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# Physical Mechanisms Behind Some Wind Turbine Performance Issues


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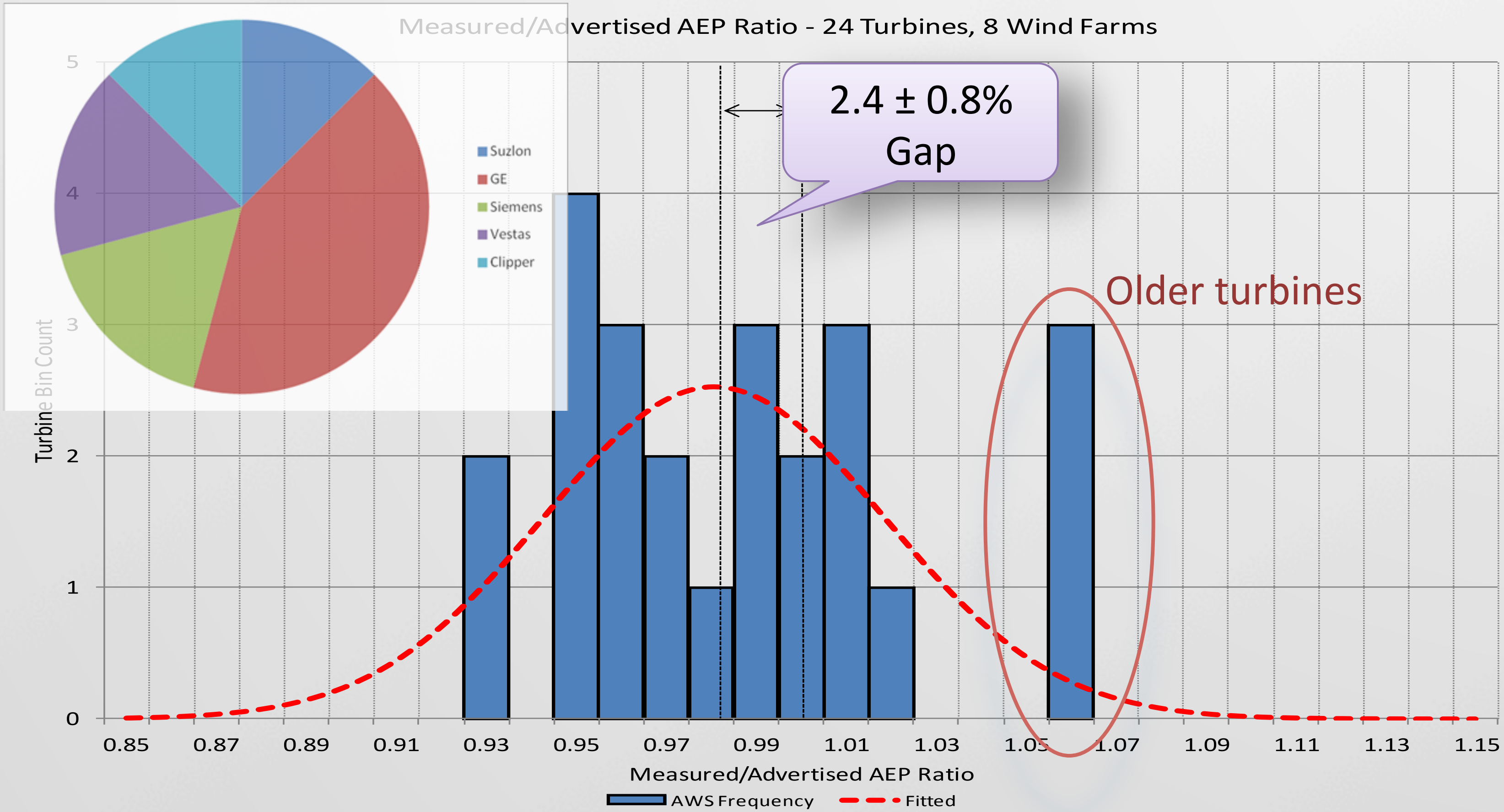
# Focus on Turbine Performance

- Ideal test conditions
  - IEC compliant
  - May be constrained by OEMs
- Non-ideal conditions
  - Extreme shear
  - Extreme turbulence
  - Inclined flow
- Operation and maintenance practices

# Turbine Performance Under IEC Conditions




Typical performance gap 1-4% in IEC-compliant power curve tests
Supported by AWST and other industry data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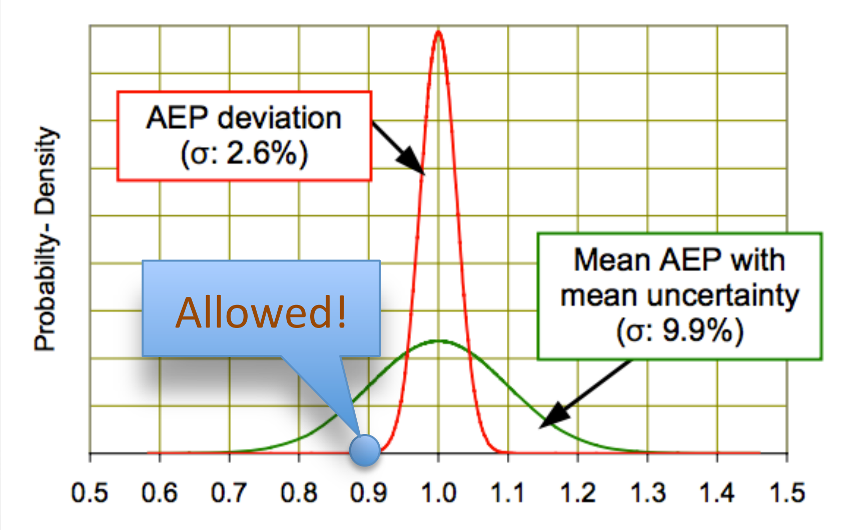
# Turbine Performance Under IEC Conditions

- Most measured deficits in annual energy production are contractually allowed
  - Minimum levels are defined generously




DEWI 2006

- Why the gap occurs is unclear. Possibilities include
  - Site conditions different from how power curves defined
  - Competitive pressures to maximize advertised capacity factor result in tighter design tolerances
  - Strategies to reduce equipment wear and tear
- Regardless, it results in a deficit in the expected production



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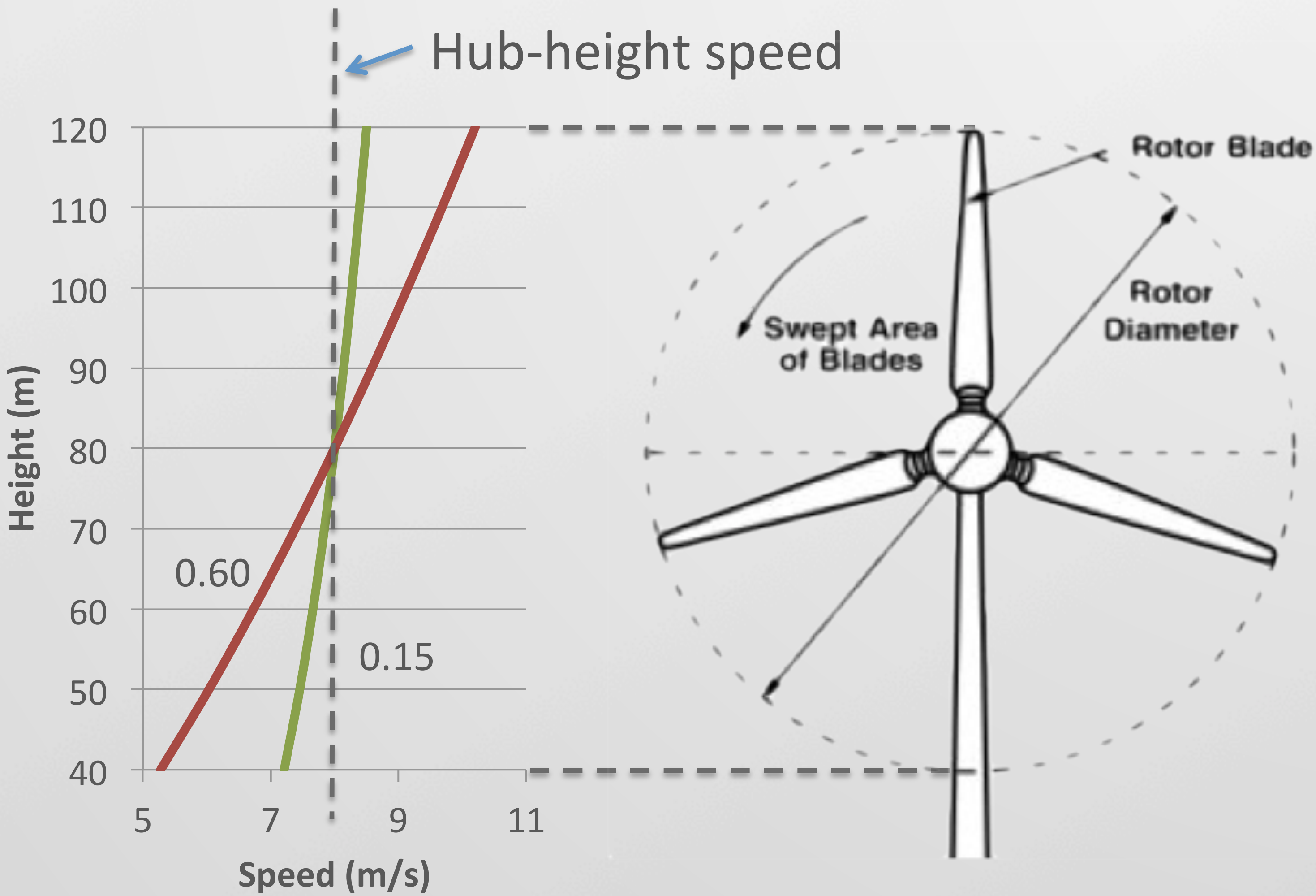
# Effect of Shear



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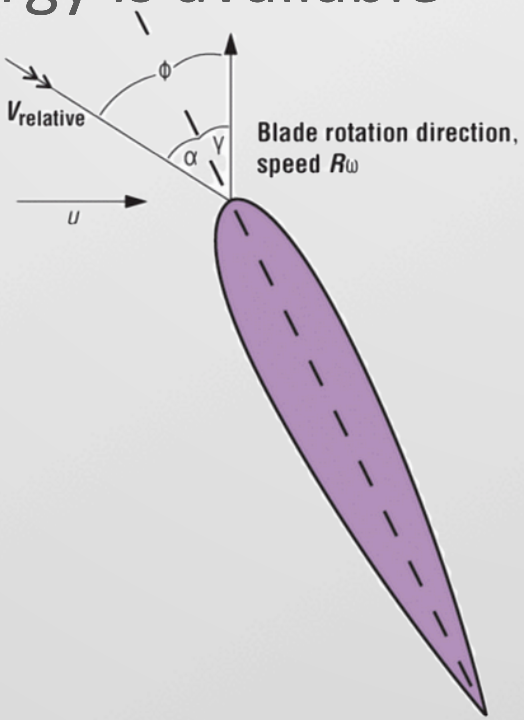
# Effect of Shear

- Power curves are defined for "normal" shear conditions (α≈0.2)
- Higher shear means more energy is available in the wind
- But turbines cannot use the extra power efficiently because the blade angle of attack is not optimal
- Individually pitched blades could mitigate this problem





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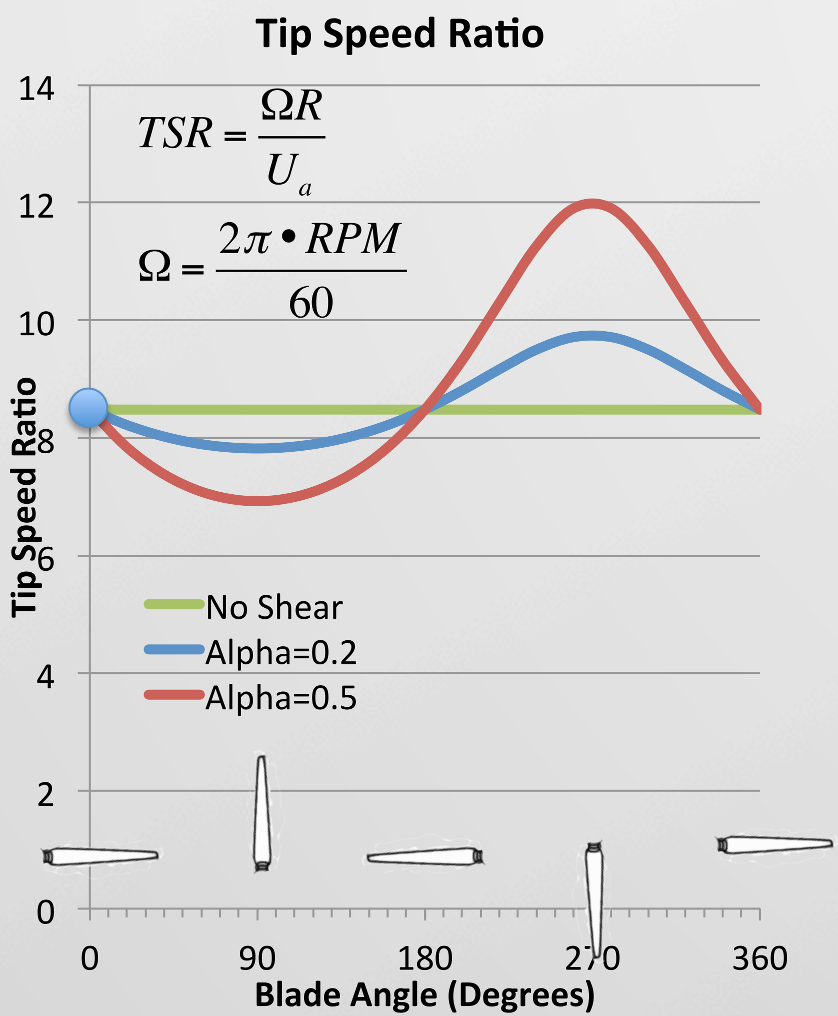


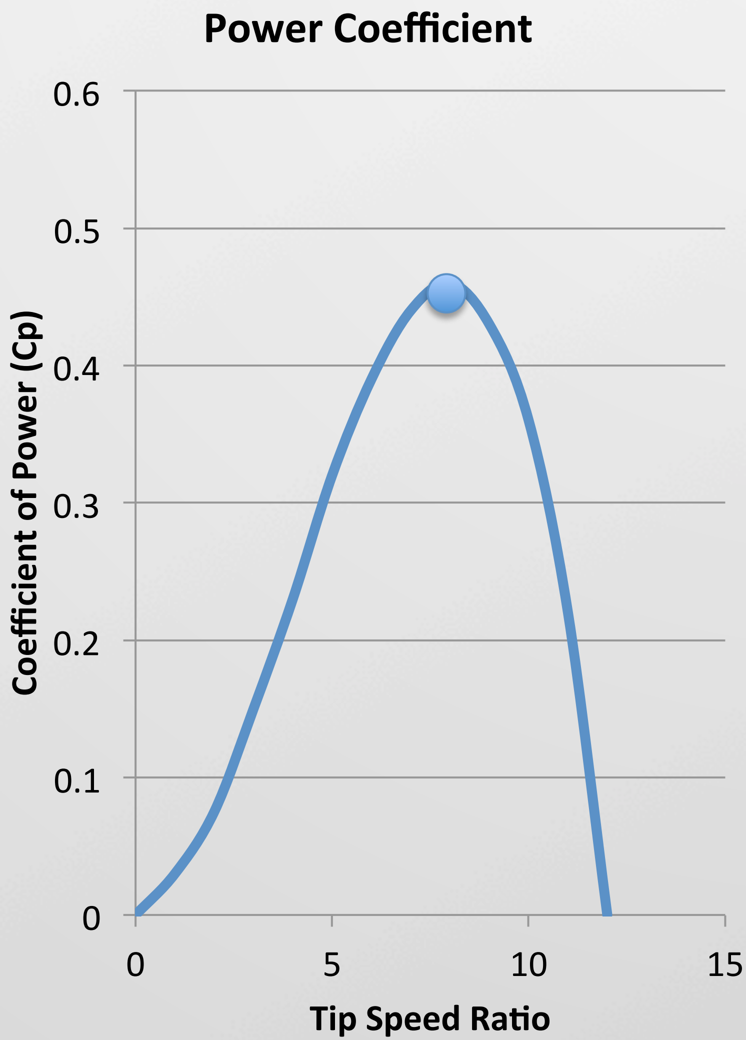

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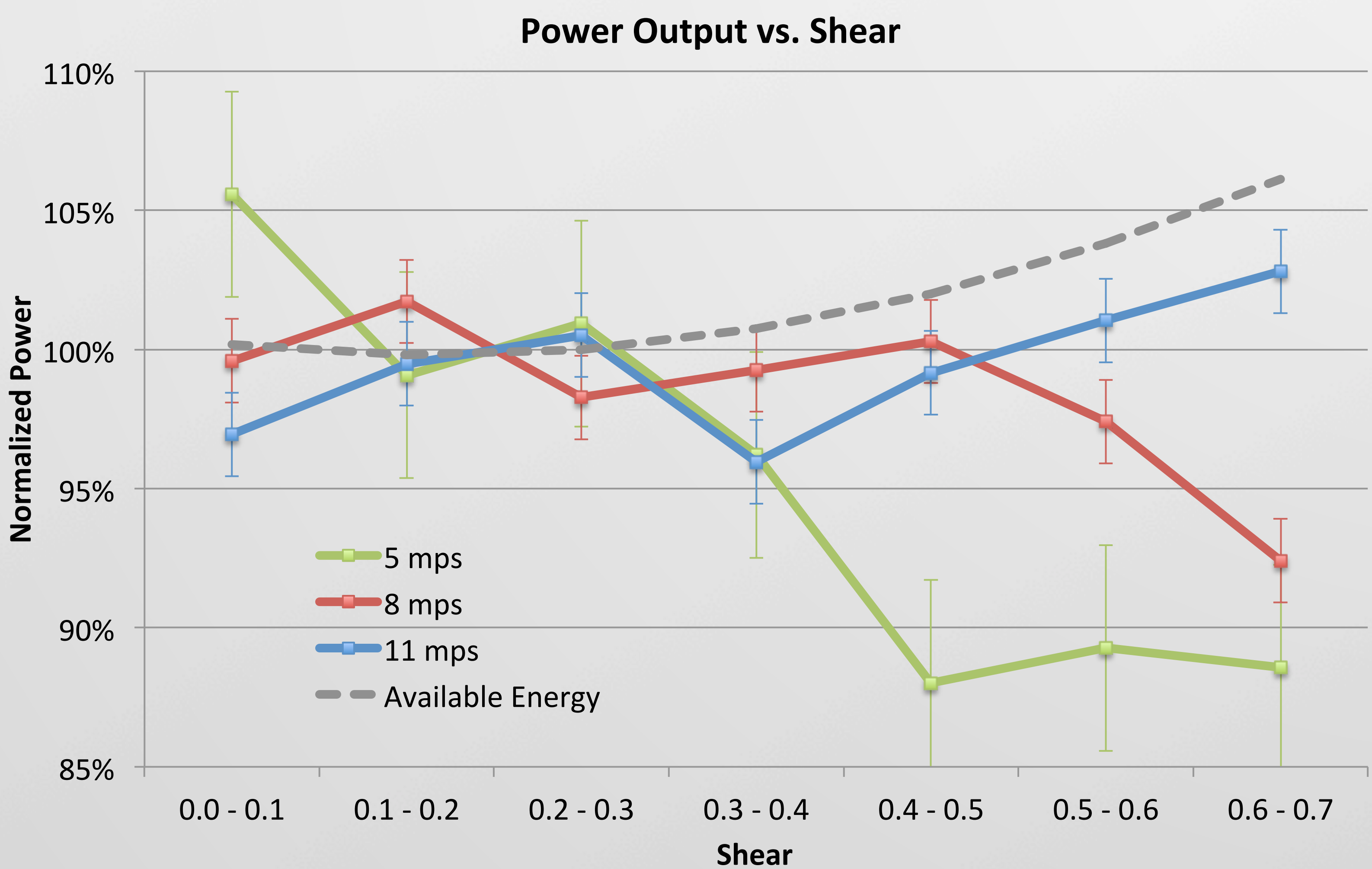
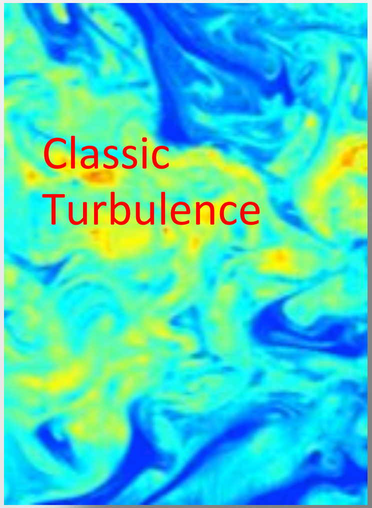
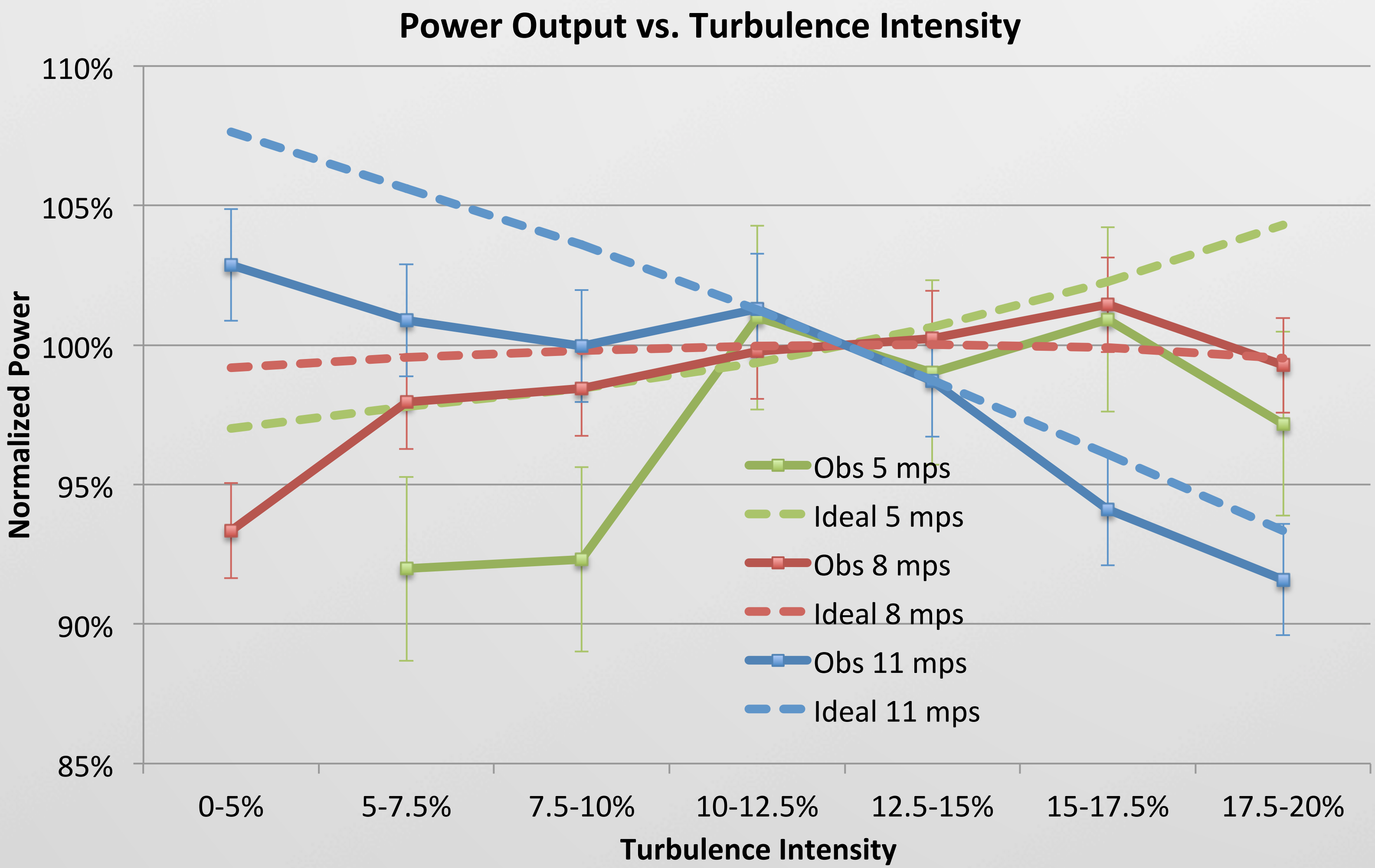


# Effect of Turbulence

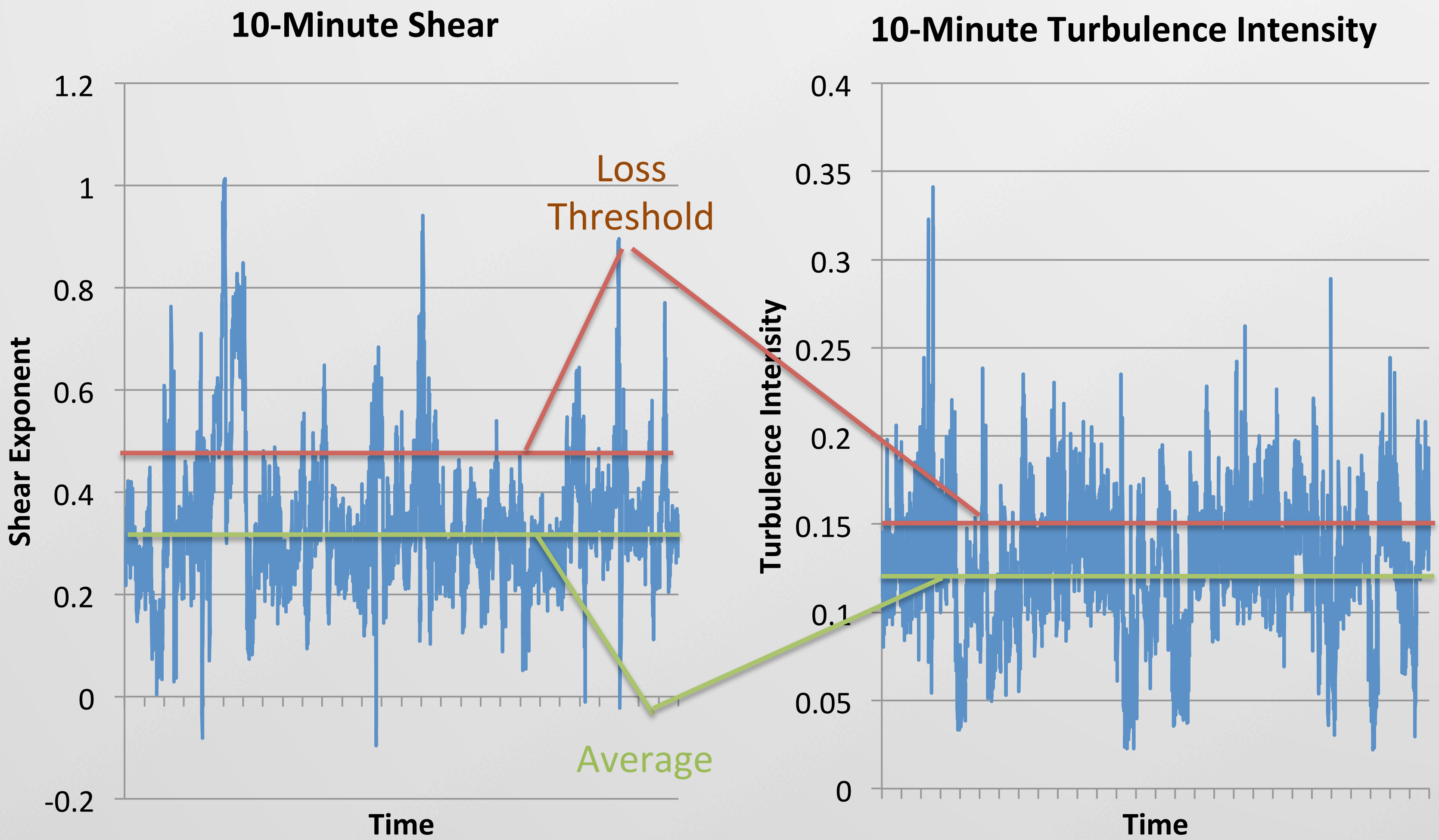
- Under turbulence, turbines experience rapid changes in wind speed and direction
- If the blade pitch can follow the changes in speed, then turbine simply moves up and down its power curve
- But at least a portion of turbulent kinetic energy is too rapid
- Losses due to directional shifts are unavoidable because yaw motors slow
- The turbulence induced by turbine wakes must also be considered




# Effect of Turbulence



# Don’t Forget the Time Dimension



# Effect of Inflow Angle

- Power curve tests assume level ground
- But in complex terrain and under certain weather conditions, significant vertical speeds can occur
- Placing turbines on ridge tops and on the edges of mesas can create a persistent bias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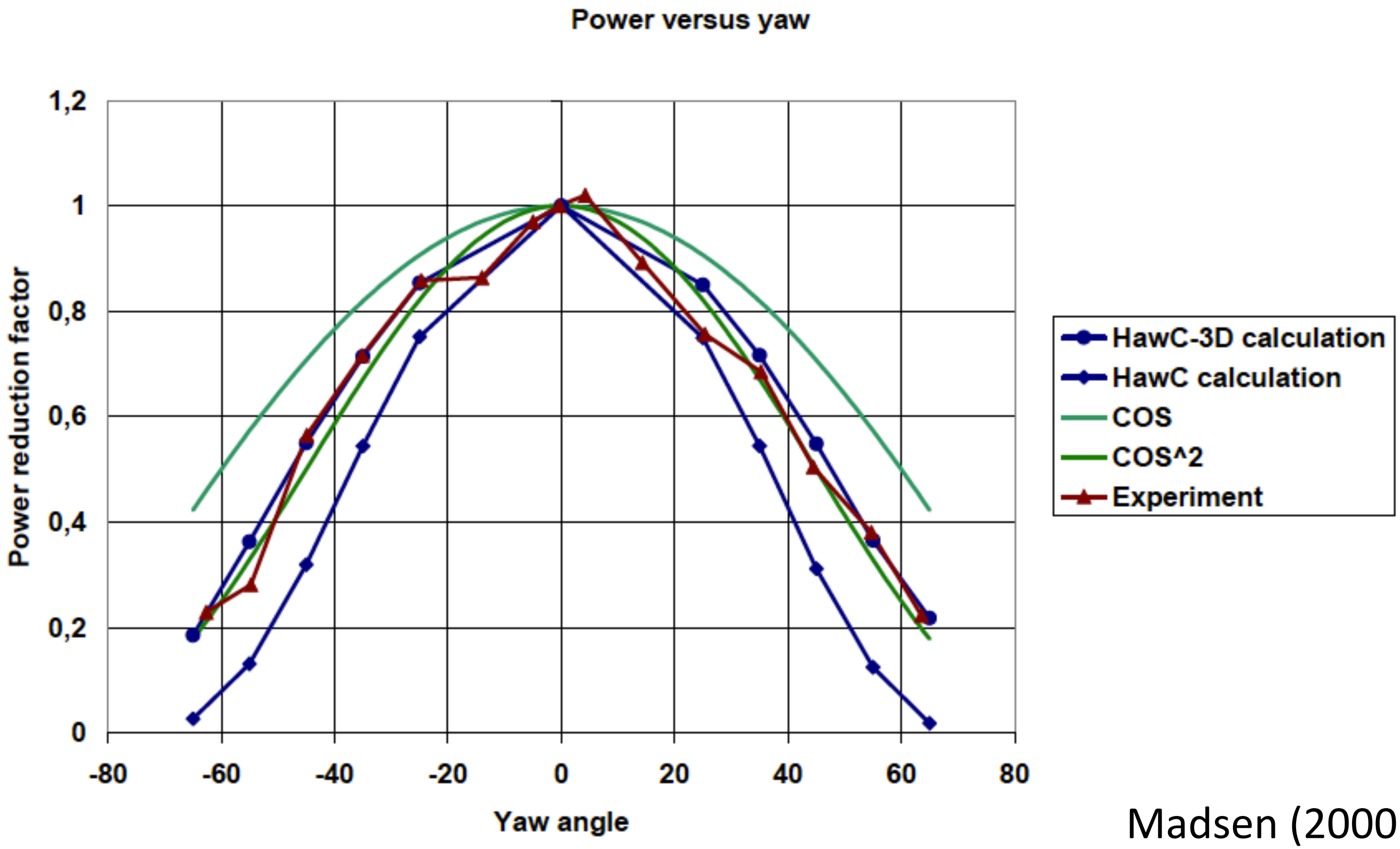
# Effect of Inflow Angle




Madsen (2000)

# Conclusions

- Deviations of shear, turbulence, inflow angle from normal conditions can cause deficits in turbine performance
  - Time-varying, not just average, conditions must be considered
- This problem can be addressed in two ways:
  - Analysts can develop adjustments based on theory, calculation, and test data. This approach is limited by available data.
  - Manufacturers can provide multi-dimensional power curves. This approach is preferred.