

Activity Two: Power in Practice and Theory

Adapted from

Boise State Wind Energy Teacher Resources
<http://coen.boisestate.edu/windenergy/wfs/teacherresources/>

Grade Level

6-12

Objectives

- Students will create graphs of wind turbine and efficiency data.
- Students will be able to calculate the theoretical power in the wind that blows through a turbine and compare it to actual data captured from a Wind for Schools turbine.
- Students will be able to calculate the efficiency of the study turbine.
- Students will be able to draw and support conclusions based on data.

Overview

Students will learn to determine the amount of theoretical, mathematically calculated, power in the wind reaching a turbine and compare it to the actual production of the school turbine. Students will use the data to determine the efficiency of the school turbine. They can then use this information to discuss the positives and negatives of the school wind turbine.

Materials

- Calculators
- Graph paper
- Internet connection
- Activity sheets

Estimated Cost of Materials

\$0

Computer Required?

Yes

Duration

2 class periods

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
- Getting Data from a School Wind Turbine

Engagement

- The wind seems like it blows much of the time in most places. Yet only some places are suitable for wind power production. Think about all the wind that blows past a turbine.
- Does all of it produce energy? How can the amount of energy produced by the wind be maximized?

- If we could use all of the power in the wind that came into a turbine's swept area, what would happen? Is there such a thing as too much wind?
- These are important questions for wind engineers.
- How good a job of converting wind kinetic energy (the energy of moving air) to electrical energy does your Wind for Schools turbine do?

Exploration/Investigation

Warm-Up

Before you start closely analyzing your turbine and its output, study the relationship between wind speed and the power produced by looking at the data collected by your turbine.

1. Look at the data from your school over the past month and pick out 5-6 readings that show a wide range of different wind speeds. Record your wind speed in meters/second.
If you can't find m/s data, convert miles per hour to meters per second by multiplying mph X .44704.
2. Make a table of watts produced and wind speed.
3. After you get a table of values, use them to graph the wind speed vs the watts. The wind speed is your independent variable and the watts produced are the dependent variable.

What do you notice? Is there a one to one relationship or does increased wind speed greatly increase the watts produced?

Instructor Note: Real data tends to be quirky and this is especially true of turbine data. Have students find places where there are several readings at the same wind speed. Use the value that occurs most frequently. Even that may not be entirely accurate! This is another good place to talk about the theoretical power curve versus the observed curve.

Part 1

You have seen that the data collected from your turbine shows you how much power is being produced at different wind speeds. In this activity, you will calculate the amount of power that would theoretically be produced at that wind velocity if all of the wind could be converted to power. How much of that power is your turbine really producing? What is the efficiency of your turbine?

The power in the wind is determined by the following equation:

$$\text{Power (W)} = \frac{1}{2}\rho AV^3$$

Where:

ρ (pronounced "rho") = density of the air

A = area swept by the blades

V = (velocity) wind speed

In the Warm-Up activity, you noticed that more wind equals a lot more power. Look at the equation for power. Can you tell why?

Power depends on the wind speed cubed, making wind speed the single most important factor in determining the power available to a wind turbine. If the wind speed doubles, how much does the power increase?

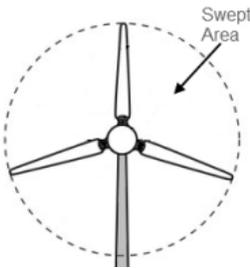
Air density is a variable that cannot be controlled by technology and decreases as elevation increases. The swept area of the blades depends on the length of the turbine blades.

As you see from the equation above, there are several values you need to find or calculate in order to find the power in the wind.

1. The first value that you need to find for this calculation is the air density. This value varies based on temperature, humidity, and importantly for our work, altitude. Altitude is something we need to pay attention to in CO! To get an approximate value for the air density value at your location, go to http://www.engineeringtoolbox.com/standard-atmosphere-d_604.html
Scroll down to U.S. Standard Atmosphere Air Properties in SI Units. Find your altitude to the closest 1000 feet in the first column. Go across to Density (ρ), the fifth column over. The value is listed in 10^{-1} kg/m^3 so move the decimal point one place to the right to convert to kg/m^3 . The standard value at sea level is 1.22. Determine ρ for your location. Record this value in column 4 in your worksheet.

Don't forget that you have just retrieved a value in SI units. Why did you have to collect your wind data in meters per second? Don't forget to collect your other values in the same system.

2. Next calculate the area swept by the turbine.



You can see that this just means the area of the circle inscribed by the blades of the turbine. The formula for the area of a circle and the radius of the circle (remember the 3.7 tells you something) are all you know to figure this out. Record the diameter and radius of your turbine in columns 5 and 6 and the value of the Swept area in column 7 of your chart. Check the Skystream brochure. How close is your value to the one they report in their literature?

<http://www.thebetterplanet.com>

3. Finally, check the wind speed reported in your turbine data and record that in column 8.
4. At the same time you look at the wind speed, record the turbine name, date and time and power produced on the worksheet.(columns 1,2,3 and 11) If you are using data from the CAES website, the turbine updates data every 30 seconds. Watch the data for a couple of minutes and see how it changes. Column 11 is your observed power.
5. Remember that the formula uses wind velocity cubed. Cube your m/s value, enter in column 9.
6. Use the formula $\text{Power (W)} = \frac{1}{2}\rho AV^3$ to calculate the power of the wind passing through the turbine. Record this value in Column 10.
7. Next , look back at the data you wrote down in column 11. How much power is your turbine is actually producing?
Note: If the reference wind speed is less than 8 mph(3.5m/s), the data will be erratic and not very useful. Why?
8. Calculate the efficiency of your turbine or , in other words, what percent of the kinetic power of the wind is it converting to mechanical energy?(Observed power/ calculated power x 100)
9. Let's see if your turbine efficiency is different at different wind speeds. Using the table you made in the first part of this activity, enter the data for each wind speed into the Efficiency worksheet. Calculate the efficiency at different wind speeds and then graph your results using the wind speed as the independent variable and efficiency as the dependent variable.

Part 2 More About Efficiency

As it turns out, no wind turbine is 100% efficient. If it were, it would stop the wind! In 1919, a German physicist named Albert Betz figured out that no wind turbine can convert more than $16/27$ or approximately 59% of the kinetic energy of the wind into mechanical energy. This is called the **Betz Limit**. Therefore, the maximum efficiency of any wind turbine design can be no greater than 59%. You'll find out more about how this works when you work with tip speed ratios in the next lesson.

1. Find 59% of the calculated power of your turbine which will give you the maximum power available given the limitations of physics. (Maximum theoretical power). Enter in column 14.
2. Then calculate what percentage of this maximum power is actually being produced by your turbine. Enter this value in column 15.

The Betz limit is one way to measure an idealized **Coefficient of Power**, or C_p . In the real world, the C_p tells us how well the turbine is actually performing in terms of the percent of kinetic energy being converted to power.

A simpler measure of performance that is often used when studying the performance of wind turbines is the **capacity factor**, or the fraction of the actual power compared to the rated power of the turbine. (See Activity One for the rated power for the Skystream 3.7) If the actual power generated at some wind speed is 10 kW and that the turbine is rated 100 kW (at its rated wind speed), then the capacity factor would be $10/100 = 10\%$. You can check out any of the locations on the Colorado ALP website at http://www.engr.colostate.edu/ALP/ALP_Sites.htm to see the capacity factor for a number of different kinds of turbines. Turbines in the best wind regimes tend to have capacity factors in the 35-45% range.

3. In the Capacity Factor section of your worksheet, calculate the capacity factor at the same wind speeds you used in the previous section.

Explanation/Class Review:

1. How does wind speed affect power production?
2. What did you notice about wind speeds at your turbine site?
3. What variable can be controlled to increase the amount of power converted to electricity?
4. Is your turbine equally efficient at all wind speeds?
5. If no, at which speeds does it function best?
6. If not all of the energy in the wind passing by the turbine is converted to electricity, what happens to the rest of it?
7. Were you surprised at the efficiency of the turbine?
8. What factors do you think effect the efficiency of your turbine?
9. What does the value in column 15 tell you?
10. Does the efficiency of the turbine based on the maximum possible power production change at different wind speeds?
11. What about the capacity factor? Does it vary at different wind speeds? Do you think that this is a useful value to evaluate your turbine?
12. How do you feel about the level of efficiency of your turbine?
13. Given the efficiency of your turbine and the amount of power being produced, make a good argument pro or con for the value of the turbine to your school.

Elaboration/ Extensions

1. We know that wind power has some positive environmental effects. But how does the efficiency of a wind turbine compare to the efficiency of another renewal resource such as solar or hydropower? How does it compare to a plant generating electricity with coal? Do a web search to find out more about the efficiencies of different power generation systems.

If efficiencies are close to the same value, what other factors might help us decide which sources to develop and use?

2. If you enjoy advanced math, some of the References show how the Betz Limit is calculated.

Instructor Notes:

1. You can have students work in group of two to collect data and discuss results.
2. To get wind turbine data, you can get data directly from your school turbine. Convert the text file you get from the SkyView software into an excel spreadsheet. See Appendix B for instructions on how to do this. Or give students the raw data and have them do it. You will need data from a long enough period of time to show a variety of wind speeds to reveal differences in efficiency at different speeds. If your school sends data to the CAES site, students can follow instructions in Appendix C to go download data to get wind speed and power readings from the last week or month. This makes a very long file, so have them scroll through and record samples of data rather than try to print. If your school does not have a turbine, select a school from the Wind for Schools list and use their data following the same directions a school with a turbine would use to access the CAES data. Students may want to look at the Wind for Schools welcome page to find a school that is close to them or that seems to be in a windy area. Hint: Try Kansas!
3. It can't be emphasized too often that real data can be erratic! If the power produced produces and efficiency greater than the Betz Limit, have students scan the data at the same wind speed to see if the value they are using is typical. Gusts of wind produce spikes in reported power that may not be accurate. Find a section where there are 4 or 5 readings at the same wind speed and use the watts value that appears most often. Try comparing data between schools.
4. Remember that all of these sites are using Skystream 3.7 turbines so the measurements are the same. However, to be a bit more precise, have students find the air density for the location they are using if it is not similar to their own.

References/Related Articles

Wind Turbine Power Calculations

http://www.raeng.org.uk/education/diploma/maths/pdf/exemplars_advanced/23_wind_turbine.pdf

Calculation of Wind Power

<http://www.reuk.co.uk/print.php?article=Calculation-of-Wind-Power.htm>

Wind Energy Math

http://www.mmpa.org/Uploaded_Files/ab/ab5c7c5c-79d9-48bd-b64d-833001b7e230.pdf

Colorado Anemometer Loan Program Website

http://www.engr.colostate.edu/ALP/ALP_Sites.htm

