Improved Power Curves when a 10 kW Bergey is connected to an Aurora Inverter compared to the performance of other BWC inverters.

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Introduction

I am currently monitoring performance of 4 different BWC XL turbines in NY State. Three are connected to a GridTek10 inverter and the 4th to the new PowerSyncII inverter. I now have evidence that my GT10 in Ellenburg, NY, does not perform as well as the other two GT10s. It is overloaded more frequently causing frequent losses of power production; sometimes the inverter automatically resets after 5 min and other times it requires a manual reset. During wind storms I usually check every 8 h. In one 12 month period I lost 4 or 5 % in annual energy production due to automatic resets and 9 to 10% because of manual resets for a total of about 15% See R#61 in http://www.ualberta.ca/~mtyree/SWIEP/Publications.html .

The purpose of this brief report (preliminary) is to show how Power-One's Aurora inverters can be used to improve the energy yield of 'old' Bergey Excel-s turbines compared to those being currently monitored.

Methods

Measured:
1) Power output (using Ohio Semitronics power sensors)
2) Wind speed (20 ft below hub height using NRG #40 anemometer)
3) Generator Hz, from which it is possible to calculate RPM and TSR (tip speed ratio) based on the number of poles in the generator and blade radius).
4) Air temperature (using NRG #110s temperature sensor)
5) Barometric pressure (using NRG #BP20 barometer)
6) All data logging done with a LabJack U9 data logger and DAQFactoryExpress software.

Used NREL methods to standardize wind speed to standard sea level air density (1.225 kg m^{-3}) and temperature (15 C). At the MSC site I also had a met tower with an anemometer at hub height (see Appendix).

At my home in Ellenburg, NY, Rob Beckers and I installed a stacked inverter system consisting of two PVI-6000 inverters and two PVI-WindBoxes as shown in `http://www.solacity.com/Docs/Dual-Inverter%20Wiring.pdf` Also in Appendix 3.

All sites have an anemometer mounted on the turbine tower at 20 ft below hub height. This lower anemometer allows measurement of a PCC (power correlation curve). The PCC differs from a PC (power curve) in that wind speed at hub height is underestimated by a few percent. If the average wind shear is 0.3, the wind speed at 20 ft lower than hub height (122 ft) would have to be multiplied by about 1.05 to equal wind speed at hub height (5% correction).

Results (Preliminary)

The Aurora Inverter system appeared to produce an improved power curve compared to all the other BWC systems monitored in NY State, which should in theory result in an improved annual energy production based on industry standard WindCad models.

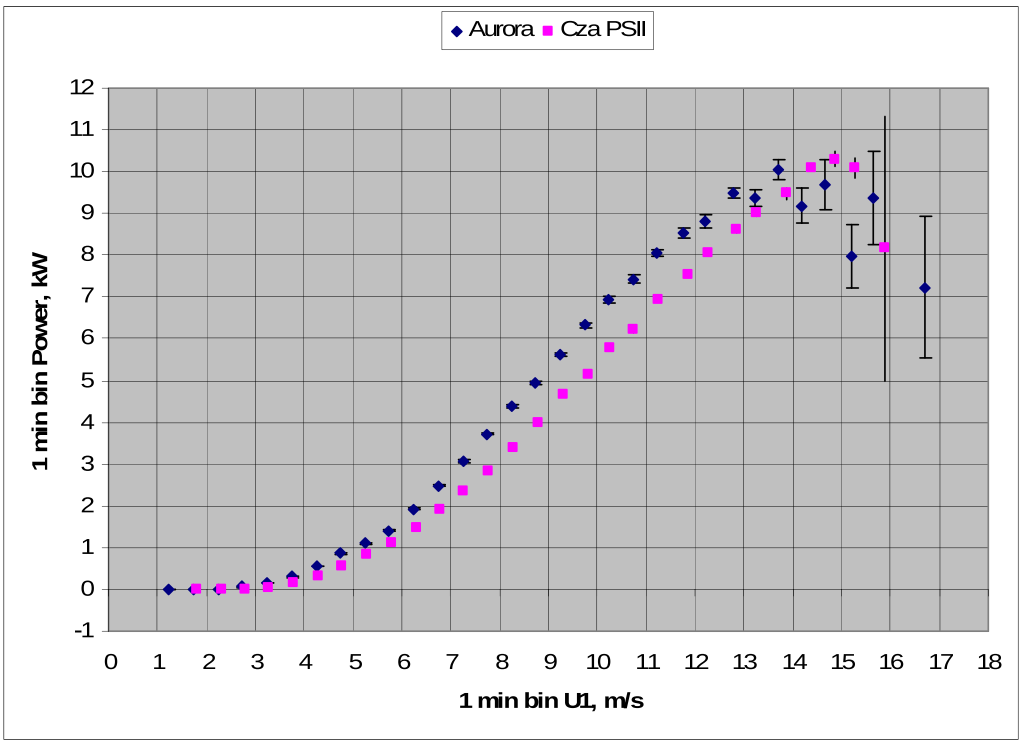

Fig. 1: Comparison of Aurora = BWC Excels connected to two stacked Aurora PVI-6000 inverters to power curve from Cza PSII = BWC Excels connected to PowerSync II inverter. All bin values are means ± sem (standard error of the mean). Wind speed at both sites measured on anemometer mounted on turbine tower 20 ft below hub height.

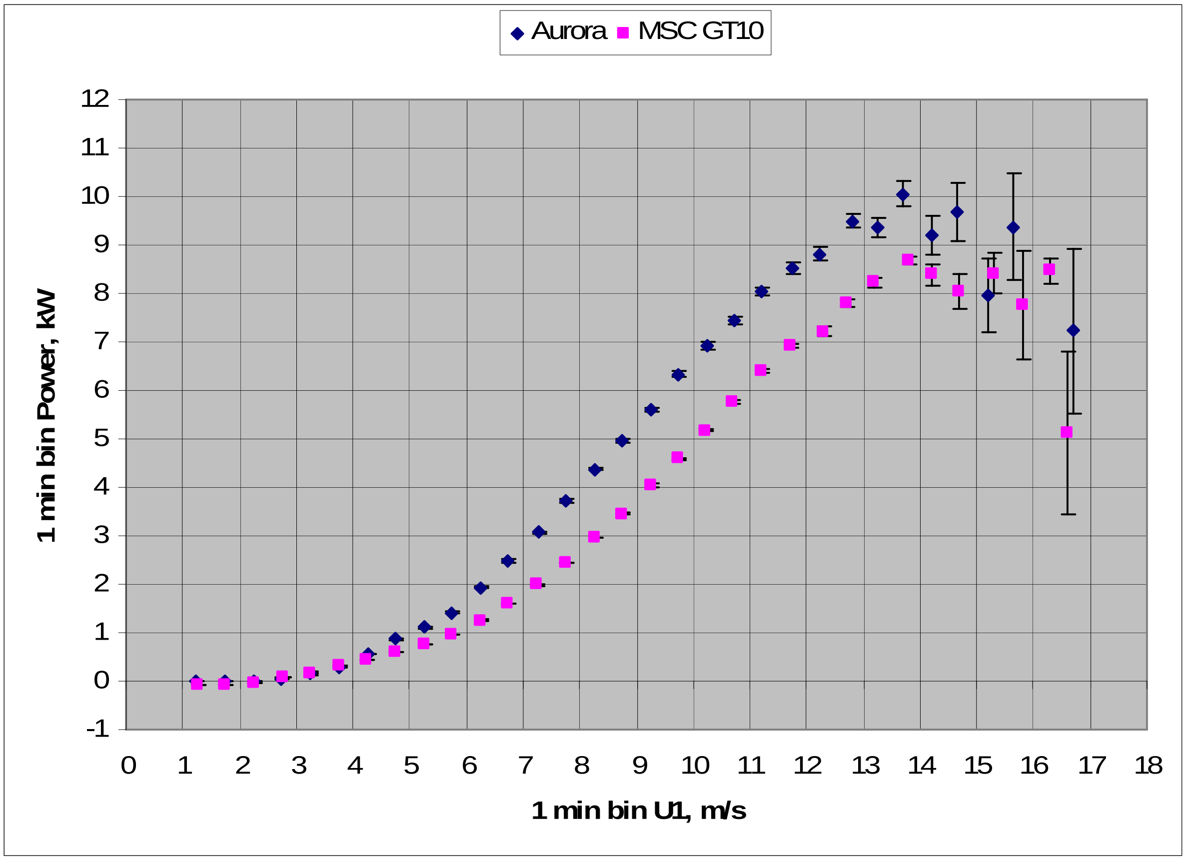

Fig. 1: Comparison of Aurora = BWC Excels connected to two stacked Aurora PVI-6000 inverters to power curve from MSC = BWC Excels connected to GridTek10 inverter. All bin values are means ± sem (standard error of the mean). Wind speed at MSC measured from met tower 3 blade diameters from turbine at hub height. The power curve measured from anemometer on turbine tower at 20 ft below hub agreed within 1 %. Because of topography the site would need calibration to get wind speed at hub height. Aurora site measured on anemometer mounted on turbine tower 20 ft below hub height. MPPT table 1 appendix 2.

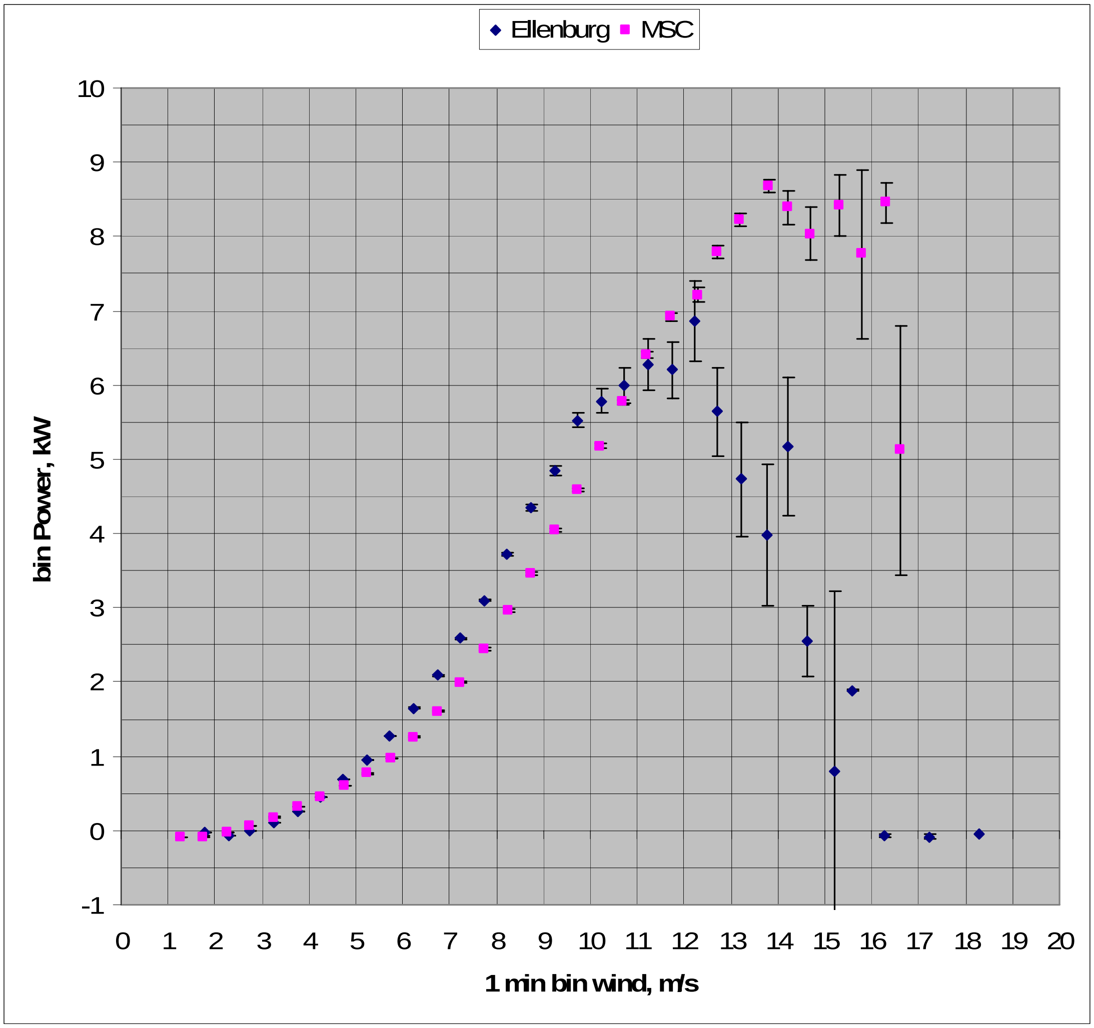

Fig. 3: These power curves demonstrate that there is something different about the equipment in Ellenburg vs MSC. Ellenburg: power curve for BWC Excels connected to my GridTek10. Data are means and sem for 10.5 months of wind data. MSC: power curve for BWC Excels connected to GridTek10 at MSC site (data for 30 Oct 09 to 26 Jan 10). In both curves the anemometer is mounted on the turbine tower 20 ft below the hub height. MPPT Table 1 Appendix 2.

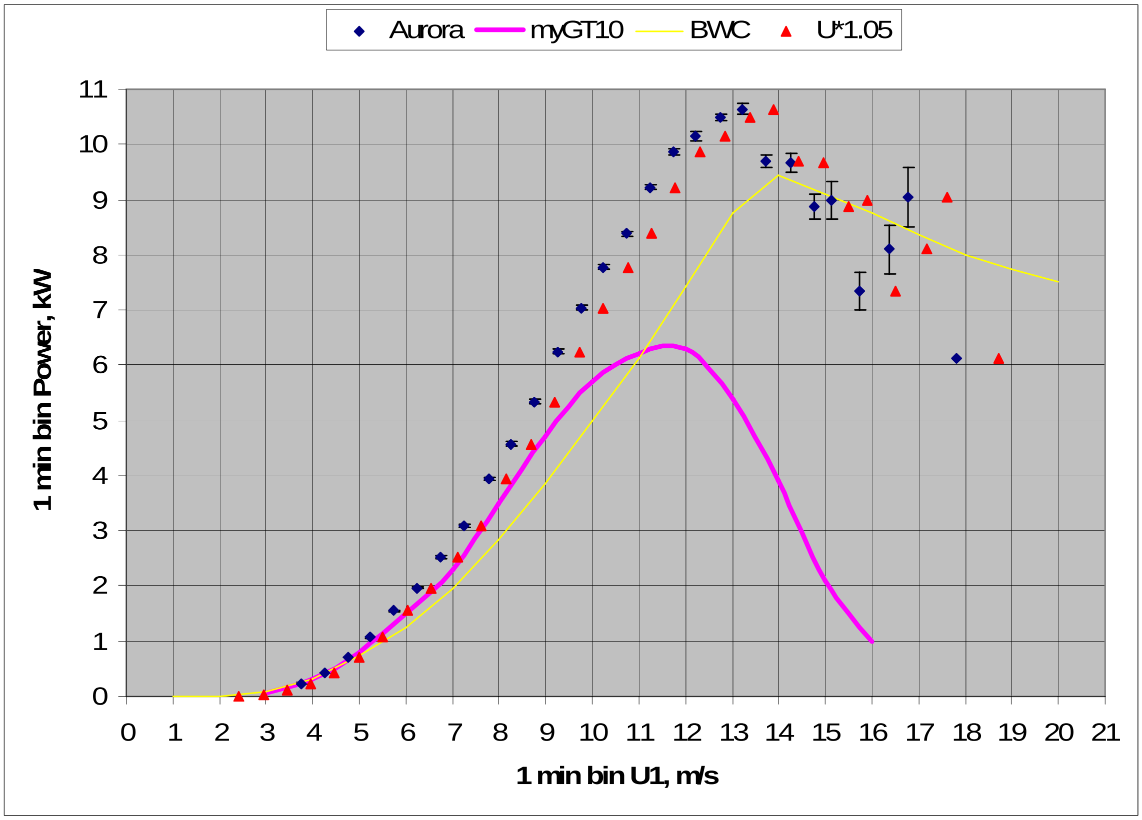

Fig. 4: Aurora: PCC that results from the MPPT proposed by Rob Beckers. myGT10: PCC from my GridTek10 based on 10.5 months of data. BWC: Bergey's official power curve for their Excels connected to a GridTek10. U*1.05: Shifed the PCC about 5% to the right on the x-axis to correct for hub height wind speed. MPPT Table 2A/B Appendix 2.

BWC is now marking a new Excel-s turbine featuring a 'Tier Neo' generator with an improved power curve. See http://www.bergey.com/Technical/WindCAD%20Tier-SH3055-23.xls The improved power curve is virtually identical that that shown in Fig. 4 U*1.05 above. So owners of old turbines can achieve the performance of the new BWC turbines by switching over to a stacked Aurora system.

Estimated annual energy production:

Last year my site in Ellenburg, NY, had a mean annual wind speed of 4.3 m/s @ 100 ft (only fair). Based on myGT10 power curve in Fig. 4, the standard WindCad model predicts an annual energy production of 8,200 kWh (measured 8,002). Based on the new power curve (Aurora) I am expecting 10,400 (a 26% increase). This WindCad model does not include the down-time when my GT10 needs a manual reset. The new Aurora inverter does not need manual resets (see R#61). Hence I am expecting a 36% to 40% increase.

Appendix 1

Equations used to correct wind speed for air density. Corrections are to sea level at 15°C:

$$P = P_b \left[1 + \frac{\beta}{T_b}\left(H - H_b\right) \right]^{-\left(\frac{g_n}{\beta R}\right)}$$

P = pressure at hub height Pa
P_b = measured pressure Pa
β = temp gradient (laps rate) = -6.5E-3 K m^{-1}
T_b = temp at barometer height
H = hub height
H_b = barometer height
g = acceleration due to gravity = 9.807 m s^{-2}
R = specific gas constant (287.053 m K^{-1} s^{-2})

$$\rho_i = \frac{P_i}{RT_i}$$

ρ_i = density over sample time period
P_i = pressure at hub height over sample period
T_i = temperature over sample time period

$$U_n = U\left(\frac{\rho_i}{\rho_o}\right)^{1/3}$$

U_n = corrected or normalized wind speed
U_i = sample wind speed over sample time period

Equations for wind shear:

$\left(\frac{U_1}{U_2}\right) = \left(\frac{H_1}{H_2}\right)^{\alpha}$ where α = wind shear coefficient which is calculated from

$\alpha = \frac{\log\left(U_1 / U_2\right)}{\log\left(H_1 / H_2\right)}$. The wind speed at hub height is computed from

$$U_{hub} = U_1\left(\frac{H_{hub}}{H_1}\right)$$

Appendix 2

Programmed MPPT tables used in this report.

Table 1: Used to obtain the PCC in Figure 1 Master and Slave have unequal loads in an attempt to reach optimum conversion efficiency in the master before the slave comes on. This table caused two fuses in the PVI-Wind Box 3-phase input to overload and blow. Equal loading would have shared the current load equally between master and slave.

Generator Hertz	Master kW	Slave kW	Total kW
11	0.00	0.00	0.00
13	0.12	0.00	0.12
20	0.16	0.00	0.16
25	0.30	0.00	0.30
30	0.59	0.00	0.59
35	1.01	0.00	1.01
45	2.24	0.00	2.24
55	3.80	0.00	3.80
70	4.28	1.37	5.65
85	4.76	2.54	7.30
100	5.24	4.29	9.53
115	5.72	5.59	11.31
130	5.96	5.96	11.92
145	6.20	6.20	12.40
150	6.20	6.20	12.40

Table 2A: The PVI-6000 inverters can be programmed in kW vs generator Hz or vs volts. However it is not clear exactly where or how input voltage is measured. I have measured both DC bus voltage and AC rms voltage and neither seems to correspond to the table values. Watts = value programmed in both master and slave inverter. Used to obtain the PCC in Fig. 4.

Volts	kW	Watts
60	0.00	0
69	0.12	60
80	0.21	105
91	0.34	170
101	0.50	250
112	0.70	350
133	1.25	625
153	2.00	1000
172	3.00	1500
191	4.20	2100
209	5.80	2900
227	7.70	3850
350	12.40	6200

Table 2B. Based on measured performance of the inverter system, Table A (kW vs V) corresponds to this table of W vs Hz below. Used to obtain the PCC in Fig. 4.

Gen Hz	Master W	Slave W	Total kW
11	0	0	0.000
13	60	60	0.120
20	80	80	0.160
25	150	150	0.300
30	295	295	0.590
35	505	505	1.010
45	1008	1008	2.017
55	1797	1797	3.595
70	3343	3343	6.686
85	4561	4561	9.121
100	5572	5572	11.145
115	6200	6200	12.400

Appendix 3

Generic stacked invert wiring diagram recommended by Rob Beckers.