Lesson Title	Power Factor
Length of Lesson	120 minutes
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Subject	Physics
Grade Level	12
State Standards	Physics: 1d and 5a
DOK Level	DOK 4
DOK Application	Analyze, Draw Conclusions, and Develop a Logical Argument
National Standards	Physics B
Graduate Research Element	Circuit analysis and design.

Student Learning Goal:

Mississippi Standards:
Physics: 1d. Organize data to construct graphs (e.g., plotting points, labeling x-and y-axis, creating appropriate titles and legends for circle, bar, and line graphs) draw conclusions and make inferences.
Physics: 5a. Analyze and explain the relationship between electricity and magnetism.

- Characteristics of static charge and how a static charge is generated
- Electric fields, electric potential, current, voltage and resistance as related to Ohm's Law
- Magnetic poles, magnetic flux and field, Ampere's law and Faraday's law
- Coulomb's Law

National Standards:
Physics:
In some materials, such as metals, electrons flow easily, whereas in insulating materials such as glass they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures some materials become super conductors and offer no resistance to the flow of electrons.

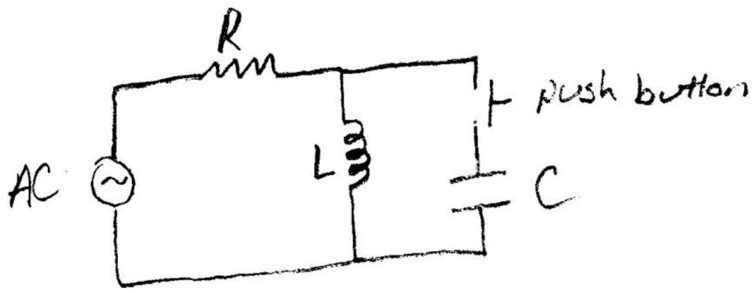
Materials Needed (supplies, hand-outs, resources):

- Resistors
- Capacitors
- Inductors
- Oscilloscope
- Function Generator
- Power Point
- Internet

Lesson Performance Task/Assessment:
The students will take the roll of consultants and try to convince a customer to buy their solution to the customer's power factor problem over their competition's solution.

Lesson Relevance to Performance Task and Students:
In order to do well in the performance task, the students will need to be able to compute power factor and explain it to a typical business person.

Anticipatory Set/Capture Interest:
I did a cool demonstration of how phase is affected by capacitance and inductance. You can build the circuit by following this diagram.



You can determine values for R, L, and C as you see fit. The oscilloscope will be attached with one probe measuring the voltage of the AC source and the other measuring the voltage of the resistor. The voltage of the resistor is used to compute the current using Ohm's Law since the resistor is know. When the circuit is hooked up to the AC source, it will be apparent that the voltage and the current will be out of phase. By pushing the button, the capacitor will be added into the circuit, which will change the phase. Since the lesson is on power factor correction, it will be helpful to choose a value for C that puts the circuit into phase, but it is not completely necessary.

Guided Practice:
The students need to know how to compute the impedance of a circuit to do this lesson. If they don't know how to do this, I suggest you go over the lesson called "Sinusoidal Steady State Analysis."

When a business's power circuits cause the voltage and the current to be out of phase, the power company typically charges the business a penalty fee because it increases the costs to the power company more than the cost of the power consumed. A good explanation of this is given by Wikipedia at http://en.wikipedia.org/wiki/Power_factor. You don't have to look at everything on the page, but the illustrations showing the graphs of power with the current and voltage are very nice. They show that as the current and voltage are moved out of phase, the average power, which the power company charges by, decreases even though the voltage and current are constant. The problem is that even though the power consumed decreases, the current is still moving back-and-forth through their system and the power distribution system, which dissipates power in the form of heat. (Remember, the power lines are like resistors with a low resistance value.) This is because power is computed using the equation

$$P = IV. \tag{1}$$

When the voltage and the current are in phase, power is always greater than or equal to zero since voltage and current are always either both positive, or both negative. When the voltage and the current are out of phase, the power plot goes negative for a portion of its period. This means the power meter will be running backwards for part of the time since it is integrating the power curve. Typically in power systems, the voltage and current get out of phase because of the presence of inductors, such as in electric motors.

In the assignment, the students will need to compute the impedance of the circuit, which is the frequency equivalent to the resistance of the circuit. Since impedance and resistance are equivalent, we can substitute impedance for resistance in the equations for Ohm's Law and power.

$$V = IZ \tag{2}$$

$$P = IV \tag{3}$$

By substituting for I and V, we get the next two equations.

$$P = \frac{V^2}{Z} \tag{4}$$

$$P = I^2 Z \tag{5}$$

Since Z typically has an imaginary component, the power also has an imaginary component. The ideal in power factor correction is to get the imaginary part to go away by putting a capacitor (in the case of an inductive load) or inductor (in the case of a capacitive load) in parallel with the load impedance. See the notes with this lesson for an example of how to do this.

Independent Practice:
For the independent practice, the students will break into groups, and roll play as consultants to a sawmill that is having serious problems with power factor. The details for several months of the sawmill's power bills can be found at http://www.ewh.ieee.org/r3/nashville/events/2009/2009.08.04.2.pdf. I am placing this file with the lesson plan in case the file is ever removed. The students will be getting the data from case study 3 (pp. 13-15). In the table on page 14, there are columns labeled KW, KVAR, and KVA. "KW" means kilo-watts, and it is the real component of the power (aka. "real power"). "KVAR" means kilo-volt-amps reactive, and it is the imaginary component of the power (aka. "reactive power" or "imaginary power"). "KVA" means kilo-volt-amps, and is the magnitude, or hypotenuse, of the power (aka. "apparent power"). The column that is labeled "Energy Charge + Customer Charge" is the amount the sawmill would be charged if they did not have the power factor problem, and the "Billed Demand Charge" is the penalty for the power factor. As you can see in the bill,

most of their charges were due to power factor penalties. Power factor is simple to calculate from the information given. It is the real power divided by the apparent power.

$$Power\ Factor = \frac{Real\ Power}{Apparent\ Power} \quad (6)$$

In the case study, the sawmill used three phase power, but in order to make calculations easier, I told the students to assume the sawmill used one phase power (that is 120 Volts amplitude at 60 Hz). From this information and the information in the table, they can compute the impedance and the capacitance needed to fix the power factor problem. (We know that this is an inductive load because the saw motors are basically inductors, so the reactive power is negative.)

$$P = KW - KVARj \quad (7)$$

(Electrical engineers use "j" instead of "i" to indicate imaginary numbers.) The students will need to solve for Z in the following equation.

$$P = KW - KVARj = \frac{V^2}{Z} = \frac{120^2}{Z} \quad (8)$$

The students will compute the capacitance needed to balance this circuit and then find prices for the capacitors needed to fix this problem on the Internet. They need to pay close attention to the voltage requirements. Otherwise they will blow the capacitors. After this, they need to prepare a presentation for a non-technical group of instructors who will represent the sawmill owners. This group will decide which students made the best presentation, and those students will get a reward. The students can use any technique they think will help them in their presentation **except lying**. If they do this, the teacher will point it out to the "owners," which probably hurts their chances of winning. I gave them some ideas about what the owners might want to hear, but they can do other things if they want. Examples of what the owners might like to see are:

- How much capacitance/inductance do they need?
- What is the cost?
- How long will it take to recover the costs of the upgrade?
- How much physical space does it take up?
- Why should they buy your product over anyone else's?
    - Handouts and other marketing techniques might help here.

Remediation and/or Enrichment:
Enrichment: Have them build a circuit and test it.

Remediation: individual IEP; partner help throughout the lesson; the teacher can observe the students and intervene during the independent practice.

Check(s) for Understanding:
During the lab, the teacher can walk around and observe the students. If some of the students appear to not understand how the equipment works or what they are expected to do, ask them some leading questions.

Closure:

Closure is the presentations they make and the rewards for the best students.

Possible Alternate Subject Integrations:
Math

Teacher Notes:
See other file. There are lots of files.
Other source:
http://www.energyideas.org/documents/factsheets/reducing_pwr.pdf

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