69

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

Nicholas J. Ward[1], and Susan W. Stewart[2]

Abstract

An evaluation of power performance field tests for a 2.4 kW Skystream wind turbine was carried out with respect to turbulent wind regime characteristics. The wind turbine is located at the Sustainability Experience Center on the Penn State University Park campus. A power curve was determined with respect to manufacturer specifications and in situ wind regime data generated from anemometers. This approach was accomplished in comparison to International Electrotechnical Commission (IEC) standards and power performance studies for small-scale distributed wind turbines [1]. The site specific data was generated at the Skystream turbine to verify manufacturer specifications and evaluate turbine performance with respect to turbulence. TurbSim was used to investigate power performance studies by integrating site specific turbulence parameters into the wind regime. The output data was then processed in WT_Perf in order to evaluate load and power performance for the wind turbine.

The first aspect of this study analyzed the turbine's performance at its location with respect to manufacturer specifications for the Skystream 3.7. The wind speeds were measured via anemometers on the tower at two different heights. These wind speed measurements were extrapolated to hub height via the Power Law in Equation 1, adapted from Sunderland et al (2013), where v and v_{ref} are the wind speeds at hub height h and anemometer height h_{ref} respectively with a power law exponent α of 0.238 [2].

$$v = v_{ref}\left(\frac{h}{h_{ref}}\right)^{a} \tag{1}$$

The data at each 3 s time step were collected via meterological packages for temperature, air density, pressure, wind speed and direction as well as power output from the turbine. The respective standard deviations for the three different anemometers were calculated in post processing. Figure 1 shows the results for 15 months of collected data from June 2013 to September 2014 at 1 min time steps in comparison with the manufacturer's power curve. Figure 2 compares that data with 10 minute intervals for IEC standards and Sunderland et al (2013) [1,2].

[1] Graduate Student, John and Willie Leone Department of Energy & Mineral Engineering, The Pennsylvania State University
[2] Assistant Professor & Research Associate, Aerospace Engineering and Research Associate, Architectural Engineering, The Pennsylvania State University

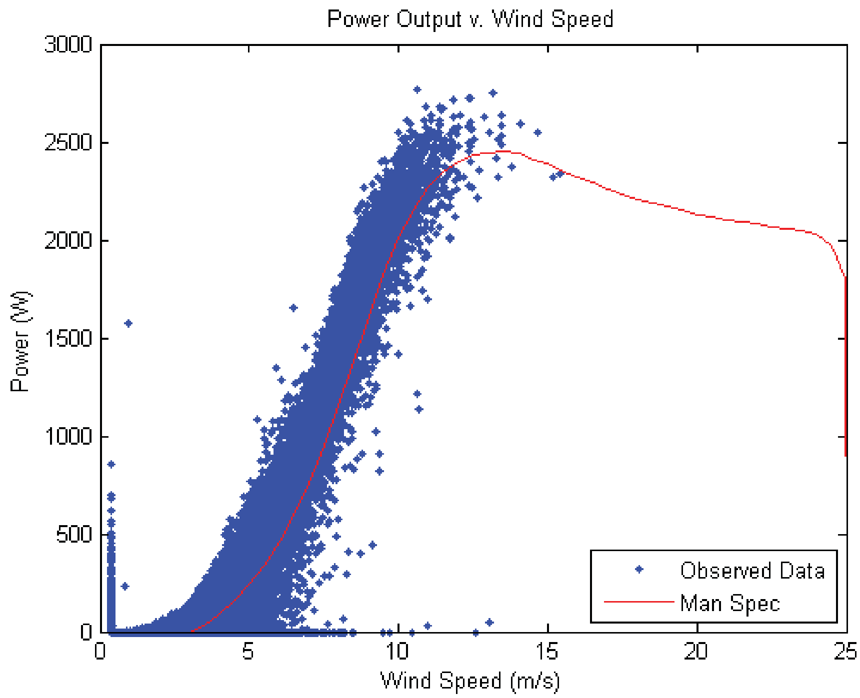

Figure 1: Skystream 3.7 Turbine Performance at Penn State's Sustainability Experience Center

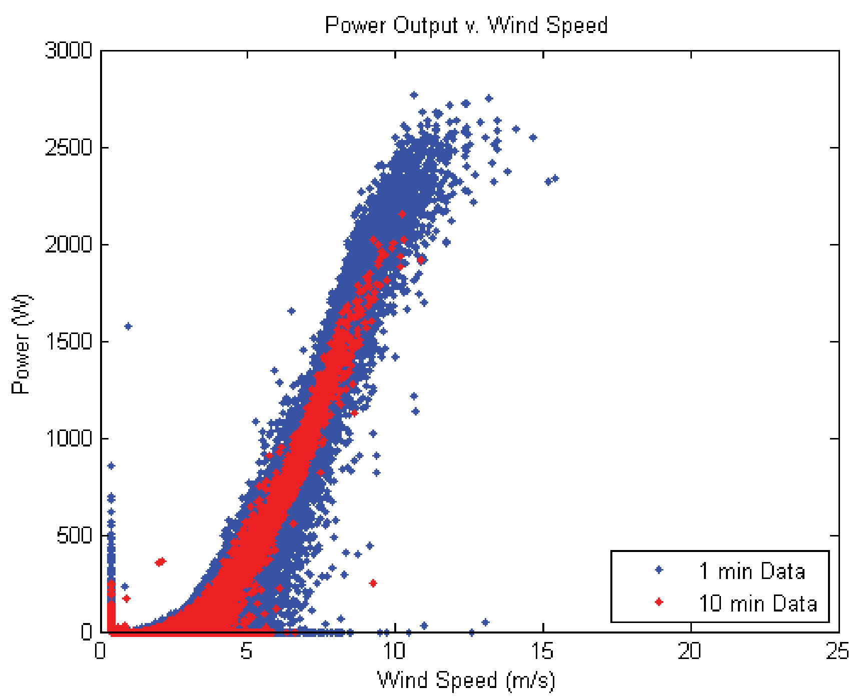

Figure 2: Power Curve for Measured and IEC Standard Time Intervals

From Figures 1 and 2, the wind turbine exhibits characteristics of overperformance compared to manufacturer specifications. Turbulence is preponderant for this wind turbine because of neighboring trees. The repercussion of this interaction is impeded turbine performance for the given location. The turbulence was quantified at each time step as turbulence intensity (TI) in Equation 2,

$$Tl = \frac{<J_U}{} \tag{2}$$

where the standard deviation σ_u and annual average wind speed v- are determined from Equations 3 and 4 at each time step [3].

$$a_u = \frac{1}{N_s - 1} I_{i=1}^{N_s} (u_i - v\text{-})^2 \tag{3}$$

$$v\text{-} = \frac{1}{N_s} I_{i=1}^{N_s} u_i \tag{4}$$

These turbulence intensities were calculated at each time step from Equation 3 for each anemometer. In order to provide an empirical formulation for turbulence interactions with the wind turbine, a statistical comparison with wind industry practices for wind speeds is proposed. The frequency of turbulence intensity magnitudes for a range of wind speeds can be determined from the Weibull distribution in Figure 3.

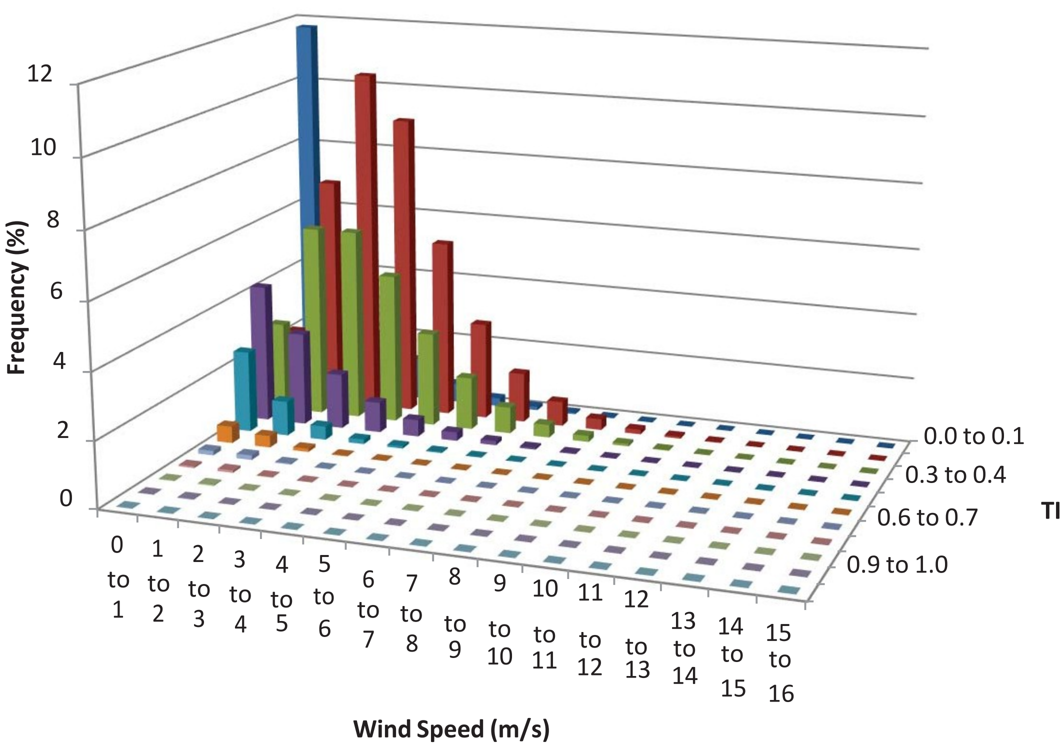

Figure 3: Three-Dimensional Weibull Distribution of Wind Speeds and Turbulence Intensities

Figure 3 indicates that for a wind speed range of 0 to 16 m/s, the turbulence intensity occurs most often between 0.1 and 0.2. These turbulence intensities provide important information on power output for the wind turbine. The turbulence intensities determine a similar statistical approach for wind speeds (i.e. Weibull distribution) at the turbine hub. The power output can therefore be quantified with respect to the turbulence intensities experienced by the wind turbine. This power output was quantified with respect to measured and IEC standard time intervals for small scale wind turbines in Figure 4 [1]. These results also correlate well with Skystream power curve results from Albers (2009) [4].

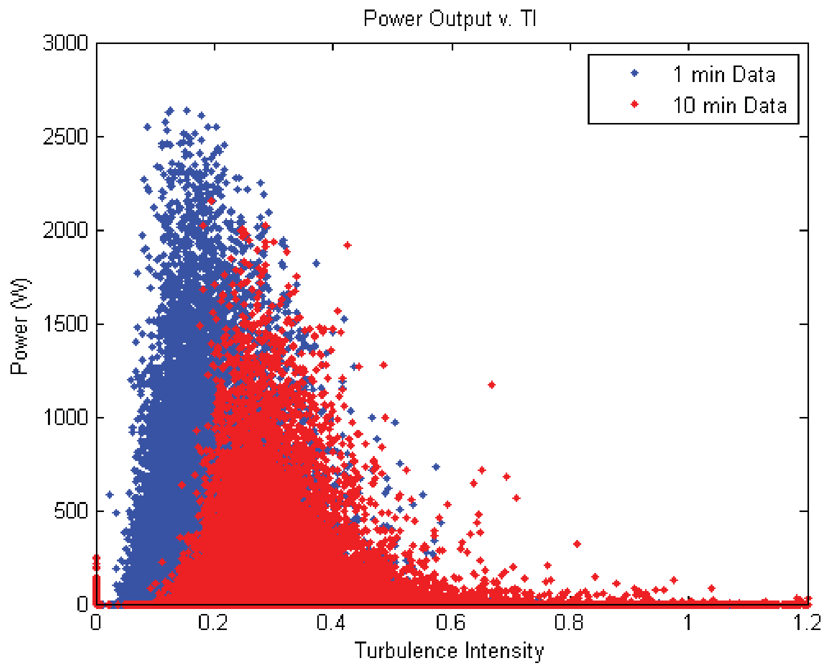

Figure 4: Power Output with respect to Turbulence Intensity for the Skystream 3.7

The results in Figures 3 and 4 indicated a statistical correlation between power performance and turbulence intensity compared to the local Weibull distribution, which enables faster computational prediction of turbine loads given real data. This also enables a more standardized approach for predicting stochastic loads due to turbulence, which can be accomplished in future works. This study demonstrated significant promise in wind turbine performance by providing a new method for assessing and analyzing turbulence interactions.

References

[1] IEC 61400-12-1. Power performance measuring of electricity generating wind turbines. IEC, 2005. 2-90. Print.

[2] Sunderland, Keith et al. "Small Wind Turbines in Turbulent (urban) Environments: A Consideration of Norma and Weibull Distributions for Power Prediction." *J. Wind Eng. Ind. Aerodyn.*, 121 (2013): 70-81. Web.

[3] Manwell, J.F., J.G. McGowan, and A.L. Rogers. *Wind Energy Explained: Theory, Design and Application*. 2nd ed. John Wiley & Sons, 2002. Web.

[4] Albers, A. "Turbulence and Shear Normalization of Wind Turbine Power Curve." (1994): 4. Print.