Speed Control of a Small Wind Turbine Using Electrical Loading

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Abstract

Small wind turbines with permanent magnet alternators (PMA) seldom have active speed control systems. The turbines rely on passive mechanisms such as furling and/or blade flutter to control the rotational speed. These passive methods cause high mechanical stresses and undesirable noise. One method to reduce the stresses and noise is to control the rotational speed of the rotor using electrical loading of the PMA. This method is known as "soft stall." The "soft stall" method was used to control the speed of a 900 watt wind turbine in wind speeds up to 15 meters per second.

Introduction

Most small wind turbines have a passive mechanical method of speed control. The turbines either furl their rotor out of the wind and/or the blades flutter to reduce the rotor performance. When a turbine's passive speed control begins to operate, the performance of the turbine can be greatly reduced while the mechanical stresses increase. In both stand-alone and grid tied applications, the load on the system ultimately controls the performance of the turbine.

Stand-alone applications, such as water pumping, create special challenges for a control system. For example, a wind-electric pumping system (WEPS) using a small wind turbine and a submersible pump will experience periods when there is more power available from the turbine than the pump can use (Velasco, et. al, 2004). When this occurs, the turbine speed will increase until the turbine's speed control begins working.

In this study, a controller, additional load, and a data acquisition system were added to a 900 watt WEPS. The WEPS was set to a simulated 75 m pumping depth. The system was allowed to pump for a period of time without the controller active and a period of time with the controller actively controlling turbine speed. This paper discusses the results of controlling the speed of a small wind turbine in a stand-alone application.

Materials and Methods

The method of speed control that was used is based on the "soft-stall" principle, where a generator's electrical load is varied to control the speed of the turbine rotor (Muljadi et al., 2000). In this method, to slow the rotor, the current in the generator windings is increased. The torque that the generator resists is proportional to the current in the windings (Mohan, N. 2003). When the torque in the generator is increased above what the rotor can produce, the rotor will slow down. To allow the rotor to speed up, the current in the winding is reduced.

The WEPS consisted of a Southwest Windpower[1], Whisper 200 wind turbine, and a Grundfos SQFlex pumping system (CU 200 control unit, IO 102 switch box and SQF 5A-6 (N) submersible pump). The wind turbine is on a 20 m tilt-up guyed tower. The wind speed is measured at a 15 m height near the turbine. The following performance parameters were measured at a rate of 5 Hz and averaged every one second: wind speed (m/s), turbine frequency (Hz), speed set point (Hz), additional load duty cycle (%), turbine AC power (watt), AC voltage (VAC), DC pump voltage (VDC), DC pump current (amps), additional load voltage (VDC), additional load current (amps), and pumping flow rate (l/m).

The additional load consisted of an electrical water heater element (240 V, 3500 W) that was connected to an insulated gate bipolar transistor (IGBT) switching module connected to a DC buss. The duty cycle of the IGBT was varied from 0 to 100% to vary the load on the system. The heating element was placed in the discharge water stream to prevent element burnout.

The controller and data acquisition system was a National Instruments Compact Fieldpoint, Programmable Automation Controller (PAC). The PAC is modular with an eight slot backplane (cFP-BP-8) with a CPU (cFP-2120), Pulse Width Modulation (cFP-PWM-520), Counter (cFP-CTR-502), Analog Input (cFP-AI-112), and Digital Input/Output (cFP-DIO-550) modules which were used in this study.

This study was performed on an existing WEPS at the USDA-ARS Conservation and Production Research Laboratory in Bushland, Texas. The WEPS had a Campbell Scientific 23X data logger that was collecting data for another study. The following parameters were captured from the 23X using the continuous analog output function of the 23X: Wind Speed (m/s) and Turbine Frequency (Hz). The following parameters were captured by paralleling the transducers used by the 23X: AC Power, AC voltage, DC Pump Voltage, DC Pump Current, and Flow Rate. The Duty Cycle, Frequency set point, Additional Load Voltage and Additional Load Current were captured from the PAC. All channels were recorded by the PAC in hourly files.

The control algorithm was based on a simple proportional integral differential (PID) control loop with the turbine frequency as the input and switching duty cycle as the output. The PID control attempts to keep the turbine at or below the set point frequency which was 65 Hz for this study. The higher the frequency is above the set point, the faster the duty cycle is increased to a maximum of 100%. As the turbine slows to the set point or below, the duty cycle is decreased to try to maintain the set point.

A total of 151 and 98 hourly files were recorded for the un-controlled and controlled time periods respectively. The hourly files were processed into one second averages. The averaged files were then joined into one file for the un-controlled time period and one file for the controlled time period. The data was binned using the method of bins based on 1 m/s wind speed bins. Data was collected until at least 10,000 samples were present in the 10 m/s bin.

Results and Discussion

A total of 530,821 and 340,589 samples were collected for the un-controlled and the controlled time periods respectively with the maximum data bin of 15 m/s for each period. Table 1 shows the number of samples in each data bin for each time period. The uncontrolled time period had a larger number of samples in the low wind speed bins. Since the purpose of this

[1] Mention of trade names or commercial products in this paper is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

study was to control turbine speed at high winds, the data collection was collected until the number of controlled samples exceeded the number of uncontrolled samples in the 10 m/s bin.

Table 1. Number of 1 second average samples in each wind speed bin.

Bin	Un-controlled	Controlled
1	12,660	11,172
2	375,555	22,433
3	128,010	80,143
4	90,441	31,826
5	78,333	27,027
6	54,501	28,166
7	66,489	59,917
8	20,157	24,684
9	15,593	19,379
10	11,782	14,951
11	11,369	16,175
12	2,407	3,252
13	1,048	1,126
14	372	268
15	104	70
Total	530,821	340,589

Figure 1 shows the relationship between frequency and wind speed for the two time periods. It was puzzling why the average un-controlled speed was lower than the average controlled speed until looking at a scatter plot of the two time periods (Figures 2 and 3). Figure 2 shows that during high winds, the turbine is staying furled, while Figure 3 shows that the turbine was not staying furled during high winds. The standard deviation of the turbine frequency in each bin also indicates that the turbine is not staying furled when the speed is being controlled (Table 2). The high standard deviation in the 7 m/s bin suggests that around 7 m/s the controller is applying the additional load.

By controlling the speed of the turbine with an additional load, the power output of the turbine was increased significantly (Figure 4). The peak AC power increased from 207 to 774 watts. Once again, notice the power peaks at 7 m/s for the un-controlled case indicating that the turbine was starting to furl. This increase in AC power is expected with the additional loading. One would expect the power that the pump is consuming to stay the same for both cases. However, the power that the pump consumed increased as well (Figure 5) from 202 to 271 watts. The power consumption levels-off in the 8 to 10 m/s bins. The flow rate shows the same relationship (Figure 6) and increased from 7.6 to 10.7 liters per minute (lpm).

The increase in power would produce an additional 669 kW-h per year at Bushland, Texas. Figure 7 shows the monthly power yield for an average wind year for the two configurations. In our case, we did not use the extra power in a useful manner. However, any additional load could be used, for example a battery charger or hydrogen electrolyzer. The increase in flow rate would produce an additional 961,000 liters per year. Figure 8 shows the monthly water yield for an average wind year for the two configurations.

Table 2. Turbine frequency standard deviation in each wind speed bin.

Bin	Un-controlled	Controlled
1	4.43	1.57
2	3.95	3.15
3	6.02	5.15
4	7.54	6.38
5	7.58	7.70
6	9.32	9.67
7	14.96	11.10
8	22.00	9.78
9	25.24	8.46
10	26.60	7.72
11	28.57	7.22
12	33.36	7.08
13	34.77	7.26
14	35.01	7.21
15	32.68	6.97

Conclusions

Small wind turbine speed was successfully controlled through electrical loading for this stand-alone application. The additional loading on the system increased the system power output as well as increased the pumping yield. This simple method of speed control could provide power for other uses.

References

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Muljadi, E., Pierce, K., and Migliore, P. 2000. Soft-stall control for variable-speed stall-regulated wind turbines. *J. of Wind Eng. and Ind. Aero*. 85(3): 277-291.

Velasco, M., Probst, O. and Acevedo, S. 2004. Theory of wind-electric water pumping. *Renewable Energy*, 29(6):873-893.

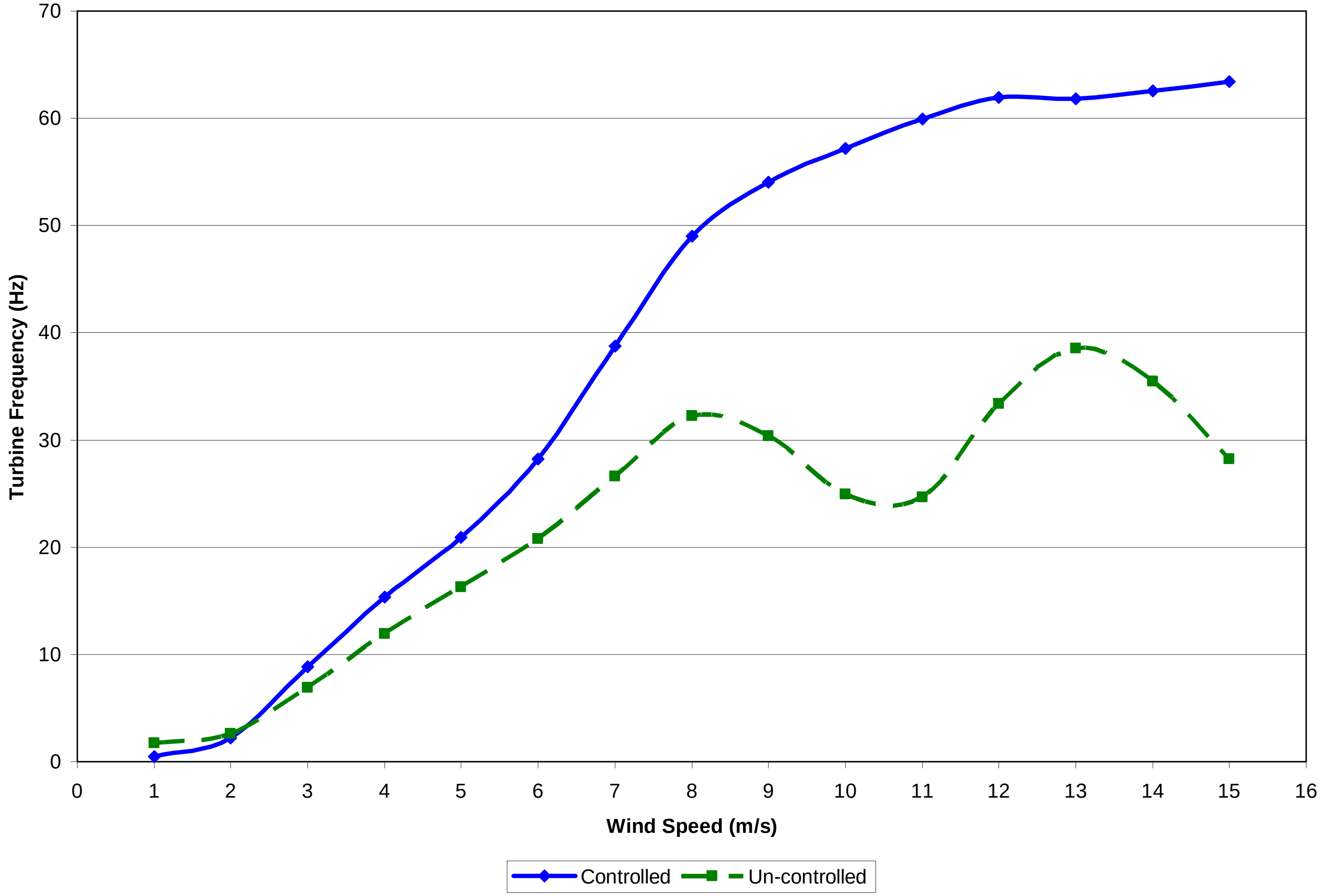

Figure 1. Turbine frequency verses wind speed.

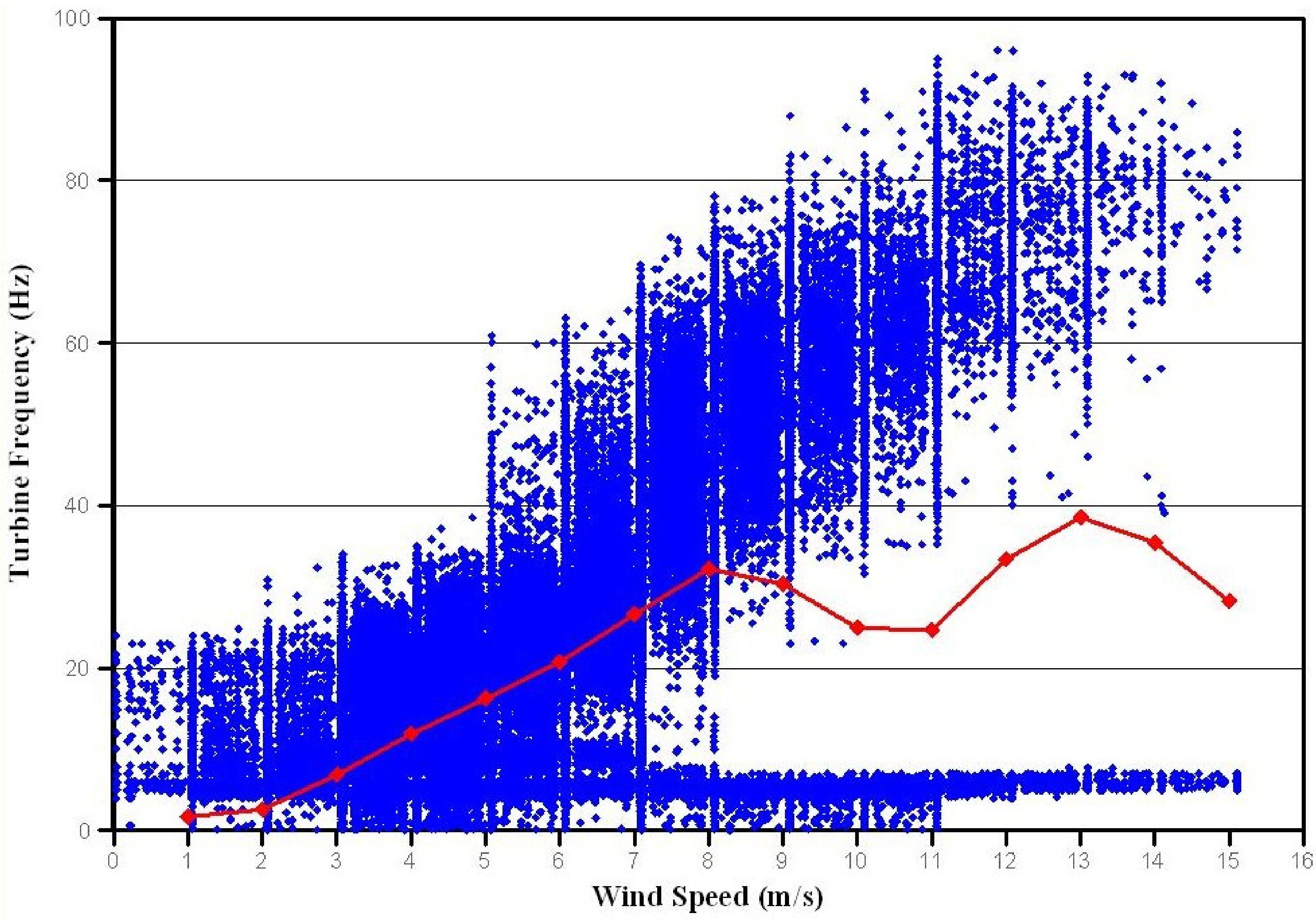

Figure 2. Un-controlled turbine frequency and bin average frequency verses wind speed.

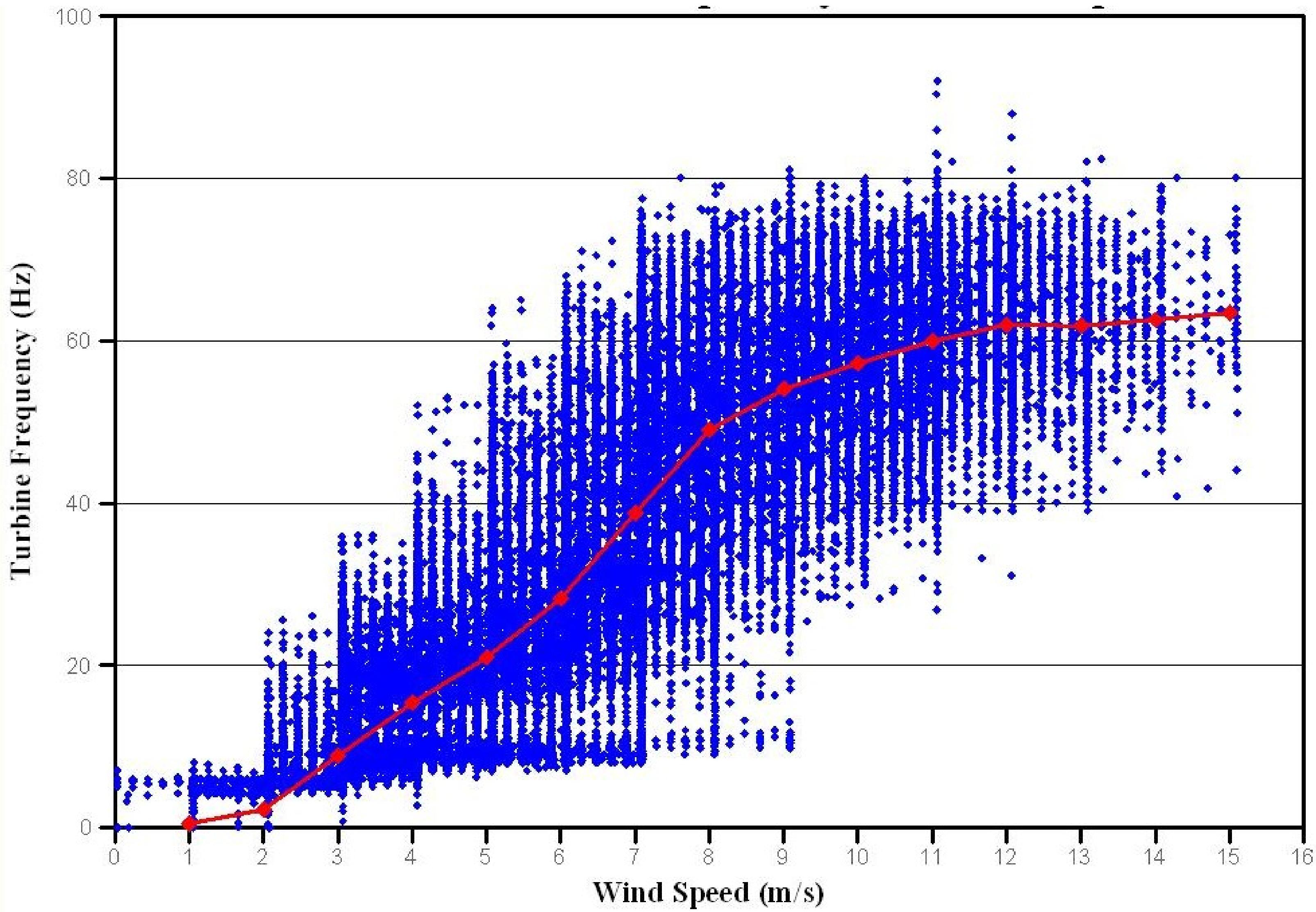

Figure 3. Controlled turbine frequency and bin average frequency verses wind speed.

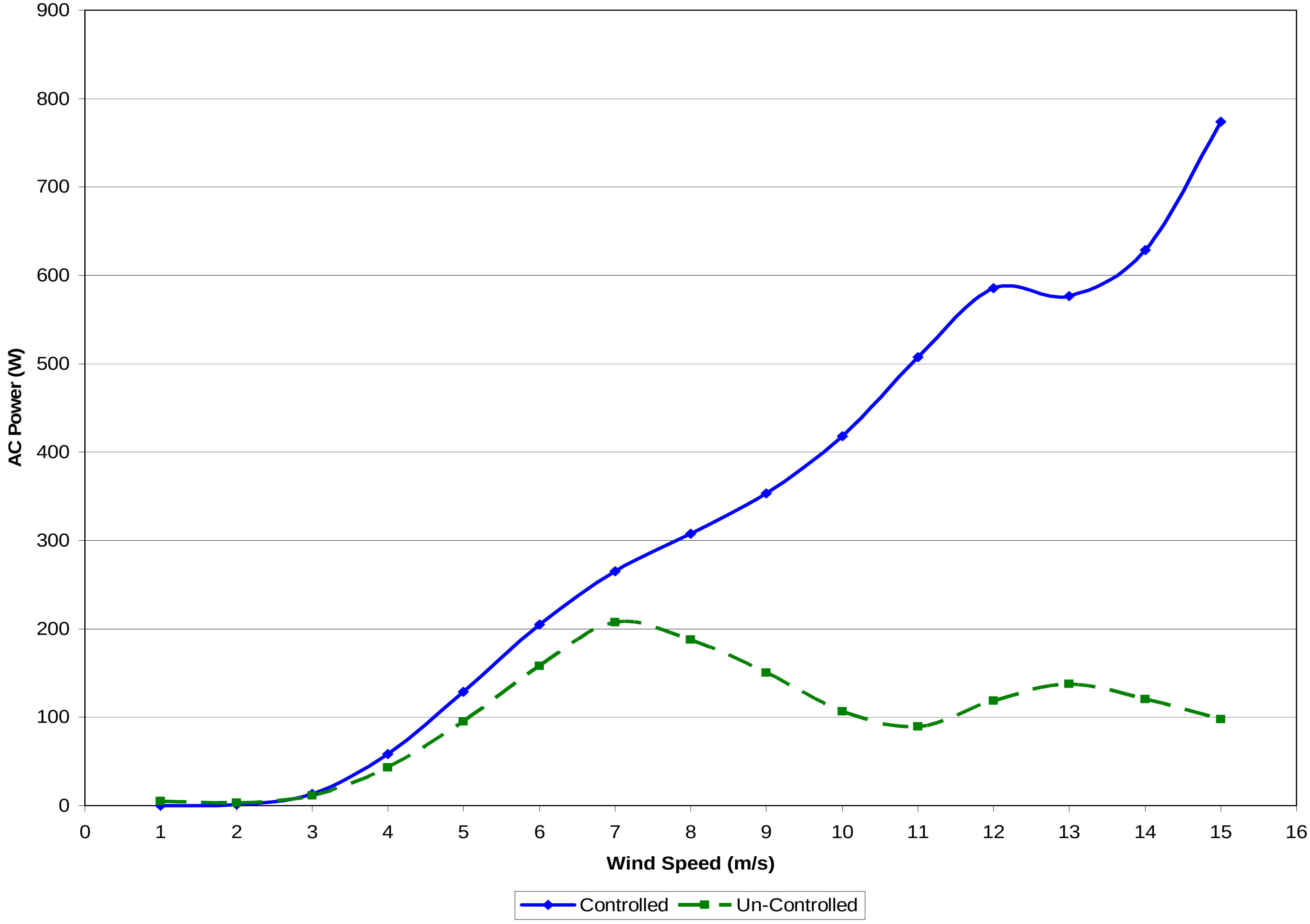

Figure 4. Turbine AC power verses wind speed.

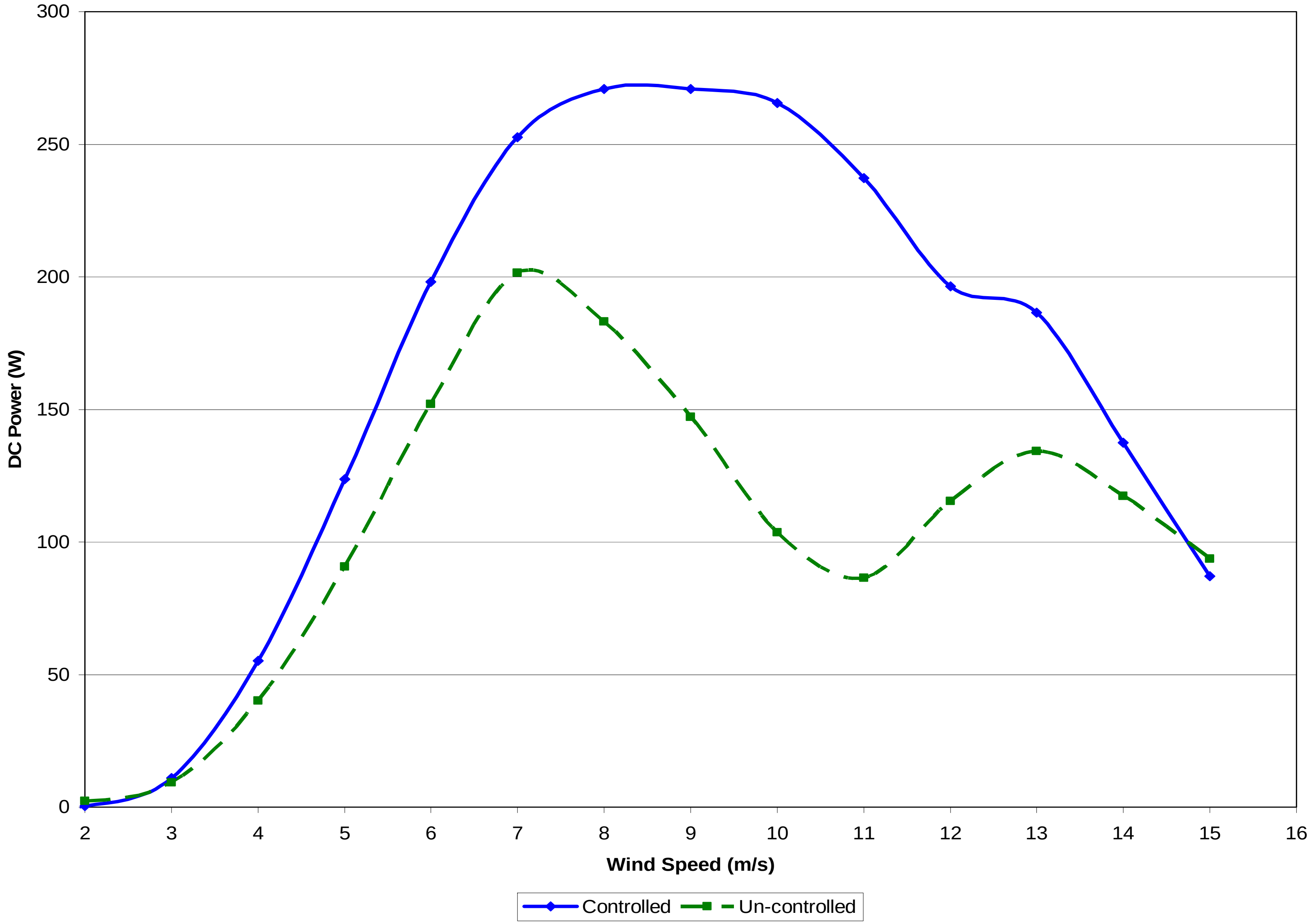

Figure 5. DC pump power verses wind speed.

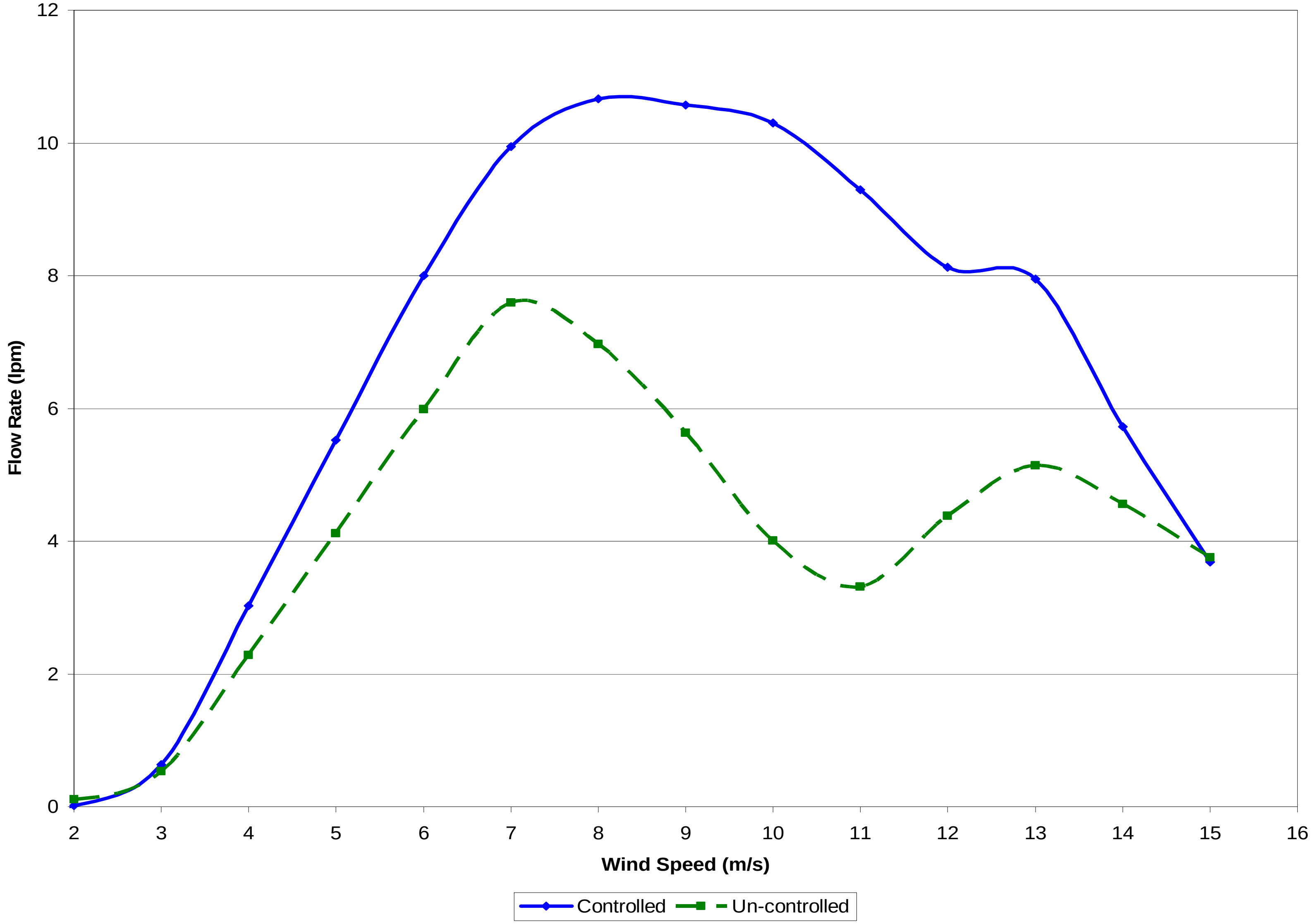

Figure 6. Flow rate verses wind speed.

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Small Wind Systems Technical and Market Developments

Small wind systems can and will play a significant role in growing the wind energy business but to do so requires successful market strategies and technology to address both the residential and the small commercial markets. This session explored examples of recent technical advancements in small wind technology that can improve performance and reduce cost and examples of market strategies for bringing small wind systems into the mainstream.

Moderator: Charles Newcomb, Regional Director - Great Plains, Entegrity Wind Systems Inc.

Alicen Kandt, Mechanical Engineer, National Renewable Energy Laboratory
Making the Economic Case for Small Scale Distributed Wind

Louis Rigaud, General Director, Halus Power Systems
Wind Turbines for Projects under 2 MW

Donny Cagle, Research Technician, Alternative Energy Institute, West Texas A&M University
Evaluation of Airfoils for Small Wind Turbines

Byron Neal, Agricultural Engineer, U.S. Department of Agriculture / Agricultural Research Service
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