Wind Power

Subject Area(s) number & operations, data analysis and probability, measurement, physical science, science and technology

Associated Unit Clean Energy

Lesson Title Introduction to Wind Power

Grade Level 11 (9-12)

Lesson # 3 of 5

Lesson Dependency Clean Energy and Energy, Power, and Electricity

Time Required 250 minutes including associated activities

Summary
Students learn the theory behind wind power, then build, test, and optimize their wind turbines for maximum power output.

Engineering Connection
Engineering is not only about creation; engineering is about creation of useful solutions that meet the urgent needs of a population and are optimized for efficiency and affordability. Wind power is one of the great engineering challenges of our time. Mechanical, electrical, and environmental engineers are working on making wind power more reliable, safe, powerful, and affordable. In this lesson we will learn the fundamental theory behind wind power. We will then use our knowledge of wind power and optimization to produce the maximum power possible from hand-made wind turbines.

Engineering Category
Engineering analysis or partial design
Keywords
power, electricity, wind, flow, fluid dynamics, kinetic energy, Ohm’s Law, turbine, generator

Educational Standards

Colorado State Science (from jesandco.net):
• 1.5.2: Use appropriate measurements, equations and graphs to gather, analyze, and interpret data on the quantity of energy in a system or an object.
• 1.5.4: Identify different energy forms, and calculate their amounts by measuring their defining characteristics.
• 1.8.1: Gather, analyze, and interpret data to describe the different forms of energy and energy transfer
• 1.15.4: Measure mass and volume, and use these quantities to calculate density.
• 1.17.2: Show that electricity in circuits requires a complete loop through which current can pass.
• 1.17.3: Describe the energy transformation that takes place in electrical circuits where light, heat, sound, and magnetic effects are produced

Colorado State Math (from jesandco.net):
• 3.16.1: Construct picture graphs and bar graphs from a data set
• 3.16.2: Read and explain information in picture graphs and bar graphs
• 4.1.3: Solve for unknown quantities in relationships involving perimeter, area, surface area, and volume

ITEEA:
• ITEEA, Standard 2, Grades 9-12, BB. Optimization is an ongoing process or methodology of designing or making a product and is dependent on criteria and constraints.
• ITEEA, Standard 1, Grades 9-12, M. Most development of technologies these days is driven by the profit motive and the market.

Pre-Requisite Knowledge
Aptitude with relationships between area, height, and volume. Intermediate skill with manipulation of algebraic equations including squares, cubes, and multiple variables. Knowledge of electrical measures such as voltage, current, and resistance. The ability to manipulate Ohm's Law. Experience with plotting scatter data and making these data into line graphs. Knowledge of how to safely use tools such as hot glue guns and scissors.

Learning Objectives
After this lesson, students will be able to:
• Define the three primary components of a wind turbine: blades, nacelle, and tower
• Explain the process of energy conversion that occurs in a wind turbine
• Calculate the kinetic energy in a column of air with a given volume, mass, velocity, area, and length
• Construct a model wind turbine using a KidWind turbine kit
• Use a wind anemometer to compute the theoretic power that could be generated by a wind turbine from a column of wind
• Use a multimeter to measure resistance of a resistor
• Use a multimeter to measure voltage across a resistor
• Use Ohm's Law and the power law of electricity to determine the power dissipated in the resistor
• Plot wind turbine power output vs. several different turbine configurations
• Analyze power vs. configuration graph to determine optimal turbine configuration

Introduction / Motivation

[Play DailyShow clip about Cape Wind]

What is wind power, and why are we looking at it as a source of renewable energy? When we talk about wind power, we are really talking about the power of moving molecules of air. The energy contained within a body in motion is called kinetic energy. Using a wind turbine, we can convert the kinetic energy of the wind into mechanical and then, finally, electrical energy.

Wind power is one of the great engineering challenges of our time. Today, wind power exists, but it is still too expensive, too unreliable, and creates too little power to make a dramatic impact on fossil fuel consumption or climate change. If you chose to be an engineer, wind energy could be one of the great challenges that you chose to tackle. All kinds of engineers are needed to make this happen: mechanical engineers to design turbine blades and towers, electrical engineers to design efficient generators, industrial engineers to design faster and more efficient manufacturing processes, and environmental engineers to determine the most effective and safest places to put wind turbines. Which challenge will you chose?

Lesson Background & Concepts for Teachers

Electricity Production: There are three primary methods of producing electricity:

• **Passing a magnetic field over a coil of wire or vice versa:** this is by far the most commonly utilized method for producing electricity. This technique exploits Faraday's Law of Induction to induce an electromotive force (EMF), and hence a current, in a closed loop system. In order to get this effect, we typically turn a magnetic shaft (rotor) inside a coiled wire "cage" (stator). However, in order to get mechanical rotation of the shaft, we must have some sort of energy source. Coal, nuclear, or solar thermal power can be used to boil water to turn a turbine, or, likewise, wind or water flow can be used to turn a turbine. See Lesson 3: Production of Electricity and Motor Theory

• **Solar photovoltaic:** we utilize the power of the sun to "knock loose" electrons from doped silicon in a transistor. We then harness those electrons to do useful work.

• **Fuel cells:** we harness the free electron released when hydrogen has combines with oxygen gas to do useful work.

Wind Power: Power is a way of measuring how much energy is being produced/used in a given time and can be described by the equation \( P = \frac{E}{t} \) where \( P \) is power, \( E \) is energy, and \( t \) is time. Wind power is defined generally as the rate of kinetic energy that can be supplied by the movement of molecules in air. Colloquially, we define wind power as electricity derived from the kinetic energy of the wind.

A wind turbine is the most common tool utilized to turn the kinetic energy of the wind into electrical energy. The term "wind turbine" is often confused with the term "wind mill." Wind
mills are typically antiquated technologies pioneered in the Denmark and the Netherlands used to grind or "mill" grain. Wind turbines, by contrast, are typically used to create electricity from the wind. A wind turbine is made up of three components

- **Blades:** usually three blades ranging from 1 to over 100 meters in diameter
- **Nacelle:** this "box" behind the blades contains the wind turbine's instrumentation cluster, gear box, and generator. Most nacelles are designed to yaw so that the plane of the blades will be incident (orthogonal) to the direction of the wind
- **Tower:** the tower is designed to raise the turbine's blades above the slow and turbulent (ineffective) wind flow near the ground.

In order to derive the equation describing the power of the wind (the available power to a turbine), let's consider a cylindrical column of moving (windy) air. This column is Δx long, r radius, has a density ρ, and moving at a velocity v:

![Cylindrical Column Diagram]

We can derive the kinetic energy of this column of moving air as follows

\[ E = \frac{1}{2} m v^2 = \frac{1}{2} \rho V v^2 = \frac{1}{2} \rho \pi r^2 \Delta x v^2 \]

We know that power is the time rate change of energy (ie P=E/Δt). Therefore:

\[ \frac{E}{\Delta t} = P = \frac{1}{2} \rho \pi r^2 \left( \frac{\Delta x v^2}{\Delta t} \right) = \frac{1}{2} \rho \pi r^2 \left( \frac{\Delta x}{\Delta t} \right) v^2 \]

We know that velocity is the time rate change of position (ie v=Δx/Δt). Therefore:

\[ P = \frac{1}{2} \rho \pi r^2 v^3 \]

This is the basic power equation limiting the power that a 100% efficient wind turbine could extract from the wind. However, no system is 100% efficient. Therefore, we must have a system for describing inefficiencies.

**Efficiency:** no energy conversion process is 100% efficient. Hence, we seek to quantify how efficient our particular system is. As an engineer, it is important not only to optimize your system, but to understand how your optimized system holds up against the “ideal.” The comparison of your system’s performance to the “ideal” is called efficiency and is symbolized with the Greek letter eta: η

\[ \eta = \frac{P_{\text{actual}}}{P_{\text{ideal}}} \]

For a wind turbine, the ideal power is \( P_{\text{ideal}} = \frac{1}{2} \rho \pi r^2 \cdot v^3 \)

**Ohm’s Law:** Ohm’s Law describes the relationship between voltage current and resistance as takes the form (V=IR). Given two of the three variables, the unknown can be solved for.

**The Power Equation:** the power of an electric current over some voltage gradient can be derived as \( P = VI \)
Derivation of other forms of the power equation: combining Ohm's Law and the power equation:

\[ V = IR \]
\[ P = VI \]
\[ P = \frac{VV}{R} = \frac{V^2}{R} \]
\[ P = IRI = I^2R \]

We will utilize the relationship \( P=\frac{V^2}{R} \) to measure the power across a load resistor.

### Vocabulary / Definitions

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
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<tbody>
<tr>
<td>turbine</td>
<td>Any machine that converts kinetic energy into mechanical (rotational) energy.</td>
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<tr>
<td>generator</td>
<td>Any machine that converts mechanical energy into electrical energy.</td>
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<tr>
<td>wind mill</td>
<td>A machine that uses the wind's energy to mill grain.</td>
</tr>
<tr>
<td>wind turbine</td>
<td>A machine that uses the wind's energy to create electricity.</td>
</tr>
<tr>
<td>nacelle</td>
<td>The &quot;box&quot; behind a wind turbine's blades contains the wind turbine's instrumentation cluster, gear box, and generator.</td>
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<tr>
<td>multimeter</td>
<td>An instrument that can measure useful electrical quantities such as voltage, current, resistance.</td>
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<tr>
<td>breadboard</td>
<td>A device that allows one to connect wires without soldering.</td>
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<tr>
<td>Ohm’s Law</td>
<td>Ohm’s Law is the equation ( V=IR ) and relates voltage, current, and resistance in simple circuits.</td>
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<tr>
<td>Faraday's Law of Induction</td>
<td>This law states that when a changing magnetic flux passes through a coil of wire, a voltage will be induced across that wire.</td>
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### Associated Activities

Wind Turbine Activity

### Lesson Closure

Wind power is one of the most promising forms of renewable energy. Wind is abundant, free, and will never run out. However, producing wind energy is expensive when compared with coal technologies. Additionally, some people are concerned about the noise, aesthetics, and environmental impacts of wind energy.

Therefore, it is critical that we extract the maximum possible power from every turbine that we build. As young engineers, the work you have done today is not unlike what a real engineer working for a turbine manufacturer like General Electric, Vestas, or Siemens. These engineers work every day to make the world cleaner and more sustainable by optimizing wind turbines to generate as much electricity as possible!
Assessment

Pres-Lesson Assessment:
Small Group Discussion: Ask students to discuss the following questions in small groups and present their answer on one question to the class:
- What is wind energy?
- How do we get electricity from the wind?
- What are three important things to consider when building a wind turbine?

Post-Introduction Assessment:
Class Observation: Interaction with students building, testing, and optimizing turbines will confirm whether students have learned how to use multimeters, bread boards, and Ohm's law to determine the turbine's power and efficiency.

Lesson Summary Assessment:
Report: Students will create a one page report on their miniature wind turbine, its power output, and what techniques were (and could) be used to increase power output.

Self Assessment:
Skeleton Notes: Students will fill out the “Introduction to Wind Power” skeleton notes as well as construct, test, and optimize their own miniature wind turbine.

Homework: None suggested

Lesson Extension Activities

None

Additional Multimedia Support
http://www1.eere.energy.gov/windandhydro/wind_how.html

References
None

Attachments
Wind Power Presentation(ppt)
Wind Power Presentation (pdf)
Wind Power Skeleton Notes and Worksheets (doc)
Wind Power Skeleton Notes and Worksheets (pdf)
Wind Turbine Activity (doc)
Wind Turbine Activity (pdf)
Wind Power Image, Figure, & Table Descriptions (doc)
Wind Power Image, Figure, & Table Descriptions (pdf)
Wind Power Summary (doc)
Wind Power Summary (pdf)

Other
None

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