

Interactive Lessons for Pre-University Power Education

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Abstract—A key need facing the electric power industry is the ongoing requirement to develop its future workforce. While university education is a crucial step in this process, studies have shown that many promising students are unaware of possible careers in the power industry. Many also lose interest in math and science during their high school and even middle school years. This paper presents lesson plans and associated applets designed to help address these needs, developed as a collaboration between electric power researchers and education specialists. Thus far, two units have been developed to engage pre-university students in the power area. The first unit, *Power and Energy in the Home*, serves as an introduction to the concepts of power and energy and provides many sample loads to illustrate the impacts of running different appliances. Special attention is paid to environmental issues by the inclusion of Energy Star appliances along with incandescent and compact fluorescent lighting. The second unit, titled *The Power Grid*, aims to inform students about the macroscopic picture of how energy gets from generators to loads. Many different generation technologies are included, along with external system connections to demonstrate how power is imported and exported. Discussion of line overloading, and how networks can be both beneficial and detrimental depending on circumstances, are facilitated by features built into the applet and provided in the lesson plans. The materials have been distributed to students and educators, many of whom have provided valuable feedback.

Index Terms—Educational technology, energy conservation, energy resources, load flow analysis, power engineering education, power systems.

I. INTRODUCTION

As noted in [1], there is a clear need for increasing interest in math and science, particularly in the power industry—“...in high school, or even grade school...”—in order to meet the future demand for electricity industry workers. One of the key reasons for this need is the aging of the power industry workforce, where 40% of senior electrical engineers and 43% of shift supervisors will be eligible for retirement in 2009 [2]. In addition to the specific needs within the power industry, stimulating pre-university students’ interest in mathematics and science is necessary in order for the United States to maintain its competitiveness in the future [3], [4].

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There has been little concerted effort towards bringing power system education to K-12 students—on the one hand, research into power system education has focused primarily on university students [5]–[7], while on the other hand, electrical engineering curricula aimed at K-12 students tends to focus on dc circuits and digital electronics. For example, IEEE’s collection of educational material for pre-university education [8] has no information on power systems. There has been some work in creating energy resource materials for teachers at the K-12 level. Many power providers and governmental agencies offer resources to teachers and students, and the National Energy Education Development Project [9] has developed some informational guides, but there is little available in the form of interactive, technically meaningful activities.

The work presented here is a result of efforts to develop technically sound, interactive, high-interest materials aimed at pre-university students. These materials are available at <http://www.tcip.mste.uiuc.edu/>. The development of the applets and lesson plans has been a consistent collaboration between electric power researchers and education specialists with decades of classroom experience. This collaboration has brought significant insight into how best to present power system concepts at the pre-university level. Also, by working closely with educators familiar with both interactive applets and national educational standards, we have been able to leverage the expertise developed in numerous past projects. Finally, we are able to take advantage of contacts between education researchers and local schools and conferences to accelerate dissemination and awareness of our materials.

II. INTEGRATION WITH NATIONAL CURRICULUM STANDARDS

For materials to be useful in the classroom environment, it is essential that they are aligned to national standards for technology, mathematics, and science. In the area of technology education, national standards call for teachers to “use content-specific tools, software, and simulations” including “exploratory environments” [10]. Because the lessons specifically target power system concepts, they clearly meet the first goal of content specificity. Secondly, by allowing students to control real-time simulations with a simple point-and-click interface, students are encouraged to explore how changes in system loading and topology affect system operations in real-time.

The National Council of Teachers of Mathematics (NCTM) includes technology as one of its principles for school mathematics [11]. The importance of interactive applets to NCTM is further evidenced by their own extensive set of web applets used to teach key mathematics concepts [12]. In addition to the technology principle, the lessons that accompany the applets address grade level appropriate expectations for NCTM’s content standards. Appendix A provides tables outlining how each of

the educational objectives met by the lessons maps to NCTM's standards.

National science education standards encourage students to work on problems of technological design in "contexts that are immediately familiar in the homes, school, and immediate community" [13]. The lessons address home and community energy usage and distribution, which are familiar contexts for students and challenge them to consider the complex interactions between power and energy supply and demand. In addition, Appendix B provides tables in which the educational objectives associated with the lessons are mapped to standards in pre-university science education.

In order to best present the correlations to these standards in technology, mathematics, and science, and to encourage teachers to use our materials in the classroom, a series of lesson plans accompany each applet. Each lesson begins with a page for teachers explaining the important features of the applet for the lesson and instructions on how to guide students through the associated worksheets. Additional resources are also included where teachers can obtain more background information on the concepts being taught. One of these pages is shown in Fig. 1. Associated with each page for teachers, there is a page for students to use in exploring the applet. Each student page consists of exercises for the student to perform while interacting with the applet and includes substantial background information that is not covered within the applets. Currently, there are seven individual lessons for students and teachers to use with the interactive applets. The particular power system concepts covered in each of the lessons are detailed in the following section.

III. LESSON DESCRIPTIONS

A. Advantages and Disadvantages of Interactive Lessons

While there are many ways to teach students about power concepts, this combination of detailed lesson plans and interactive applets is exceptional for several reasons. First, including interactive, open-ended materials encourages students to explore the different processes at work in power systems. For a generation that is accustomed to highly interactive media such as the Internet and video games, this is a natural fit. In fact, a recent study of university freshmen and seniors found that 53.3% of the respondents like to learn through video games and simulations, compared to 31.6% who say that they do not like to learn using these novel teaching tools [14]. Secondly, the success of interactive materials in helping students to understand concepts from statistics [15], calculus [16], and physics [17] indicate that applets can serve as an excellent teaching tool. The most often cited reason for the success of interactive applications is that they encourage students to explore and formulate their own understanding of key concepts.

The inclusion of lesson plans is also important in providing teachers and students with useful materials for learning about power systems. It has been shown in several studies that teacher guidance in using computer-based materials has a positive impact in the education of students [18], [19]. The lesson plans allow teachers to provide this guidance to students using the applets. In addition, the lesson plans allow teachers, particularly those with little to no preexisting knowledge of power systems, to effectively answer students' questions or guide them through a thorough exploration of the applets. Finally, the up-to-date ref-

Power and Energy in the Home Lesson 1

This lesson uses the applet at <http://tcip.mste.uiuc.edu/applet1.html>

The applet shows power flowing through the transformer drum, the kilowatt-hour meter and into the circuit breaker panel. From the panel it powers various appliances including video game consoles, kitchen appliances, and light bulbs.

When the applet opens time is passing and the kWh meter is running. The meter shows the energy used since time started and the cost of that energy at \$.10 per kWh.

Elapsed time (hours and minutes) and Current power consumed are displayed near the bottom of the pole. Remind students that energy use and cost are determined by the amount of power used and the amount of time it's used.

The applet window can be scrolled and resized or it can be opened in it's own window for better viewing.

Encourage students to explore the applet. There are blue switches to click with your mouse. Choose appliances from the drop down menus and see the flow of power increase and decrease. Use your mouse to click the blue switches near the appliances. These switches act like the circuit breaker switches in the circuit breaker panel. In your home, however, one circuit breaker switch may control the flow of electricity to an entire room of appliances. When you click open the blue switch nearest the transformer all of the power stops flowing. Students can explore various combinations of appliances with opened and closed switches and view the changes in Current power consumed, the meter readings and in the arrow sizes.

More Resources

- Home Energy Saver <http://hes.lbl.gov/>
- A Consumer's Guide to Energy Efficiency and Renewable Energy http://www.eere.energy.gov/consumer/your_home/appliances/index.cfm/mytopic=10040
- Energy Savers Website <http://www.eere.energy.gov/redirects/consumerinfo.html>
- Energy Information Administration's Energy Kid's Page <http://www.eia.doe.gov/kids/index.html>

Fig. 1. Example teacher page from lesson plans for power and energy in the home.

erences to resources in the teacher guides enable even further exploration and discussion of the concepts introduced by the applets.

B. Technical Background

In developing the interactive applets, well-tested programming platforms and libraries were used. As the use of the term "applet" suggests, the Java programming language [15] was used for this project. Java was chosen for several reasons. The biggest benefit derives from Java's "write once, run anywhere" architecture; because of this language design, the applets run on the most popular operating systems, such as OS X, Windows, and Linux, without any extra programming effort. This is particularly important in the K-12 environment, where the choice of operating systems is extremely varied. Another key benefit of using Java is that the applets can be embedded inside web pages and are then accessible from any modern web browser. This is extremely important when updates are made to the applets—the new version is simply uploaded to the web server, making deployment a single-step process masked from the end user. Finally, because Java is a well-established programming language, there are many software libraries available which make applet development much easier. The two key software libraries used for the applets, JAMA [21] and JFreeChart [22], allow for easy integration of matrices and plots, respectively, into the applets.

C. Power and Energy in the Home Unit

1) *Technical and Operational Description:* The first applet, pictured in Fig. 2, is aimed at teaching students about power and

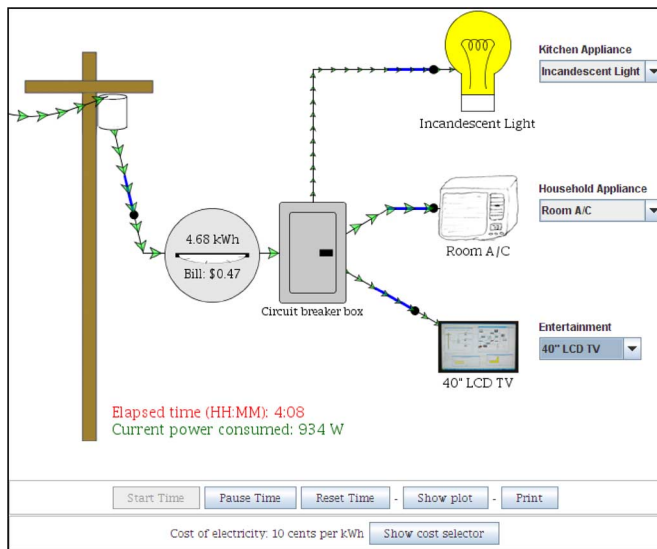


Fig. 2. Primary interface for the Power and Energy in the Home applet, accessible at <http://www.tcip.mste.uiuc.edu/applet1.html>.

energy in the context of their homes. To achieve this goal, the applet was designed with a straightforward interface. Lines connect from a transformer, through a meter, to the circuit breaker box, then to three selectable load slots. Students are able to select from many different loads, grouped into three categories: kitchen, household, and entertainment. Clickable switches are included on all lines to allow students to interrupt power flow on the lines.

Built into the interface are two key concepts from power engineering—the idea of power flow (represented by the animated motion of arrows in the direction of power flow) and the usage of one-line diagrams. By introducing these concepts in the context of home power usage, students are then able to interpret the more complex diagrams typically used to display power systems (e.g., the more complex power system display in the Power Grid unit).

2) *Educational Objectives:* The Power and Energy in the Home unit addresses these objectives:

- Energy is delivered from the distribution network to the various loads throughout the home.
- Different electrical loads vary greatly in their power demands.
- Energy is power used over a period of time.
- Energy is metered and priced over time in units of kilowatt-hours.
- Energy (and money) can be conserved by using more energy-efficient loads.

3) *Meeting the Educational Objectives:* The applet was designed to explicitly meet each of the enumerated objectives, as detailed below:

- As shown in Fig. 2, the applet shows the transformer drum, circuit breaker, and loads in a clear manner. Furthermore, the lines connecting these devices, along with the animated flow arrows showing the direction of energy flow, clearly show how energy is delivered from the distribution grid to electrical loads in the home.
- A total of 24 distinct loads are provided, with power ratings ranging from 17 W for a Nintendo Wii to 4500 W for a hot water heater. By including a wide range of popular

household loads, our hope is that students gain an appreciation for the extremely varied power demands of various loads within the home.

- To dispel any confusion between the concepts of power and energy, substantial information about the relationship between these two concepts is included in both the applet and the associated lesson plans. On the applet itself, there is an analog kWh meter, which spins with a speed proportional to the current power demand and keeps a running total of energy consumption. At the same time, the “Current power consumed” text field gives a numerical value for the current power demanded from the distribution network. Additionally, a pop-up plot window, opened by clicking on the “Show Plot” button within the main applet window and shown in Fig. 3, graphically shows the relationship between the two concepts, with the y-axis representing power demand, the x-axis representing time, and the shaded area under the curve representing energy consumption. In addition, the lesson dealing with energy conservation demonstrates that the amount of energy consumed is a function of both time and the amount of power the load demands.
- The electricity meter between the transformer and the circuit breaker panel provides a running total of the energy consumed and the cost of this energy. This feature allows students to better understand that they are charged for power usage over time, rather than the instantaneous power consumption. Students can also modify the cost of electricity within the applet using the cost selector (opened by clicking the “Show cost selector” button within the main applet window and illustrated in Fig. 4). As a result, students could approximate their own power bill with the correct combination of loads, the amount of time each load is on, and the designated price of electricity.
- Both Energy Star [23] and non-Energy Star versions of the following loads are included:
 - dishwasher;
 - refrigerator;
 - ceiling fan;
 - air conditioner;
 - clothes washer.

By including Energy Star and non-Energy Star devices, students can clearly see the energy and cost savings associated with moving to Energy Star appliances within the household. An additional lesson compares the energy usage of incandescent and compact fluorescent lighting, both of which are included as selectable loads within the applet.

D. Power Grid Unit

1) *Technical and Operational Description:* Building on the interface used in the Power and Energy in the Home unit, the applet used with the Power Grid unit (see Fig. 5) takes a more macroscopic view of the power system. As in the first applet, each of the lines in the system has a switch which can be opened or closed by clicking on it. The actual power system, however, is much more complex in the second applet. There are 16 buses in the system model of the Power Grid applet; six of the buses are substations, two are external system connections, and the

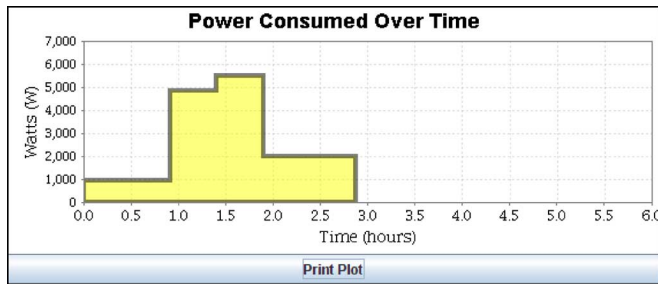


Fig. 3. Plot window for the power and energy in the home applet showing how power and energy are related.

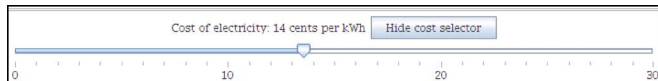


Fig. 4. Electricity cost selector for the power and energy in the home applet.

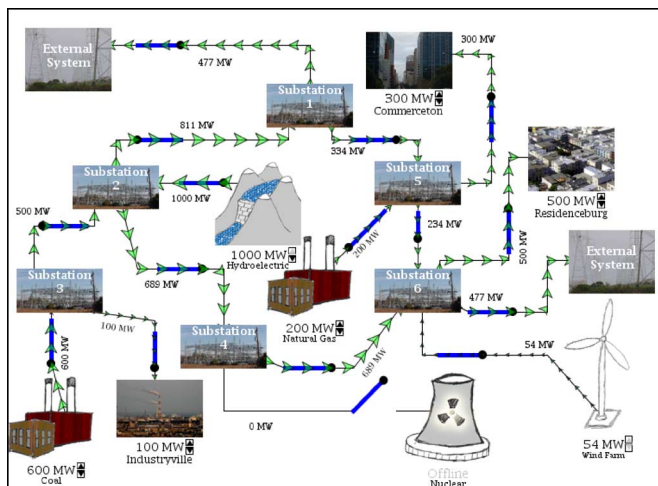


Fig. 5. Primary interface for the power grid applet, accessible from <http://www.tcip.mste.uiuc.edu/applet2.html>.

remaining eight buses represent loads and generators. Because students can arbitrarily change the load demands and generation amounts, the external system connections are necessary in order to handle any surplus or shortfall in power demands.

In order to model the power system for simulation within the applet, the dc power flow equations are used [24]. Although this is not the most accurate system model, it provides a reasonable simplification of the computationally and conceptually complex ac power flow equations. The primary benefit of using the dc power flow equations is the speed of solution, due to the linear nature of the equations. Another benefit of using the dc power flow equations is that the system is solvable as long as slack buses are properly defined for each island.

In the system model for the Power Grid applet, the upper-left external system connection serves as the default slack bus when the system is not islanded. To balance the external system power flows, an extra calculation is performed in order to split the exported or imported power between the two external system connections. When islands are created in the system, each of the external system connections can serve as a slack bus. If an island is created which has no connection to the external system, the

system is considered blacked out. Island detection and dc power flow solutions are performed regularly and quickly, resulting in a truly interactive experience where the network flows change near-instantaneously upon changes in load, generation, or network topology.

This applet also introduces the concept of a network, a key concept which shows up in several engineering disciplines. Although networks are ubiquitous in our society, rarely do students at the pre-university level get a chance to delve into the different issues associated with networks. Our hope is that introducing networks in the context of power systems will also foster discussion of networks in other areas of electrical engineering, such as communication networks (e.g., the Internet).

2) *Educational Objectives*: For the second unit, several key educational objectives are covered which are fundamental to understanding the power grid:

- Energy is transferred from generators to loads through a network of transmission lines, substations, and transformers.
- There are benefits and drawbacks to having a networked system.
- At every place in the system, power and energy are conserved.
- The typical power ratings, controllability, and environmental impact of generators varies based on the fuel type.
- Lines which are carrying power in excess of their capacity are typically disconnected if kept in their overloaded state. Once this occurs, it can lead to a set of cascading outages where the system's transmission capacity is too low to support the given load and generation amounts.

3) *Meeting the Educational Objectives*: The components and capabilities of the second applet are designed to meet each of the educational objectives listed above:

- By following the flow arrows, identical to those used in the first applet, students are able to see how energy moves from the generators in the system to the loads in the system. Also, the routing of energy (as determined by solution of the dc power flow equations) as lines, generators, and loads are opened and closed shows how the grid responds to changes. The inclusion of several different loads, generators, and substations allows students to explore how a complex system such as the power grid operates based on physical laws and control settings.
- To show the benefits of having an interconnected system, loads can be supplied from a combination of local generation and the external system. This is one of the key reasons for interconnection and illustrates for students how generation shortfalls and surpluses are handled within the power grid. The drawbacks of having an interconnected system, such as the possibility of an event in one part of the system having an adverse impact on the remainder of the system, are illustrated through a cascading outage which is detailed in the accompanying lesson plans. An example state of the system after undergoing a cascading set of line outages is shown in Fig. 6. Notice that, although the left hand side of the system has blacked out, the right hand side is still connected to the external system and Residenceburg is still being supplied with energy.
- Power and energy conservation is a key concept that students may already have familiarity with. To see how this

concept applies to power systems, there are numerical labels adjacent to each line in the system that give the precise values of power flowing on the lines (see Fig. 5). Looking at any node within the system, students can sum the entering and exiting power flow values to learn that power and energy are conserved.

- d) Because the mix in generating unit types on the power grid is a key aspect of power system operations, five different generation types are included in the Power Grid unit: coal, hydroelectric, natural gas, nuclear, and wind. Each of these units has a default output power assigned to it, and for those units with controllable output (coal, hydroelectric, and natural gas), there are clickable arrows so that students can see the effects of increasing and decreasing output power. To mimic the real controllability of different generation types, the following ranges of output power are defined for each generation type:

- coal: 300–700 MW;
- hydroelectric: 500–1000 MW;
- natural gas: 0–500 MW;
- nuclear: 900 MW;
- wind farm: 54 MW average, with random variation.

In addition to the generation characteristics embedded within the applet itself, there is substantial discussion within the lesson plans comparing the different generation technologies.

- e) With the exception of the lines connecting the three cities to the grid, each of the lines in the applet represents a transmission line with a capacity of 1500 MW. As with the real power system, if a line is made to carry power in excess of its rating for a period of time, the line will be opened. To illustrate this concept for students, the color of the power flow arrows changes based on loading levels. When a line is carrying less than 85% of its capacity, the arrows are green, indicating that the flows are within normal operating conditions. As the flow moves past 85% of the line rating (1275 MW), the arrows turn orange, indicating that the lines should not be made to carry much more power. As the flow continues to increase past the rated value of 1500 MW, the arrows turn red. If the arrows remain red (i.e., the line remains overloaded) for approximately 10 s, the line automatically opens and a notification is displayed. All of these effects are illustrated in Fig. 7. The lines to the cities are limited to carrying 1000 MW, 2000 MW, and 1000 MW for Industryville, Residenceburg, and Commerceton, respectively. Because these lines have different limits, one of the lessons associated with this applet has students discover the different limits on each of the lines by varying the cities' demands.

IV. DISSEMINATION AND FEEDBACK

A. Dissemination Efforts

In addition to developing applets and lesson plans to accompany the applets, there has also been dissemination of this work to teachers and the public at large. Dissemination activities include press releases, presentations at university open houses, presentations to individual elementary and secondary schools, and presentations at educational conferences.

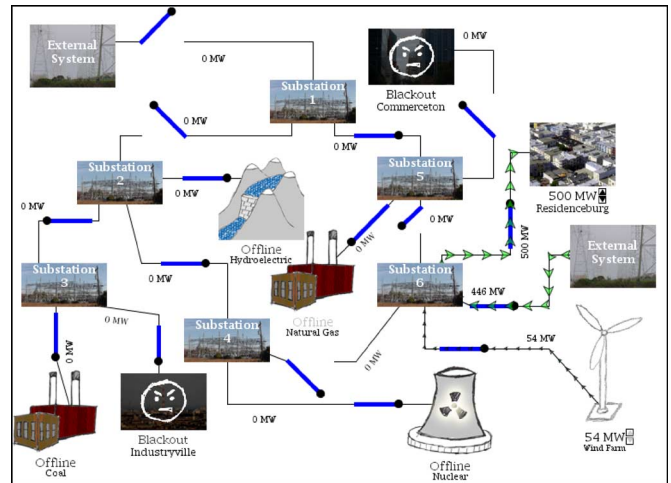


Fig. 6. Partial blackout of system in the power grid applet.

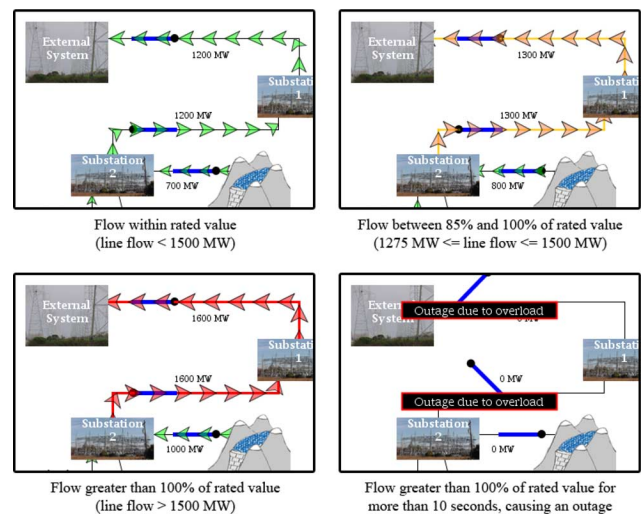


Fig. 7. Effects of line loading changes in the power grid applet.

In addition to presentations, the applets are disseminated through the Office of Mathematics, Science, and Technology Education (MSTE) website. Because the applets are only publicly accessible from this website, it is possible to maintain a very accurate count of user sessions for the applets, shown in Fig. 8. The most significant aspect of this data is that the monthly user sessions have been consistently in excess of 1000. There was an expected dip in user sessions during the summer months because most schools are not in session. As dissemination continues, the number of sessions is expected to increase. Also, there will soon be links to the materials on the IEEE PES web site, which should further boost awareness.

Based on further outreach efforts at the national level, these materials will have a significant national educational visibility and, hopefully, represent the beginning of an increased awareness of power and energy as an important area of investigation in the pre-university classroom.

B. Feedback and Responses

As mentioned above, an important aspect of the development process is the collaboration between engineering and education

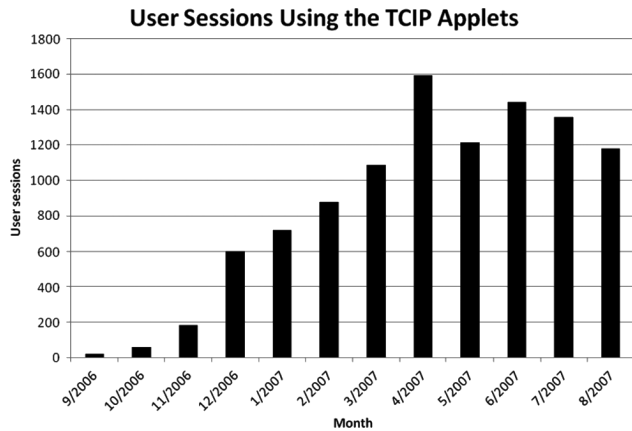


Fig. 8. User sessions for applet access.

TABLE I
NATIONAL MATHEMATICS STANDARDS ADDRESSED BY THE POWER AND ENERGY IN THE HOME UNIT

Unit Objective	Mathematics Standard
a. Energy delivery to the home	Geometry – Use visual tools such as networks to represent and solve problems
b. Differences in load demands	Measurement – Understand measurable attributes and the units, systems, and processes of measurement
c. Power and energy relationship	Algebra – Use graphs to analyze the nature of changes in quantities in linear relationships
d. Energy metering and pricing	Algebra – Model and solve contextualized problems using various representations, such as graphs, tables, and equations
e. Reducing energy consumption	Measurement – Solve simple problems involving rates and derived measurements

TABLE II
NATIONAL MATHEMATICS STANDARDS ADDRESSED BY THE POWER GRID UNIT

Unit Objective	Mathematics Standard
a. Energy transfer from generators to loads	Geometry – Use visual tools such as networks to represent and solve problems
c. Conservation of energy and power	Algebra – Model and solve contextualized problems using various representations, such as graphs, tables, and equations
e. Line ratings and outages based on overloads	Numbers and operations – Work flexibly with fractions, decimals, and percents to solve problems

experts. The education collaborators were able to pilot the applets with young students early in the development phase. In performing these early tests of the applets, several important lessons were learned and the applets were modified accordingly. Taking one example, the computer screens in schools were smaller and of lower resolution than anticipated. When fifth graders used the first applet, they had trouble putting the

TABLE III
SCIENCE STANDARDS ADDRESSED BY THE POWER AND ENERGY IN THE HOME UNIT

Unit Objective	Science Standard
a. Energy delivery to the home	Physical science – Transfer of energy
b. Differences in load demands	Science and technology – Studying technological products and systems
e. Reducing energy consumption	Science in personal and social perspectives – Science and technology in society

TABLE IV
SCIENCE STANDARDS ADDRESSED BY THE POWER GRID UNIT

Unit Objective	Science Standard
a. Energy transfer from generators to loads	Physical science – Transfer of energy
b. Benefits and drawbacks of a networked system	Science and technology – Studying technological products and systems
c. Conservation of energy and power	Physical science – Transfer of energy
d. Differences in generation technologies	Science in personal and social perspective – Science and technology in society
e. Line ratings and outages based on overloads	Science and technology – Studying technological products and systems

entire applet on the screen and switching between the main simulation screen and the associated plot. Based on this feedback, the web interface was changed so that resizing the containing web browser results in resizing the applet. Another important change made due to feedback is an increase in the variety and number of loads within the applet. Originally, the only loads that students could use were light bulbs, a hair dryer, and a clothes washer; after speaking to teachers about the applet, the other 21 loads which are now in the applet were added.

V. CONCLUSIONS AND FUTURE WORK

The lessons developed thus far can have a significant educational impact, providing an excellent foundation for understanding and interest in the power industry. One extension currently in development is to better address the environmental impacts of different generation technologies along with discussion of both capital and marginal costs of each technology. Furthermore, the inclusion of more generation types (e.g., biomass and solar) could be beneficial, particularly as renewable generation becomes more prevalent.

There has already been significant dissemination of the lessons, as evidenced by the number of user sessions every month, and the reception has been overwhelmingly positive. To increase exposure of these materials, additional presentations are planned for local, state, and national conferences. In addition, a mechanism for formal evaluation of the lessons is being developed in order to gauge their impact on teachers and students.

APPENDIX

A. Alignment of Educational Objectives to Mathematics Education Standards [11]

Tables I and II give the most applicable national mathematics standard addressed by each unit objective. Due to space constraints, only the standards from grade levels 6–8 are provided here; a more comprehensive list of the applicable standards is available at the project website.

B. Alignment of Educational Objectives to Science Education Standards [13]

As with the mathematical standards, Tables III and IV concentrate on only one grade level, 5–8. A more comprehensive list of the science education standards addressed by the units is available on the project website.

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