

**Initial Report on Energy Loss During Windy Events:  
Apparent design deficiencies in the Bergey Excel 10 kW turbine when combined  
with the GridTek10 inverter.**

*AN OPINION PAPER*

by

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### **Introduction**

I recently visited Prof. L. Chang, Department of Electrical Engineering, University of New Brunswick, Fredericton, NB, Canada. His research team specializes in the development of inverters for micro-generations systems, such as photovoltaic, turbine, and small hydro-electric systems. He has designed two inverters for 10 kW turbines: a single phase output inverter for a Ventera turbine and a 3-phase output inverter for a Bergey Excel. I asked him about details of the generator design in the Bergey Excel, which is proprietary information but can be deduced by “reverse engineering”. If the information I give below is inaccurate I must assume responsibility for misunderstanding Prof. Chang.

Prof. Chang told me the generator coils in the Bergey Excel are designed to generate continuously only 10 kW. The coils can sustain 12 to 13 kW for brief periods only and a continuous output of, say, 15 kW is likely to overheat and/or burn out the coils. Furthermore, he said that overheating can also demagnetize the permanent magnets in the generator even if the coils survive repeated period of overload. If the magnets are demagnetized then the power curve will be reduced irreversibly. The generator is overloaded by an airfoil that is too big for an unregulated generator. The only control provided by the Bergey is the mechanical auto-furling mechanism that moves the tail and hence turns the turbine out of the wind. However the auto-furling mechanism is too slow to avoid brief periods of overload, hence the inverter has to be designed to disconnect the loads when power output exceeds about 12 or 13 kW. Prof. Chang said he had an easier job in designing an inverter for the Ventera because it controlled power output by using a mechanism that rapidly changes blade angle to limit power output in high wind speeds. See [www.venteraenergy.com](http://www.venteraenergy.com)

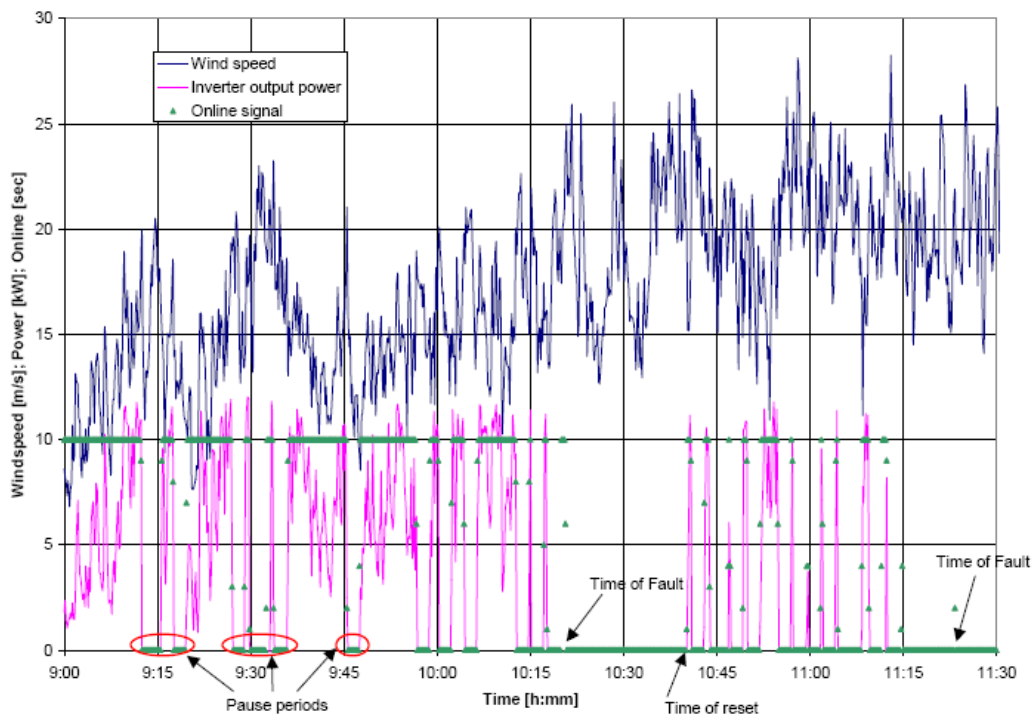
About a year ago, I communicated with Mike Bergey saying that, in my opinion, I might be loosing 10 to 30% of my annual energy production because of the tendency of their inverter to go off-line during windy events. Mike emphatically disagreed with me, because the inverter goes off line only when the wind speeds exceed about 16 m/s and this happens less than 1% of the time based on probability distribution function of wind speeds at my location in Ellenburg Depot, NY This statement encouraged me to monitor power output on the GridTek10's LED by taking a webcam photo once per minute during a wind storm.

An example of power loss was reported in SWIEP publication R#12, which can be downloaded from [www.ualberta.ca/~mtyree/swiep/publications.html](http://www.ualberta.ca/~mtyree/swiep/publications.html) . During this 30-

hour wind storm my inverter generated 35.3 kWh but lost a total of 110 kWh. So how much does this translate into power loss during the windiest period of the year (Sept to April)? I was encouraged by the results in R#12 to purchase equipment to do more intensive monitoring. This initial report applies to data for 1 Sept to 10 Nov 2008.

### Background information.

Bergey, of course, has known about periods of power loss since NREL did testing of their turbine/inverter in 2002-2003 (NREL report number 33963 or SWIEP download R#3) and I reproduce Fig. 5 from the NREL report as an illustration. When 10-s average wind speeds exceed about 16 m/s the GridTek10 is prone to going off line for 5-min periods in order to protect the inverter and/or generator. When wind speeds are  $> 20$  m/s the inverter is offline more cumulative time than it is online (right side of figure below). The problem is that the inverter goes back online after a 5-min delay regardless of the RPM of the generator. The inverter knows and reports the RPM at all times, but it doesn't use this information to predict a potential bus voltage overload condition. If the GridTek10 used this information it could prevent most or all of the bus voltage overload faults! My observations indicate that if the inverter goes back online when  $RPM > 430$  it is very likely to detect a bus voltage overload causing a fault conditions that shuts down the inverter until someone, usually the owner, performs a manual reset.



**Figure 5: Time series of inverter output power, wind speed, and online signal (10-second data).**

Here is what is wrong with Mike Bergey's opinion. Let's say my wind speed exceeds 16 m/s only 0.2% of the time. Well there are 31.536 million seconds in a year and if 16 m/s wind speeds occur randomly in time then there will be 63,072 s of speeds  $> 16$  m/s. Let's assume these events are equally spaced over time and that after each 1 s

event the inverter might be offline for 300 s. With a little math we see that  $300 \text{ s} \times 63,072 = 18.921$  million seconds or 60% of the year. Of course, this is an upper bound estimate of how much energy might be lost because the events with  $> 16 \text{ m/s}$  wind will be clustered around rather brief windy times. However at windy times a disproportionately large portion of the year's energy will be produced. So some detailed monitoring will be required to figure out how much less than 60% the energy loss might really be.

From the figure above it is clear that power loss can be estimated if (1) performance is measured with a high time resolution (10 s averages or less) and (2) the wind speed or some proxy for wind speed is known when the inverter is offline.

In my preliminary study (SWIEP R#12) the proxy information for wind speed used was the average power production before and after the inverter went off-line; I used a 30 min average each side of the offline period. However, in order to get these data I had to stay up all night to reset the inverter whenever a bus voltage overload fault occurred. In this study I use a more automated method.

### Methods used to estimate power/energy loss.

A Personal DAQ3005 was used to monitor DC voltages from various sensors (See <http://www.iotech.com/catalog/daq/persdaq3000.html>). Over the voltage ranges in this study the 16-bit DAQ3005 can measure to better than 0.01% of full scale. The GridTek10 outputs 230 VAC @ 45 A or less for normal operation. Power production (kW) of the GridTek10 was computed from RMS current (A) and voltage (V). RMS current was measured with a CT-coil (model ACT), see:

[http://web1.automationdirect.com/adc/Overview/Catalog/Sensors\\_-z-Encoders/Current\\_Sensing\\_Transducers/AC\\_Current\\_Transducers](http://web1.automationdirect.com/adc/Overview/Catalog/Sensors_-z-Encoders/Current_Sensing_Transducers/AC_Current_Transducers)

The ACT coil was placed next to the circuit breaker on the service panel that supplies power from the inverter to the service panel. The coils were set to a calibration of 0-100 A = 0-10 VDC. RMS V was measured using a custom built circuit consisting of a 115 VAC to 12 VAC step down isolated transformer (0.35 watt) going to a full wave rectifier and terminated by a 25 K resistor going to a 40  $\mu\text{F}$  capacitor to ground in parallel with another 25 K resistor to ground. The DC output was calibrated with a Variac voltage transformer and a Digital VOM accurate to 0.2%.

Two of the above circuits were used to measure  $V_{AC1}$  and  $V_{AC2}$ , one to measure the RMS Voltage on each side of my service panel. Power was computed from:

$$\text{power} = A_{\text{RMS}} (V_{\text{AC1}} + V_{\text{AC2}})$$

Data were collected at 1 Hz based on 256 measurements per second and data very similar to those from NREL result (see Fig 3 below). Energy (kWh) is computed from the time integral of power.

The merits of measuring wind speed versus a proxy for wind speed.

I attended an NREL conference on measuring performance of small wind turbines and concluded from this experience that my site is not conducive to easy measurement of wind speed at hub height. IEC/AWEA standards say that power curves have to be measured by placing a cup anemometer on a met tower at hub height and 2 to 4 blade

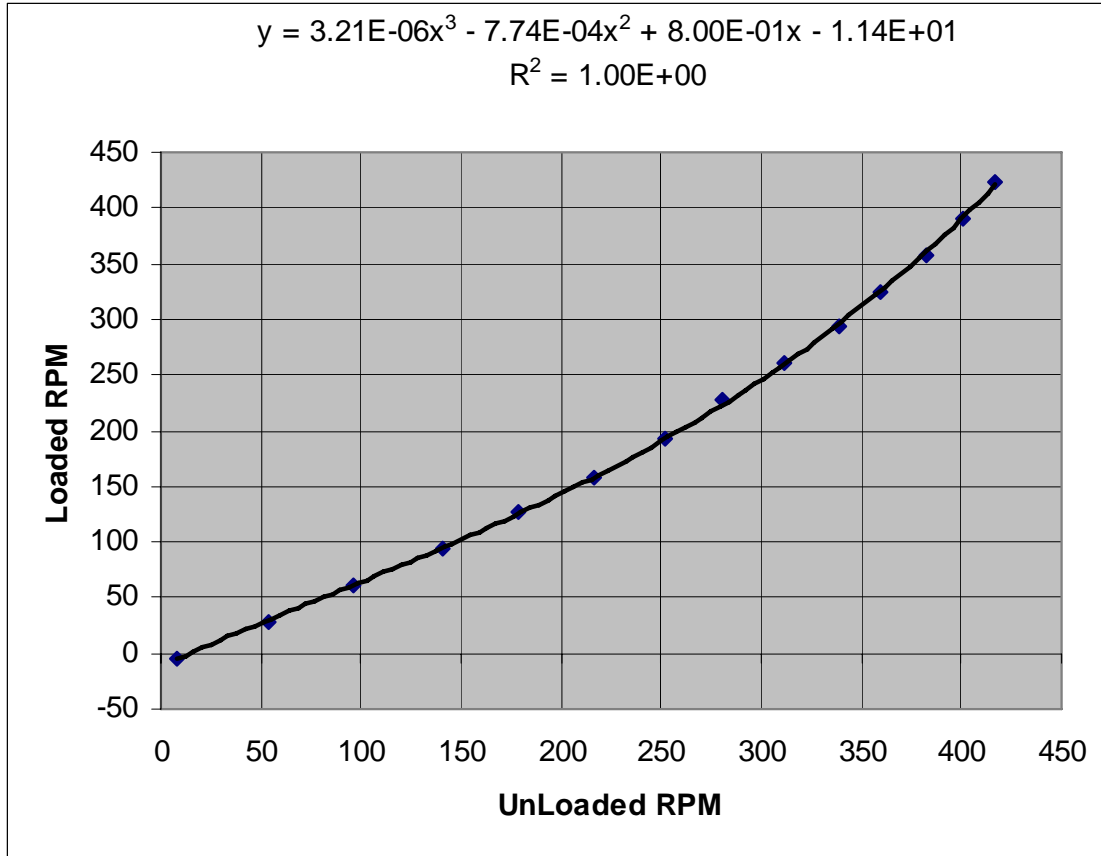
diameters from the hub. If the site is sufficiently flat without obstructions (trees, buildings, other turbines etc) too close to the turbine then one can assume the anemometer wind speed agrees with the wind speed at the turbine with only a small time lag, e.g., if the anemometer is 30 m from the hub and the wind speed is 10 m/s then there can be a +/- 3 s time delay depending on wind direction with respect to the placement of the turbine and met tower. However, if there are obstructions then wind-shadows result meaning that the wind speed at hub location may not be the same as at the met tower, depending on wind direction.

Readers interested in the impact of trees and building on wind speed and power production of nearby turbines will have fun playing with the Wind Shade Calculator at the Danish Wind Industry site. <http://www.windpower.org/en/tour/wres/shelter/index.htm>

My site has a house and trees within 3 or 4 tower heights of my wind turbine, which sits on a 120 ft tower. IEC/AWEA standards in my situation suggest a 'site calibration'. A site calibration involves erecting a met tower and removing my Bergey from its tower and replacing it with a cup anemometer and calibrating wind speed at the two sites versus wind direction for several weeks. This option would require about \$20,000 for the met tower, the anemometers and the lease of a crane. Cranes are very hard to find at my rural site. So I elected to use a proxy for wind speed, namely the generator (blade) RPM. Power output from a generator is a function of RPM squared. However, RPM is higher at any given wind speed when the turbine is unloaded (free spinning) than when loaded by an inverter.

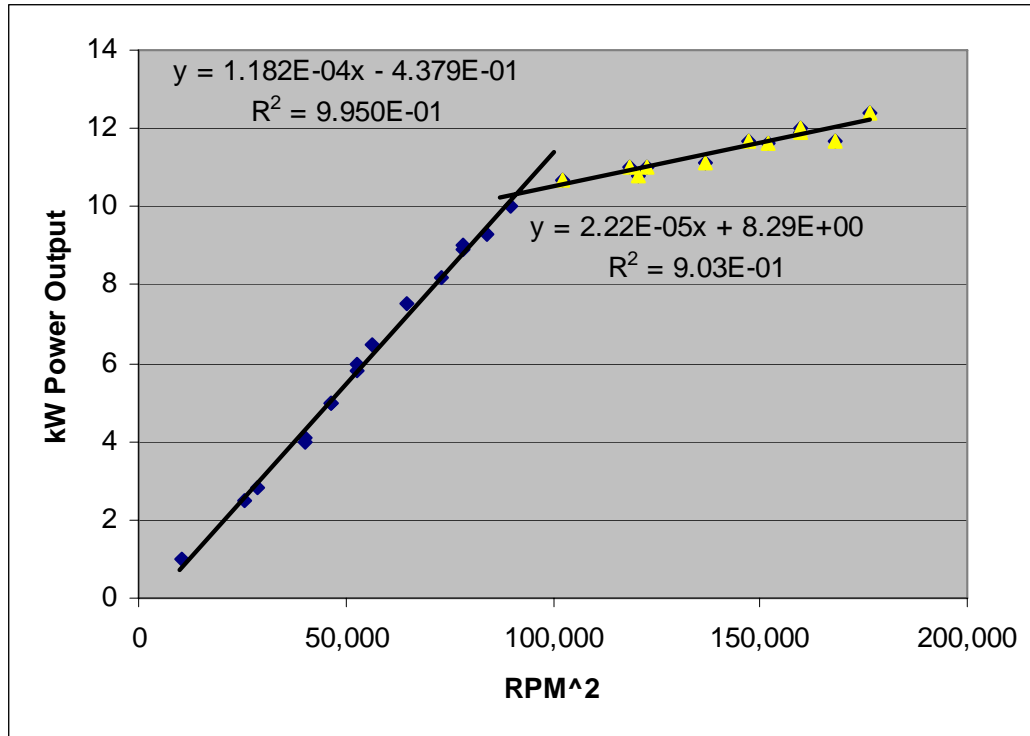
Figure 8 in NREL report #33963 shows the mean RPM versus wind speed for a loaded and unloaded Bergey Excel. I digitized the values of loaded and unloaded RPM at corresponding wind speeds and have plotted the result (parametric plot) in Figure 1.

So I built a circuit to measure RPM based on the generator output frequency. For the Bergey  $RPM = Hz * 60/19$ , where 60 converts Hz to cycles per minute and 19 = the number of pole-pairs in the Bergey. I connected a mW transformer between two of the three phase lines where they enter the inverter. I used a 240 VAC to 12 VAC 30 mW transformer. The output of the 12 V windings were connected to a 1 K resistor and two signal diodes (opposed in parallel) to ground. The diodes produced a rounded square-wave of 1 volt peak-to-peak with a frequency equal to the generator output. A couple more chips turned this into a TTL pulse that could be counted by the digital I/O input of the DAQ3005 data-logger. The RPM was logged at 1 Hz. When the output of the inverter was >0.4 kW the RPM value was taken as loaded, but when the PRM was > 20 and inverter output < 0.4 kW the RPM was taken as the unloaded value.



**Figure 1:** Loaded generator RPM (Bergery 10 kW Excel turbine) versus Unloaded generator RPM. Data were extracted from NREL's publication #33963 (SWIEP report #3 available at [WWW.ualberta.ca/~mtyree/swiep/Publications.html](http://WWW.ualberta.ca/~mtyree/swiep/Publications.html)). In Figure 8 of the NREL report are found mean loaded RPM versus bin wind speed and mean unloaded RPM versus bin wind speed. At each bin wind speed I extracted the Loaded and Unloaded RPM values for wind speeds from 3 to 16 m/s. At speeds > 16 m/s the RPM values become unpredictable because of the mechanical furling mechanism on the Berger 10 kW Excel.

The unloaded value of RPM was plugged into the regression equation in Fig. 1 to compute what the RPM would be if the inverter were on line. Using the data logger I could measure kW output from the inverter versus RPM squared and found this was identical to that previously measured by me using the GridTek10's LED display (R#12) see Figure 2 below.

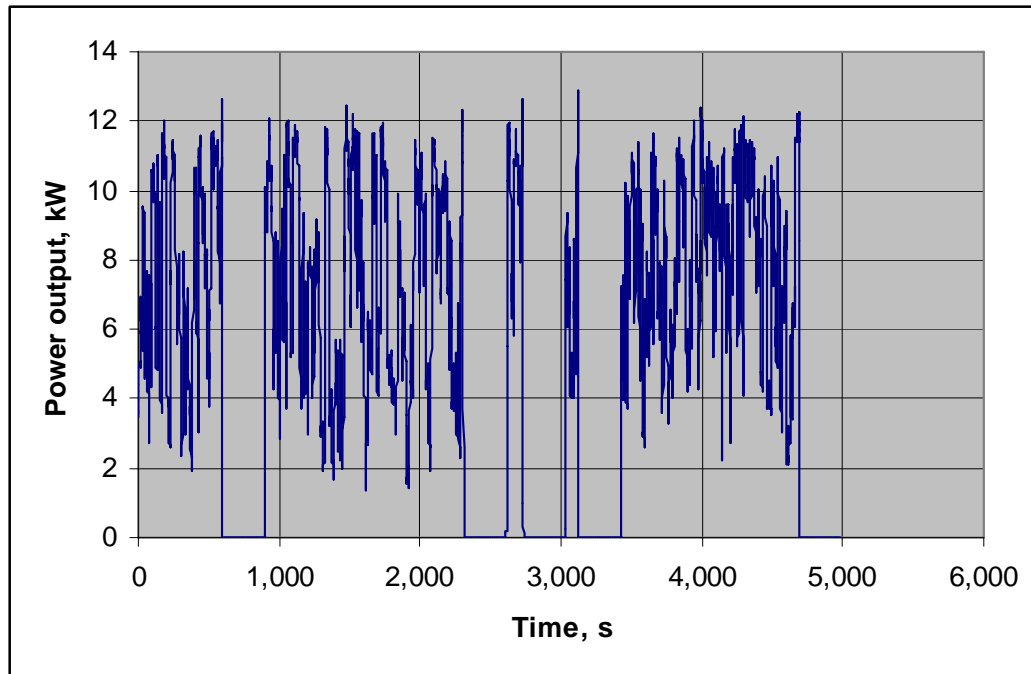


**Figure 2:** Y-axis = power output, X-axis = generator RPM squared. All parameters collected from the GridTek10 LED display, however essentially identical data were collected from my data-logging system.

When the inverter is at maximum output (12 kW) the loaded RPM is 420. When the turbine is unloaded the RPM can be > 420 when unloaded and pointing into the wind or < 420 when unloaded and furlled, i.e., pointing out of the wind. I took a conservative approach to estimate power loss when the turbine is unloaded. If the measured RPM was > 420 I used the lower value (420). This keeps the estimated loss of power within the range of Fig. 2, and, hence, this computational method underestimates potential power production if the inverter had not put the turbine offline. Otherwise I used all values of RPM < 420 to compute lost power regardless of whether the turbine was furlled or not. Again this is likely to underestimate the lost power because an unfurlled unloaded turbine would spin faster than when it is furlled. I am trying to give Mike Bergey a break and avoid overestimating a problem which he clearly underestimates.

## Results

Figure 3 shows a typical result of GridTek10 power output versus time during a windy event. The time course looks very similar to the NREL results on page 2 of this report. On Oct 28 the turbine overloaded the inverter 4 times and the inverter went offline for four 5-minute periods in order to protect the turbine's generator. After this the inverter went offline a fifth time and when it tried going back online it 'saw' a bus voltage overload and ended production with a Fault Code.



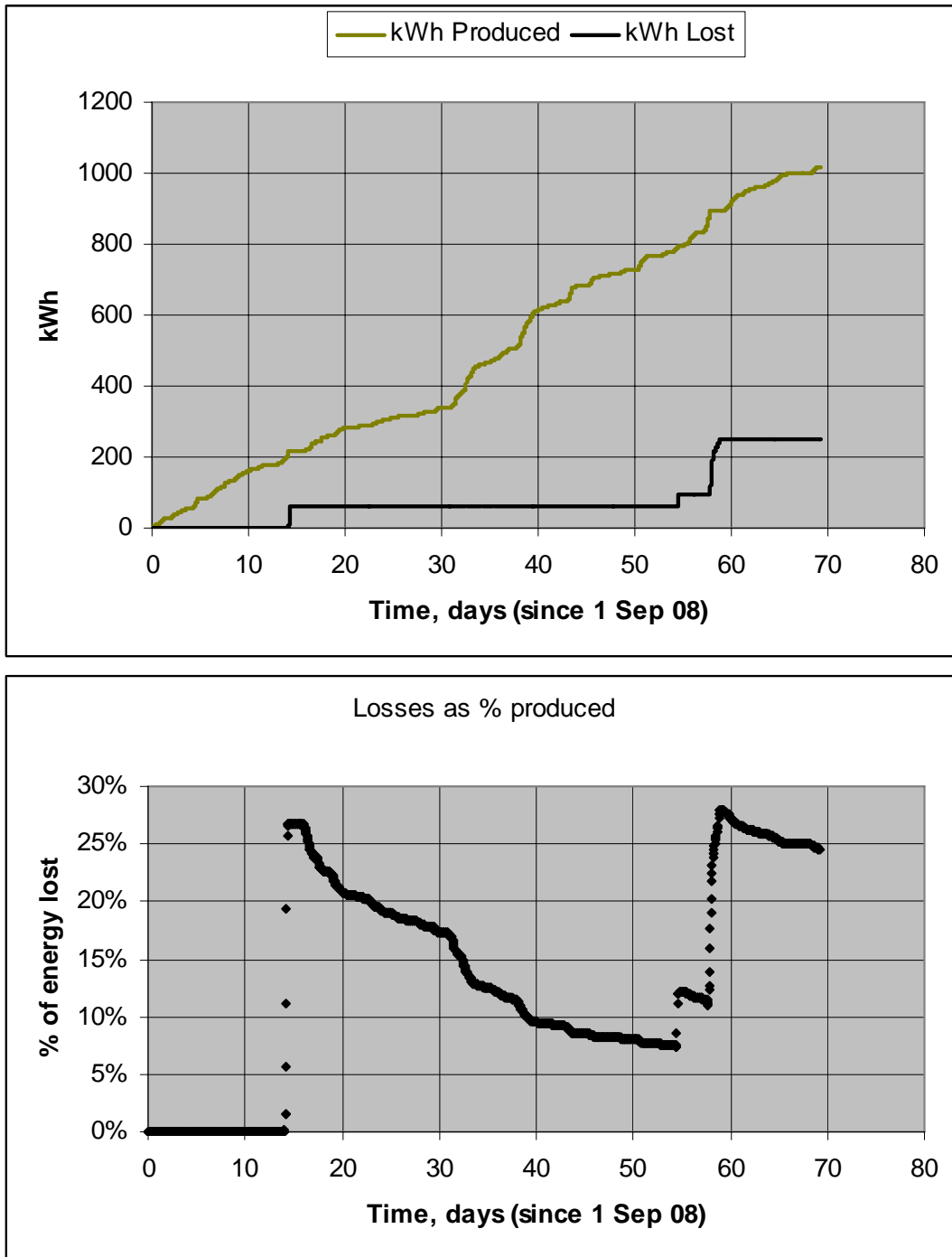
**Figure 3:** One second readings of power output from a GridTek10 inverter and Bergey 10 kW Excel turbine starting at 10:23 PM 28 Oct 2008. The inverter went off-line for four 5-min periods due to power overload at times = 600, 2307, 2733 and 3119 s and returned to production after a 300 s delay each time. At 4695 the inverter went off-line again but stayed off line because at time = 4995 it attempted to come back on-line during a bus voltage overload condition and went into a fault mode requiring a manual reset.

Figure 4 below shows the cumulative energy production measured since 1 September 2008 versus time (green line). In the last 69 days there were three wind events when the inverter was overloaded and went repeatedly offline. The resulting cumulative loss of energy is shown in the black line. In the last two events the inverter required a manual reset. My plan was to reset the inverter as often as ‘prudent’ owner might do, i.e., I check the inverter for the need of reset every 12 h at approximately 7 AM and 7 PM each day. I could do resets even when away from home because I have a remote reset capability (R#39 on SWIEP). However even a prudent owner cannot be around all the time to baby-sit the inverter. This happened on day 57 (the third wind-storm) because I was on a plane to Europe at the time. However, the data revealed that most of the energy loss occurred between 7 PM and 7 AM, i.e., between the times when I normally monitor the status of the GridTek10.

The cumulative estimated loss of energy expressed as a percentage of the produced energy is shown in the lower graph (Fig. 4) and this value finished at 24% after 69 days of measurements. This is early in the season and windy events are likely to be more frequent later.

The average turbine owner might be less vigilant than I am, i.e., many owners have told me that they check their inverters only once or twice a week. How often the inverter is checked will impact the amount of energy lost. However, I feel the results in

Fig. 4 are likely to be representative for my wind regime (5.5 m/s mean annual wind speed). However, in windier locations the % of lost energy is likely to be more.



**Figure 4:** Upper = Cumulate total energy produced in kWh and energy lost versus time in days since 1 September 2008. Lower = Energy lost as a percentage of power produced. As data collection continues the variation in % energy lost will become more gradual (stable) with time. The rapid drop between day 14 and day 55 is a mathematical consequence of a short sampling period, i.e., low amount of cumulative energy production.

## **Conclusions**

I have no general conclusions yet because this is an interim report. I will update this report every two months until April 2009 and then draw more general conclusions. We must await the end of the study to get a final estimate of % energy lost due to poor design of the turbine/inverter in this study.