Exploring Wind Turbines

For thousands of years, people have been harnessing wind energy to do work—from traveling around the world on sailing ships to milling grain using windmills. Today, wind is becoming more common as a renewable energy source through the use of wind turbines.

Wind turbines have four basic parts–a tower, turbine blades, a gear box, and a generator–that function together to convert kinetic energy from the wind into electrical energy. As the blades turn, they cause the gear box to turn, via a shaft. The turning gear box causes the generator to turn via a second shaft. The turning of the generator generates electricity.

The amount of electrical power that can be generated by a wind turbine is affected by many variables. In this experiment, you will explore variables that affect how a turbine turns. You will then use data-collection equipment to quantitatively investigate the effect of fan speed on the power output of a wind turbine.

OBJECTIVES

- Explore how wind turbines turn.
- Predict variables that affect how fast a wind turbine turns.
- Investigate the effect of fan speed on the power output of a wind turbine.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Energy
items needed from Advanced Wind Turbine Kit:
  Wind Turbine Tower
  Base
  Nacelle, assembled
  Hex Shaft
  2 Hex Locks
  8-tooth Pinion gear
  32-tooth gear
  Hub
  Blade Pitch Protractor
  2 wires with clips
fan
blade materials
scissors and hot glue
safety goggles

PROCEDURE

Part I Exploring wind turbines qualitatively

In Part I, you will use a fan and a wind turbine to learn more about how wind turbines work. You will make changes to the setup to explore how variables affect the wind turbine and how it turns.

1. Set up the fan and wind turbine.
   a. Assemble the turbine with three blades spaced evenly apart.
   b. Position the fan so the center of the fan is in line with the center of the hub of the turbine. The fan should be about 15 cm from the turbine.
   c. Clear off your area and make sure that when the fan and the turbine are moving, nothing is in the way.
2. Explore: What affects the direction in which a turbine spins?
   a. Put on safety goggles and turn on the fan to its lowest setting. In what direction is the turbine turning? If it is not turning, adjust the blades so that the turbine turns. **Caution**: Do not stand in the plane of rotation of the wind turbine rotor.
   b. Create a plan to make the turbine turn in the opposite direction.
   c. Carry out your plan after it is approved by your instructor.
   d. Were you successful in making the turbine turn in the opposite direction? Explain what you did to make the turbine change direction.
3. Explore: How does fan speed affect turbine speed?
   a. Make a prediction about how fan speed affects how fast the turbine turns. Explain why you think it will have this effect.
   b. Create a plan to investigate how fan speed affects how fast the turbine turns. What are you purposefully changing in this investigation? What will you keep constant?
   c. Carry out your plan after it is approved by your instructor.
   d. What is your conclusion about the relationship between fan speed and turbine speed based on your observations?
4. Explore: How does the distance between the fan and the turbine affect the turbine speed?
   a. Make a prediction about how the distance between the fan and the turbine affects how fast the turbine turns.
   b. Create a plan to investigate how the distance between the fan and the turbine affects how fast the turbine turns. What are you purposefully changing? What will you keep constant?
   c. Carry out your plan after it is approved.
   d. What is your conclusion based on your observations?
5. Explore: What are some additional variables that affect turbine speed?
   a. List at least three other variables that could affect how fast the turbine turns.
   b. Choose one variable and create a plan to investigate the effect of the variable on turbine speed.
   c. Carry out your plan after it is approved.
   d. What are you conclusions based on your observations?

Part II Exploring wind turbines quantitatively

In this part of the experiment, you will add a Vernier Energy Sensor and a Variable Load to the setup. You will explore how wind speed affects the wind turbine, but this time you will measure the electrical power generated.

6. Set the switch on the Energy Sensor to Internal Load. Launch Graphical Analysis. Connect the Energy Sensor to your Chromebook, computer, or mobile device.

7. Set up the equipment (see Figure 1).
   a. Connect the wind turbine to the Energy Sensor Source terminal wires.
   b. Adjust the blades so the turbine is set up with three blades spaced evenly apart and pitched at 30°.
   c. Position the fan so the center of the fan is in line with the center of the hub of the turbine. The fan should be about 15 cm from the turbine.
   d. Clear off your area and make sure that when the fan and the turbine are moving, nothing will be in the way.

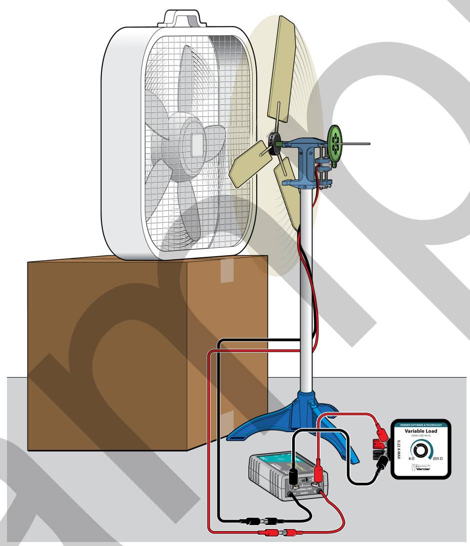

Figure 1

8. Check the current and voltage values.
   a. Put on safety goggles, and then turn on the fan. The wind turbine should be spinning. **Caution**: Do not stand in the plane of rotation of the rotor.
   b. Note whether the current and voltage values are positive, negative, or zero.
   c. Turn the fan off.
   d. The setup is correct if the values are positive. If the values are negative or zero, switch the wires connected to the Source terminal wires so they are connected to the opposite terminal wires.

9. Collect data.
   a. Click or tap Collect to start data collection. Data will be collected for 30 seconds. When data collection is complete, graphs of potential *vs*. time and current *vs*. time are displayed.
   b. Turn off the fan.

c. Click or tap View, , and choose 1 Graph.

d. Tap the y-axis label and select Power only. A graph of power *vs*. time is displayed.

e. Click or tap Graph Tools, , and choose View Statistics to determine the mean power value. Record the value in the data table.

10. Collect additional data and determine the mean power.
    a. Turn the fan to the next setting. Wait 30 seconds, or until the fan and the turbine blades reach a constant speed.
    b. Click or tap Collect to start data collection.
    c. When data collection is complete, turn off the fan. Click or tap Graph Tools, , and choose View Statistics to determine the mean power value. Record the value in the data table.

11. If your fan has more than two settings, repeat data collection and analysis once more, for a total of three trials.

DATA TABLE

Fan setting	Power (mW)

DATA ANALYSIS

1. Create a graph of power *vs*. fan setting.

2. Write a statement that describes the relationship between fan setting and power output of the wind turbine.

EXTENSION

Using the list of variables that you created in Part I, choose one and design an experiment to measure the effect of the variable on the power output of the turbine. Have your experimental design approved by your instructor before testing your prediction.

Exploring Wind Turbines

In this experiment, students are introduced to wind turbines. They begin with a qualitative examination, exploring how different variables affect how the wind turbine spins. In the second part of the experiment, students quantitatively measure how fan speed affects the power output of the wind turbine using data-collection equipment.

In the Electronic Resources you will find multiple versions of each student experiment—one for each supported data-collection program (Graphical Analysis 4, Logger *Pro*, or LabQuest App). Deliver to your students the version that supports the software and hardware they will use. Sign in to your account at **www.vernier.com/account** to access the Electronic Resources. See Appendix A for more information. **Note**: The printed book and the PDF of the entire book (found in the Electronic Resources) include only the Graphical Analysis (Go Direct sensors) versions of the experiments.

RELATED SKILLS

- Zero sensors, if using the Vernier Energy Sensor.
- Use the Statistics tool in the data-collection app to calculate statistics.
- Create a graph from data collected during data collection.
- Change what is plotted on the graphs.

ESTIMATED TIME

We estimate that data collection and analysis can be completed in one 45-minute class period. You may want to limit the number of variables that are investigated in Part I or assign groups to a variable.

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking questions and defining problems Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations and designing solutions Engaging in argument from evidence	PS3.A Definitions of Energy (HS-PS3) PS3.B Conservation of Energy and Energy Transfer (HS-PS3)	Patterns Cause and effect Scale, proportion, and quantity Systems and system models Energy and matter

EQUIPMENT TIPS

1. Set up a safe testing area.
   - Clear the area of debris and materials.
   - Instruct your students to not stand in the plane of rotation of the turbine blades. Also tell them that they should not touch the blades while they are spinning. Blades can be moving very fast and can hurt if they hit someone.
   - Provide safety goggles for your students. Students should wear safety goggles when they are working with a turbine that is spinning.
2. Assemble the wind turbine towers in advance, if they are not already assembled. The video found at **https://vimeo.com/114691934** shows how to assemble the tower, nacelle, and generator mounting.
3. This experiment was designed using a KidWind Advanced Wind Turbine and three blades. Any of the classroom KidWind wind turbines will work for this experiment, as they all use a DC motor for a generator. Different generators will produce different power levels and may have a different internal resistance.
4. This experiment was designed using an energy sensor. It may also be done with a current probe and a voltage probe; students will need to create a calculated column in the data-collection app to calculate power. For more information, see **www.vernier.com/til/3184**
5. If you do not have a Vernier Variable Load, you can perform this experiment using the Vernier Resistor Board (order code: VES-RB). Otherwise, students can build a circuit to create the appropriate resistance value.
6. A classroom set of blades that are known to give good results will be helpful for this experiment. Blades that start near the hub of the wind turbine work well. For best results, the radius of the wind turbine should not exceed the radius of the fan. See Appendix B for additional tips about designing blades.

DATA-COLLECTION AND ANALYSIS TIP

For Part I, give students time to explore their wind turbine before giving them the answer.

SAMPLE RESULTS

Fan setting	Power (mW)
High	50.87
Medium	27.65
Low	10.30

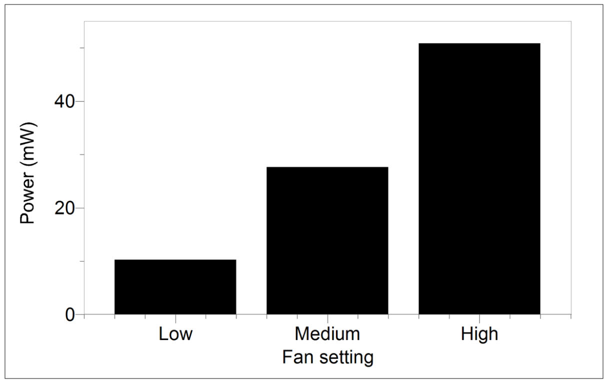

Figure 1 Power output levels for different fan settings

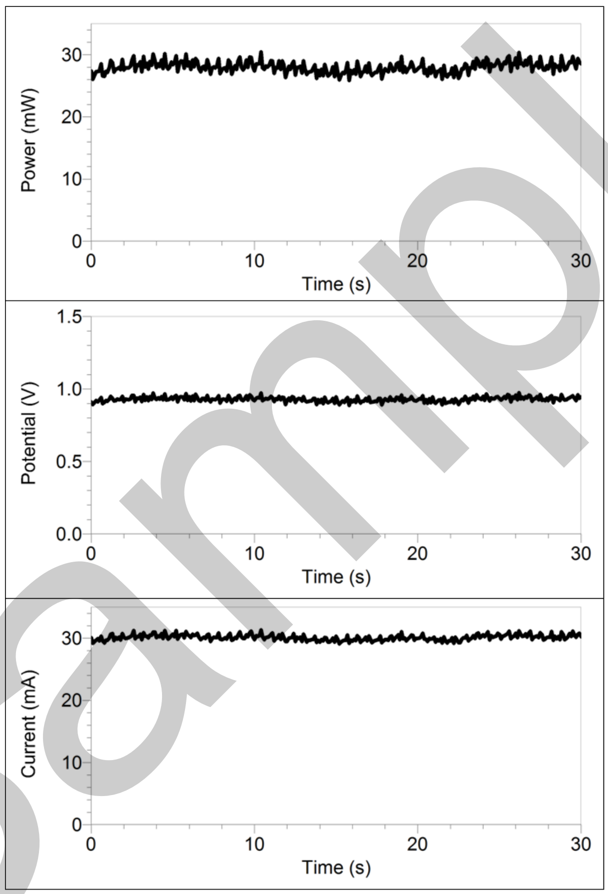

Figure 2 Raw data for a fan set to the medium setting

ANSWERS TO ANALYSIS QUESTIONS

1. See Sample Results.
2. The higher the fan setting, the greater the power production.