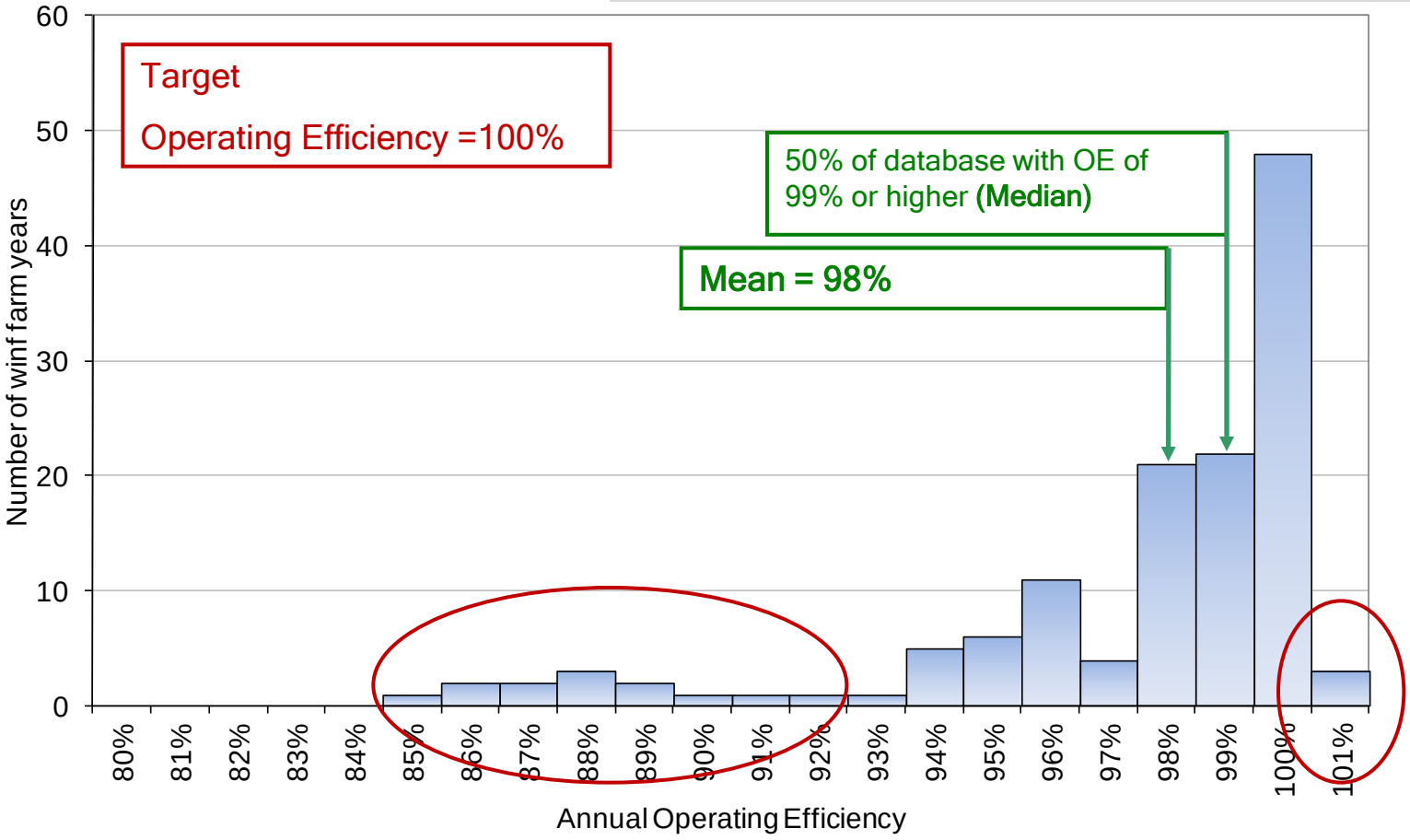


Category 2: Mechanical sub-optimal performance - What can be expected?

Database
62 wind farms across Europe
Between 1 and 6 years of operation
134 wind farm years

Definition

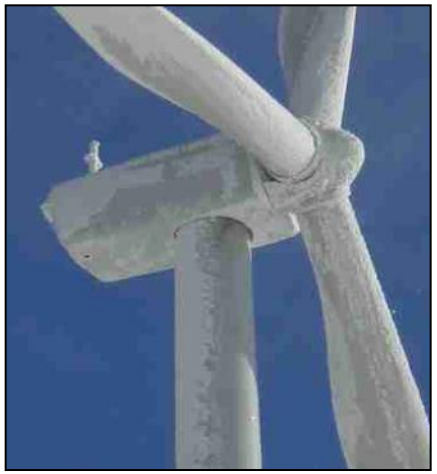
$$\text{Operating Efficiency (OE)} = \frac{\text{Energy produced}}{\text{Energy expected with 'normal' power curve}}$$

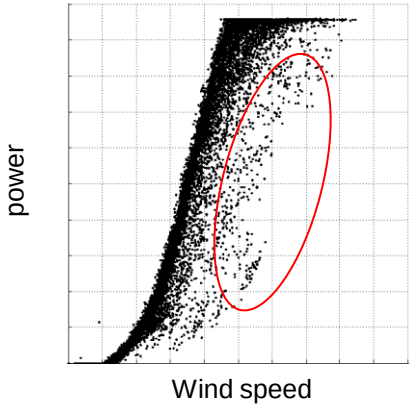


Category 3: Environmental - causes

Icing

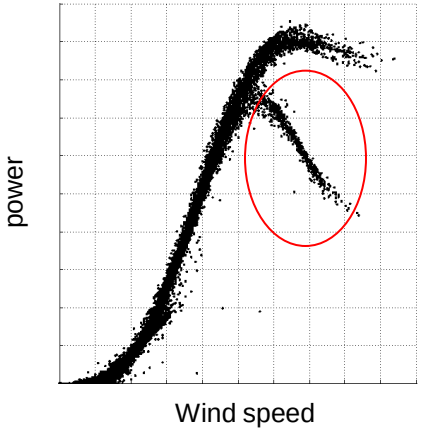
High impact on some sites





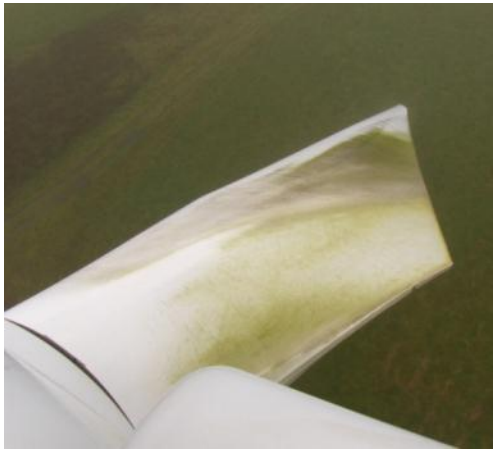
Bugs

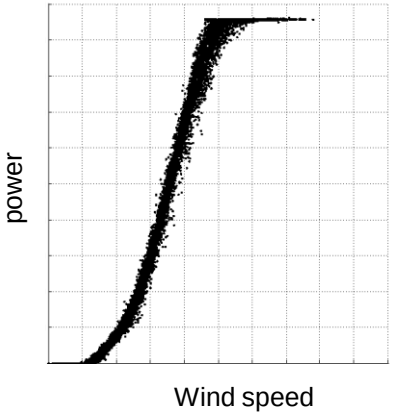
High impact for short periods



Dirty blades

Subtle impact but persistent





- Typical range -3% to -0.2% and very region specific

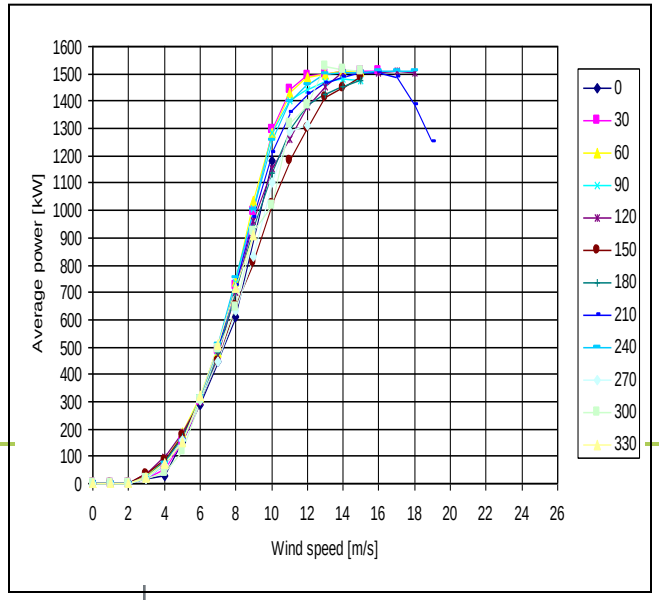
Category 4: Wind conditions

The power curve is impacted by:

- Flow inclination
- Turbulence intensity (TI)
- Shear profile
- Air density

Influenced by:

- Atmospheric stability (TI, shear, density)
- Complex terrain (flow inclination, TI, and shear)
- Forestry (TI and shear)



Category 4: Wind conditions:
Flow inclination impact on power curve (Extremes)
GLGH validation of Madsen/Pederson research for MW-scale wind turbines

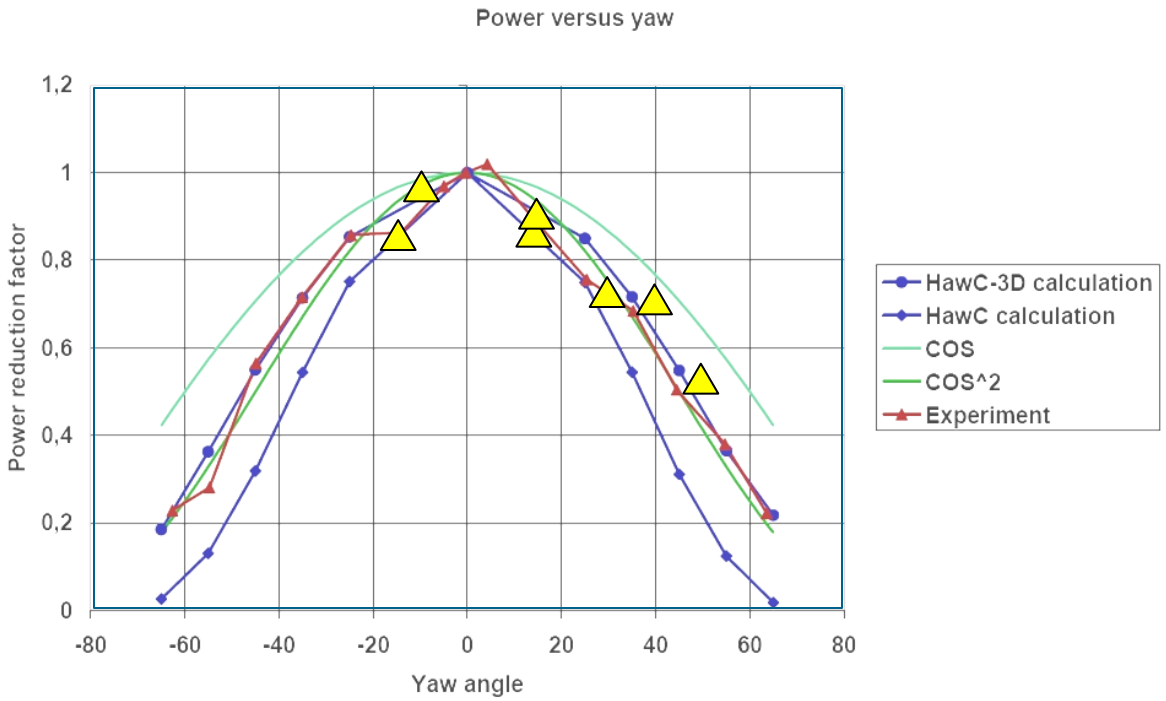
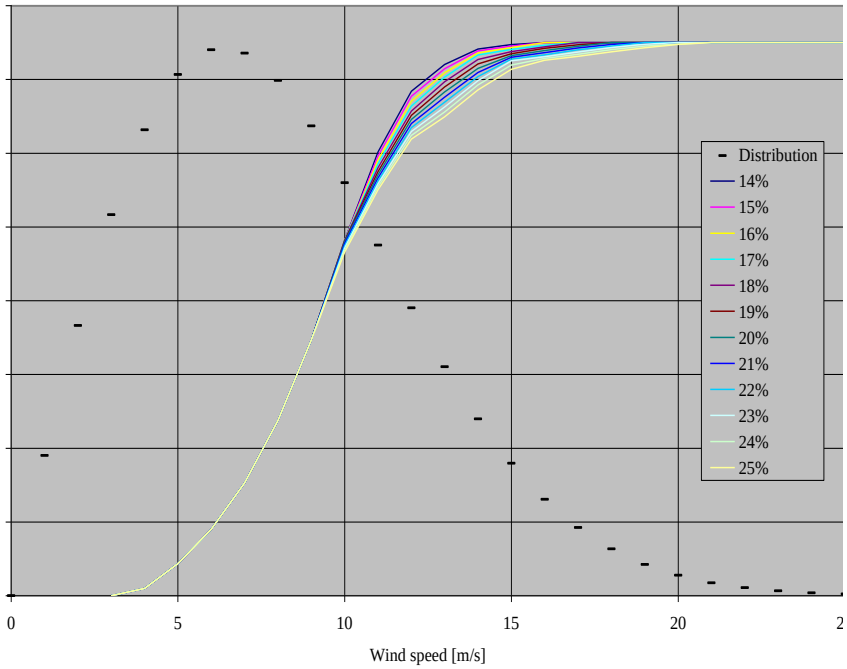
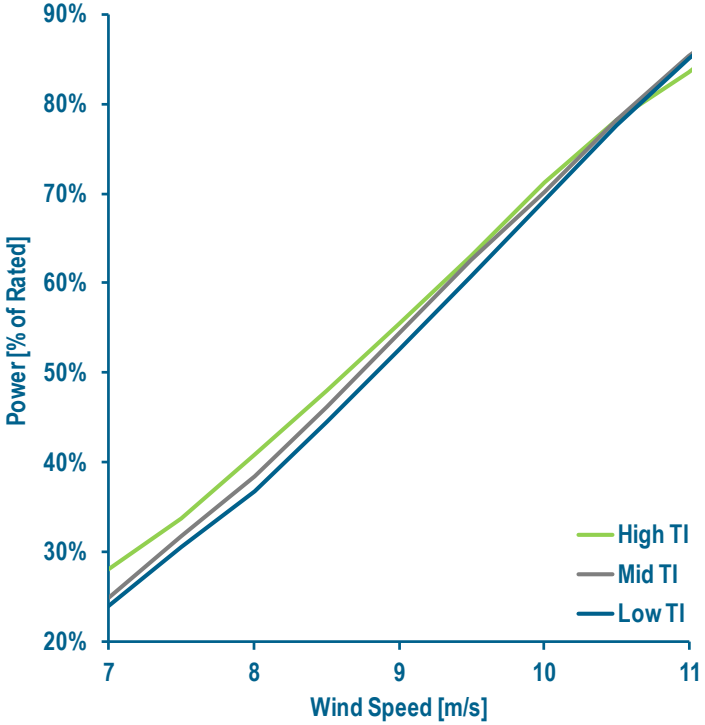


Figure 6-1 Measured and calculated relative power reduction for an experimental 75kW wind turbine at 8-9 m/s from Ref. 26

△ Yaw error observations for MW-scale turbines (GLGH)

Category 4: Wind conditions
Turbulence Intensity (TI) and Shear impact on power curve (Extremes)





High TI case:

- 2% drop in nominal energy between TI of 14% and 20% due to ‘rounded knee’ for a high wind speed site

Low TI case:

- 3% drop in nominal energy during periods of low TI (<8%), which corresponds to stable atmospheric conditions

Conclusions

- Real world turbine performance does generally deviate from sales power curves
- Causes can be grouped and quantified based on observations from operational analyses

Category	Typical range of loss(-ve)/gain(+ve) (nominal energy %)	Median (nominal energy %)
1. Generic power curve performance	-5% to +3%	-1% (model specific)
2. Mechanical sub-optimal performance	-5% to +0%	-1% (operator specific)
3. Environmental	-3% to -0.2%	-0.5% (region specific)
4. Wind conditions – turbulence intensity, shear and flow inclination	-5% to +1%	-1% (site specific)

Questions?

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