Activity Three: Tip Top Tip Speed

Adapted from

KidWind, "Wind Energy Math Calculations"

Grade Level

6-12

Objectives

- Students will be able to explain the importance of the tip speed ratio to turbine performance.
- Students will use a tachometer to measure revolutions per minute.
- Students will be able to calculate tip speed and tip speed ratio.

Overview

It might seem that the faster your turbine turns the more power it generates. But is this actually the case? Your Skystream turbine blades appear to turn very quickly. A large wind farm turbine's blades appear to turn much more slowly. Which is producing more power? The speed at which the blades travel helps to determine the tip speed ratio and being able to calculate a tip speed ratio allows us to maximize the power generated by a wind turbine.

How does the speed at which the turbine is spinning relate to the power produced? Clearly, if the blades spin too slowly, a lot of the potential power will blow right through the turbine. If the blades spin very fast, they can create a solid wall and no wind can blow through, producing no power. When fast-moving wind can blow through a fast spinning turbine, the turbulence created in the wind stream by one blade will interfere with the travel of the next blade if it arrives too quickly. In order to design a turbine that gets the maximum power from the wind, the best "tip speed ratio" must be determined. In other words, there is a speed of the blade tips that should be matched to the speed of the wind for the best results.

Materials

- Your school turbine
- Tachometer
- Wind speed meter
- Activity Sheets

Estimated cost (per group)

$50 for one tachometer and one wind speed meter

Computer needed?

Yes

Duration

2 class periods (One class period to collect and analyze outdoor data and one for computer data calculations, discussion and research.)

Primer References

- Using the Power of the Wind: Tip Speed Ratio
- How to Find Tip Speed Ratio
- Tip Speed Ratio and Coefficient of Power

Engagement

- Is it true that the faster your turbine spins, the more power the turbine generates?
- Is the highest wind always the best for power generation?

Exploration

Finding the Tip Speed Ratio of your school turbine

Part 1 –Using data gathered at your site

The tip speed ratio is the ratio of the tip speed of the turbine blade to the speed of the wind.

$$\text{Tip Speed Ratio}(\lambda) = \frac{\text{Tip Speed of blade}}{\text{Wind Speed}}$$

1. Find out how far the tip of the turbine blade travels in one revolution.
   This distance is the circumference of the circle traced by the tip of the blade.
   Circumference = $\pi 2r$ or πD
2. Sadly, the tachometer in your kit cannot determine RPM (revolutions per minute) on the actual turbine. You can get this from your turbine data or go outside and see if you can find a strategy for estimating the RPM of your turbine. When you get a value, you need its inverse, or minutes per revolution, and you need seconds rather than minutes, so just take the RPM value and divide it into the number 60. That will give you how long it takes for a blade to go around one time in seconds.

3. Speed = Distance (circumference) divided by time (for one revolution). Calculate the speed of the tips of your turbine.

4. Use your wind speed meter to determine the wind speed that is moving your turbine blades at this speed.

5. Determine the Tip Speed Ratio by dividing the tip speed by the wind speed. Remember that the units in your calculations all need to be in the same system.

6. Observation and data collection has shown that this formula is an accurate way to find the optimum TSR for maximum power output:
   $$\lambda \text{ (max power)} = \frac{4\pi}{n} \quad \text{(n = number of blades)}$$
   λ = Tip speed Ratio or TSR
   What is the optimum TSR for your turbine using this formula?

7. Research using some of the sites listed in the References below to find out how the optimum tip speed ratio can be increased.

Part 2 –Using Data from Your Wind for Schools site

1. Record the date and time of your data set.

2. Record the RPM of your turbine.

3. Record the wind speed.

4. Calculate the circumference of the circle traveled by your turbine blades. (Hint: Is this different than the value you found in Part 1?)

5. Calculate the tip speed based on this data.

6. Calculate the tip speed ratio based on this data.

7. Look at some of the past month's data for your turbine. Pick two different wind speeds. Record the RPM associated with each wind speed. Repeat steps 2-6 to calculate the tip speed ratios at those speeds. Does the tip speed ratio change with changing wind speeds?

8. At what wind speed, is the TSR value optimal?

Explanation
Class Discussion

1. What exactly does the tip speed ratio describe?
2. Why is this ratio important?
3. What happens at the optimum TSR? What is happening if the TSR is less than the optimum value? What is happening if it is higher than the optimum value?
4. Do you think the TSR of your turbine is a constant value? Why or why not?
5. The optimal or optimum tip speed ratio predicted by the formula used earlier can be increased by making some changes to the turbine. What are some of the changes you learned about?

Elaboration/Extension

1. How does the tip speed of a large wind turbine compare to the speed of the Skystream turbine? The Cedar Point Wind Farm in Limon, CO uses Vestas v90 turbines. The rotor on this turbine has a diameter of 90 m. At the nominal wind speed of 12m/s (the lowest speed at which the turbine produces the rated power), the rotor turns at 16.1 RPM. Using your Tip Speed Ratio worksheet, calculate the Tip Speed and the Tip Speed Ratio for this turbine. How do the values compare to those of the smaller turbine? To look at more of the technical specifications of the Vestas v90 3.0MW turbine, see page 14 of the brochure at http://www.vestas.com/Files/Filer/EN/Brochures/Vestas_V_90-3MW-11-2009-EN.pdf

Instructor Notes

For a discussion of the higher level math used in calculating the Betz Limit, Power Coefficient and Optimal TSR, see
http://www.raeng.org.uk/education/diploma/maths/pdf/exemplars_advanced/23_wind_turbine.pdf

References

http://www.windynation.com/articles/wind/tip-speed-ratio-how-calculate-and-apply-tsr-blade-selection
Warning: we did not calculate TRS as they did, but the rest of the information is useful

Optimal Rotor Tip Speed Ratio
http://mragheb.com/NPRE%20475%20Wind%20Power%20Systems/Optimal%20Rotor%20Tip%20Speed%20Ratio.pdf

Calculating the Tip Speed Ratio of your Wind Turbine
http://www.mmpa.org/Uploaded_Files/2c/2c48c69c-303d-4fc7-8d88-2153190d1fcc.pdf

A whole collection of tip speed ratio problems and handouts
http://www.energyforeducators.org/lessons/TipSpeedRatio/tip_speed_ratio_lesson_plan.pdf

Find a Coefficient of Power to TSR graph here
http://www.reuk.co.uk/print.php?article=Wind-Turbine-Tip-Speed-Ratio.htm

Tip Speed Ratio - Observed Data								
Turbine Location	Date	Time	Rotor Circumference	RPM	Time for 1 Revolution	Tip Speed	Wind Speed m/s	Tip Speed Ratio

Tip Speed Ratio - Turbine Data

Turbine Location	Date	Time	Rotor Circumference	RPM	Time for 1 Revolution	Tip Speed	Wind Speed m/s	Tip Speed Ratio