Are wind turbines anemometers?
An Opinion Paper
by

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Doug,
You attacked the Cadmus Group report on the basis that turbines are anemometers. The basis of the argument is that turbines are anemometers and hence if a site has low production it means the site has no wind. That is your argument, right? You are among many people who have thought this. Even I used to believe the argument and other notable people in the small wind business have advanced the notion, e.g., Mike Bergey when trying to get me off his back! You might be in a majority if a popularity vote were taken, but science is not based on popularity votes.

I really did not want to get into this so soon, but after more consideration I can't leave the question unanswered. This is a little premature because I am still formulating an opinion paper to publish in SWIEP but here goes what I have…

What the h*** is Mel talking about!
If you define an anemometer merely as some instrument whose output increases monotonically (perhaps not linearly) with v = wind speed then yes … a turbine might be an anemometer. In a turbine the power, P, increases with v and RPM increases with v. In a cup anemometer RPM increases quite linearly with v. But the loading on the two classes of anemometers is different. In a cup anemometer there is only frictional loading. In a turbine there is frictional loading and inverter loading, because the inverter is making power and, hence, the RPM of a turbine will change with loading.

Let us resolve the question further.
Is a turbine anemometer in the same class as a cup anemometer? By class I mean do the two types respond to wind in the same way? Logically I would have to say 'no'. In fact this simple question is very central to the issue of model building. There are several ways I can justify this 'no' answer.

1. Logical consequences of the 'site selection debate'

It is obvious that lots of consideration has gone into site selection for power curve generation. An 'un-calibrated site' must meet standards of Section A.1 of the IEC standard; see page 37 of NREL report 33450.pdf. Click on R#26 in:
http://www.ualberta.ca/~mtyree/SWIEP/Publications.html
The concern is that site conditions will influence the shape of the power curve. If this concern is justified then the corollary to this concern is that site does affect how the turbine anemometer functions relative to the cup anemometer. Hence the cup and turbine anemometers are in different classes. NREL has put lots of thought into their site, which meets most criteria but not all desirable considerations. The implication is that if I did a power curve at my more turbulent site in Ellenburg, NY, the result would be different and

hence not ‘accepted’. The same is true about using a truck to measure a power curve. Turbulence around a truck will be different than in Ellenburg and different than NREL. Hence, logically, we can already conclude that a turbine does not respond to wind like a cup anemometer and hence must be in a different class.

2. Experimental evidence.

Look at the power curve measured at Alfred University. It is VERY different than the power curve measured at NREL on a Bergey 10 kW turbine. Now, you can take the opinion that the Engineering Department at Alfred University did the measurement incorrectly. But if you look at likely sources of error then you might not be able to explain all the observed difference. Anyway, if anybody wishes to debate the notion that the site does NOT affect power curves then you have to reopen the debate on how power curves are created, i.e., the notion of what is a ‘good’ site for testing.

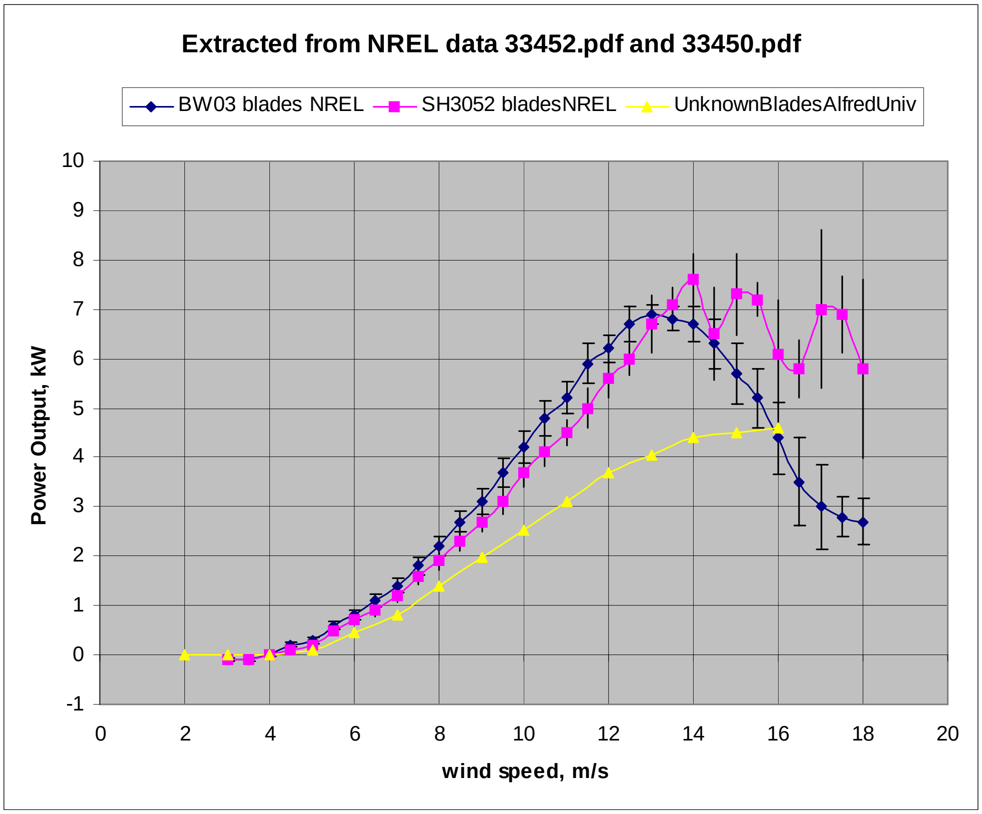

Fig. 1: Curves from two different sites. NREL = low turbulence Alfred Univ. = high turbulence. Both sites use cup anemometers to measure wind speed, but the same Bergey turbine has different performance at the two sites. For Alfred University data go to:
http://ceer.alfred.edu/Research/windturbine/windturbine.html
or download R#29 at SWEIP site.
http://www.ualberta.ca/~mtyree/SWIEP/Publications.html

3. Compare and contrast anemometer classes.

Cup anemometers.

The cup anemometer was invented by John T.R. Robinson in 1846 and he argued on the basis of physics that the RPM should be a linear function of v with a constant, K, predictable from basic principles. He was right, but he got the K value wrong. It took many decades for the mistake to emerge, but wind tunnel test show that RPM (or frequency of switch closures) on a cup anemometer is quite (but not perfectly) linear, see R#27 in the SWIEP link above. Physically the cup anemometer is of very small scale compared to a Bergey turbine. The cup anemometer is small compared to the scale of turbulent eddies, the axis of rotation is perpendicular to the average wind vector, and the plane of rotation is parallel to the wind vector.

Turbine anemometers.

Turbine anemometers (Bergey type) are larger compared to the scale of turbulent eddies. (I am talking with Earth and Atmospheric Scientists about this so this part is not complete.). The axis of rotation is parallel to the wind vector and the plane of rotation of the blades is perpendicular to the wind vector. Also the loading on the turbine anemometer is quite different. All these differences, I put to you, will make the output respond differently.

However the differences in class behavior might be quite subtle. If you look at NREL data on the Bergey anemometer you see a rather surprising thing. Turbine RPM is a linear function of v! Wow! Just like a cup anemometer.

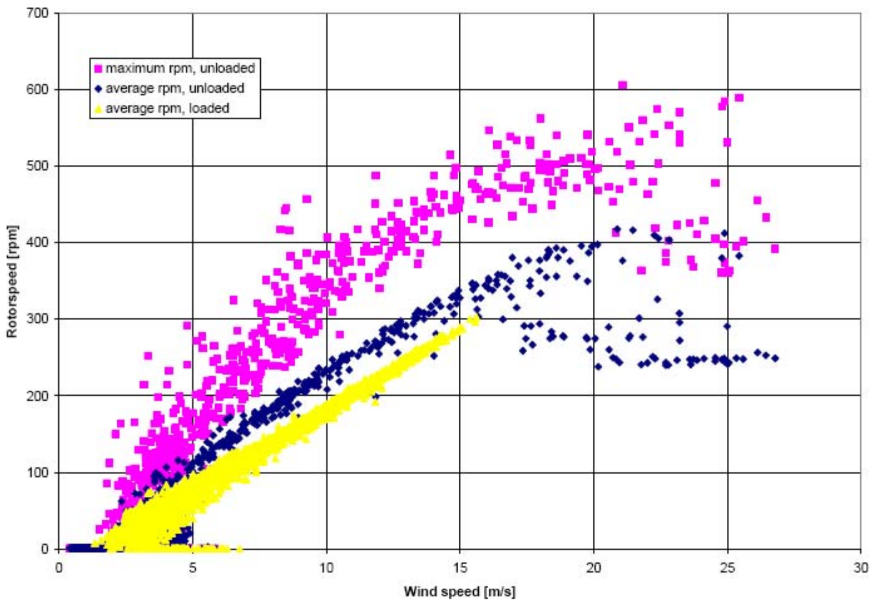

Figure 8: Rotor speed as a function of wind speed (10-minute statistics).

Fig.2 Is Fig 8 extracted from NREL report 33963.pdf

I didn’t expect that! The linearity under load probably reflects the ‘effort’ of the inverter to maintain MPPT. But if you look closer you see that RPM changes with loading and linearity is lost as the Bergey auto-furls. In NREL data a Bergey turbine looks kind of like an anemometer, but not exactly. Why? Because there is a flat region at low v followed by an approximately linear region, then a peak followed by a drop off at highest v. Most of the peak and drop off is confounded by non-loading. The GridTek10 inverter used in this study frequently overloaded and went off line at v > 17 m/s and this issue has been address in SWIEP reports before (R#3, R#11, and R#12). So this is not a monotonic anemometer. We could widen the definition of anemometer to include devices with outputs that are sigmoid with a peak maximum and drop-off, but that would put a turbine anemometer into a class of its own, i.e., worthless anemometers. The best kind of anemometer is a linear anemometer which is the class that includes cup anemometers. Hence turbines are very poor anemometers. So the likelihood is that at different sites with different turbulence the linearly-loaded part of the curve might have different slopes depending on the amount of turbulence. This is a rather important fact, because it gets back to the question of: Can you use a power curve from NREL (low turbulence site), and add on to the model corrections for turbulence, and get a predictive model? On the surface of it, the Cadmus report says that so far the industry standard models can’t do it.

4. How might differences in scale put the turbine anemometer into a different class?

This is the part I am trying to work out. I don’t know how precisely I can answer this question. Here are the considerations so far:

The turbine anemometer operates over a much larger scale, i.e., the sweep area of the blades. How does the sweep area average the wind velocity, v, and transform this to power, P? We have surface roughness in the terrain around the turbine which causes wind shear and turbulent eddies. So velocity versus height, h, from the ground will change with site condition. How, exactly does the scale of eddies and the shear affect P within the sweep area of the airfoil? Or to put it in another way: If you have two sites with the same average v and different turbulence values will the power P be the same? The preliminary answer from the Alfred University site is NO, because the power curve is vastly different (see Fig. 1 above).

Bottom line Doug, it is far from obvious to me that low productivity at a site means that the site has no wind. A cup anemometer might pick up wind that is of poor quality for power production because of turbulence. And this question of the different class of behavior of cup versus turbine anemometer cuts to the central question of HOW DO WE IMPROVE CURRENT MODELS FOR PREDICTING Ym/Yp.?

It is true, however to say that low turbine production at a particular site proves you have poor wind resources at that site. But this information does nothing to help us improve predictive models from ‘wind resource’ maps that use cup anemometer data. If you have already installed a turbine the value of a predictive model to the customer is moot.

WARNING: Never ask a professor a simple question. You will almost always get abused by a lecture, because simple questions rarely have simple answers in the view of Professors. But if we are going to make progress on wind turbine models we have to use logic and logic takes time and words.

Best regards,
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