

The Effects of Large Scale and Small Scale Turbulence on the Power Output of a Small Horizontal Axis Wind Turbine

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Research is being conducted to assess the relationship between power output of a small horizontal axis wind turbine and the turbulence of the wind's velocity. The power generated by the wind is highly dependent upon the wind's velocity and is given by the relationship,

$$\text{Power} = \frac{1}{2} * \rho * A * v^3,$$

where ρ is the density of air, A is the area determined by blade diameter, and v is the wind's velocity. A wind turbine has the potential to extract a portion of this power, which is limited by Betz law to 59%. Since the power varies with the cube of the wind's velocity, average wind speeds cannot be used to calculate average power; i.e. higher wind speeds will have a much larger capacity to produce power than lower wind speeds. Therefore, in order to determine the amount of energy produced, it is necessary to incorporate wind velocity distributions. Wind speed distributions are generally skewed, consisting of a greater frequency of low speed winds and few high speed gusts. Combining wind speed probability with its corresponding power output determines the energy output. So even though the wind blows more frequently at lower wind speeds, the bulk of energy produced will be found at higher speeds because the power content at these speeds is orders of magnitude greater than those at lower speeds.

For wind turbines, power curves are formulated to relate average wind speed to average power output. These graphs are generated by collecting actual power output data and averaging this data over the wind speed at which it was recorded. (See figure 1.) Every curve contains some level of error because of its dependence upon how the averages are obtained. In a situation with turbulent, or highly fluctuating, winds, an average over a large period of time may not give an accurate representation of the velocity data. (See figure 2.) This is important because the power produced changes rapidly with velocity.

Therefore, turbulence on both large and small scales will be analyzed. Large scale turbulence

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¹¹refers to deviations from a 10 min, daily, monthly or annual mean whereas small scale turbulence focuses on mean values on the order of seconds.

A 1 kW Bergey XL1 wind turbine was erected at Potsdam airport in 2002 for research purposes at Clarkson University. A second turbine was installed last year and is used as a prototype in hopes to find ways to improve the turbine for lower wind speeds³. Data is being collected from both turbines at a frequency of 1 Hz, or 1 point/sec, to obtain a variety of information including voltage, current, and resistance. Meteorological data, including direction and velocity, is also acquired every second at the same height as the turbine.

Since this data was readily available, a number of analyses were performed to explore large scale turbulence effects. To reduce error in energy output estimates, a set of graphs was produced for each month in the past year. A power curve, a velocity distribution and an energy output graph were produced using ten minute averages of the 1 Hz data. (See figures 3 and 4.) Also, an ideal energy output graph was produced by a program that relied on a large wind velocity average (monthly or annual) and Weibull's probability distribution. (See figure 5.) A comparison between the actual and ideal energy output graphs showed the relevant amount of error produced for different turbulent situations.²

To further explore the possible relationship between power output and turbulence, the ten minute averaged data, including velocity and its standard deviation and the actual power output, for the time period of a month was sorted and separated according to velocity. For each one half m/s interval, the power output was plotted versus the standard deviation of the average velocity. This was done in order to keep the average velocity relatively constant (or the average input power) in order to observe how deviations from the average affect the power output. Though conclusions have yet to be drawn from this data, it has been predicted that smaller deviations from a high velocity mean will affect power output more greatly than larger deviations from a low velocity mean.

3. Humiston, Christopher and Visser, Kenneth, "Full Scale Aerodynamic Effects of Solidity and Blade Number on Small Horizontal Axis Wind Turbines." Department of Mechanical and Aeronautical Engineering, Clarkson University (2003)

A similar analysis will be conducted concerning small scale changes in wind speed. A hot wire will be used to collect wind speed data at 10,000 Hz, or 10,000 pts/sec. The instrument consists of a very thin piece of metal that heats up to about 300 °C and records changes in resistance. These resistance changes are then calibrated with velocity in order to obtain useful data. Ideally, the hot wire would be placed at the hub in order to detect changes as they happen to the turbine but this could not be done without distorting the wind flows. Therefore, an apparatus was designed that holds a hot wire on either side of the turbine, parallel to the center. A tail was added to keep the wires in the direction of the wind. The construction and installation of this hardware is not yet completed and so results are to follow.

Appendix 1: Figures

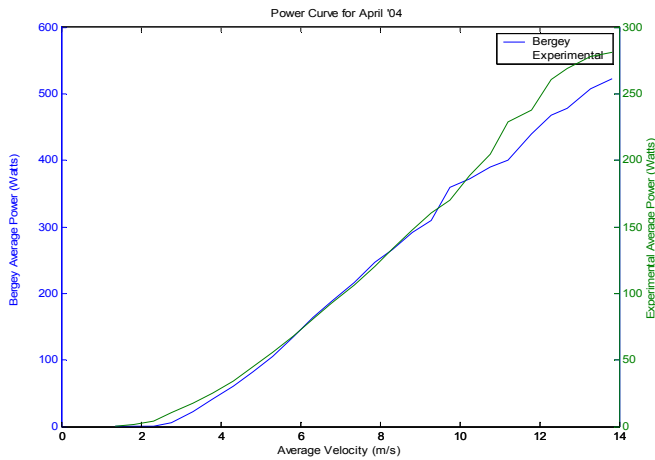


Figure 1: Power Curve

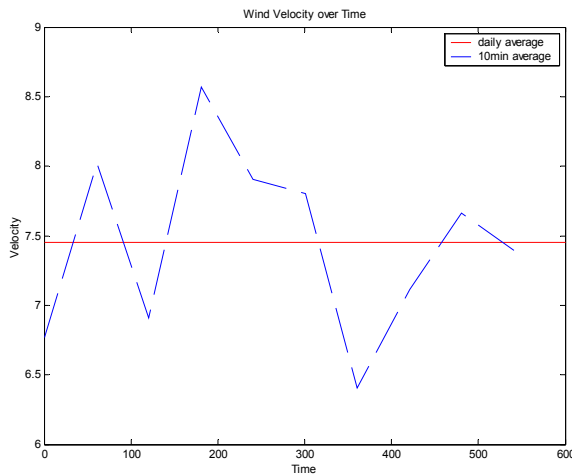


Figure 2: Average Wind Velocity with deviations

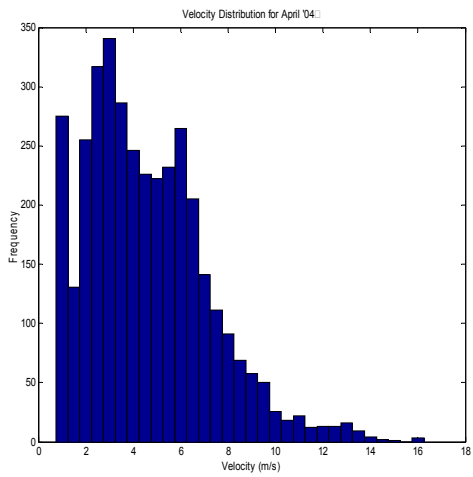


Figure 3: Wind Velocity Distribution

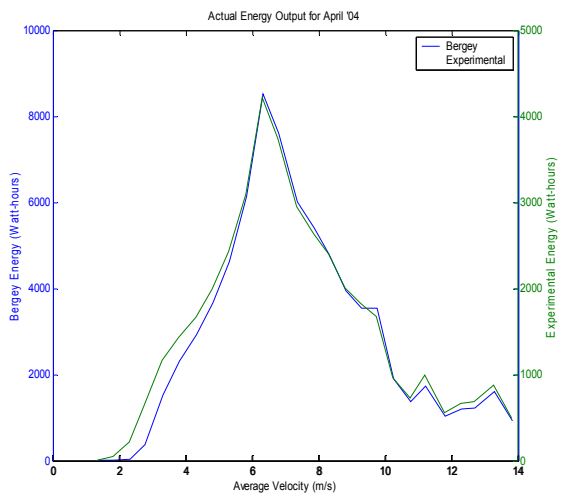


Figure 4: Actual Energy Output

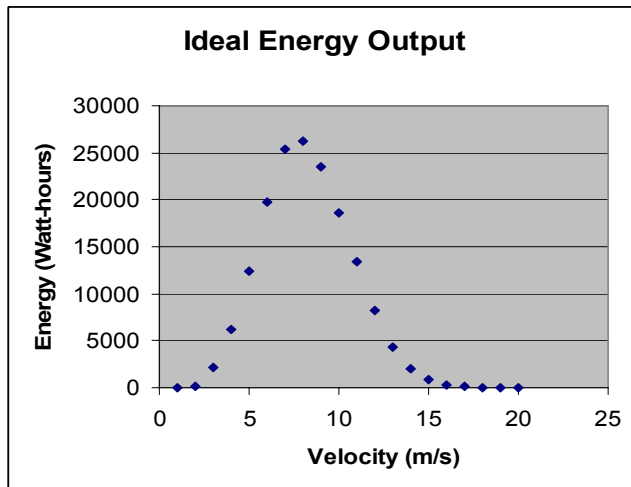


Figure 5: Ideal Energy Output