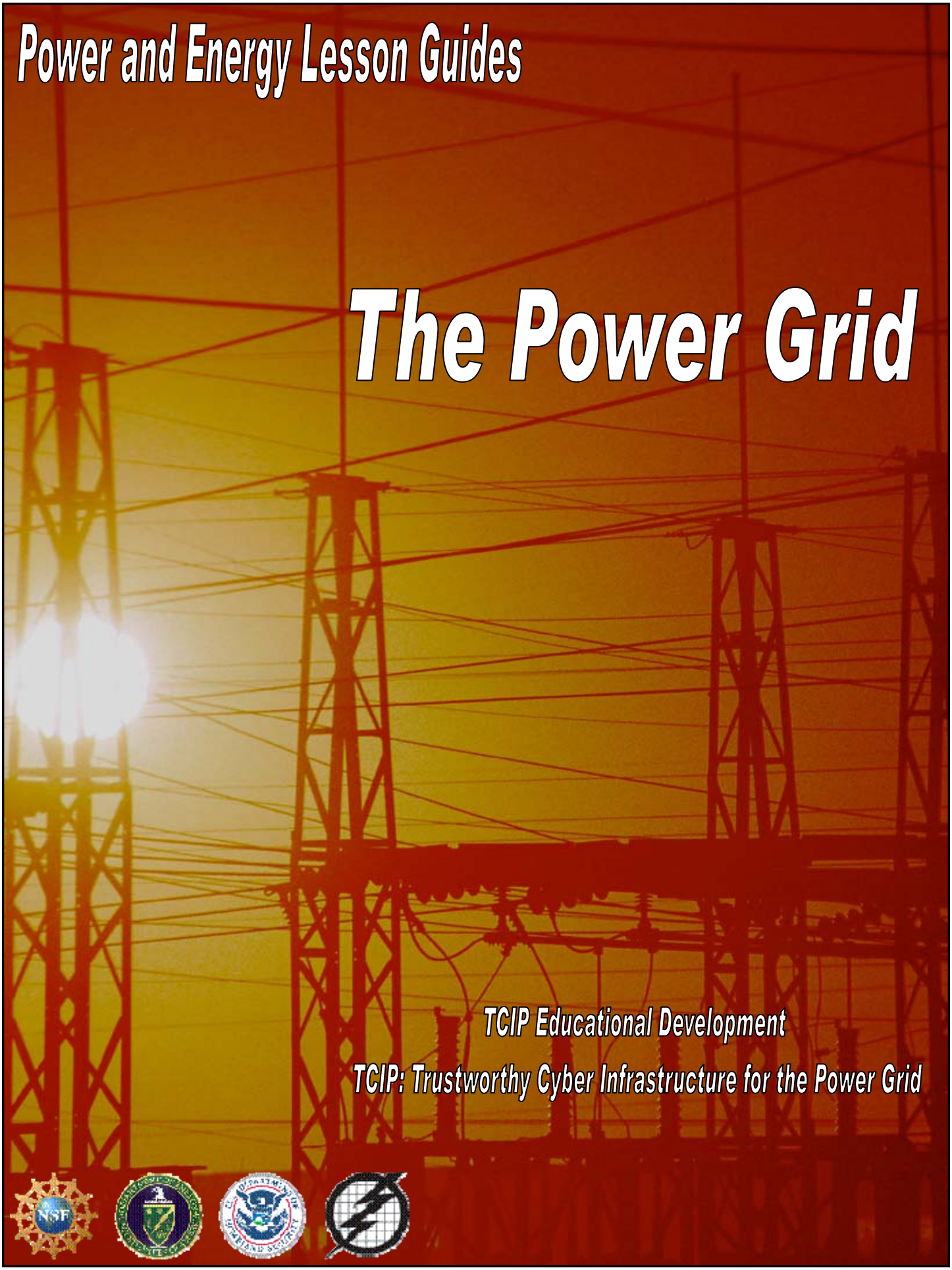
Power and Energy Lesson Guides

The Power Grid



TCIP Educational Development

TCIP: Trustworthy Cyber Infrastructure for the Power Grid

The Power Grid

Lesson 1

Comments for Teachers

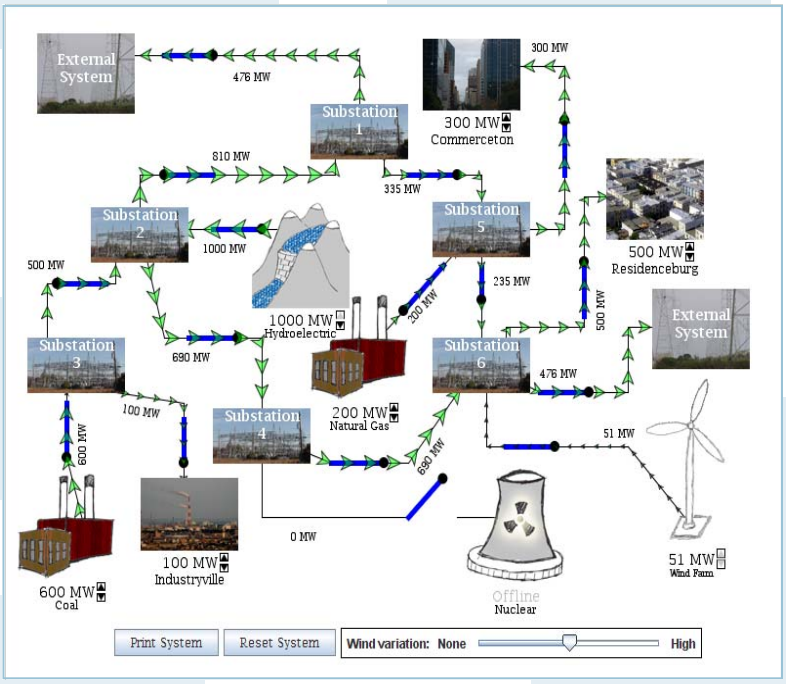
The applet at http://tcip.mste.uiuc.edu/applet2.html provides a simulation of a large scale power system network.

Encourage students to explore the applet. Then use the lessons on the student pages to focus their explorations.

- The green arrows show the direction the power is moving. The current is flowing out of the generators, through the substations and into the communities. Bigger arrows indicate more power.
- You can open or close the blue switches by clicking them with the mouse.
- There are five generators represented in this simulation. The coal, hydropower and natural gas generators have adjustable outputs. The others do not. Click on the up and down arrows to the right of MW output labels to change the production. All of the generators have blue connection switches.

There are more than 6000 utility scale generators in the U. S. They are powered by burning coal, oil or natural gas, or by nuclear fission, falling water or wind.

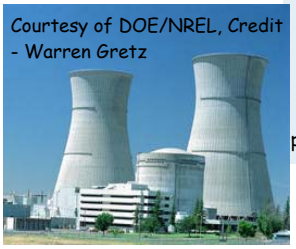
Hydroelectric generators use differences in water elevations to drive turbines. One famous example is the Hoover Dam.



Natural gas generators tend to be expensive to operate, but they are capable of changing their output quickly.

Coal generators are the cheapest fossil based generators. They can change their output a little less quickly than the natural gas generators.

Wind turbines are clustered together to make wind farms capable of producing utility scale power levels. Their power output varies with wind speed and often good wind sites are far from areas that need the most power, so wind accounts for only a small portion of generated power. The U.S. Department of Energy proposes that wind might supply 20% of the nations power by the year 2030.



Nuclear generators are powered by a uranium fission process. They are expensive to build, but inexpensive to operate. They provide large amounts of power.

Simulation Generators and their outputs

- ◊ Wind, 200 MW, varies with wind speed
- ◊ Natural gas 0 MW - 500 MW, adjustable
- ◊ Coal, 300 MW - 700 MW, adjustable
- ◊ Hydroelectric, 500 MW - 1000MW, adjustable
- ◊ Nuclear, 900 MW, not adjustable

More Resources

- How Power Grids Work http://www.howstuffworks.com/power.htm
- The Power of the Wind http://www.mste.uiuc.edu/projects/wind
- *The Magic School Bus and the Electric Field Trip* by Joanna Cole. Illustrated by Bruce Degen. Scholastic Press, New York. 1997.

Information Trust Institute, University of Illinois at Urbana-Champaign
11/7/2008

The Power Grid


Courtesy of DOE/NREL, Credit - Warren Gretz

Use the applet at http://tcip.mste.uiuc.edu/applet2.html to explore how power is distributed from generators to the communities. In the applet there are five different types of generators delivering electricity to three communities. When the applet opens, are the generators making more or less power than the communities are using? ____ Some of the generators are able to vary their production. Click on the up and down arrows to the right of MW output labels to change the production.

Read about the power grid here.

The **power grid** refers to the system of producers and consumers of electricity. It includes power generators, the users of electricity, switches that control the electricity, and the system of substations, power lines, and transformers that deliver the electricity.

A community might have a generator to provide its power. The generator may be able to vary its production as the usage of the customers changes, but there may be times when the demand for energy is too great for the generator. Then the community buys electricity from another source.

One estimate of home energy use states 3.3 MW are needed for 1000 homes

At other times the generator may be making more electricity than the community is using, so it wants to sell it.

Find the five generators. List the types and their outputs here. If a generator is able to vary its output, give its range.

1. _____
2. _____
3. _____
4. _____
5. _____

The arrows show the direction of the power flow and indicate the amount. Open or close the blue switches by clicking with the mouse. Explore the system by changing the power outputs and opening or closing the switches.

When the applet opens (or is reset), power is being produced by four of the five generators.

Find the total amount of power being produced. _____ You can see the power moving from the generators through the substations and to the users in Commerceton, Industryville, and Residenceburg. Find the total amount of power being used by these communities. _____Any power that is not used by the communities in the system is sent to other users in other systems. How much power is being sent to external systems? _____

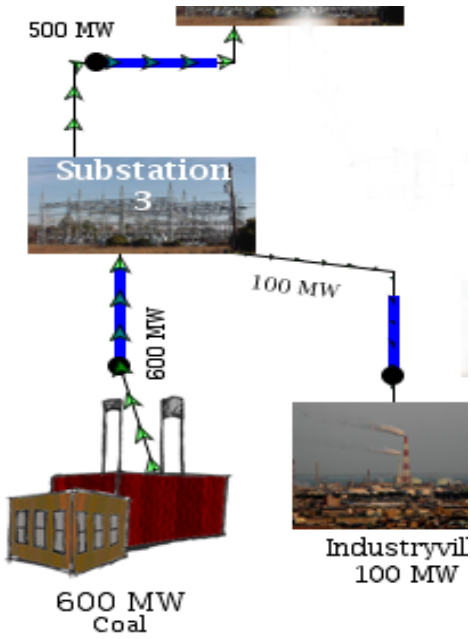
The Power Grid

Lesson 2

Comments for Teachers

When the applet at http://tcip.mste.uiuc.edu/applet2.html opens, power is being produced by four of the five generators. You can see the power moving from the generators through the substations and to the users in Commerceton, Industryville, and Residenceburg. Any power that is not used by the communities in the system is sent to users in other systems. If the generators in this system are not producing enough power, power will be purchased from other systems. In the applet this is indicated by the two External Systems. This simulation is designed to blackout if both External Systems are disconnected from the system.

The sum of the power entering a substation must equal the sum of the power exiting that substation. For example, when the applet starts (or is reset), the coal generator is sending 600 MW of power to Substation 3. Industryville is receiving 100 MW of that power and 500 MW is going to Substation 2.



Ideally, a local power system would generate exactly as much power as it uses, but because power demand is constantly changing, this is often not possible. There is no easy or economical way to store large amounts of electricity, so any "extra" power is sent to other users. Generation systems, like the one in the applet, are interconnected to allow electricity to travel. This interconnected system is the **power grid**. There are more than one hundred energy control centers across North America. Here power system operators monitor power production, transmission and use. They try to make sure that power demand across the grid is equal to power generated. They also try to keep costs low and make sure equipment is operating safely. They may ask a generator to produce more power or less at times. When you are interacting with the applet, you are acting like a power system operator.

More Resources

- The Midwest Independent Transmission System Operator, Inc. in Indiana works to manage transmission for an area from Ohio to Manitoba http://www.midwestiso.org/home

- Take a virtual power plant tour at http://www.energyclassroom.com/powersource.html.

McNeil Generating station control room
Courtesy of DOE/NREL

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The Power Grid

When the applet at http://tcip.mste.uiuc.edu/applet2.html opens (or is reset), power is being produced by four of the five generators. Close the switch to put the nuclear plant online. What changes? _____

_____

_____

Watch the arrows and the numbers alongside the transmission lines to see changes in thesystem.

Now, how much power is being sent to external systems? _____

What happens if the switch to one of the external systems is opened?

_____

_____

How can you match the power generated to the power used? _____

_____

When do the arrows change direction? _____

Take all of the generators offline. What happens?

_____

Put only the hydroelectric plant back online. Now what happens? _____

You see some parts of the power grid all around you. There is probably a power pole with a transformer drum very near where you live. If your neighborhood has underground power, the transformer is in a green box that is about one meter on each side. There is a power substation like the one in the photo nearby too. Substations can split the power distribution into two or more directions, but they do not make or use power. So the power entering a substation is equal to the power leaving the substation. Another job of the substation is to take the high voltage power produced by the generators and transform it to a lower voltage that can be used in homes, schools and businesses.

A power substation

Reset the system, then answer these questions. Adjust the coal power plant to be on line at maximum power. How much electricity is flowing into substation 3? _____ How much electricity is flowing out of substation 3? _____ Where is it going?

_____

_____

What changes when you open the switch on the line leaving the coal plant? _____

_____

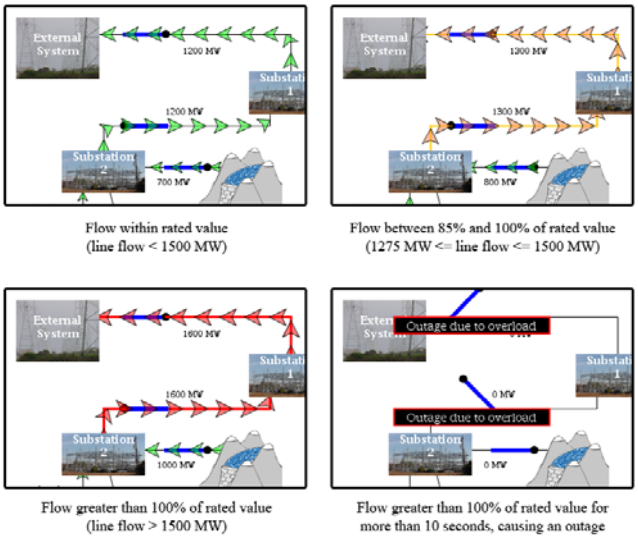
_____

The Power Grid

Lesson 3

Comments for Teachers

- The transmission lines in the applet have varying capacities. They range from 1000 MW to 2000 MW. The line flow for each line is noted near the line and changes as the power flow changes.
- 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 capacity, 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 maximum, the arrows turn red. If the arrows remain red (i.e., the line remains overloaded) for approximately 10 seconds, the line automatically opens and a notification is displayed



- If a community demands more power than the transmission line that serves it can carry, the community will blackout. A community may also blackout if a line is damaged. In the applet as well as in reality, a transmission line problem in one area of the system can cause blackouts in several areas.
- Power lines are designed with maximum capacities. The large diameter, more expensive high voltage lines leaving a generating plant are designed to carry the maximum that the plant can produce. It's more difficult to design a transmission line that supplies a community because growth and demand are harder to estimate.

More Resources

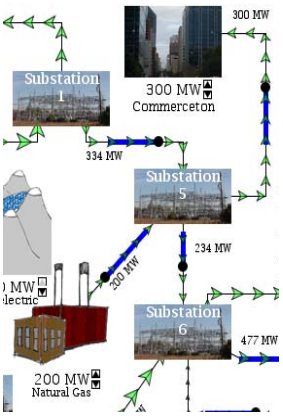
- Electric Power Generation, Transmission and Distribution: Illustrated Glossary (OSHA) http://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/index.html
- CBS News coverage of the power blackout in August, 2003 http://www.cbsnews.com/stories/2003/08/14/national/main568370.shtml
- *Energy Story*, California Energy Commission http://www.energyquest.ca.gov/story/

Victoria Towers residents sit outside with their flashlights during the power blackout Aug. 14, 2003, in Meriden, Connecticut (Photo AP)

The Power Grid

Lesson 3

When the applet at http://tcip.mste.uiuc.edu/applet2.html opens (or is reset), all of the power flow arrows are green. The transmission lines have varying capacities. Just as in an actual power system, if a line is asked to carry too much power the line will be opened creating a power outage. To make it easy for the system operator (that's you!) to see when lines are in danger of becoming overloaded, the arrows in the applet change color. **Reset** the system and notice the line leading from Substation 5 to Commerceton. How much power is this line carrying? _____ Click on the up arrow to increase Commerceton's power demand. What happens to the arrows on the line? _____



At what load do the arrows change to orange? _____ What color are the arrows when the demand is 1000 MW? _____ What happens when the load on the line is increased again? _____

How can you fix it? _____

Explore the applet to find the line maximum capacities for all the lines.

Power leaving the generating plant is carried by high voltage, long distance transmission lines to a distribution substation. These lines look like the photo. The power leaves the substation on the lines you see strung from power poles. The transmission lines that have the largest diameters are designed to carry the most power. Transmission lines become hot and expand if they carry more power than they are designed to carry. This can cause the line to sag and touch the ground or some other object. When this happens the line is opened and a power outage will occur.

Reset the system, put the nuclear power plant online and then increase the power demanded by Residenceburg to 1850 MW. What's causing a problem? _____

Reduce the potentially dangerous line overload without taking the nuclear plant offline. How do you do this? _____

_____

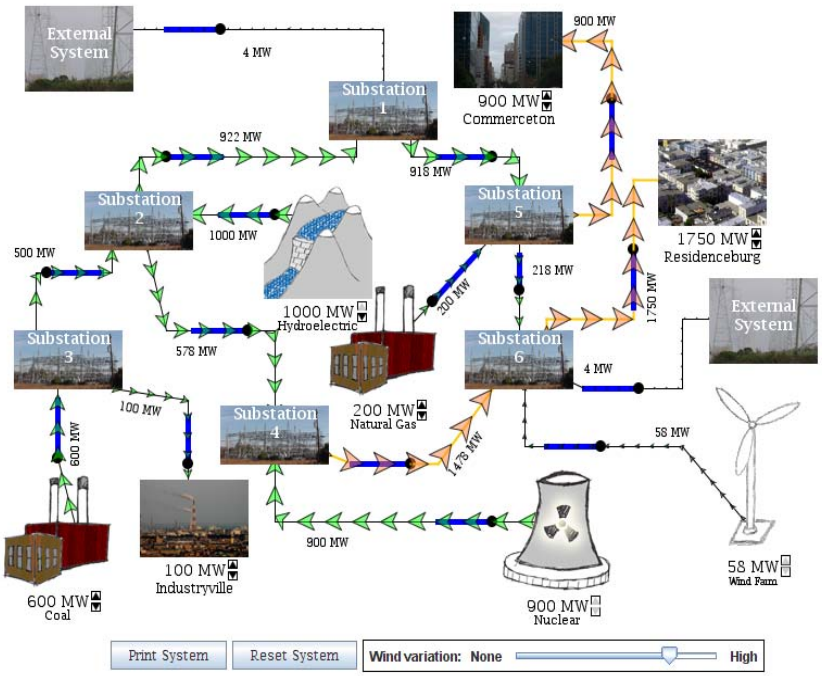
It's a hot summer day and power demand in Residenceburg is 1600 MW. Commerceton is demanding 850 MW and Industryville needs 800 MW. You put all of your generators online at maximum capacity. Are all of your lines operating safely? _____ Are you able to produce enough power to meet the demand or do you need to get power from the external system? _____

The Power Grid

Lesson 4

Comments for Teachers

This configuration of the applet at http://tcip.mste.uiuc.edu/applet2.html shows Residenceburg and Commerceton demanding power that is near the maximum transmission capacity of the power lines that supply their communities. The generators in the system are able to provide the demanded power with very little demand on the external systems, but if either or both of these communities demand much more power the transmission line supplying it may open and blackout the community. The high demand from these communities also puts a high load on lines elsewhere in the system. This is an example of how a problem is one part of the power grid can become a massive outage.



Discuss with students the benefits of combining local generation with the external system to allow for changing demands from users. While the interconnected grid allows for more efficient use of generated power, there is always the danger of a problem in one part of the grid affecting large areas of the system. Power engineers and others in the power industry are working to find ways to maximize the reliability of the power grid.


Courtesy of DOE/NREL, Credit - Linenberger, Mike

More Resources

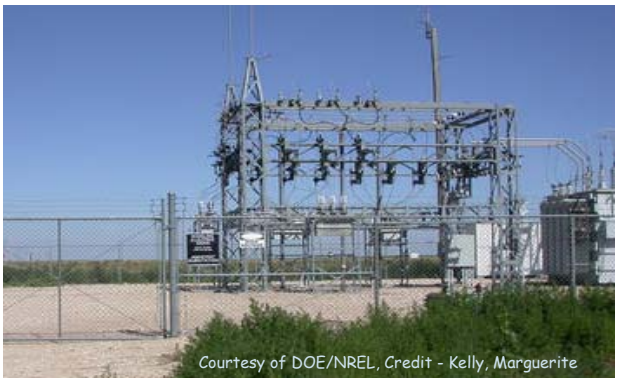
- The Federal Energy Regulatory Commission is responsible for the reliability of high voltage transmission between states. http://www.ferc.gov/about/ferc-does.asp

- AREVA has some animations and videos of their operations at http://www.areva.com/servlet/understand/ouroperations-en.html

- Energyville is an energy game sponsored by Chevron Corporation. http://willyoujoinus.com/energyville

The Power Grid

When the applet at http://tcip.mste.uiuc.edu/applet2.html opens (or is reset), the generators are producing more power than the communities are using, and power is being sent to the external system. Power system operators try to match power generation to demand, because this is the least expensive. When communities need more power, the generators are adjusted. The transmission line flows need to be kept at safe levels too.


Courtesy of DOE/NREL, Credit - Kelly, Marguerite

Reset the system and then set the power demand for Residenceburg at 1500 MW, for Industryville at 600 MW and for Commerceton at 800 MW. Turn the nuclear power plant on to meet this increased demand.

Bad weather can sometimes cause breaks in transmission lines. What happens to the system when you open the line between substations 4 and 6? _____

_____

_____

Reset the system, turn on the nuclear power plant and then open the line between substations 1 and 2. What happens? _____

_____

What is the problem? _____ Fix it by changing one switch. What did you do?_____

There are six major Regional Transmission Organizations (RTO's) or Independent System Operators (ISO's) in the United States. These voluntary, independent organizations monitor electricity generation and demand and communicate with power plants and utilities to balance supply and demand. The Federal Energy Regulatory Commission (FERC) encourages the formation of these nonprofit organizations because they promote efficiency in wholesale electricity markets.

Reset the system and then set both the coal generator and Industryville to 600 MW. What is happening between substations 2 and 3?

_____

_____

Open the line between substations 2 and 3. Now what is happening? _____

What happens to the other communities?

_____

Which line is this system do you think is most likely to overload? _____

_____

TCIP is funded by:

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