How Much Power will a Wind Turbine Produce

How much power will your wind turbine produce? In this article, we discuss the three factors that determine output from your wind turbine and talk about some simple design considerations that can help you design an efficient and cost-effective system.

The formula for the power in the wind is made up of three factors:

Air density

Denser air is better. Cool air is denser than warm air, dry air is denser than moist air, and air near sea level is denser than air at the tops of mountains. At any given location, the actual air density can vary by an average of 16% from day to day and throughout the year.

Sweep area

This is the circular area for a HAWT type turbine or the Height x Width area for a VAWT type turbine. The larger the sweep area, the more wind power that can potentially be captured.

Wind Speed

Wind power increases by the cube of the wind speed. This is very important to understand. The wind power at 10 mph with a given rotor size might be 100 watts but at 20 mph will be 800 watts. As the wind speed doubles, the wind power goes up by a factor of 8. The basic wind power formula is:

Power (watts) = 1/2 x the density of air x the sweep area x wind speed^3

The next consideration is called Coefficient of Performance (C_p). Sometimes this is referred to as efficiency. It is simply the percent of wind power that a given turbine is able to deliver.

In 1919, a German physicist named Albert Betz determined that no machine could achieve a C_p > 59.3%. This is referred to as "Betz' Law" or the "Betz Limit". Most modern large turbines with variable pitch rotor blades are able to achieve a 40-45% C_p in 10-35 mph winds, while fixed pitch blades achieve usually between 15-35% C_p in similar winds. This C_p takes into account the combined efficiency of the blades and the generator.

Let's compare the power produced for a given rotor size (sweep area) at various C_p levels to see what can be expected for performance. The example we share here is for a typical 5-foot diameter turbine.

So what ways are there to achieve a high C_p, such as 35%?

Blades

Well designed and made from either wood, metal, or advanced composite. They are stiff, strong, and quiet. They are contoured to produce lift and are well balanced as a set. Blades that bend, vibrate, or twist are relatively inefficient, falling to less than a Cp of 10% in high winds.

PMA

Well matched to the rotor size and blade performance (RPM vs. wind speed). They are purpose-built rather than salvaged from some other application (i.e.: automobiles or ceiling fans). They have low winding resistance (ohms), no cogging, and are sealed from the weather to prevent rusting and bearing wear.

Tail design

Properly sized and positioned to allow good tracking of the wind. If tracking is poor, either due to the yaw action being too stiff, or the turbine hunting for the correct direction to point, performance will suffer. Read our article on proper tail design [1] considerations.

Comparing Turbine Sizes

Let's compare and contrast the expected performance for the most common size small wind turbines, from a 46-inch Air-X size to a 112-inch (2.88m) Drone size. The chart below is set at a C_p=28% which assumes a turbine with a good set of blades, PMA, and tail configuration. Note that the power produced is directly proportional to the rotor size/sweep area, so size DOES matter. An 80-inch turbine such as the WindTura 750, for instance, has a swept area and a resultant power output that is 84% higher than a good 59-inch wind turbine such as the Windmax HY-400, with all else being equal.

Now keep in mind that this chart is just a guideline. Some specific turbines do better (above C_p=28%) and some do worse. Be aware that the C_p is not fixed across the wind speed range, but from 15-20 mph the value will be its highest on most well designed turbine systems and then will fall off from there. We generally recommend using 15 mph as a point of reference for comparisons as this is a wind speed that is pretty common in many areas where wind power is an attractive energy source. It is also interesting to observe how little power is harvested in low winds under 10 mph. The lesson to learn is to be skeptical of advertisements for wind turbines claiming superior low wind capabilities.

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