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SMALL TURBINE COLUMN:

Back to the Basics 6: Estimating Annual Energy Output

--Mick Sagrillo, Sagrillo Power & Light

When shopping for a wind turbine, cost is frequently the first consideration of the potential owners. While cost is certainly important, what people really need to know is how much electricity the system will generate over the course of a year, a metric known as the annual energy output (AEO), at the site where it will be installed—assuming that the turbine will run for its 20-30-year design life.

The first place that people go to find out the AEO for their turbine of interest is the manufacturer of that model. However, while most manufacturers attempt to distinguish themselves from their competition with their listed AEO, some small wind observers have branded various manufacturer claims for AEO as wildly optimistic at best and outright fraud at worst. What is the potential small turbine owner to believe?

AEO variables

Various people have suggested formulas for calculating the AEO of a wind turbine. I took a look at a good handful of these calculations, and, while they all use slightly different formulas, all come very close to the same answers. I've concluded that, while not always obvious from their equations, they are all along the same lines, relative to the inputs for the various equations. These inputs include some standard considerations that are relatively easily pegged, like swept area, average annual wind speed, the density of the air, and different conversion factors between metric and English units.

But these equations also include some assumptions that are considerably more difficult to nail down, especially for different turbine designs and sites.

The primary variable that is affected by the different turbine designs themselves is the overall turbine efficiency (OTE), which includes the coefficient of power of the blades, the generator efficiency, the operating characteristics of the governing system, and the inverter conversion efficiency—all of the things that affect the conversion of wind energy to usable electricity. It turns out that turbines operate anywhere between about 15% and 25% efficiency in typical wind distributions, with many manufacturers hoping to someday achieve the 35% that typical wind farm machines operate at. This range is partly due to the design choices that different manufacturers have made in order to make their products competitive in the marketplace. In addition, the range is partly due to what wind speed the blades and turbine designs are optimized for, and how the OTE varies as wind speed varies. Finally, these formulas assume that a given average annual wind speed distribution occurs over the course of the year, by utilizing and algorhythm to account for the wind's annual variability (know as a Weibull distribution).

Since characterizing wind variability is a crude science at best for small wind, the only real variable that can actually be manipulated in any AEO equation is the OTE. And since the OTE for any given turbine varies with its design and the energy density of the wind, I've come away feeling that, while all of these AEO equations are approximations, the results that they produce have often proven to be more accurate than advertised AEOs, based on reports of real-world installation performance. However, even they must be considered with some understanding of their limitations to be useful.

Calculating AEO

One of the simplest and most user friendly equations comes from Dean Davis of Windward Engineering. Dean's equation states:

$AEO = A \times V^3 \times 0.085 \times OTE$

where A = swept area or the rotor (in square feet);
V = average annual wind speed for your site (in miles per hour); and
OTE is the overall turbine conversion efficiency (electricity generated as a fraction of power available in the wind)

Those who supplied me with OTE equations all believe that most small turbines actually operate in the 20% efficiency range. I chose a more liberal 25% as an optimistic yet sometimes achieved overall efficiency for small wind turbines, and plugged that number into Dean's equation as a standard OTE, then ran five popular small turbines through the calculation. The following table gives a comparison of the calculated AEOs at average annual wind speeds of 10 and 12 mph at 25% OTE versus the manufacturers advertised AEOs from their respective Web sites.

	10 mph	12 mph
Southwest Windpower Skystream (115.7)		
AEO at 25% OTE	2459 kWh	4249 kWh
manufacturer's AEO	3000 kWh	4560 kWh
calculated manufacturer's OTE	30.5%	26.8%
Endurance S250 (256)		
AEO at 25% OTE	5440 kWh	9400 kWh
manufacturer's AEO	7909 kWh	12305 kWh
calculated manufacturer's OTE	36.3%	32.7%
Endurance S343 (343)		
AEO at 25% OTE	7289 kWh	12595 kWh
manufacturer's AEO	9498 kWh	14065 kWh
calculated manufacturer's OTE	32.6%	28.0%
Bergey Excel (415)		
AEO at 25% OTE	8818 kWh	15238 kWh
manufacturer's AEO	9677 kWh	15910 kWh
calculated manufacturer's OTE	27.4%	26.1%
Abundant Renewable Energy 442 (442)		
AEO at 25% OTE	9393 kWh	16230 kWh
manufacturer's AEO	15132 kWh	22680 kWh
calculated manufacturer's OTE	40.3%	34.9%

*swept area of the rotor in parenthesis

The next thing that I did was to calculate the OTEs for these five turbines using a variation of Dean's equation that states:

OTE = manufacturer's AEO / (A x V^3 x 0.085)

You can see from the table (Calculated Manufacturer's OTE) that all of these turbines operate at efficiencies higher than the liberal 25%, per the data that is published by the manufacturers. Some would state that these are exaggerated claims, and that small wind turbines cannot and do not operate at such high efficiencies. Others note that these efficiencies are only achievable at a perfect wind site (whatever that is). Without some sort of a measurement and verification effort for small turbines and their sites, where kilowatt-hours are documented as a function of the measured wind speed at their sites, this quandary will remain unresolved.

What to do?

In the last five columns we've established the problems associated with ground drag and turbulence, and how to minimize these two resource hindrances by using a tower sufficiently tall to maximize average annual wind speed. I've also laid out the importance of the rotor size, the wind turbine's "collector," to a wind system in capturing winds to convert to electricity. By now, hopefully you understand that the turbine rotor area and the average annual wind speed at your site are the two most important criteria for generating a given amount of electricity.

As for the AEO issue, my suggestion would be to talk to as many owners of the equipment you are interested in as possible to get a sense of what their AEO is, based on their documented or estimated wind resource. Given whatever level of confidence you can glean from these conversations, you might consider arriving at a ballpark AEO for yourself by picking some number in between a more conservatively calculated AEO and the advertised AEO for your wind resource. If you depend on manufacturers' AEOs to predict performance, be advised that "your mileage may vary." Maybe considerably.

At the end of 2009, the AWEA Standards Committee approved a new standard for small wind turbines. Included in the standard is a process for documenting and reporting AEO. These will be verified and certified by the Small Wind Certification Council (SWCC), which is now taking applications for turbine certification. In the future, interested buyers will be able to look for the SWCC-certified AEO for all turbine that have gone through the process. Hopefully, this will instill confidence that small wind turbines will perform as advertised.

Regardless, keep in mind that the greatest influence on the output of your turbine is going to be the wind resource at your site. And that is something that you have control over with the tower height you select.

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Editor's note: The opinions expressed in this column are the author's and may not reflect those of AWEA's staff or board.