An Interactive Game Introducing Power Flow Optimization Concepts

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Abstract

We present a prototype simulation game, the OptiPower Game, to introduce basic concepts of power demand optimization to high school students (grades 9-12). Students decide how to allocate limited energy resources while anticipating they must meet power demands under challenging, randomized scenarios generated by the simulation. The team that supplies the most periods, at the least cost, wins the round. There are several learning objectives of the OptiPower Game: introduce students to power systems; teach concepts of supply, demand, and reserves; introduce pros/cons of different energy resources; and illustrate the difficulties of generating optimal power supply to meet uncertain supply and demand. The OptiPower Game, played in teams, is useful for short (1-2 hour) sessions. It was designed using Excel VBA, and has been piloted with 110 high school students as part of two design competitions. Informal feedback was gathered from students to improve future versions of the game.

Introduction

Integrating renewable energy sources into the existing power grid has become a primary prerogative of the 21st century. In 2007, Congress passed the Title XIII of the Energy Independence and Security Act of 2007 (EISA), which mandated the Department of Energy modernize the national power grid using technologies like the “smart grid.”¹ The smart grid “accommodates a wide variety of generation options, e.g. central, distributed, intermittent, and mobile,” and a key feature is the use of “IT to continually optimize the use of its capital assets while minimizing operational and maintenance costs.”² Designing the smart grid to meet the challenges of the 21st century requires capable engineers well versed both in electrical engineering and operations research.

The Optipower Game is designed to introduce high school level students (grades 9-12) to the fields of electrical engineering and operations research, and their practical interdisciplinary applications in the field of power systems. The game introduces multiple concepts to students: renewable resources; cost and emissions associated with different electricity resources; supply, load, and reserves; and optimization under uncertainty.

Several existing games or simulations have been developed to introduce K-12 or college students about various aspects of the power grid. McJunkin, et al. (2016) created a simulation game for college students, but the focus of their game is to defend against cyberattacks and give students a unique view of automation challenges.³ Antaya, et al. (2014) developed a first and second year community college curriculum that featured several modules and games regarding sustainability; the Energy modules, in particular, emphasized supply, demand, transmission, and renewables concepts. Existing commercially-developed board games like Power Grid by Rio Grande Games and Super Energy Apocalypse by Lars a Doucet were used in conjunction with the modules so students could learn about different types of power production systems and energy strategies.⁴ Plumanns, et al. (2016) created a real-world SmartCity demonstrator where students could supply power to a miniaturized Lego town using a mixture of renewable sources while taking into account varying demand throughout the day.⁵ Similar to the OptiPower Game, students were
asked to reflect on difficulties of power distribution and strategies to deal with it. Tang, et al. (2012) created a virtual reality game, *Power Ville*, to teach students about different energy choices (coal, wind, solar, nuclear), and the different impacts of the resources. Students navigate throughout the game, speak with “power experts,” and use a *Simulator* and *Optimization* tools to formulate their choices about how to power the city of *Power Ville*.  

The OptiPower Game is interactive and competitive, with the goal of providing a fun experience that communicates power system concepts to students. In addition, the game is crafted specifically for high schoolers, whereas the previously mentioned games are mostly designed for college students. High school instructors can easily bring this game to their own classrooms, without installing any special software, and modify it in Excel VBA for their own purposes. 

The paper is structured as follows: the game design is described, followed by a description of the implementation and results, as well as future steps to be taken. The implementation discussed in this paper is a prototype meant to pilot the game and gather informal feedback; further ideas for future implementations are discussed in the results.

**Game Design**

**Overview**

Before the game, game facilitators teach a 10-20-minute lesson that establishes concepts that help the students understand and play the game. The facilitators discuss the history of the power grid, basic structures of the electric system, supply and demand of energy, renewable resources, base load resources (i.e., coal and natural gas) and peaking resources (i.e., natural gas), and balancing intermittency with reserves.

The OptiPower Game was designed and implemented in Excel using Excel VBA. The purpose of the game is to teach students the difficulties of providing power to a power system. Students are divided in groups of 2-3, and are assigned to a computer. The game is divided into two phases. The intent of the two separate phases is to first teach students how to navigate the interface in Phase 1, before introducing more difficult concepts like reserves and uncertainty in Phase 2.

**Phase 1**

In Phase 1, students provide power to a power system using a limited number of resources, while trying to do so under the lowest cost possible. See Figure 1 for the Phase 1 interface with the initial game setup. The interface displays the demand for power for seven hours, with different levels of demand each hour.
In *My Control Panel*, students fill out the orange columns to allocate coal, gas, and wind to provide power for each hour. For example, if the demand at Period 1 is 2 units, power can be supplied by providing 1 unit of coal and 1 unit of wind. As students change the amount of each resource they supply, the Supply line automatically adjusts in the Power Supply and Demand graph. See Figure 2a for an example of the new Power Supply and Demand graph once 4 units of coal are supplied for Period 3. See Figure 2b for the Power Supply and Demand graph when supply matches demand for every period.

![Power Supply and Demand](image)

(a) Supply power for one period  
(b) Supply power for all periods

Figure 2: Power Supply and Demand graph

In addition, each resource has a different unit cost, availability, and emissions. For example, gas has a unit cost of $2/unit and only 20 units are available for the day. If a player uses more units
of a resource than are available, the “Remaining” cell will highlight red to warn the player that too many units have been used, as shown in Figure 3.

<table>
<thead>
<tr>
<th>Resource Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Used</strong></td>
</tr>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>Gas</td>
</tr>
<tr>
<td>Wind</td>
</tr>
</tbody>
</table>

Figure 3: Resource Costs information box

To win the round, students must meet the demand for the day (providing enough power for the demand at each hour), at the minimum cost solution relative to the other teams. One round of the first phase is usually adequate for students to feel comfortable enough to move on to the second phase.

*Phase 2*

The fundamental difference between Phase 1 and Phase 2 is the introduction of uncertainty into the game, and the use of reserves to mitigate that uncertainty. In Phase 2, students now allocate reserves, in addition to the wind, gas, and coal resources, for each period. See Figure 4 for the Phase 2 interface. The goal of Phase 2 is for students to anticipate random scenarios and allocate enough backup power, using the given resources, to meet demand even when something unpredictable happens. The team with the lowest cost solution (in which they provide adequate power despite uncertainty) wins.

Figure 4: Phase 2 interface initial setup
Students allocate reserves in *My Control Panel*. The use of reserves creates an envelope around the supply; as shown in Figure 5. One unit of reserves in period 1 means that the supply can increase/decrease by 1 unit to accommodate uncertainty. We assume reserves have a unit cost, but there is unlimited availability; we also assume that reserves are emissions-free for simplicity. Future versions of the game could model reserves from different sources (e.g., natural gas power plants vs. hydropower plants) and their associated emissions.

![Supply and Demand Table]

<table>
<thead>
<tr>
<th>Period</th>
<th>Demand</th>
<th>Supply</th>
<th>Supply + Reserves</th>
<th>Supply - Reserves</th>
</tr>
</thead>
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<td>1</td>
<td>4</td>
<td>4</td>
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<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

![Figure 5: Power Supply and Demand graph with reserves]

A random scenario generator generates different scenarios in each round, simulating real-world challenges that change supply/demand or prices. A list of example random scenarios are as follows.

1. Hurricane! All wind allocations double.
2. Crisis in the Middle East! Gas prices double.
3. Wind power receives government subsidies. Costs go down by 1.5x.
4. No wind today! 0 power generated from wind.
5. It’s a hot week and everyone turns on their air conditioners! Demand for electricity goes up by 2 units each period.
6. The crisis in the Middle East is solved! Gas costs goes down to $1/unit.
7. New demand response program tries to keep demand balanced throughout the day. Demand is now 3 units for every period.

Students enter their solution into the interface, and then click the random scenario generator. All teams face the same random scenario. After the random scenario is applied to the teams’ solutions, the winning team is determined by 1) generating a list of the teams that supply the most number of periods and 2) determining which of the team on the list has the lowest cost solution. Consequently, the teams’ solutions depend heavily on wise utilization of reserves (providing enough reserves such that they survive the random scenarios, but not so much that the cost is too high and prevents them from winning) and the diversity of their chosen resources.

Once players become comfortable with the random scenario generator, game facilitators introduce carbon emissions concepts into the OptiPower Game. For example, the winning solution might be the one that has the lowest carbon emissions. Each resource has carbon
emissions emitted per unit used. Another way to reinforce the idea of lowering carbon emissions is implementing a carbon emissions cap; if players exceeded the cap for their solution, a dollar penalty is added to their final cost. See Figure 6 for the scoreboard; the total cost calculation can easily be edited to implement different scoring methods regarding the emissions cap.

![Total Cost Table](image)

Figure 6: Total Cost of generating power using coal, gas, wind, reserves

**Student Discussion**

Throughout the game, students work closely with their teammates to discuss strategies and decide which resources to allocate. Facilitators encourage the students to think about tradeoffs in the allocation of resources, costs, and emissions factors, while ensuring power supply meets demand.

**Optimal Solution**

Consideration has been made whether an optimal solution is possible to generate for this game, so students’ answers can be compared to a benchmark. The optimal solution obtained by solving a stochastic optimal power flow problem (i.e., using some knowledge of the uncertainty as in Zhang, et al.,\textsuperscript{7} Jiang, et al.,\textsuperscript{8} Zhao, et al.,\textsuperscript{9}) may not be the same as the winning solution, which is optimal with respect to the particular uncertainty instances realized during game play. However, the winning solution can be computed after game play - once the random scenario has been generated - by solving a deterministic problem as in Alguacil, et al.\textsuperscript{10}

**Implementation**

The OptiPower Game has been piloted at the Power Up Tech Camp in July 2016 and Tech Day in October 2016. The Power Up Tech Camp is a weeklong summer camp, hosted by the University of Michigan Department of Electrical Engineering & Computer Science, for high school students entering grades 9-11. Thirty students played the game, with the entire session lasting 90 minutes. Tech Day is a daylong recruitment activity hosted by the University of Michigan. Tech Day provides an opportunity for prospective college students (usually grades 11-12) to interact with various engineering departments at the university, and students participate
in interdisciplinary design challenges during the Design Competition component. Four 90-minute sessions were run, and 80 students total played the game.

Results and Next Steps

The OptiPower Game was designed for high school students between grades 9-12 to develop interest in STEM fields, specifically electrical engineering and industrial engineering. The OptiPower Game saw some small changes in design between the Power Up Tech Camp in July 2016 and Tech Day in October 2016, but overall the players found the design straightforward to play. This game accomplished the goals set forth for it: students received an introduction to basic power principles and learned the difficulties of generating optimal power supply under uncertainty.

The students worked well together in teams of two or three, and gave thoughtful answers for the solutions they provided. With each round of the game, students were also able to improve upon previous solutions – for example, some students utilized more reserves, or relied less heavily on one resource and used a more balanced combination. Students also demonstrated a good understanding of reserves and the cost and emissions of different resources they used when strategizing about what solution to create.

Based on informal student feedback and interactions during the pilot phase, several short-term adjustments were made and future adjustments considered. For example, in the first pilot of the OptiPower Game, students were given a physical implementation in addition to a computer interface. The physical implementation consisted of large sheets of paper with demand profiles and colorful paper rectangles cut out to represent different power resources. Students were asked to fill out the demand profiles on the sheets with the paper rectangles. However, facilitators found that the students had trouble connecting the physical implementation with the computer interface. For the second pilot, the physical implementation was eliminated and the game was played on computers only. Students did not report any confusion and found the computer interface to be straightforward to learn.

Although the OptiPower Game was designed in Excel, and programmed using simple code in VBA, it could be implemented in a different programming language. However, use of Excel made the game easy to maintain and update, enabling fast-prototyping. The undergraduate and graduate students who programmed the game had never used VBA before and learned the language easily.

Next steps involve migrating the game onto an online platform with a cleaner user interface and performing more rigorous evaluation to assess its educational quality. A pre-game survey and post-game survey will be given, which tests players’ knowledge of power concepts before and after the game. For example, survey questions might include some of the following topics:

1. Students’ understanding of supply, demand, reserves, and uncertainty
2. Students’ understanding of different energy resources and pros/cons
3. Students’ interest in studying power systems (scale of 1-5, where 1 = no interest and 5 = high interest)
In addition, feedback will be collected on the interface and how players believe the game can be improved. Overall, initial game play by students showed that game has considerable potential in teaching students basic concepts about the power grid.

Acknowledgements

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References


