

Comparing the PowerSyncII to the GridTek10 Inverter while Connected to a
Bergey Excel 10 kW Wind Turbine Generator (Revised 3 June 09)

by

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Introduction

As many readers of SWIEP know, I am a scientist and owner of a rather nice turbine, a Bergey Excel 10 kW turbine connected to a Xantrex GridTek10 inverter. Overall, I am pleased with the performance, with the durability of the system and with the warranty service received when my turbine crashed to the ground. But as a curious scientist I am also interested in how it works and whether the systems can be improved. I suspect the systems can be improved, because the GridTek10 inverter is prone to shut-down when winds exceed 16 m/s with a consequent loss of annual energy production. Since writing an earlier report (SWIEP R#41 & R#42) Bergey Windpower Corp (BWC) has started selling their new PowerSyncII inverters with new installations of their 10 kW Excel-s turbine.

The purpose of this report is to present measurements of the electrical output characteristics of the new PowerSyncII inverter and compare it to the older GridTek10 inverter. SWIEP is also a consumer reports group and I feel that an informed buyer is a wise buyer. I hope that SWIEP reports will inform and help future buyers of small wind turbines.

I did use a very different method than used once by NREL (National Renewal Energy Lab). NREL measured the efficiency of the GridTek10 using 10 min binned values for power-in and power-out. I didn't like that method because inverters can respond to changes in power rather quickly < 1 s so using 10 min means doesn't give any information about rapid response of an inverter while it is trying to MPPT given that wind speeds and hence power-in changes rapidly with time. For example when the mean power in = 7 kW averaged over 10 min the instantaneous power can change from < 1 to > 12 kW during that 10 minutes.

Methods

The BWC inverters (GridTek10 & PowerSyncII) converts variable voltage variable frequency 3-phase power to DC power then back to AC power at 60 Hz, which is compatible with residential homes. Single phase power (P) is delivered by pure sine wave voltage and current waveforms and is equal to AC voltage (V) times AC current (I), $P = VI$. The AC V and I are also referred to as RMS, root mean square, values. So on the output of the BWC inverters there are two energized (live) wires, a and b, plus a neutral (ground). If you measure AC voltage between a and b and current in one of the wires then output power is given by:

$$P_{out} = V_{ab} I_a = V_{ab} I_b \quad (1)$$

However, the Bergey Excel 10 kW wind turbine is a 3-phase generator with variable voltage and variable frequency output. I consulted Prof. Andy Knight, a power electronics engineer at the University of Alberta, and he told me that 3-phase generators have 3 energized wires (a , b , and c) and no neutral. The 3 energized wires carry AC or RMS voltage (V) and current (I). The instantaneous power at time t , $P(t)$, is generated by the instantaneous voltage and currents (v and i , respectively) and is given by the sum of the power going through the three wires:

$$P(t) = v_a i_a + v_b i_b + v_c i_c \quad (2)$$

A characteristic of 3-phase generators is that at any instant $i_a + i_b + i_c = 0$ so with a little algebra it follows that:

$$P(t) = (v_a - v_c) i_a + (v_b - v_c) i_b \quad (3)$$

And if the generator arms are 'balanced', i.e., identical design and working normally, then both terms in Eq(3) are equal, hence

$$P(t) = 2(v_a - v_c) i_a = 2(v_b - v_c) i_b. \quad (4)$$

Finally the average power generated is equal to the time integral of Eq.(4) over one AC cycle. Lets call this generated power the input power into the GridTek10, P_{in} :

$$P_{in} = \int_{cycle} P(t) dt = \int_{cycle} 2(v_a - v_c) i_a dt \quad (5)$$

I approximated Eq(5) using a digital oscilloscope to obtain many instantaneous values of $V_{ac} = v_a - v_c$ and $I = i_a$. If there are n samples in 1 cycle then by definition of the integral in Eq(5):

$$P_{in} \cong \sum_n 2V_{ac} I \quad (6)$$

Usually to get an accurate value of P_{in} you want $n > 200$ instantaneous readings equally spaced in time. A similar kind of instantaneous sum of readings can be used to compute power out, P_{out} , as an alternative to using RMS values in Eq(1).

$$P_{out} \cong \sum_n V_{ab} I \quad (7)$$

All instantaneous voltages and currents were recorded on a Tektronix digital oscilloscope (model TDS2004). This provided 4 channels of data at a 60 MHz sampling rate, with each oscilloscope scan having 2,500 A/D samples per channel. Differential input (V_{ac}) and output (V_{ab}) were measured with a model P5200 differential voltage probes, see:

http://www2.tek.com/price/tk_ec_pricepage.msrp?product=TDS2024B&service_only=N

Instantaneous currents were measured with Fluke model 80i-110s AC/DC current probes that have a useful operation range from DC to 1 kHz and currents from 0 to 100 A, see: [http://ca.fluke.com/caen/products/AccessoryDetail.htm?cs_id=2106%28FlukeProducts%29&catalog_name=FlukeCanada&category=PRCU\(FlukeProducts\)](http://ca.fluke.com/caen/products/AccessoryDetail.htm?cs_id=2106%28FlukeProducts%29&catalog_name=FlukeCanada&category=PRCU(FlukeProducts))

The Fluke current probes are a cheaper alternative to the similar Tektronix probes for the frequency range used in this study (20 to 140 Hz).

Michael Klemen objected to the use of the 80i-110 current probes in the earlier report on the grounds that they may not be accurate enough for the tests performed in this study. Hence, in this report I add Appendix I that examines the accuracy of the 80i-110 current probe.

Results

Examples of raw data and summary results can be downloaded from the SWIEP website as R#57 (<http://www.ualberta.ca/~mtyree/SWIEP/Publications.html>). The computed efficiency of two BWC inverters are given in Figure 1. The % Efficiency is defined as $100P_{in}/P_{out}$. The efficiencies I observed are from 79% to 83% for P_{out} from 1 to 12 kW. These efficiencies a little lower than reported by NREL (Report 33540 Fig. 9 Eff=87% and Report 33452 Fig 8 Eff=86%). The NREL reports do not clearly state how they measured P_{in} hence it is not clear if the differences in efficiency are due to differences in measuring technique or due to production-run differences between GridTek10 units as they come from the Xantrex factory.

In my 3 June revision I have added efficiency data provided by Tod Hanley, BWC, on another PowerSyncII unit. Tod's data were posted on the s-w-h Yahoo! Group site without much methods details. This unit has much higher efficiency. So I have told Tod that I will be returning to my site to measure the efficiency again with the methods described above and with Ohio Semitronics power sensors. My idea is to check for mistakes in my method and compare that to another methods. Readers should look for another revision in August or September. I will confirm with Tod to use methods he thinks are okay. Tod thinks the normal variation between PowerSyncII units should be less than in Figure 1. The polite thing to do is to assume Tod's values are more correct than mine until I have a chance to measure it again.

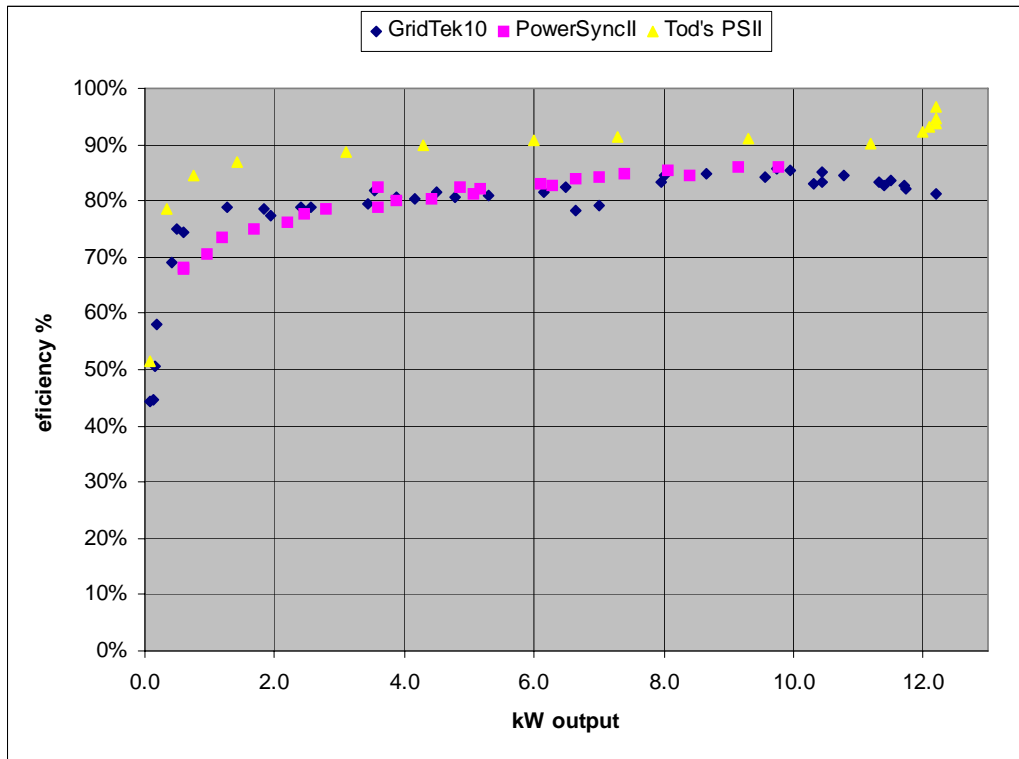


Figure 1. Efficiency of power conversion of the BWC inverters =

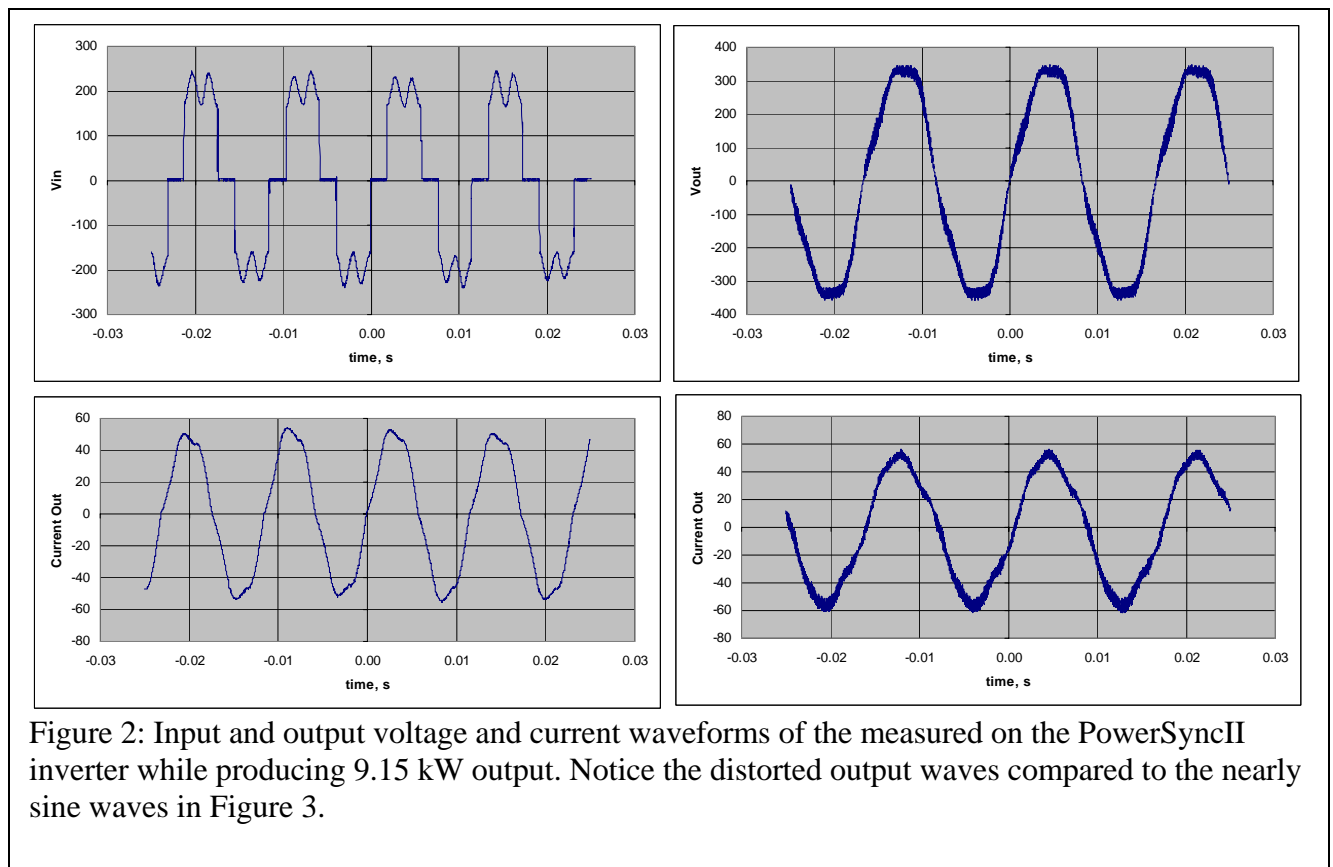
(power output)/(power input from the Bergey 10 kW Excel generator).

Y-axis: % Efficiency = $100 \times (3\text{-phase power in}) / (\text{power out})$. X-axis: power output, kW.

Between 7 & 10 kW output the inverter is keeping V_{in} approximately constant but increasing A_{in} . From 10 to 12 kW the inverter is limiting output power, hence V_{in} is increasing rapidly.

Figures 2 and 3 show the input and output wave-forms for the two BWC inverters. An unloaded generator (10 kW Excel-s) produces sine-wave voltages and zero amps, but the waveforms become quite distorted when under load. In the process of loading the generator, the full wave rectafier system and inverter feedbacks cause the distortion on the inputs as show. Andy Knight, Professor of power electronics at the University of Alberta, explained to me that differences in the input waveforms are due to the propriatary differences in the two BWC inverters. Hence without reverse engineering the two systems it is difficult to explain the differences.

In Figures 2 & 3 the output waveforms that send power into the grid are also different. Andy Knight informed me that the PowerSyncII has much more pronounced power harmonics that 'account' for the differences in the waveforms but that these distorted power harmonics might be the fault of the power companies grid rather than the consequences of the different internal design of the PowerSyncII versus the GridTek10. That is, the PowerSyncII inverter may be trying to match the power quality in the grid at the location of the PowerSyncII inverter. Andy said the harmonic distortions in Figure 2 (output) are within the range of harmonics he has seen at different locations in North America and the U.K.



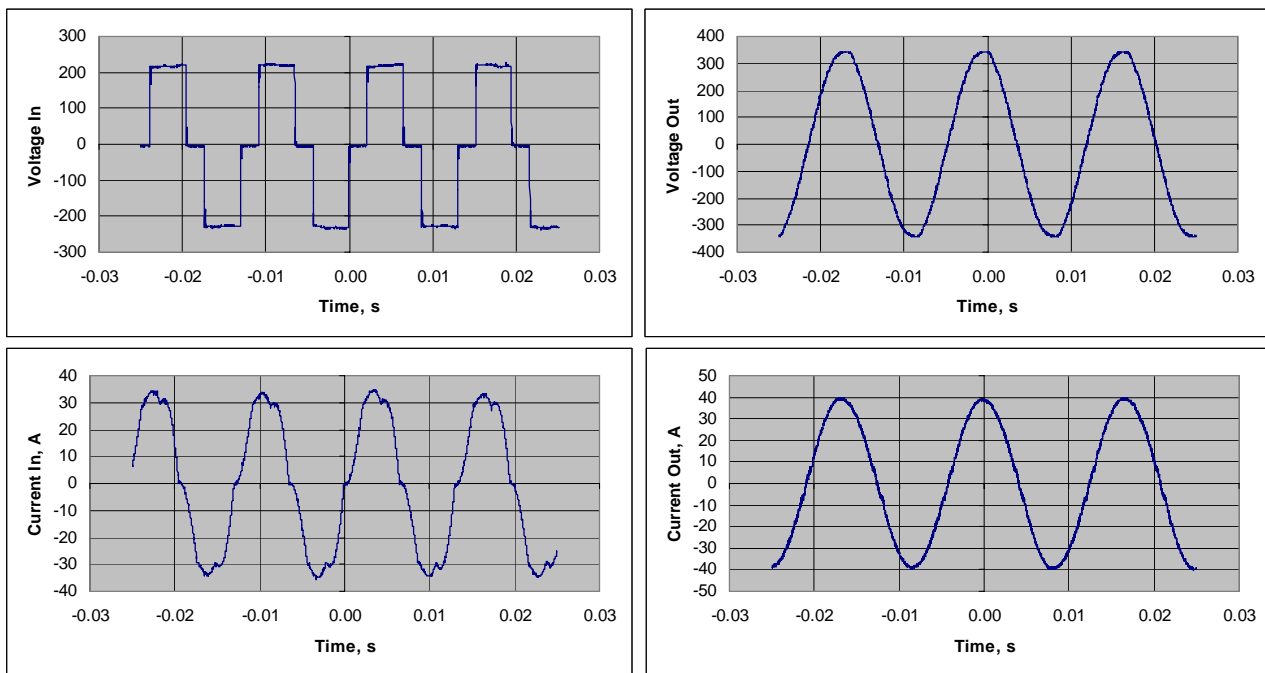


Figure 3: Input and output voltage and current waveforms of the measured on the GridTek10 inverter while producing 6.64 kW output. Notice the output waves are much nearer to sine waves than the output of the PowerSyncII inverter.

Conclusions

Readers of SWIEP will know that I am interested in documenting how often the GridTek10 shuts down because of overload conditions and how much this impacts annual energy production. The third interim report R#52 can be downloaded from SWIEP, which reports a >24% loss of energy in the first 180 days of the study. As of today's date (260 days) the figure is still > 20%. The study will conclude with a final report after one year of monitoring.

The purpose of the present report is related, because I am trying to document quantitatively the conditions under which the two BWC inverters shut down. Studies are under way on the PowerSyncII so a comparison cannot be made.

I also want to know the efficiency of the GridTek10 compared to modern inverters. In this instance, the PowerSyncII, superficially, is not any better than the GridTek10. However, more studies may reveal if the PowerSyncII is superior or not compared to the GridTek10. To answer this questions we need to compare power curves generated by the same turbine with the two inverters. If the PowerSyncII is off line less often or has a superior MPPT system (maximum power point tracking system), then the new inverter may indeed be better.

This information is necessary to do a cost-benefit analysis for any present owner of a GridTek10 who wishes to correct the problem. How much might it cost to improve matters and is the cost worth it? An example of a cost-benefit analysis outline can be downloaded from SWIEP (R#44).

As always, I welcome comments from readers. Any errors made in this draft will be corrected with acknowledgements to whoever helps out with suggestions for improvement.

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Appendix 1

After Michael Klemen voiced some concerns about the accuracy of the 80i-110 current probe, I consulted with Prof. Andy Knight, a power electronics engineer at the University of Alberta. He told me that the 80i-110 is perfectly acceptable in terms of accuracy in the frequency range used in this study, i.e., 20 to 150 Hz. He says this probe has been used for studies published in peer reviewed journals such as IEEE. Nevertheless, I asked him to demonstrate to me that the 80i-110 compares well to another more-expensive and accurate probe (TCP50ADC), for spec sheets see:

http://www2.tek.com/cmsreplive/psrep/13540/60W_16458_2_2009.05.15.15.30.06_13540_EN.pdf

and

<http://assets.fluke.com/datasheets/80i-110s-Spexs.pdf>

In our quick comparison the two probes measured the same instantaneous currents within 0.64% of each other based on the slope of the regression lines (Figure A1). Readers can upload the digital traces from SWIEP R#58. I own three 80i-110 probes. In another quick study I placed all three on the same wire and found agreement between them within 0.5%. In another measurement I measured instantaneous current versus time on a resistive load (heater on my hot water tank) for about 2000 points over two cycles at 60 Hz. I computed the RMS current from these 2000 points and compared the RMS current output of a CT-coil good to 0.5 %. These values agreed within 0.8 %.

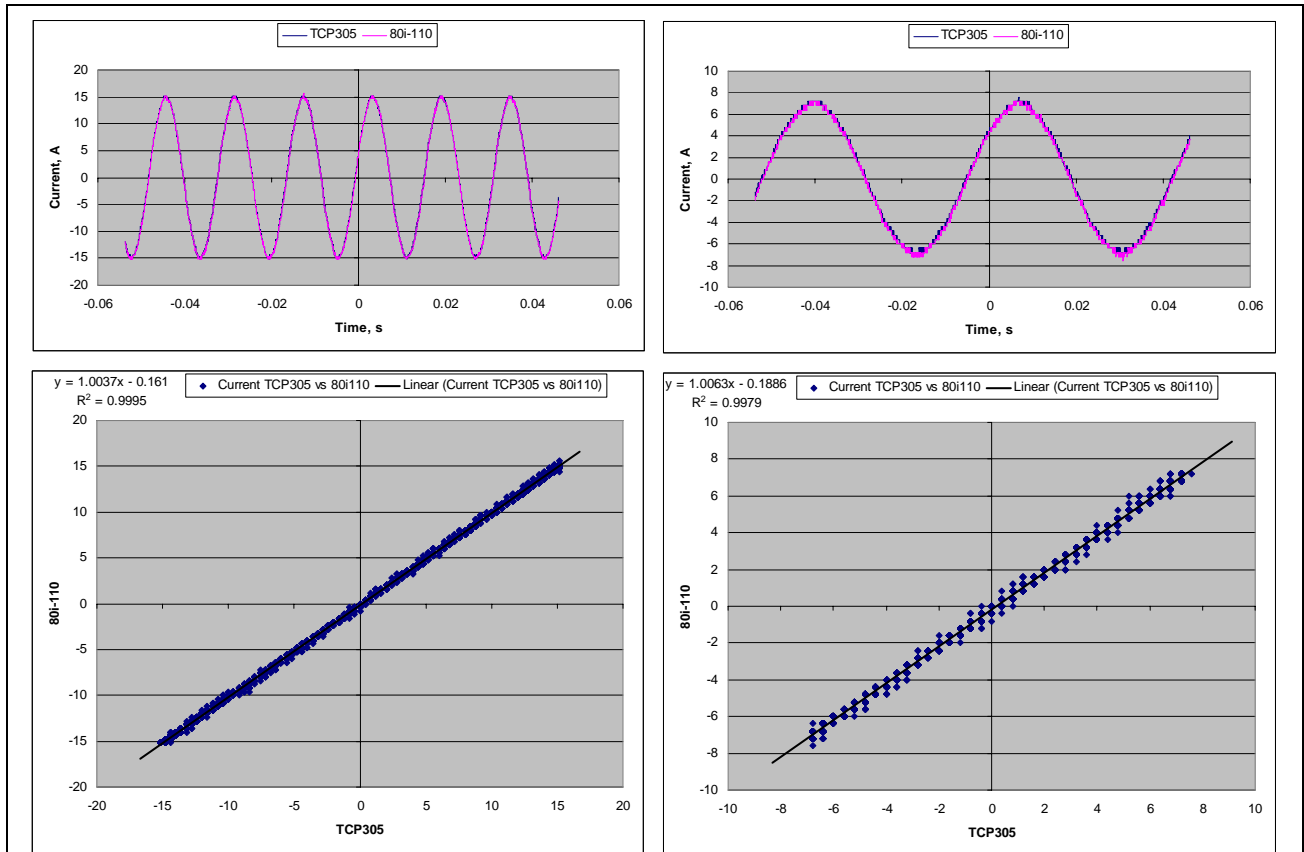


Figure A1: Comparison of ‘instantaneous’ power current measurements at 63 Hz (left figures) and 20 Hz (right figures). Notices that the more expensive and accurate TCP305 probe agrees with the 80i-110 probe within better than 0.63%