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SMALL TURBINE COLUMN:

Size matters!

--Mick Sagrillo, Sagrillo Power & Light

I often get queries from people who are interested in installing a wind turbine and have come across an advertisement for an inexpensive device with a very small rotor that will generate incredibly large amounts of electricity relative to its cost. Recently, someone asked about a wind turbine with a price tag of only $2,800 that claimed the ability to generate 1,580 kilowatt hours (kWh) per year—a real bargain!

Digging for details, I was only able to unearth the following features:

- 5-foot rotor diameter,
- Rooftop mounted, and
- "Power generation at wind speeds less than 2 mph."

The prospective purchaser's questions for me, meanwhile, included:

- Will this turbine actually do what is claimed?
- If it won't produce as claimed, then what size wind turbine do I need?

He was wise to ask such questions. Since the rotor is the "collector" of the wind turbine, collecting wind to convert it into electricity, the larger the swept area, the more electricity you will generate. Turbines with small swept areas can only generate small amounts of electricity. Physics, unfortunately, dictates that there are no exceptions to this rule.

Digging for details

Not surprisingly, a web search turned up no sites at which I could access the turbine specifications. I also could not find any details such as the product's rated wind speed, power curve, annual energy estimates at different average annual wind speeds, or rated output. I did, however, come up with hundreds of press releases, each touting the low cost, small size, and excellent energy generating performance for this renewable energy "breakthrough."

A check with author Paul Gipe revealed that it might be possible (key word: "might"), maximizing the laws of physics, for a micro wind turbine with a small rotor diameter of 5 feet to generate 1,600 kWh/year; the turbine's location, however, would require an average annual wind speed of nearly 18 mph. While there are certainly some locales in the U.S. with such high average annual wind speeds, they are generally not where people live, but in the mountain passes where wind farms are located. In addition, high average annual wind speed at such wind farms is seen atop rather tall towers, not at rooftop level.

Regarding the claim that the device in question can generate power at 2 mph, the branch of physics known as fluid dynamics tells us that there is essentially no usable power in the wind until the wind speed reaches about *7 mph*, and even then the energy generated is minimal.

So how much electricity will this turbine be able to generate?

A bit of math

A simple math exercise can give you an idea of what is meant by "minimal." It is well understood that a doubling of the wind speed results in an eightfold increase of power available in the wind. This is due to the cubic relationship of power to wind speed, a fundamental law of fluid dynamics. The power available to a wind turbine is defined by the equation:

$P = 1/2dAV^3$
where *P* is power, *d* is the density of the air, *A* is the swept area of the rotor, and *V* is the wind speed.

We can simplify this equation for the sake of example to

$P \sim V^3$

This assumes a given location so the density of the air, *d*, does not change, as well as a given wind turbine so that the swept area, *A*, does not change. By simplifying, we can see that doubling the wind increases the power output of the turbine by eight times. (In reality, all sorts of other factors may be at play; therefore, this simple ratio may or may not hold up for any given wind turbine, but it will do just fine to demonstrate the point.) This means that going from a 10-mph wind speed to 20 mph results in the potential of an 800% increase in power output. In other words:

$2V \sim 8P$

I like to turn turbine principles like this on their heads to see what I can learn from them. It follows that if doubling the wind speed increases the power available in the wind by eightfold, than halving the wind speed would have the effect of cutting power available to 1/8 of that in the original wind. In other words,

½ V ~ 1/8 P

But what does this mean for us?

Let's assume that the wind turbine described above is rated at 500 Watts at 28 mph wind speeds. This would be comparable to other mature microturbines of equivalent swept area available in the marketplace. How much electricity might it generate at an average residential site atop a tower, sitting above obstacles and in minimal wind turbulence?

Using the above ratio, 1/2V ~ 1/8P, halving 28 mph to 14 mph results in a power output of 62.5 Watts (1/8 x 500 Watts). Cutting 14 mph in half to 7 mph gives us all of 7.8 Watts. This amount of power could easily be consumed by the wiring in the controller, to say nothing of the wire running from the top of the tower to the controller. This is why I said earlier that wind turbines begin generating usable power at about 7 mph.

Going further to point out the ludicrousness of claims about generating power at 2 mph, cutting 7 mph in half to 3.5 mph results in a bit less that 1 Watt of power. We're in LED (light emitting diode—e.g., the higher efficiency light bulbs now available) territory at this point. But remember the claim that this device generates electricity "at wind speeds less than 2 mph." So cutting 3.5 in half to "less than 2 mph" results in about 1/8 of a Watt. All of this assumes that this wind device with its small rotor diameter is actually rated as high as 500 Watts at 28 mph.

So keep all of this in mind when considering the claims made by the purveyors of such products.

Add some fuel

A reasonable average annual wind speed for someone who wants to install a wind turbine is about 10 mph at the hub height of the tower on which the turbine is to be installed. Good practice dictates that the entire rotor of the wind turbine be at least 30 feet above mature trees and other obstacles within a 500 foot radius of the turbine. In most cases, this means that towers will need to be installed at a height in the range of 80-120 feet, depending on the height of mature trees in the area and the size of the rotor. Using this rule of thumb, people residing in areas with a decent wind resource can often achieve a 10-12 mph average annual wind speed at hub height on a tower suitable to the site. However, even in areas with a decent wind resource, they will likely never see these average annual wind speeds at their roof top, to say nothing of the 18 mph needed to generate 1,600 kWh/year.

In a column last summer, I reported on a case study of the Valley Community Library in Peckville, Pa. Since there is a small wind farm about 16 miles away on a ridge, the library was advised that they are located in an area of the state with a good wind resource. The library board was told that they could put a wind turbine on their roof that is "designed to work at full force in 8-mph winds," and that the turbine would help drive down the $4,500-$6,000 monthly electrical bills.

The area does in fact have a good wind resource for *properly sited* small wind systems, estimated at 12.5-14.3 mph at 164 feet above ground level. Anyone would jump at such a seemingly good investment, but the library staff, concerned about due diligence in spending taxpayer dollars and knowing that their-two story building is not 164 feet tall, decided to invest in a $500 wind datalogger and anemometer to actually record the wind resource before investing tens of thousands of dollars in a wind system. After nearly a year of logging wind speeds, the library staff reported that the average wind speed above the roof where the proposed turbine would be mounted was a mere 2.6 mph.

So, what would this turbine have generated on a rooftop?

Now let's go back to the turbine advertised with the five-foot rotor diameter. I calculate that in an ideal location on top of a tall tower and with little turbulence from trees and buildings, the unit would generate about 385 kWh/year, given an average wind speed of 10 mph—not the advertised 1,580 kWh/year. But if installed on a rooftop, even in a "good wind resource area" like the Valley Public Library which recorded only 2.6 mph at the roof, this turbine is calculated to generate nearly 3 kWh/year. That's right—1/4 kWh per month.

In such a situation, rather than running through the calculations as I did, the only way of knowing how much energy a microturbine like this will generate is to do what the library did: monitor the wind speed at the exact proposed installation location on your roof. But you can only do this if the manufacturer provides a table of annual energy outputs for various average annual wind speeds, not a blanket annual energy claim. Anything less is gullibly swallowing what the seller of the equipment advertises—without knowing what the wind resource at the site really is and without any basis for the claims.

Well then, what size is required?

The size turbine you need is essentially dependent on two things: how much electricity you want to generate and your wind resource. Once you know your needs and how much fuel you have, you can determine the turbine size you need. Assuming that you are in a decent wind location with an annual average of 10-12 mph, the following table will give you a good idea of the turbine size that will do the job for you. Assuming that you have a 10 mph average annual wind speed at hub height, just scroll down the "kWh/year @ 10 mph" column to find a turbine that will meet your loads. Keep in mind that assuming you have a 10-mph annual average wind speed is a huge assumption, but it will at least give you a realistic idea of how much money you are really looking at for a wind turbine.

One interesting column to review in this table is the swept area of the rotor. Remember the opening premise that small swept areas generate small amounts of electricity. This is obvious from the table, and is fundamental science, but it is not well understood by most consumers. For reference, the turbine cited in this article—the one that claims it can generate power at wind speeds of less than 2 mph—sports a swept area of a mere 19.5 square feet.

“Typical” Prices and Typical Outputs for Installed Systems (January, 2009)

Model	Swept Area of Rotor	‘Rated output’	Typical Tower	Turnkey Installed Cost	kWh/year @ 10 mph	kWh/year @ 12 mph
Proven 2.5	97	2.5 kW	105' T	$36,000	2,730	4,080
ARE 110	110	2.5 kW	105' T	$30,000	2,580	4,080
Skystream	115	2.4 kW	84’ T	$19,000	1,640	2,730
Whisper 500	175	3 kW	105' T	$32,000	2,470	3,940
Endurance	254	5 kW	126’ T	$45,000	3,670	6,530
Proven 6.0	254	6 kW	120' G	$68,000	6,840	10,490
Ventera	380	10 kW	110’ G	$55,000	6,200	10,500
BWC XL-S	415	10 kW	120’ G	$62,000	6,550	10,750
ARE 442	442	10 kW	120’ G	$71,000	11,220	17,520
Jacobs 31-20	754	20 kW	120' F	$80,000	12,750	21,990
Gaia-3Ø	1425	11 kW	120’ F	$85,000	19,700	30,210

Entegrity EW 15	1,902	50 kW	120’ F	$230,000	47,800	85,120
V-15 35-1Ǿ	1,964	35 kW	110’ F	$185,000	40,000	64,320
V-17 90-3Ǿ	2,462	90 kW	132’ F	$230,000	64,590	105,000
PGE 20/35-1Ǿ	3,120	35 kW	120’ F	$290,000	58,760	83,350
PGE 20/35-3Ǿ	3,120	50 kW	120’ F	$300,000	66,860	94,760
NW 100-3Ǿ	3727	100 kW	120’ F	$435,000	87030	137,450

Table key:

- Swept area of the rotor—compare this to the turbine cited above
- Typical tower—a common tower used with this turbine. Note that the height you require is dependent on the trees and building around your site, not necessarily what is listed in the table. Key to tower type is
  - T = tilt-up tower
  - G = guyed tower
  - F = freestanding tower
- Turnkey cost—this is the cost of the wind turbine, tower, all wiring and electrical, excavation for the foundation, concrete and rebar, crane costs if applicable, shipping, sales tax, and all labor, mileage, and other expenses to install the wind system. Note that these prices are for the Midwest. Prices for other parts of the country will likely be higher.

Back at the store…

So don't be deluded into thinking that you can generate mega-amounts of electricity with a micro-sized rotor. If that were the case, don't you think you'd see utilities mount these microturbines on all of the millions of utility poles scattered across the countryside? With their incredible buying power, they'd pay far less than retail for the turbines, making them an even bigger money maker. There must be *some* reason why utilities haven't gotten into this business.

If you want to generate more than micro amounts of electricity, you need more than a micro wind turbine.

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[Editors Note: The opinions expressed in this column are those of the author and may not reflect those of AWEA staff or board.]