

Measuring the power output and efficiency of your wind turbine on your own is very doable and will help you perform well in competitions. This manual tells you everything you need to know to get started. Remember that the Performance Calculator will make your life easier when crunching these numbers. You are about to become a turbine building expert, all you need is a multimeter to collect data. There are four things you'll be learning to calculate: Power Output, Energy Output, Turbine Efficiency, and Tip Speed Ratio. But before you take the plunge, here are some basic terms you'll want to know.



Definitions of Key Terms

Voltage

Voltage (measured in volts) is a measure of the amount of “potential energy” available to make electricity flow in a circuit. Think of it as the electric “pressure” causing the current to flow.

Current

Electric current is a measure of the rate at which electric charge (electrons) flow through a circuit. It is measured in amperes (amps). Smaller amounts of current are often stated in “milliAmps” (mA), which are 1/1000 of an amp. We always speak of electric current flowing through a single point in a circuit, whereas we refer to voltage existing across or between two points in a circuit.

Resistance

Electrical resistance is the opposition to the flow of electricity. Measured in ohms, it reflects how much voltage (electric “pressure”) is required to push a given amount of current through a device. If resistance is high, it will take a lot of voltage; if resistance is low, the current will flow easily, even with a small voltage applied. We always test out turbines load using resistors that range from 10-100 ohms.

Energy

Energy is the ability to do work. We need energy to do many things in our daily life: heat our homes, move our cars, light our rooms, and make our bodies move. The primary unit of energy is the joule (J), defined as the work required to move an object one meter against a force of one Newton. This is approximately the energy required to lift a 12 oz soda can one foot straight up.

Power

Power is the rate at which energy is consumed or generated and is measured in watts (w), which is one joule transferred every second, or J/s.

Multimeter

A multimeter is a handy tool that will allow you to quantify the voltage and/or current your turbine is producing. Learning how to accurately measure the voltage and current for a range of situations will help you compare data when testing blades, comparing gearing, or changing any other variables on small turbines. You will also need this information if you want to calculate the power your turbine produces.

Power and Energy Output

You're going to use your multimeter to measure your turbines power and energy output.

Measure Voltage

Attach the wires from the generator to the multimeter. Polarity is not relevant at this point. To check the voltage, select DC volt (V) and set the number to 20. Place your turbine in the wind and let it spin. It's normal for the voltage readings to fluctuate: it's often unsteady because of the inconsistent nature of the wind or unbalanced blades. Voltage is related to how fast the DC generator is spinning. The faster it spins, the higher the voltage. When there is no load on the generator, it has little resistance and can spin very fast. You can measure voltage with no load, but it is more realistic to place a resistor in the circuit and measure the voltage across the resistor. We commonly use 30, 50 or 100 ohm resistors.

Measure Current

To calculate your turbine's power output, you will need to measure current as well. To collect amperage data, you will need to place a load, preferably a resistor, in series with the multimeter so that the generator is forced to do some work.

When measuring current, you are monitoring how many electrons are being pushed through the wire by the turbine. We measure current from our turbine in milliAmperes (recall that 1A =1000mA). Refer to these great videos [here](#) and [here](#) on how to measure voltage and amperage.

Calculate Power Output

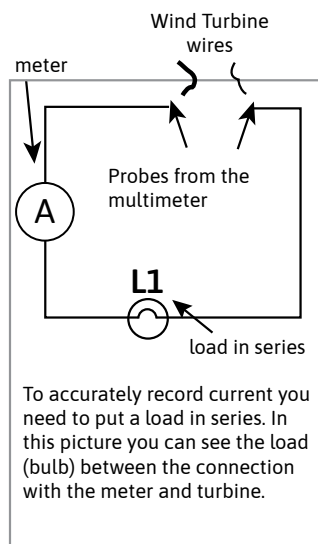
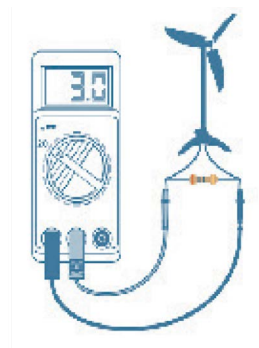
If you measured voltage across a resistor, you have enough information to calculate power output.

Power = voltage x current

We have taught you how to measure voltage and current, but it can be hard to measure them both simultaneously. You'd need two multimeters and lots of clip cords, which can get a little messy! In certain situations, we can make this easier using Ohm's law. If we know the voltage that our turbine is producing and the size of the resistor in the circuit, we can determine our power output by only recording the voltage using the equation below.

Power = voltage² / resistance (ohms)

Remember to check out our Turbine Performance Calculator that lets you find the power output with a simple click of a mouse.



Advanced: Calculate Energy Output.

Knowing how powerful your turbine is can be helpful, but many times you will need to calculate how much energy (not power) your turbine produces over a 60 second trial. Knowing the difference between power and energy is very important. Here's an easy trick: the difference between power and energy is a lot like the difference between speed and distance. Power is a rate, energy is a quantity.

Think about this: A small wind turbine with a low power output in a windy place produces lots of energy. A large wind turbine with high power output in a not-so-windy place will produce little energy. So, when planning the location of a wind turbine, the amount of energy it will actually produce is more important than its maximum power output.

While you can use fancy software and data collectors like Vernier to calculate how much energy your turbine produces in one minute, you can also just use your plain, old-fashioned multimeter and a stopwatch. To measure the energy output we use a small unit for measurement: millijoules, or 1/1000 of a joule. If you measure and record the voltage across the resistor at 5 second intervals, you can calculate how much energy your turbine produces.

You may notice your readings are fluctuating. If this is happening, it's because the wind coming out of your fan is fluctuating. This can also be caused by your blades not spinning smoothly or changing shape as they spin. Additionally, if your blades are not balanced, evenly distributed, or are producing unequal amounts of drag your readings will be irregular.

Power in the Wind and Turbine Inefficiency

If a huge truck were barreling toward you at a high speed, you would move out of the way, right? Why? Because you know that this moving object has a great deal of energy due to its mass and motion. And you know that you absolutely do not want to be on the receiving end of that energy!

Just as large moving objects have energy because of their mass and motion, so does the wind. Wind is the movement of air from one place on Earth to another. Air is a mixture of gas molecules, and if you get lots of them (and we mean lots of them) together in a gang and they start moving quickly, they will give you a serious push. Just think about hurricanes, tornadoes, or a very windy day! The velocity of those gangs of gas molecules have a dramatic impact on whether or not we will be able to remain standing on our feet.

You can experiment with your turbine and test to increase efficiency. The three biggest factors are wind speed, blades, and diameter of driveshaft, gear additions, etc. To test for wind speed, place your turbine in front of a fan at three different distances. How does the power output change? Why does it change? Make a graph and discuss. Think about this in relation to the Power in the Wind equation.

Blade design refers to the length, shape, number, materials, pitch, and weight of your turbine blades. For an electricity-producing turbine, your goal is to make the rotor spin as fast as possible to spin the generator faster. Experiment and tinker with these elements to identify the most powerful design.

A simple equation for the power in the wind is described below. This equation describes the power found in a column of wind of a specific size moving at a particular velocity.

$$P = \frac{1}{2} \times \rho \times (\pi r^2) v^3$$

P = power in the wind (watts)

ρ = density of the air (kg/m³)

r = radius of your swept area (m)

v = wind velocity (m/s)

$\pi = 3.14$

From this formula you can see that the size of your turbine (r) and the velocity of the wind (v) are very strong drivers when it comes to power production. If we increase the velocity of the wind or the area of our blades, we increase power output. The density of the air has some impact as well. Cold air is denser than warm air, so you can capture more energy in colder climates.

This formula tells you the available power in the wind. Your turbine cannot capture all of this power. Even if you built the best turbine ever you could only extract 59% of this power. You can blame this on something called the Betz Limit.

What is the Betz Limit?

Wind turbines are limited in how much power they can capture from the wind. A guy named Albert Betz figured out that even the most perfect turbine can only extract 59.3% of power in the wind stream, and we now call this number the Betz limit.

So what causes this? Some of it is caused by generator inefficiency, blade design, or friction in the drive train. But most importantly, Betz was considering wind flow through and around the wind turbine.

A wind turbine cannot capture 100% of the power in the wind, because that would mean that the wind would have to be stopped completely. For a turbine to work properly, some wind has to move out the back of the wind turbine to keep the blade spinning.

So what's my turbine's efficiency? To determine the efficiency of your small turbine you need to know the following:

1. How much power your turbine is generating (we can calculate this).
2. How much available power is in the column of wind hitting your turbine (we can calculate this if we know the wind speed and the rotor diameter).

Our Turbine Performance Calculator will help determine your turbine efficiency. The hardest variable to get a number on is the wind speed hitting your turbine.

Fortunately for you, we have a [wind speed cheat sheet](#) that allows you to estimate the wind speed of the fan you are using. Otherwise you can buy some wind meters, or make one of your own (Easter Egg Anemometer - Wind Speed Meter or Simple Anemometer).

Tip Speed Ratio

One last performance parameter of your wind turbine is the Tip Speed Ratio (TSR). TSR is a ratio of how fast the tips of your turbine blades are moving relative to the wind hitting the turbine. For example, if the wind hitting your turbine was traveling at 5 m/s and your blade tips were moving at 5 m/s you would have a TSR of 1.

What is the optimal TSR?

That depends on a number of factors like rotor diameter, number of blades, blade pitch, revolutions per minute (RPM) needed by the generator, and oncoming wind speed. Typically, higher TSRs are better for generators that require high RPMs – but the wind speed characteristics at your particular site will make a big difference.

If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. But if the rotor turns too quickly, the blurring blades will be like a solid wall to the wind and also not produce any energy.

When a turbine blade passes through the air it leaves turbulence in its wake. If the next blade on the spinning rotor arrives at this point while the air is still turbulent, it will not be able to extract power efficiently from the wind. However if the rotor spun a little more slowly, the air hitting each turbine blade would no longer be turbulent and the turbine would be more efficient.

Measure TSR

If you know the diameter of your wind turbine rotor, the velocity of the wind, and your RPM you can calculate TSR. Generally the higher your TSR the more electricity you are going to be able to generate on a three bladed turbine. But this has some limits, too.

Check out the Performance Calculator and calculate the TSR of your wind turbine. Experiment at a variety of wind speeds and see what happens!

