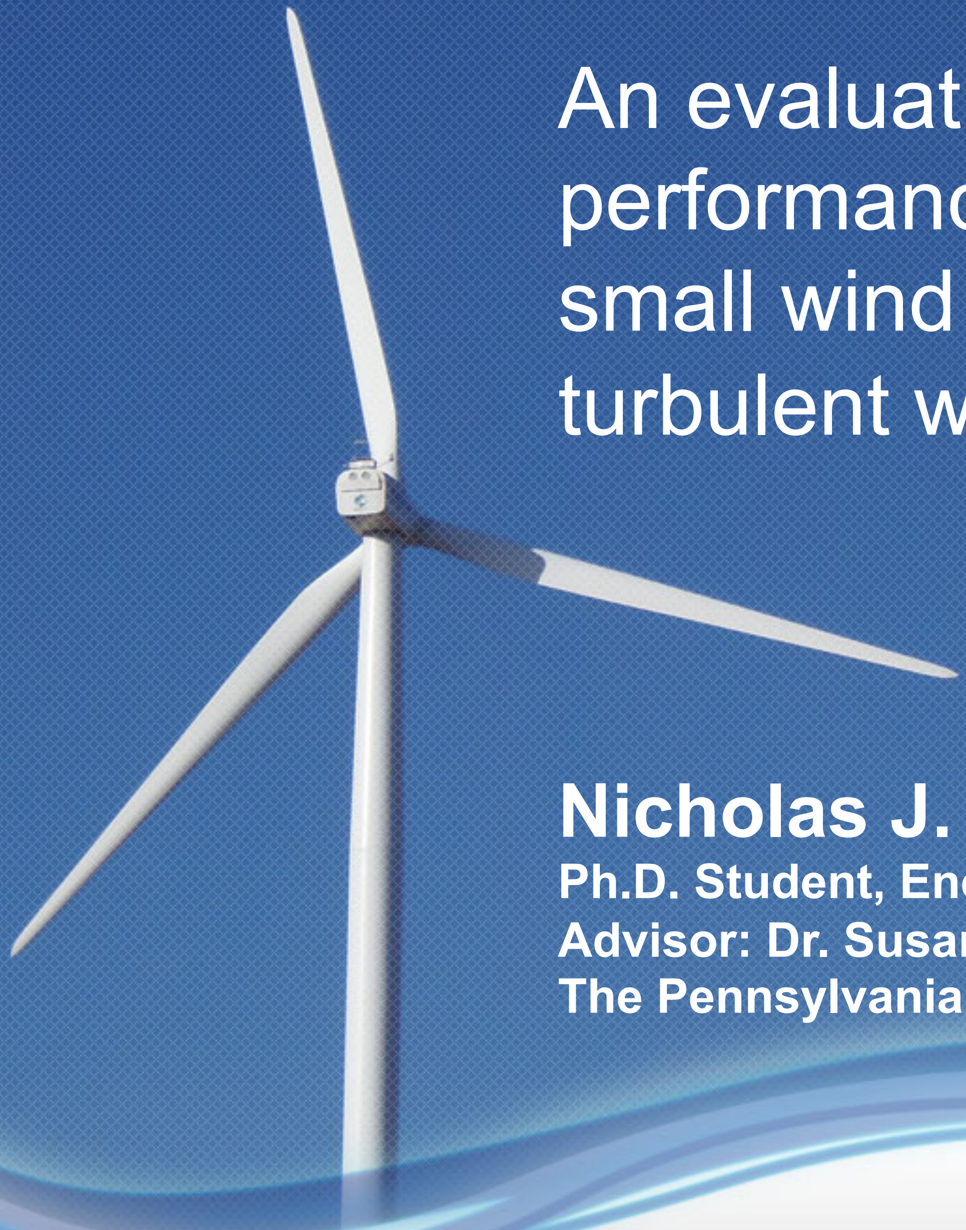

An evaluation of power performance for a small wind turbine in turbulent wind regimes

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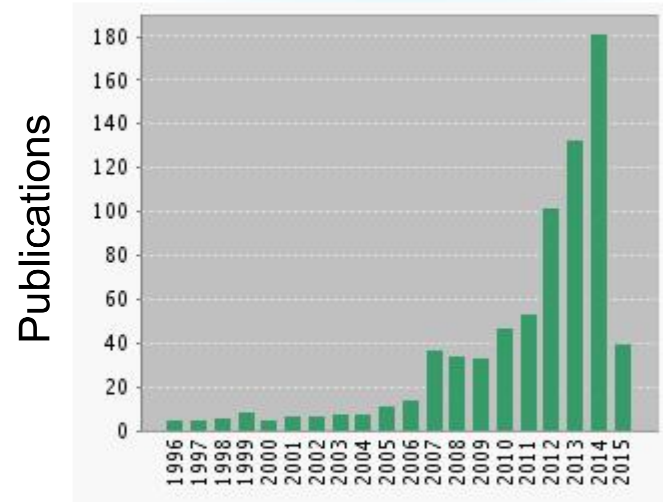
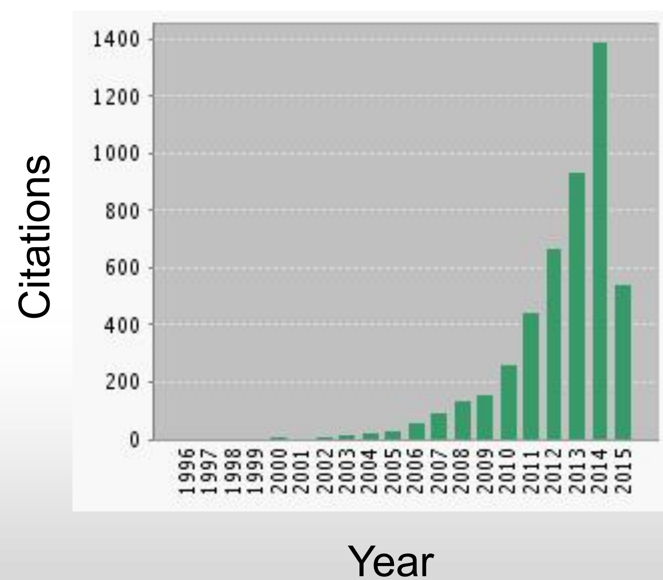
Why study turbulence?

- Increased attention towards engineering and economic feasibility in lower wind speed regimes [Ewing et al (2008)]
- Progressive damage and shortened turbine lifetime via stochastic loads [Saranyasootorn & Manuel (2008)]
- Increased interest in turbulence for future academic study [Web of Science]
  - 180 publications in 2014 (top)
  - 1400 cited articles in 2014 (bottom)

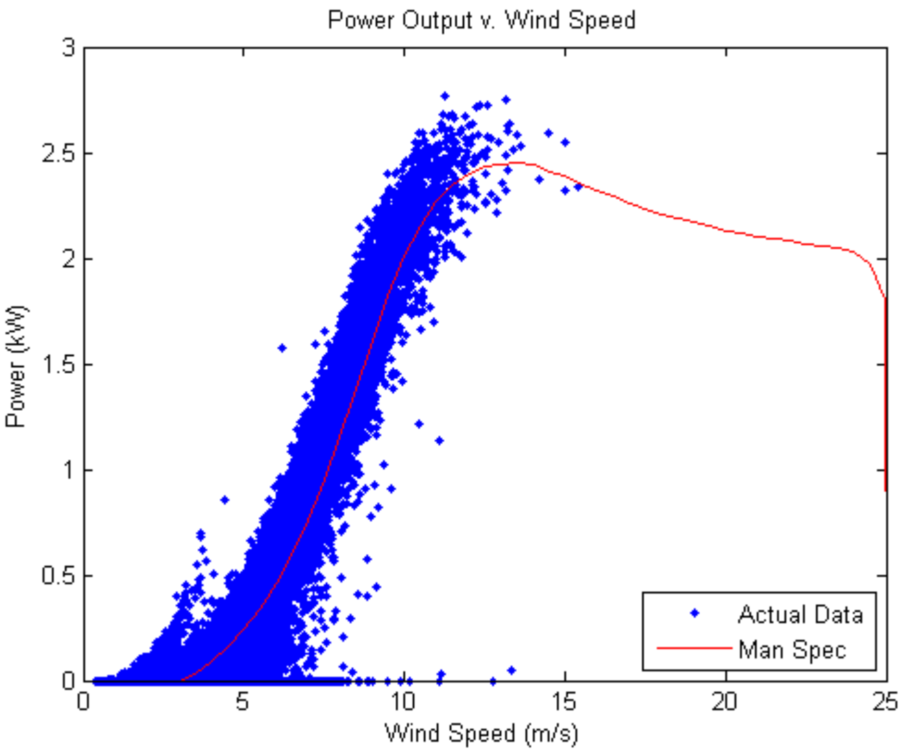




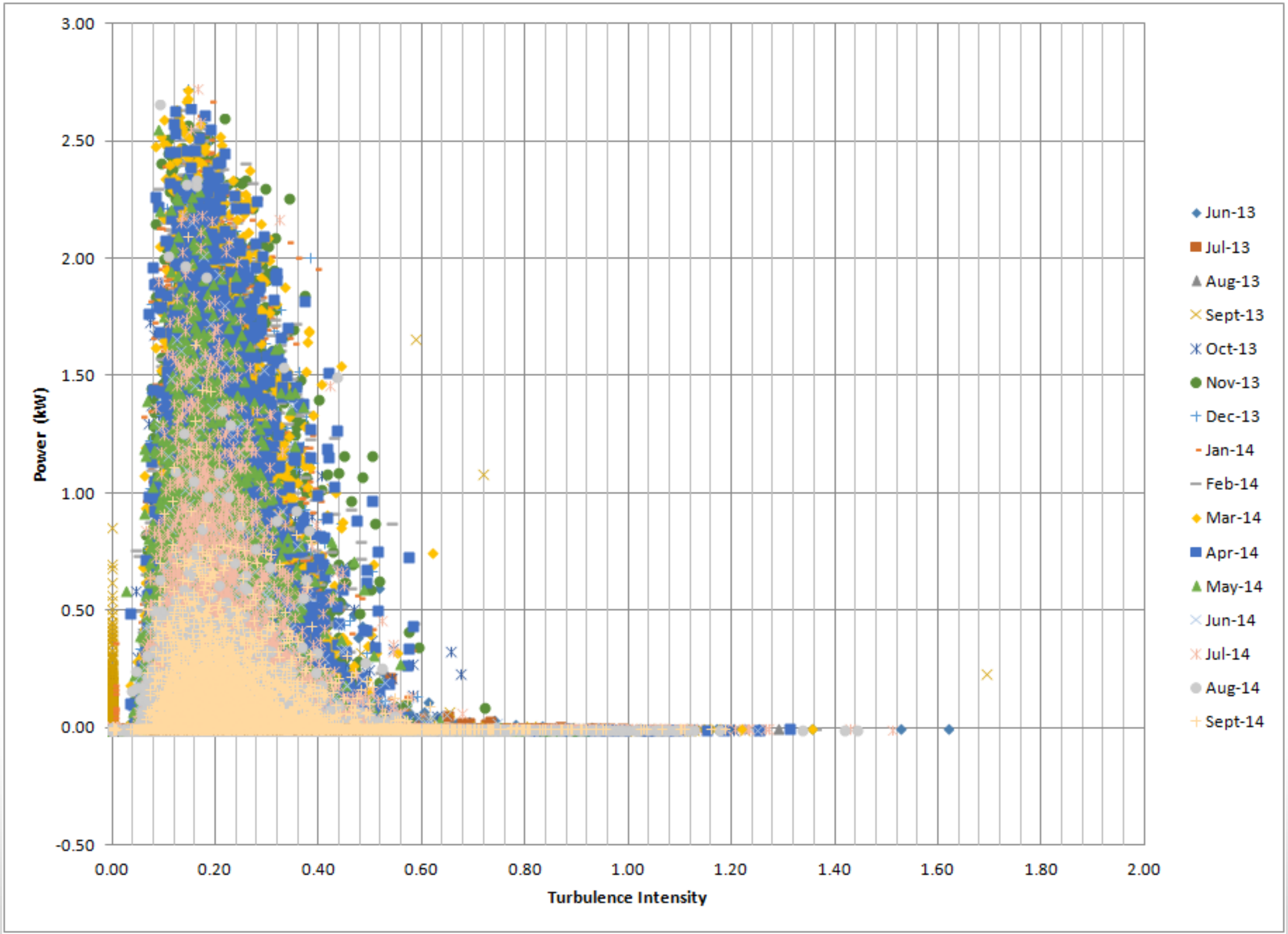
Wind Turbine & Site

Methodology

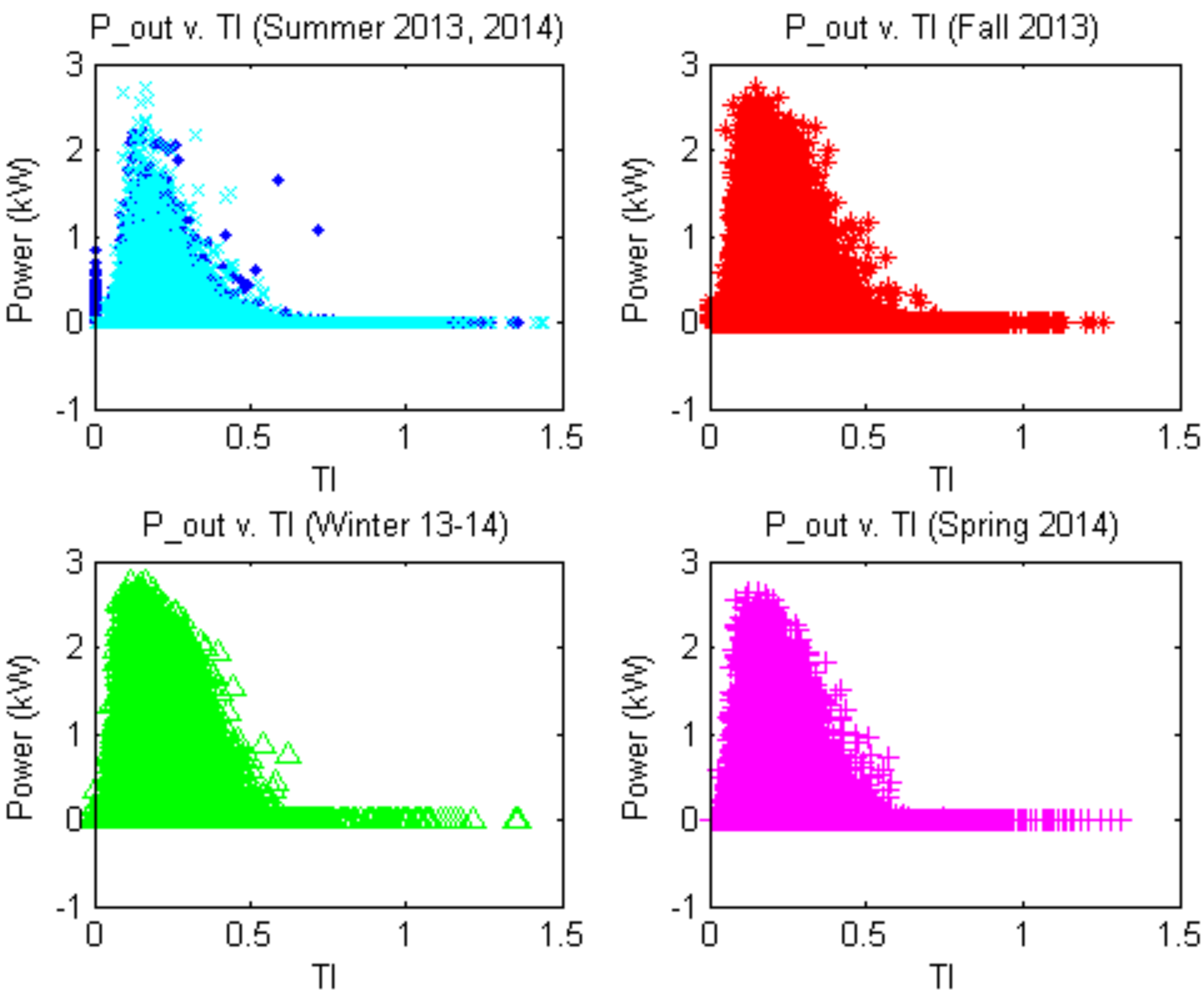
- Collect site characteristics data from wind turbine location
- Determine relationship between *P* and *TI*
- Quantify statistical distribution of in situ *TI* frequency
- Verify/compare results with IEC standards, Albers (1997) and Sunderland et al (2013)



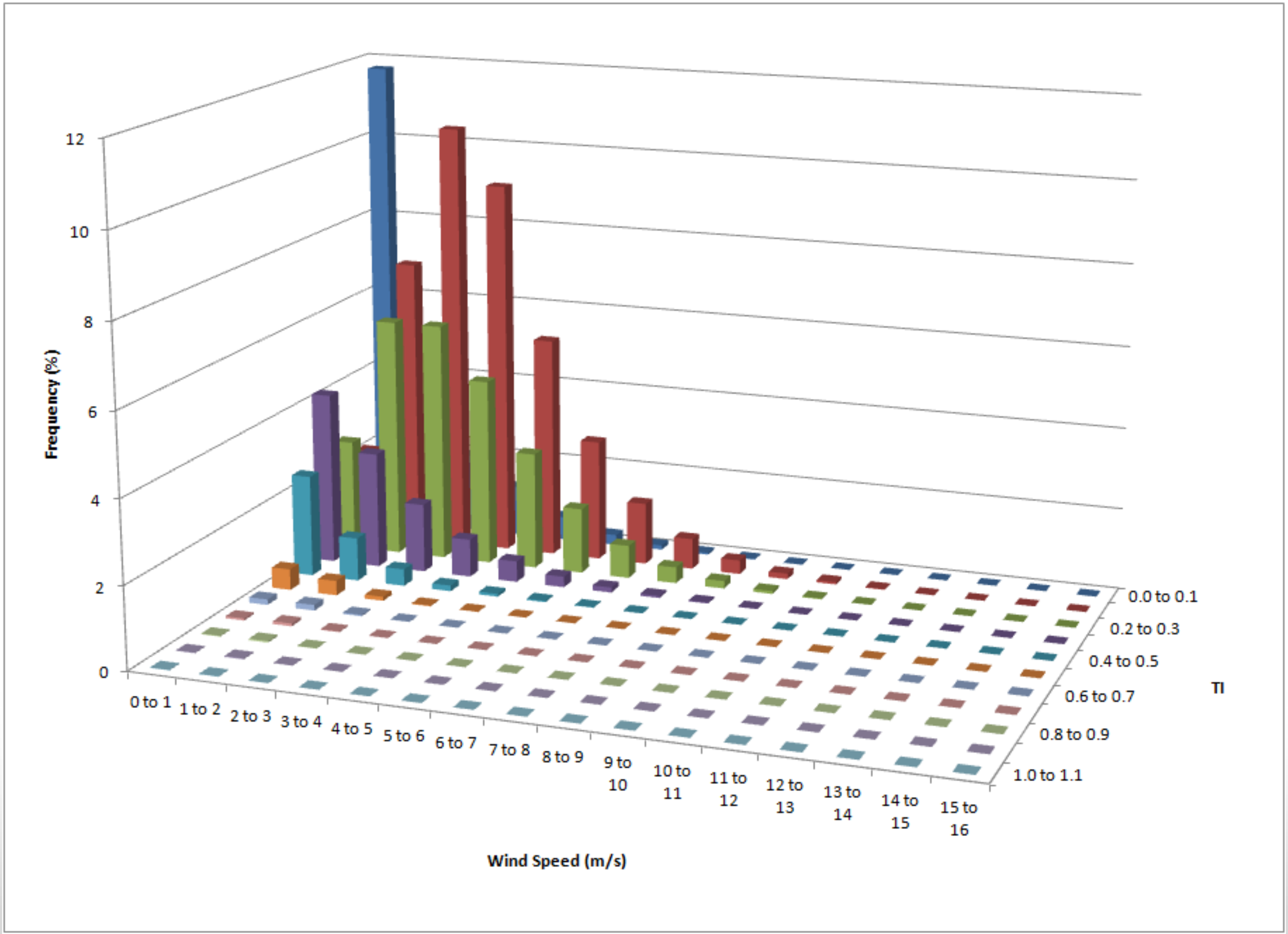
The turbine power and turbulence intensity were quantified over 15 months (6/13-9/14). Excluding anomalies like turbine maintenance, power exhibits strong statistical correlation with turbulence intensity.



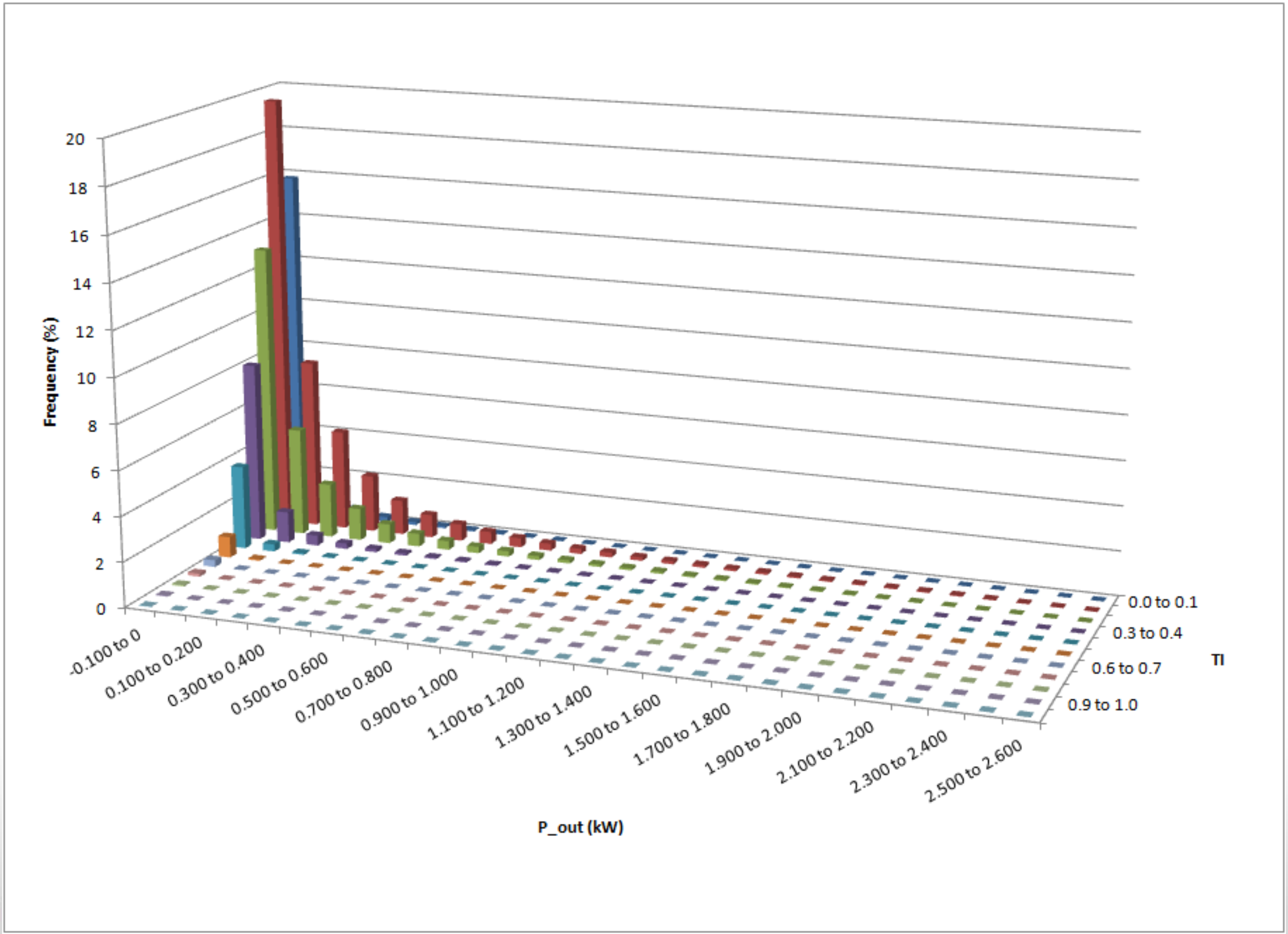
Seasonal Variation of Power & Turbulence Intensity



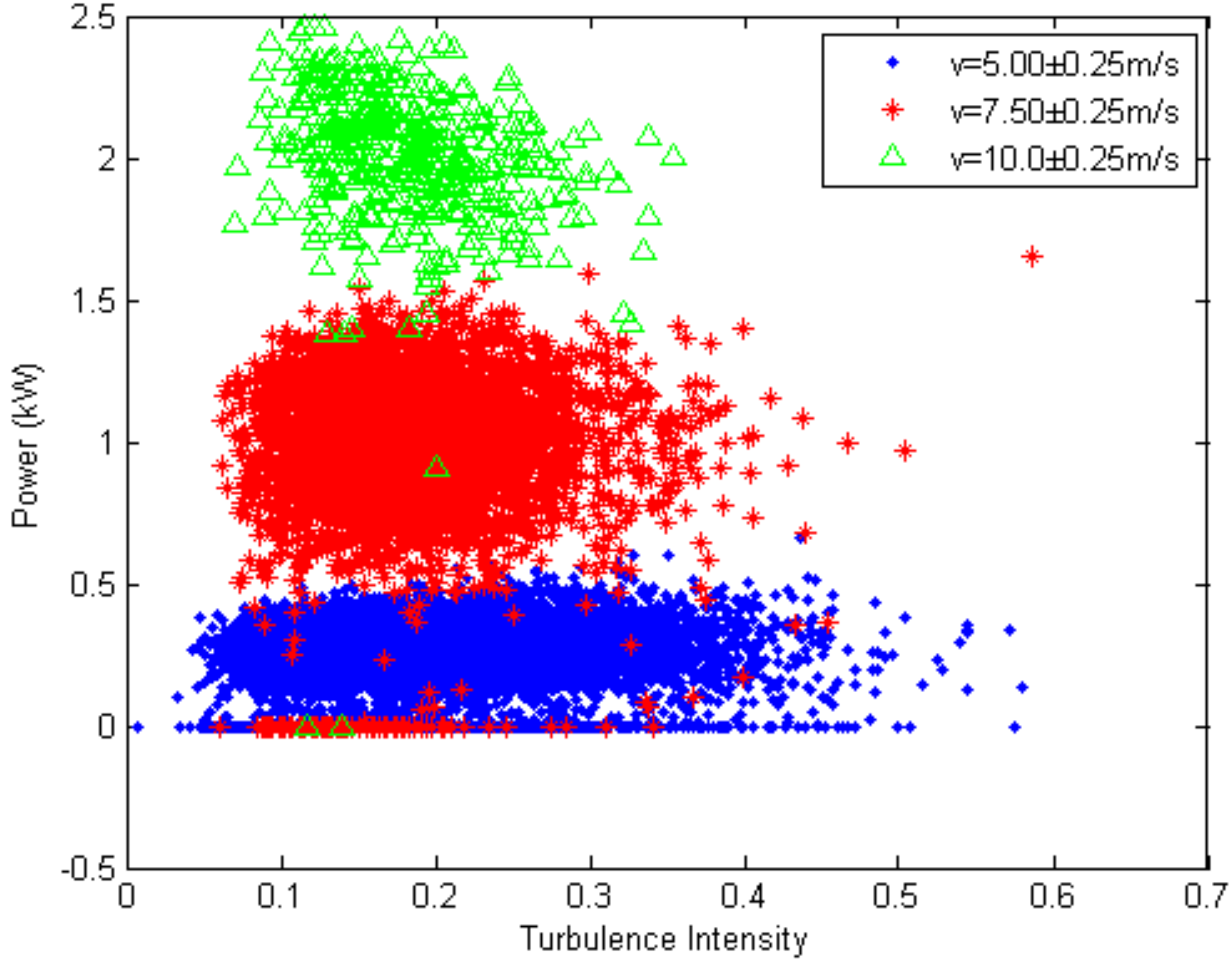
Common industrial practice requires a Weibull distribution for frequency of wind speed [Woolmington et al (2014)]. However, an empirical distribution match for turbulence intensity is more difficult.



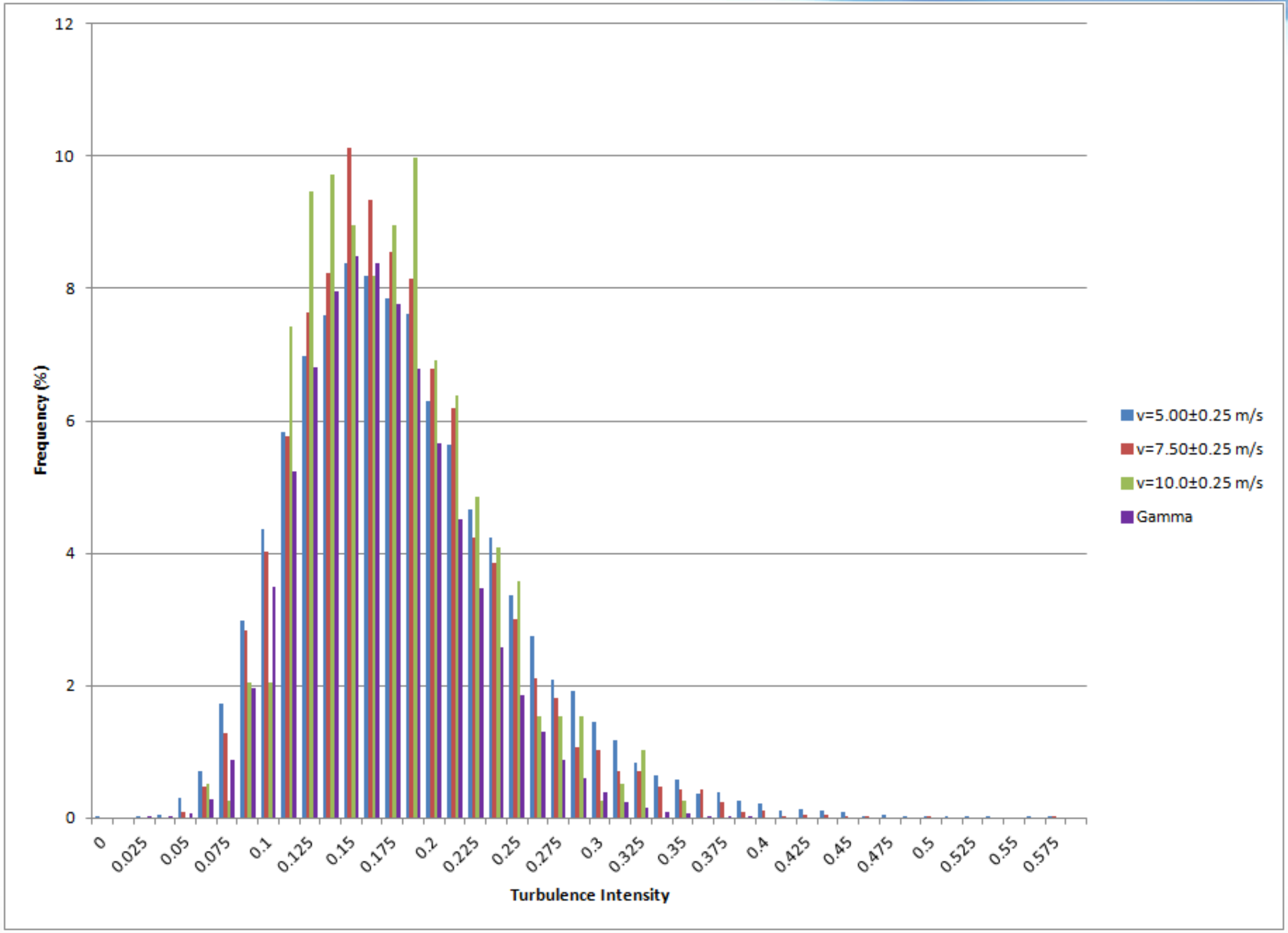
Wind speed dependence for the turbine power curve enables statistical correlation between frequency of occurrence for power and *TI*.



The culmination of these turbulence intensities at constant velocities enable “binning” of turbine power output. With smaller wind speeds, the power output increases for increased *TI*, exhibiting periods of overdrive.



Turbulence intensity tends to follow a Gamma distribution (k=12, θ=0.014) at constant wind velocity.

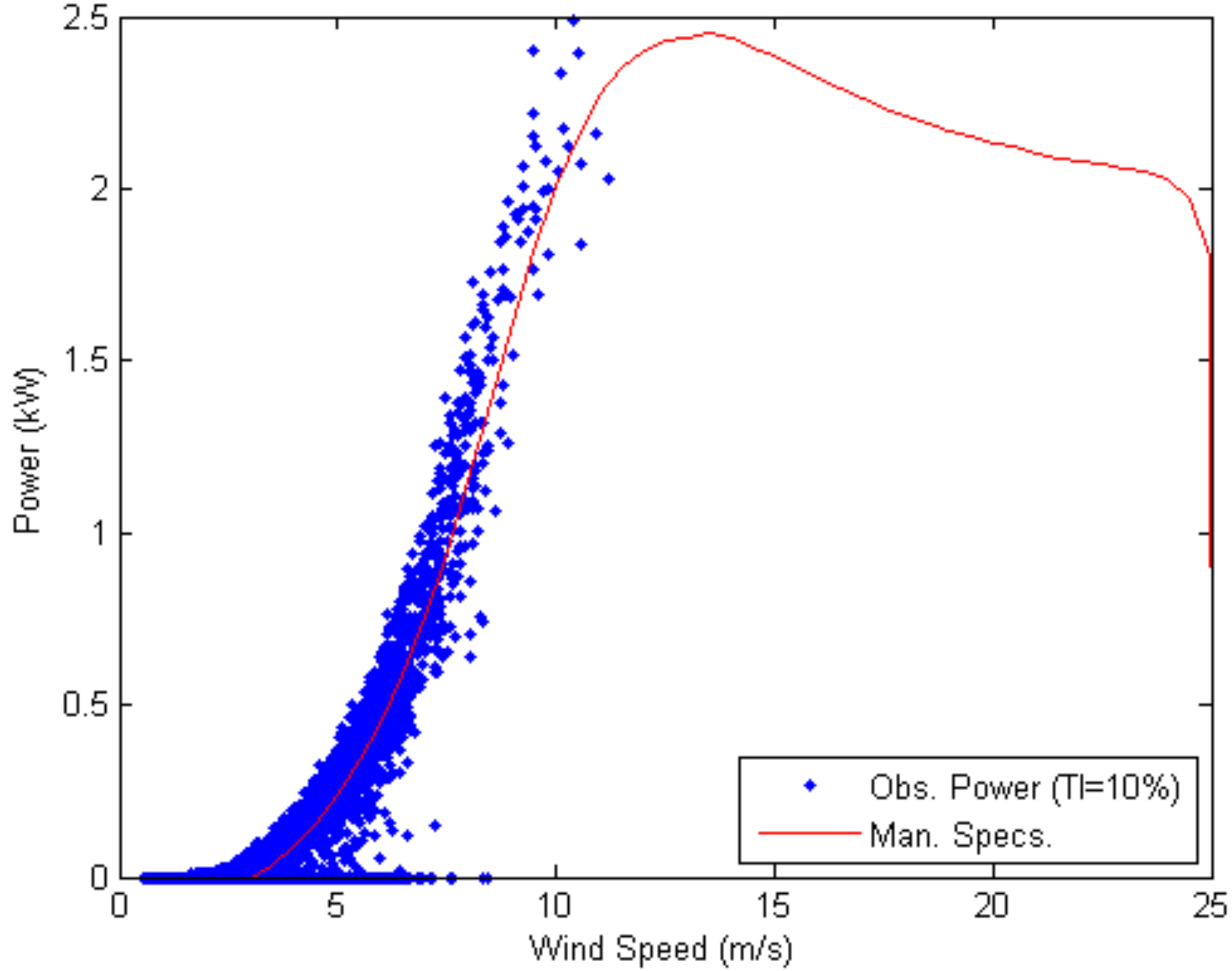


$$f(x;k,\theta)=\frac{x^{k-1}e^{-x/\theta}}{\theta^k\Gamma(k)};x,k,\theta>0$$

Relative Error Between Gamma Function and Observed *TI*

Wind Speed (m/s)	Min Error (%)	Max Error (%)	Mean Error (%)
5.00±0.25	0.00	1.66	0.45
7.50±0.25	0.00	1.67	0.42
10.0±0.25	0.00	3.18	0.79

Example of TI Integration into Wind Turbine Power Curve



Conclusions & Future Work

- The gamma function is a good indicator to estimate power performance incorporating *TI*
- Power output increased by as much as 60% for lower wind speeds at higher *TI*, but decreased power by as much as 17% for high wind speeds and *TI*
- A more standardized approach for *TI* integration into the power curve was tested and correlated well with results from Sunderland et al (2013) and Albers (1997)
- Over-performance is possible for low wind speed regimes with high *TI*
- This process can be integrated into (or verified by) industry accepted programs like WT_Perf and FAST for computer simulations predicting stochastic loads due to turbulence and their effects on power production for any turbine size in any location

Acknowledgments

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- Aerospace & Energy Engineering Departments
- Penn State Center for Sustainability

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Questions?

Quantifying Power and Turbulence

- Turbine power (*P*) is a function of the cube of the velocity (*v*), air density (*ρ*) and rotor area (*A*) [Manwell et al (2010)]

$$P = C_P \frac{1}{2} \rho A v^3$$

- Turbulence intensity (*TI*) is the ratio of the standard deviation (*σ*) to the mean wind speed (*V*) [Wang et al (2014)]

$$TI = \frac{\sigma}{V}$$

- It can therefore be quantified that turbine power can related to turbulence intensity

$$P = f(TI)$$

Sunderland et al (2013) Key Figure

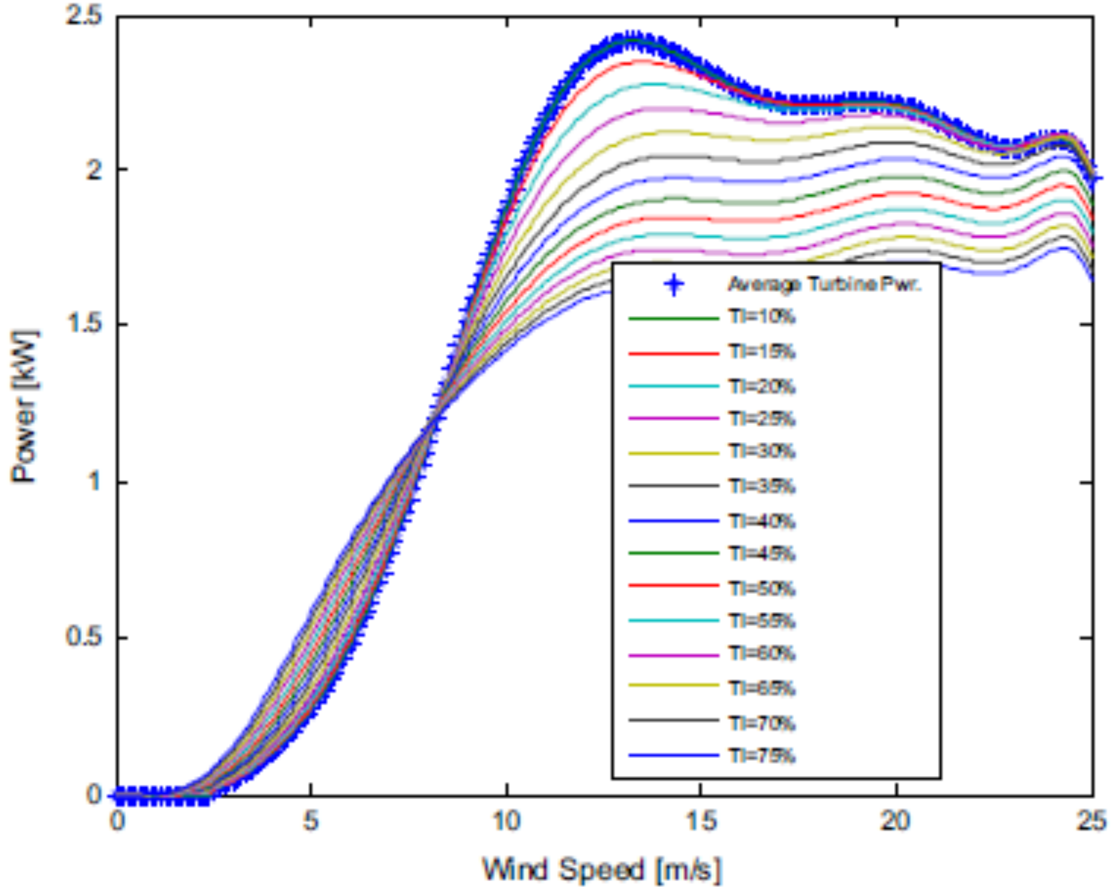

Fig. 5. Albers normalisation of the Skystream 3.7 (2.4 kW) power curve in terms of varying *TI* and wind speed.

Albers (1997) Key Figure

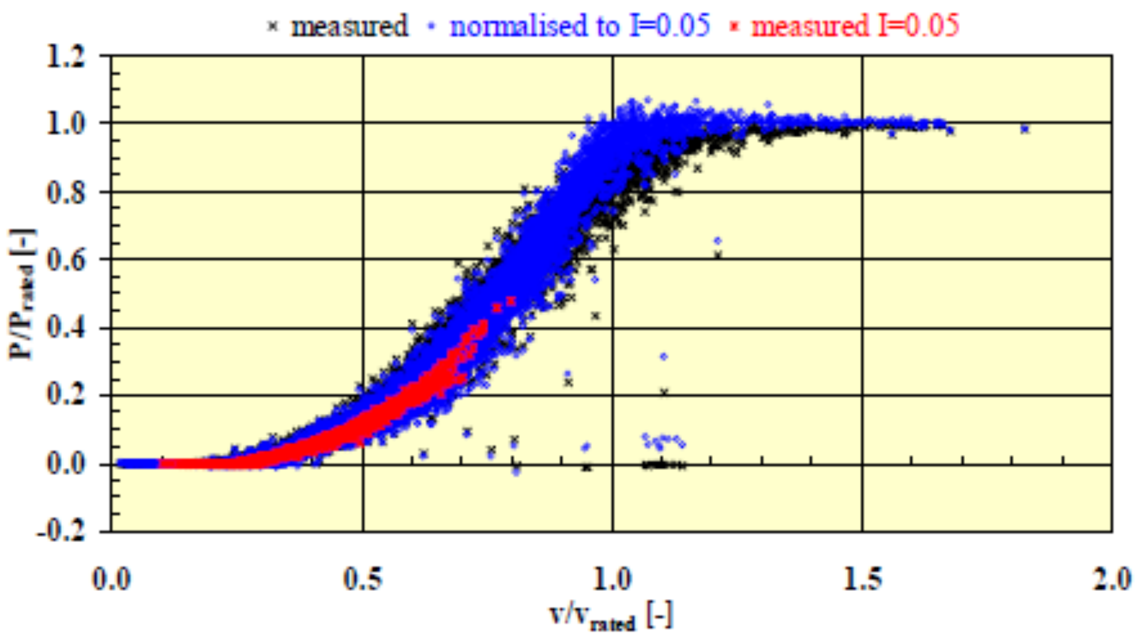

Figure 6: same as Figure 4 but normalisation to 5 % turbulence intensity (blue) and filtering to turbulence range 2.5%-7.5 % (red).