Activity Four: Modeling Power Efficiency and Tip Speed Ratios

Adapted From
KidWind "Wind Turbine Blade Design" and "Building the Basic PVC Wind Turbine"

Grade Level
6-12

Objectives
Students apply concepts learned about what makes an efficient wind turbine to building a model turbine and using data collection skills and mathematics knowledge to determine the efficiency of their model.

Overview
Students will work in teams to build what they believe will be the most efficient model wind turbine in the classroom. They will calculate and measure power and tip speed ratio and design experiments to explore the variables that can affect turbine efficiency.

Materials
For each group of 3-4 students

- Wind turbine kit (hub, dowels, generator, holder)
- Materials for making turbine blades – poster board, foam core board, balsa wood, etc.
- Scissors or exacto knives for cutting blade materials
- Strong Tape or hot glue
- Tachometer
- Multimeter
- Box Fan
- Wind Speed Meter
- Masking tape
- Activity Worksheets

Estimated Cost (per group)
$150 per group if premade kits are used.

Computer required?
None, unless worksheets are done on the computer. They can also be printed out.

Duration
Two to three 40-45 minute class periods to build turbines, carry out experiments and discuss results

Primer References

- What is Wind and What is Wind Energy?
- How Wind Turbines Work: Blade Design and Function
- Using the Power of the Wind: Determining the Power in the Wind
- Understanding Wind Speed; the Power in the Turbine
- The Energy in the Wind; Tip Speed Ratio
- How to Find Tip Speed Ratio
- Tip Speed Ratio and Coefficient of Power
- Getting Data from a School Wind Turbine

Engagement

Usually scientists and engineers will use models to explore larger, real time phenomenon. You have been collecting data and analyzing it to explore the efficiency of your school turbine as well as larger wind farm turbines and now you will apply the principles you learned about turbine efficiency to try to build a highly efficient wind turbine model. Based on what you learned in the two previous activities, your team will try to build the most efficient wind turbine in the class.

- What characteristics contribute to maximum power generation?
- What should your blades be like; how many, what size, shape and pitch?
- What other factors should you consider?

Exploration/Investigation

Using your wind turbine kit, design a turbine that will produce the greatest amount of power at the highest degree of efficiency.

Super Power

1. With your team, draw a blueprint of the wind turbine you plan to build.
2. Once you are satisfied with your design, get the construction materials and carefully cut out your blades and firmly attached them to the dowels that will go into your hub.
3. Measure the length of your blades and record your turbine radius and diameter on the worksheet.
4. Find and record the air density for your location.
5. Measure the wind speed at the tape mark with the fan set at setting 3.
6. Calculate the energy your turbine can potentially produce.
7. Place the hub on the turbine and place it at the test site.
8. Connect the generator to the multimeter.
9. Record volts and milliamps produced at each fan setting and calculate power produced at each setting. Remember you are most likely measuring milliamps when you take your readings and do your calculations.

Instructor Note: In order to measure current (amps) with the multimeter in this kit, a resistor must be placed in series with the multimeter and turbine. There are small 50 Ω resistors in the kit that can be incorporated into the circuit using an alligator clip. The literature in the kit also explains how to calculate power using volts and resistance.

Tip Top TSR

Can engineers increase the TSR of a wind turbine? Experiment with some possible factors.

1. Determine the RPM of your turbine using the tachometer. You and your partner will need to work together to do this. Place a small square of reflective tape near the tip of one blade. Find a spot where you can aim the laser light directly at the square. Turn on the tachometer and make sure it is aimed in the spot you chose. This will be near the edge of the blades. One person will turn on the tachometer and watch the screen. The other will call out “reading’ every 10 seconds and record what the holder says. When you have 60 seconds of readings, average them to get an rpm reading. The readings may vary widely but the averaging should help give a useable value.
2. Measure the wind speed.
3. Calculate the TSR for your turbine. What does the TSR tell you about your design?
4. Think of another variable to test. If necessary, look back at some of the references you consulted in the Tip Top Speed activity. Remember to only change one feature at a time when you are testing for differences!

Explanation

1. Which classroom turbine produced the most power? What about its design made it work so well?
2. Which design should theoretically have been the most efficient? Was it? Why or why not?

3. Compare class Tip Speed Ratios. Did turbines with longer blades produce more power than those with shorter blades? Would you expect them to? Why? If they didn't, why not?
4. Does the TSR change with the length of the blades? What other factors affected TSR?
5. Does a larger TSR lead to more power produced? Should it? Why or why not?
6. Which factors seem to have the most effect on optimizing TSR?
7. What factors are designed into real wind turbines to bring TSR as close to optimal as possible?

Extension

Work with other groups in your class to design a wind farm using several of your model turbines. Calculate the efficiency and the power produced by the farm. Does putting turbines together in a farm format increase the overall efficiency of production?

Instructor Notes

Set up a test area with a box fan placed 18 inches from the turbines. Use tape to mark a spot where all turbines will be placed for testing.

References

KidWind has lots of materials about blade design. This activity has some god hints about blade design variables to try.
http://learn.kidwind.org/sites/default/files/blade_design2.pdf

Another good resource available at the KidWind site is a turbine Performance Calculator that actually allows students to put in their data and have results calculated for them.
http://learn.kidwind.org/challenge/web/turbine_performance_calculator

KidWind also has a good overall primer on wind energy, turbines, farms and on electricity concepts. There is a useful section on wind farms and model wind farms including how to wire models in series and parallel and a good discussion on the "wind park effect."
http://learn.kidwind.org/sites/default/files/learn_wind.pdf

Using the Tachometer

Your kit includes a very basic tachometer that turns out only to work within 6 feet of the spinning object you are timing so it will not work for measuring the RPM of your school turbine. There may be a larger scale tachometer available through one of your high school science teachers.

1. To use the tachometer, first put the battery in. Press the TEST button to see if it comes on.
2. Place a 1/2 inch piece of reflective tape on one of the blades, near the outer edge.
3. Find a spot where the laser beam that does the counting can be aimed fairly straight and level at the blade with the tape. The easiest way to do this is to have the blade pointing straight down in front of the turbine tower and aim straight at the tower and brace the instrument on the turbine. This will help you keep it in the same position when you are measuring.
4. Start the turbine. Aim at the edge of the spinning "wheel", staying level with the spot you noted on the tower and press the TEST button. You may have to hold it for a while or press it on and off before data starts to show.
5. Once you get a reading, have a partner call out "Reading" every 10 seconds and record the reading. You will find that the readings may be very erratic. Repeat 3 times.
6. You will notice that the readings go up and down, but that there will be a period of time when the same value stays on the screen. Over the course of 3 trials, you may find that this value is fairly close in all three trials. If that is the case, average these 3 together.
7. If you have widely spaced, jumpy data, you may want to throw out your outliers and average the 3 or 4 values that are closer together for each trial. Then average the 3 trial averages to get an estimated RPM.

This is a good chance to discuss experimental error with the class.

Activity 4 Modeling Power and Efficiency

Team name - Rotor description	Volts produced	Current produced mA	Power Produced mW	Power Produced W	Rho	Blade radius m	Swept Area m^2	Wind speed m/s (V)	V cubed	Calc. Power (w)	Observ. Power (w)	% Energy Produced to Power Observ./Calc. X100
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					0.82							
					0.82							
Notes:												
Calc.= Calculated Power												
Observ. = Observed Power												

Modeling Tip Speed Ratio

Team name	Rotor Diameter m	Rotor Circumference m	RPM	Time for 1 Revolution	Tip Speed	Wind Speed m/s	Tip Speed Ratio