Wind Speed Data and its Application to Wind Generated Power

Michael Klemen

Wind speed data is not a very good tool to use in measuring the wind resource available for a wind-powered generator unless the wind speed data was taken with that particular purpose in mind. Wind speed is measured by an anemometer. As the anemometer spins in the wind, it generates pulses of voltage. The anemometer is typically connected to an analog device which counts the number of pulses over a certain time period. This time period is of vital concern to the person recording wind speed data to estimate the wind resource available for a wind driven generator.

Response Time

In order to estimate the wind available for a wind generator, the resource needs to be measured in the same time frame that the wind generator can respond to the wind (response time). The data often taken by these analog devices will record the average wind speed every 15 minutes. This means that the device counts pulses for 15 minutes, then records the number of pulses for those 15 minutes. The number of pulses can then be converted to a wind speed. The problem with this data is that the response of a wind generator to the wind speed is much faster than a 15 minute delay. A wind generator will often respond to a wind gust in a matter of seconds.

Averaging Time vs. Recording Time

Before things get too confusing, it is important to distinguish the difference between the time interval used to acquire the data and the time interval used to average the data. The time interval used to acquire data should be on the order of the response time of the wind generator. In other words, the data should be acquired every couple seconds at worst. The time interval used to average the data should also be the same as the time interval for acquiring data. If we take data every two seconds, but don't use a two second average, we have lost some important details in our data.

Gusting Power

The difference between averaging data at ten second intervals and fifteen minute intervals seems to be kind of trivial. For the sake of knowing at what speed the wind is blowing, it is a very trivial difference. For the sake of trying to figure out how much power a wind generator will produce, it isn't. The reason this difference is NOT trivial is because the amount of power available in the wind is not linearly proportional to velocity, it is proportional to the velocity cubed:

$$P = \rho AV^3$$

where

- P = power available
- ρ = air density (primarily a function of temperature)
- A = swept area of a wind generator's blades
- V = velocity of the wind

This formula is a formula for the amount of power available in the wind. It is *not* a formula for the amount of power available from a wind generator. More variables would be needed to account for the performance of the wind turbine blades, friction, and other things. What is of far more importance is that every time the wind speed doubles there is an eight-fold increase in the amount of power available in the wind. This is critical because every wind gust is important in calculating how much power a wind generator can produce. If wind speed data doesn't record every gust it won't be an accurate tool to use to figure out how much power a wind generator can produce.

Let's look at a simplistic example, comparing 15 minute averaged data and data averaged on a 5 minute interval. We will assume for this example that the ρ A term is a constant. For the 15 minute period let's say the average wind speed was 10 mph. This means that there are 10^3, or 1000 power units available in that wind. There are a lot of ways to get a 10 mph average wind speed for 15 minutes. Let's consider the ridiculous for a moment, and break this data down into 3 different data points of 5 minutes each. If the wind was completely still for 10 of those 15 minutes, we can still get a 10 mph average wind speed for 15 minutes if the wind speed was 30 mph during one 5 minute segment. Now, for the 5 minute intervals that had no wind speed, there is no power available. For the 5 minute interval where the wind speed is 30 mph, we have 30^3, or 27,000 power units. This makes the 1,000 power units look trivial. We could break down the 15 minute data into smaller pieces of, let's say, 1 minute in length and exaggerate this important problem in wind speed data even more, but this example was probably sufficient to raise one's curiosity.

My Data Acquisition System

I have been taking data for over one year on a site in west-central Wisconsin. This data agrees with my theory that the time interval for taking data is VERY important when considering the feasibility of a wind generator. My tower is 50 feet tall with an open field to the north and west (our prevailing winds). I am using an analog anemometer like described above, with one exception. Since I do computer programming (and enjoy data acquisition) I plugged the anemometer into the data acquisition board in my PC, which converts the analog voltage of the anemometer into digital form. My data acquisition board is a Data Translation DT2838, which is capable of taking data on eight input signals at a speed of 260,000 samples per second (which is much faster than I need for this application). My data acquisition computer is a Dell 386 running at 25 MHz, with a 300 MB hard drive and 4 MB of RAM.

I was anxious to start taking data to compare the problems with the 15 minute data to the real-life wind generator scenario I presented above. I started taking and recording data at 1 minute intervals 24 hours a day since December 8, 1995. Each daily data file required 93 KB of storage on the hard drive.

When I was at the Midwest Renewable Energy Fair last year, I asked Mick Sagrillo of Lake Michigan Wind and Sun how long it really takes a wind machine to respond to a gust of wind. His answer was that a small machine can respond in a split second, and a bigger machine like the Jacobs 10 kW will take maybe a couple of seconds. This got me thinking about my data and how inaccurate it would be for the 1 minute intervals I was using. I re-wrote my program to take and record data at 10 second intervals. From the 10 second data I could put six data points together to get a 1 minute average. I could also put 80 data points together to build a 15 minute average wind speed. Then I could compare their respective results. My 10 second data begins July 1, 1996. The data file for each day requires about 530 KB of storage on my hard drive.

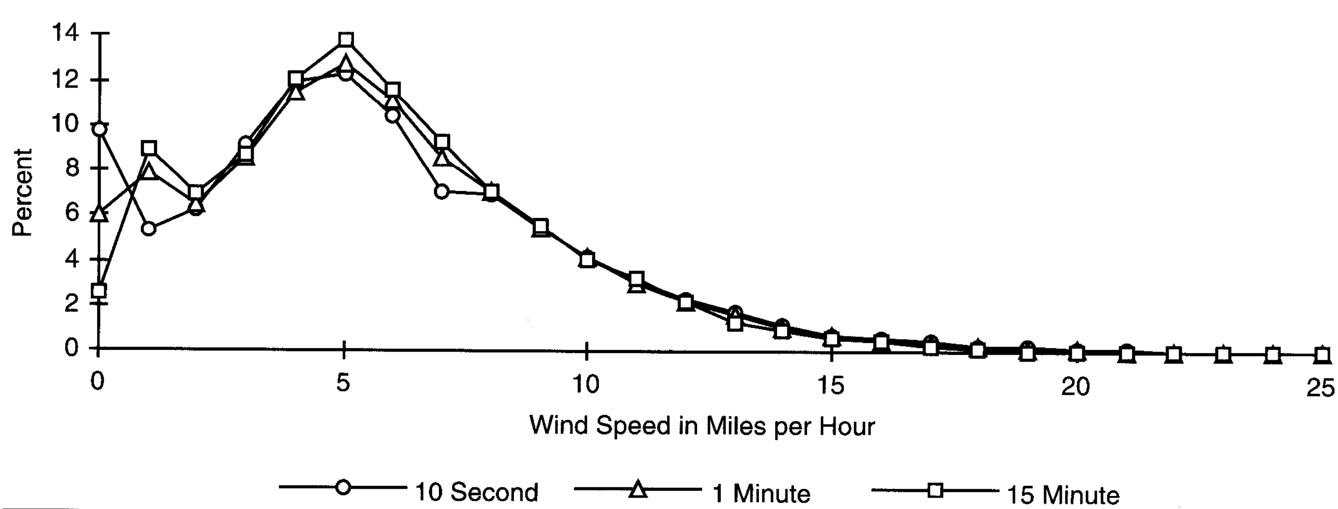
Anemometer Resolution

I chose to take and record 10 second data rather than a shorter time period due to the resolution of the anemometer. The signal generated by my anemometer is a sine wave. I am simply counting the pulses during the 10 second interval. If I was using a faster computer, I might try to distinguish where the data starts on the sine wave, and where the data ends, thereby increasing available resolution. By taking data at 10 second intervals, I am guaranteed a resolution of 0.17 mph, as compared to 0.28 mph for a 6 second interval. As the time interval gets smaller, the resolution of the wind speed gets worse. Since I wanted to compare the differences for actual wind generators, I needed to maintain resolution and accuracy. If a 6 second interval gives me 0.28 mph resolution, that means for the worst case scenario I would only have three data points for some 1 mph increments. For example, I would put 2.27, 2.55, and 2.83 mph in the 2 mph increment. I didn't find that to be acceptable, so I opted for the 10 second data with a resolution of 0.17 mph.

The Results

Next, I interpolated the power curve for various wind machines. My choice was almost completely random. My parents had talked about putting up a wind

Figure 1—Wind Speed Distribution since 1 July 1996



machine, and I thought the Jacobs 10 kW would be a realistic choice for them. (To be more honest, I was intrigued by the flatness of the power curve when the wind machine starts to govern.) I also decided that I needed to compare more affordable machines like the Whisper 3000 and 1000. I tabulated the number of data points at each 1 mph increment for each day, and subsequently for the entire period of data acquisition (for the 10 second, 1 minute, and 15 minute data). Next, I plugged that wind speed distribution into the power curves for the various wind machines. I came up with some rather interesting results. The wind speed distribution curve came out as expected. In Figure 1, the 15 minute data shows a larger distribution of lower velocity wind than the 10 second data. Conversely, the 10 second data shows higher wind speeds than the 15 minute data (which is where we get more power from a wind generator).

I can now plug the wind speed distribution into the power formula to get a reasonable look at the difference between taking the data at 15 minute or 10 second intervals. (For those of you who may not catch the difference between power and energy, power [kW] is instantaneous energy [kWh]. So, when I plug the distribution into the power formula, I get energy because the distribution happened over time.) In Figure 2, there are two curves for each data interval. The first curve is for the energy available at the given wind speed. The second curve is the sum of all energy for each data interval (10 second data, 1 minute data, and 15 minute data). I summed up the energy available only for wind speeds of 7 mph or above (this is where many wind generators will start to generate power). It is easy to see that there is more wind energy available if we account for the increased energy due to gusting (by using 10 second data).

The 15 minute average wind speed doesn't accurately reflect the energy available in the wind. The question that now arises is: "Is this available wind energy really going to give an increase in performance for a real wind generator?" Next, I took this data and plugged it into the power curves for the Jacobs 10 kW, Whisper 1 KW, and 3 kW. The results were not surprising (Table 1).

Noticing Some Differences

There are a couple of questions about the data which have logical explanations. The reason each of the wind machines has a different response to the data lies in the power curve for the given wind machine. The Jacobs 10 kW machine has a gearbox and additional friction as compared to the Whisper wind generators. It is also important to bear in mind that I read the output from each wind machine from a graph to put it into digital form. There is bound to be some error in doing this as compared to having the precise numbers from the manufacturer of the wind machine. Thus, when comparing the theoretical (energy units) percent increase to that of the stated wind generator, there is bound to be some discrepancy. In the case of the Whisper machines, it is noticeable, but marginal.

There is one more thing I should mention with regard to renewable energy systems. The days that had relatively little output from the wind generator benefitted most from this analysis. On a day that averaged 2 or 3 mph, the 15 minute data might have suggested that we would have generated 0 to 5 kWh (with the Jacobs 10 kW machine), whereas the 10 second data indicated that we would have generated 100 to 300% more power.

Figure 2—Available Wind Energy using data since 1 July 1996

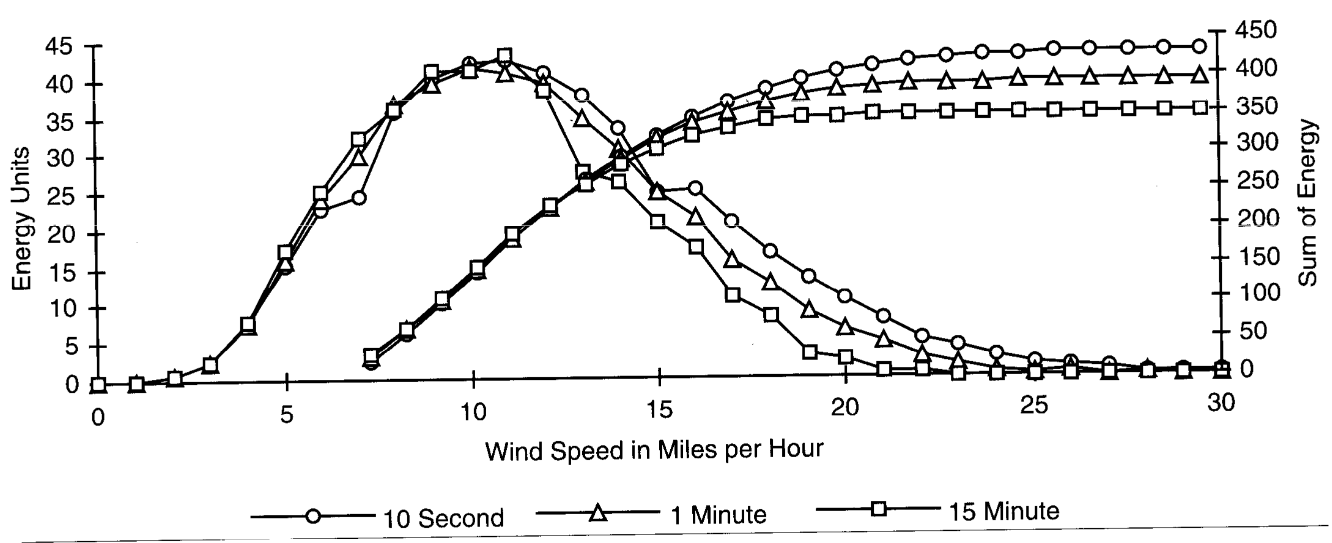


Table 1: Energy Produced

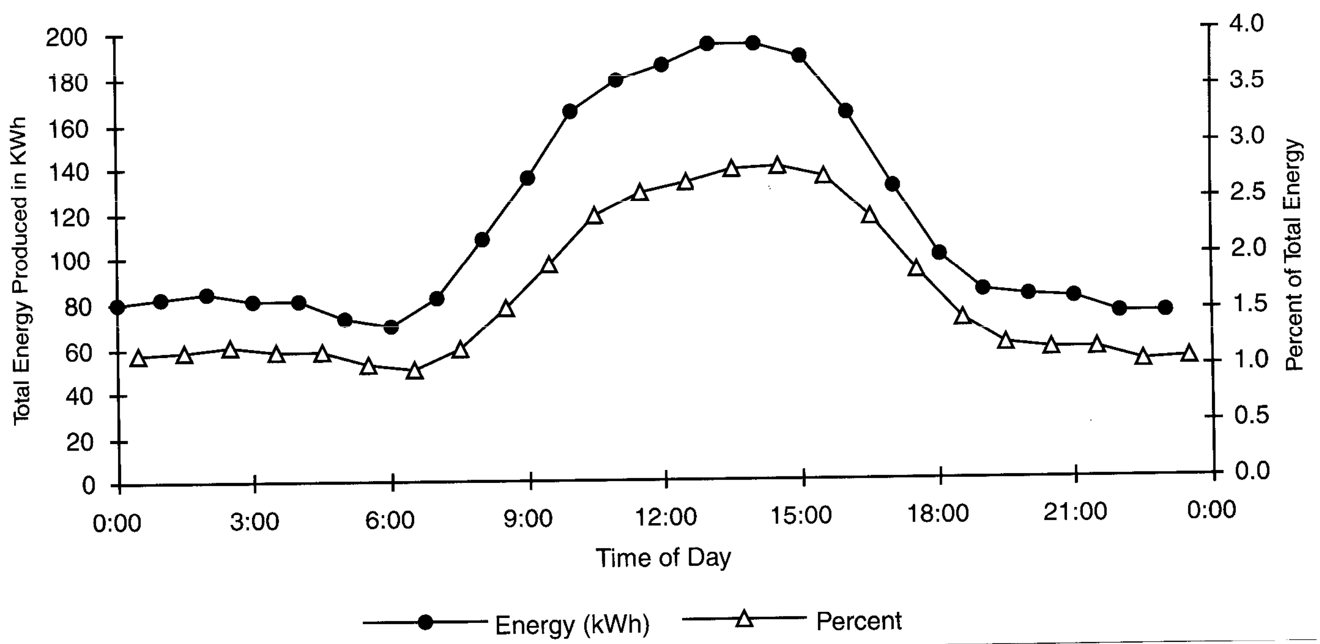
Wind Generator Make/Model	10 Second Data	1 Minute Data	15 Minute Data	*Percent of Power Increase* from 15 Min to 1 Min Data	from 15 Min to 10 Sec Data	from 1 Min to 10 Sec Data
Jacobs 10 kW	2070.40 kWh	1948.92 kWh	1799.88 kWh	8.28%	15.03%	6.23%
Whisper 3 kW	595.08 kWh	545.29 kWh	480.86 kWh	13.40%	23.75%	9.13%
Whisper 1 kW	196.04 kWh	179.52 kWh	157.93 kWh	13.67%	24.13%	9.20%
Theoretical	430.82	392.19	347.97	12.70%	23.80%	9.85%

Is 25% More Power More Affordable?
The fact remains that we see a 15 to 25% increase in energy output from wind generators by looking at the wind speed from the generator's response time rather than 15 minute data. For any renewable energy system, that kind of increase in output is significant. Maybe if you have seen local data, such an increase in energy output would make a renewable energy system more affordable. I would like to remind you that this data was taken at our site. These increases in energy are only increases over the energy expected from the 15 minute average wind speed data. Our tower is 50 feet high. By raising our tower, I would expect that the fluctuations in the wind speed will be smaller, thus reducing the amount of gain possible over the indicated data. But, also by raising the tower, I expect our average wind speed to pick up, increasing the energy output of a wind generator. Your site and output will vary from this data.

Utility Intertie?
I was curious how much a utility might benefit from connecting a large wind generator to the grid. I know that utilities do not like peak load times because the electrical generation plants must be designed for them. Since I recorded the time of each data point taken, I re-analyzed the data with respect to the time of day. In Figure 3, I plotted the percent of total energy produced (with a 10 kW Jacobs) with respect to the time of day to see if a wind turbine at our site would produce power when the utility wished it had more power.

The results are self-explanatory and understandable. Winds are caused by ambient pressure differentials, which are caused by the uneven heating of the earth's surfaces by the sun. I would have expected to see a reasonable amount of wind during the day, during utility peak times.

Figure 3—Total Energy Produced and Hourly Percent of Total Energy since 1 July 1996



What's Next?

Preliminary results from my sister's Whisper 4500 indicate that 10 second data increments are quite insufficient for that particular wind machine. During 6 days of monitoring, I found that the wind machine output was able to change very significantly during 10 seconds. One data point I found jumped from 1501 watts to 3144 watts output. This is about a 110% increase in 10 seconds. Likewise, the output decreased from 4350 watts to 2590 watts, a 40% drop in output. I would like to install an anemometer at her site, comparing the wind speed from the anemometer with the output from the wind machine (to verify the power curve). I will also reduce the time increment from 10 seconds to something markedly smaller. In order to get reasonable resolution from an anemometer, I will be forced to find the phase of the cycle of the anemometer rather than just counting the pulses I get. This may tax the 386 computer a little, and I may have to move my data acquisition board into my 486, and heaven forbid, use the 386 at home!

If you have any questions about wind power, data acquisition systems, programming, or about my data in particular, please feel free to write.

Access

Author: Michael Klemen, PO Box 86 Tuttle, ND 58488