Interactive Lessons Addressing Wind Integration and Time-of-Use Pricing

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***Abstract*—This panel presentation will focus on our latest efforts in developing and disseminating interactive lessons for pre-university power engineering education. The focus of our most recent work has been on two concepts that are becoming increasingly important in power system operations—wind integration and time-of-use pricing—and are likely to become even more important over the next several decades. We will provide both a detailed description and a demonstration of the new materials and discuss the major concepts addressed within each. In addition, we will provide an overview of our dissemination activities and topics we would like to explore in the future.**

***Index Terms*—educational technology, wind power, renewable integration, wind power, energy storage, time-of-use pricing, power engineering education, smart meters**

I. Introduction

INCREASING the amount of electricity generated from renewable energy sources has become a major policy priority for many countries around the world, and the massive push to "green the grid" is becoming a reality. While reducing the environmental footprint of electricity generation is a laudable goal, too often the information presented to the general public is over simplified, with only a token acknowledgement of the potential challenges associated with massive increases in distributed and variable generation. To help students (and the public at large) better understand some of these challenges, we have developed a new set of interactive lessons focused on the integration of wind generation on the power grid.

Another major change taking place within the power industry jurisdictions is the transition from fixed-rate to time-of-use pricing for residential customers, which is becoming increasingly practical due to the widespread deployment of advanced home energy meters. Many of the intended benefits of time-of-use pricing, such as reduced peak usage and greater energy conservation, are contingent upon the ability of government agencies and utilities to educate customers about these new pricing schemes. To help students of all ages understand the implications of these new pricing methodologies, we have developed a set of interactive lessons that let students experiment with changes in consumption patterns (e.g., examining the effect of turning on a clothes washer at 9pm rather than 6pm) and pricing schemes (e.g., hourly vs. 3-tiered pricing).

To facilitate greater understanding of existing and emerging issues related to the design and operation of the power grid, the authors have worked over the past five years to develop a suite of interactive lessons accompanied by substantial pedagogical resources [1]-[3]. Our motivation for providing an interactive simulation environment is based on the demonstrated ability of interactive, visually-compelling lessons to foster engagement and learning within engineering in a wide variety of areas (e.g., engineering design projects [4], computer-aided design [5], and acoustics [6]) and can be particularly effective in engaging women and minority students [7]. Supplementing the interactive applets with supporting literature for both students and teachers is also a key component of our approach, as this changes the activity from a less-effective "pure discovery" [8] methodology, in which students are asked to extract meaning on their own, to the more-effective methodology of "guided discovery" [9], in which students' explorations are assisted by expert advice in the form of teacher instruction along with supplementary written and audiovisual material.

In this panel session, we will discuss both the motivation and development process used to define and create the latest set of interactive lessons for K-12 power system education. We will also discuss our continuing (and continuous) efforts to disseminate these materials to educators around the world and future plans for both development and dissemination.

II. New Interactive Lessons for Power Engineering Education

Our initial work in K-12 power engineering education focused on fundamental concepts related to electricity usage and management. The new sets of interactive lessons move from broad concepts (such as the difference in power and energy and the redistribution of network flows) to more specific concepts such as the benefits combining energy storage with wind generation and the changes in consumption patterns that are best suited to different time-of-use pricing schemes.

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A. Wind and Storage

Students and their families are becoming increasingly conscious of environmental concerns such as climate change and appreciate the potential benefits of transitioning from a fossil fuel-based generation mix to one in which wind and solar energy play a major role. At the same time, most are not aware of the challenges associated with the integration of large amounts of variable, renewable generation. To help students to understand some of the complexities inherent in running the power grid of the future, a simulation system has been developed that includes the following components (see Fig. 1):

- Residential, commercial, and industrial load centers that illustrate typical daily load variations for different load types
- Coal and natural gas facilities that represent legacy generation resources, each with a capacity of 1500 MW
- A wind farm with output power that follows a diurnal pattern based on measured wind speed data
- A "generic" storage device with capacity & energy limitations of 100 MW and 1000 MWh, respectively
- Transmission lines connecting these components together

Three key system parameters can be changed interactively by manipulating sliders on the main applet window:

- Peak community power demand: to see how changes in demand result in changes in unit commitment and dispatch on the system, the power demand at each of the three load centers can be scaled such that the peak demand varies from 250 to 5000 MW.
- Wind power capacity: the maximum output of the wind farm, corresponding to the period of peak wind speed on the system, can be scaled from 195 MW to 3902 MW, allowing students to explore the impact of small, medium, and large penetration of wind power.
- Capacity of the transmission line from Substation 1 to Substation 2: the transmission line between Substation 1 and Substation 2 is the transmission line that carries the energy from the wind generators and storage device to the load centers. By varying the capacity of this line, students can explore the interdependency of transmission availability, storage capacity, and variable generation output.

The lessons cover a variety of topics related to the interaction if wind, storage, and transmission; some examples are:

- The demand profile of a load varies depending on the customer type (industrial, residential, or commercial) and corresponds to typical work schedules
- If the peak demand exceeds the baseload capacity (coal, in this system), more expensive generation (natural gas) must be brought online
- Wind only has a significant effect on the system costs and CO_2 emissions if there is sufficient transmission capacity
- If there is insufficient transmission capacity to export the wind power output, the energy is either lost (if no storage is available) or, if storage is available, can be used later when wind speeds have decreased

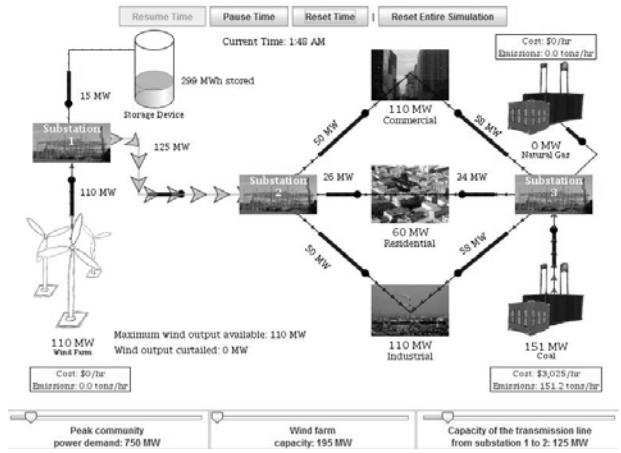

Fig. 1. Simulation environment for Wind and Storage interactive lessons.

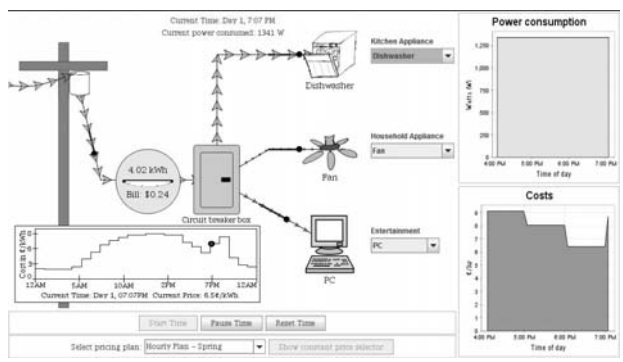

Fig. 2. Simulation environment for Electricity and Time-Sensitive Pricing interactive lessons.

B. Electricity and Time-Sensitive Pricing

While time-of-use pricing has only been implemented in a few North American cities [10], there are some very large jurisdictions (such as the Toronto metropolitan area) that have converted a large percentage of customers over to time-sensitive pricing. The impact of changing from time-insensitive to time-sensitive pricing is explored through a series of interactive lessons based on the simulation environment shown in Fig. 2.

Some of the key features of this simulation environment are:

- Hourly time-of-use pricing is based on actual prices downloaded from Ameren Illinois [11]. Representative days were chosen for each of the four seasons.
- Three-level time-of-use pricing is based on the time-of-use pricing scheme currently in use within the Canadian province of Ontario [12].
- Cost and energy consumption are shown alongside the

main circuit diagram, clearly indicating the new dependence of electricity costs on both amount and time of consumption

In addition to the new simulation environment, new lessons have been developed to help students understand some of the implications of time-of-use pricing, such as:

- Given the option of using energy at high-price (peak) or low-price (off-peak) times, significant savings can be had by shifting load to off-peak consumption (e.g., getting up 30 minutes earlier to blow dry your hair can halve the cost)
- Staying up late to play video games makes good financial sense, considering the typical variation between afternoon and late-night electricity prices
- The financial benefit associated with having a roof-mounted solar system is dependent on the active pricing scheme

Fig. 3. The Orpheum Children's Museum's "Mission Smart Grid" exhibit

III. Outreach Efforts

A. Web accessible

To ensure that the developed materials reach the widest possible audience, all of the lessons are freely available from the University of Illinois Office of Mathematics, Science, and Technology Education (MSTE) website. We also maintain an up-to-date collection of the applets for offline usage (e.g., for classrooms without network connectivity).

B. Museum exhibit

We have been collaborating with the Orpheum Children's Science Museum in Champaign, IL on an exhibit entitled "Mission Smart Grid". Museum visitors are invited to become members of the "Smart Grid Tech Force" and are offered a mission related to securing the power grid. Tech Force candidates visit various training centers and workshop areas located throughout the museum to learn about electricity production and transmission. The main "Control Center" is a 72 in. SMART board (shown in Fig. 3) that features the interactive lessons developed by our team.

C. Project Lead the Way Curriculum

Project Lead the Way, the largest non-profit provider of science, technology, engineering, and mathematics education programs [13], has incorporated these interactive lessons into its most recent middle school curriculum. In 2010, twenty-three affiliate universities, representing as many states, offered Project Lead the Way's two-week summer professional development institutes for middle school teachers introducing the new Energy and the Environment module. Students at approximately 1000 middle schools are receiving this curriculum beginning in the 2010-2011 school year. The Energy and Environment module will be offered at twenty-six summer institutes will be offered in 2011.

D. Conferences and Public Workshops

Reaching students directly can be difficult, so another major component of our outreach efforts is to take the lessons we have developed to math and science teacher conferences and get teachers engaged in this area. The lessons have also been demonstrated in a variety of public forums, such as the University of Toronto Sustainable Energy Fair.

E. Measuring Success

Because of the many different avenues through which we distribute the work described here, developing effective metrics for success is challenging. Because the free accessibility of the materials is a key aspect of our work, we use detailed weekly and monthly reports to gauge the impact of the materials (over the past year, we have received an average of 1800 unique visitors per month). We are also working to develop a more formal method of evaluating the impact of the lessons on student learning, e.g. through the utilization of pre- and post-tests, but these efforts are still at the planning stage.

IV. Future Work

Moving forward, we intend to continue developing unique, pedagogically sound lessons that teach important concepts related to power engineering. Some of the topics we are considering for future lessons are:

- Smart thermostats
- Pluggable hybrid electric vehicles
- Distribution automation

There are also some technical challenges that we would like to address in the future, such as converting the applets from Java to a more widely accessible language (such as JavaScript).

V. References

[1] *TCIPG Education Home* [Online]. Available: http://tcipg.mste.illinois.edu

[2] J. E. Tate, J. Sebestik, and T. Overbye, "Collaboration and dissemination efforts related to pre-university power lessons," in *Proc. 2008 Power and Energy Society General Meeting*, Pittsburg, PA, July 2008.

[3] J. E. Tate, T. J. Overbye, J. Sebestik, and G. C. Reese, "Interactive Lessons for Pre-University Power Education," *IEEE Trans. Power Syst.*, vol. 23, no. 3, pp. 824 -830, Aug. 2008.

[4] A. A. Renshaw, J. H. Reibel, C. A. Zukowski, K. Penn, R. O. McClintock, and M. B. Friedman, "An assessment of on-line engineering design problem presentation strategies," *IEEE Trans. Educ.*, vol. 43, no. 2, pp. 83-91, May 2000.

[5] J. A. Nestor, "Experience With the CADAPPLETS Project," *IEEE Trans. Educ.*, vol. 51, no. 3, pp. 342-348, 2008.

[6] Y. E. Kim, T. M. Doll, and R. Migneco, "Collaborative Online Activities for Acoustics Education and Psychoacoustic Data Collection," *IEEE Trans. Learning Technol.*, vol. 2, no. 3, pp. 168-173, 2009.

[7] M. B. McGrath and J. R. Brown, "Visual learning for science and engineering," *IEEE Comput. Graph. Appl.*, vol. 25, no. 5, pp. 56 -63, Sep. 2005.

[8] R. E. Mayer, "Should There Be a Three-Strikes Rule Against Pure Discovery Learning?: The Case for Guided Methods of Instruction," *American Psychologist*, vol. 59, no. 1, pp. 14-19, Jan. 2004.

[9] D. Leutner, "Guided discovery learning with computer-based simulation games: Effects of adaptive and non-adaptive instructional support," *Learning and Instruction*, vol. 3, no. 2, pp. 113-132, Jan. 1993.

[10] Smart Power Devices Ltd., (2011, Feb. 1). *What Regions & Dynamic Pricing programs are covered by Power Stoplight?*[Online]. Available: http://www.powerstoplight.com/?page_id=41

[11] Ameren Services, (2011, Feb. 1). *Real Time Prices* [Online]. Available: https://www2.ameren.com/RetailEnergy/realtimeprices.aspx

[12] Ontario Energy Board, (2011, Feb. 1). *Time of Use Prices for Smart Meters* [Online]. Available: http://www.oeb.gov.on.ca/OEB/_Documents/For+Consumers/TOU_prices.pdf

[13] Project Lead the Way, (2011, Feb. 1). *PLTW | STEM Education Curriculum for Middle and High Schools* [Online]. Available: http://www.pltw.org

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