Week 1 Day 1

Introduction

- Conservation
- The Cost of Electricity
- Energy Sources
  - Today
  - Tomorrow
- Alternative Energy
  - Solar
  - Wind
- Transmission
- Energy Storage
- Class Talk Topics
- "Bird’s Eye View"
Energy Surge

Electricity required for low-end servers, in watts per square foot

Source: American Society of Heating Refrigerating and Air-Conditioning Engineers
Juiced Up

The cost of powering and cooling installed servers world-wide, versus the spending on new machines (in billions).

New Server Spending  Powering and Cooling

Source: IDC
Less is More

Electricity needed to light one kilometer of road annually by type of lighting technology, in kilowatt-hours

<table>
<thead>
<tr>
<th>Lighting Technology</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury vapor</td>
<td>17,800</td>
</tr>
<tr>
<td>High-pressure sodium</td>
<td>8,075</td>
</tr>
<tr>
<td>Philips' CosmoPolis (metal halide)</td>
<td>6,020</td>
</tr>
</tbody>
</table>

Note: Figures assume lighting spaced 25 meters apart, except CosmoPolis (29 meters); 1 km = 0.62 miles
Fig. 2a. The digital dimmable electronic ballast performs multiple functions in a DALI system. Its microcontroller stores information about each ballast under its control and takes commands from the digital bus and feeds them to the ballast control and ballast output stages. These analog stages interface directly to the fluorescent lamps.
Fig. 2b. The ballast can be packaged in a compact form factor suitable for connecting to many fluorescent lamps.
But consumers making an effort to go greener at home—and who also want to ditch their bulky old TV set—can be in a bit of a bind. The energy savings gleaned from swapping out incandescent light bulbs for energy-efficient compact fluorescent lights, for example, can easily be canceled out by the pileup in entertainment gear... when buying appliances, but she was unaware that Energy Star, for now, doesn’t cover sets when they are turned on.

“I’m retired, so my TV is on pretty much all the time,” she said. “I definitely would want better information before buying one of these, especially if there’s a lot of difference between them.”

Consumer electronics are expected to account for 18% of the average electricity bill by 2015.
1. Standby energy losses (kWh) become significant when multiplied by the number of units in operation.
Fig. 1. The voltage channel of the reference electric meter consists of a simple voltage divider providing a ratio of 400-to-1.
Fig 3. Hardware components of the reference design meter: Because of the highly integrated microcontroller, all that is needed is a display, a power supply, a nonvolatile memory, physical devices for communication, and passive signal conditioning for measuring voltage and current.
INTELLIGENT POWER

- Software agents use neural networks to monitor power consumption.
- Agent-enabled systems link to power meters; costs start in the thousands.
- System could eventually be integrated into small embedded modules.
Figure 6. The smart grid will be able to connect distributed energy resources through microrings. In this illustration, the squares represent generation and storage devices, such as fuel cells and batteries, that are distributed at or near consumers (circles). The microrings communicate via electricity routers (triangles).
Way Beyond ‘The Clapper’

At home, ZigBee sensors and switches build a network of appliances that can talk to each other, and to a central computer. This technology is less expensive than Wi-Fi or BlueTooth, and can be used to monitor and adjust the temperature, check whether a door is open, or turn on or off appliances.

Air Traffic Control

How ZigBee compares to the two major wireless-networking technologies:

<table>
<thead>
<tr>
<th>NAME</th>
<th>BANDWIDTH (megabits/sec)</th>
<th>BATTERY LIFE</th>
<th>USES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wi-Fi</td>
<td>11.00</td>
<td>1-3 hours</td>
<td>Internet browsing, PC networking, video monitors</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>1.00</td>
<td>4-8 hours</td>
<td>Hands-free cell phone, headsets, wireless print</td>
</tr>
<tr>
<td>ZigBee</td>
<td>0.25</td>
<td>2-3 years</td>
<td>Wireless switches and sensors, meter readings</td>
</tr>
</tbody>
</table>

Environmental use

Scientists planted sensors to monitor nesting conditions of Leach's storm petrel, left, a rarely-observed seabird.

Agricultural use

A vineyard installed sensors that track climate changes to help predict when certain grapes are ready to pick.

Source: WSJ research
Fig.3. The interface between a microcontroller (a PIC16F628) and a dimming control IC (an IR21952) is fairly straightforward. The controller stores values that determine the light output of each fluorescent and converts commands from the DALI bus for the control IC to execute.
Fig. 1. A DALI-based lighting system can control a building's fluorescent lighting by sensing the ambient light level and whether or not a specific light is being used by a person. The digital dimming ballasts can control each light fixture from full on to completely off.
Alternative energy still can't compete with fossil fuels on price. But the margins are narrowing, particularly since oil and gas prices have been rising. The math looks even more favorable if you consider the environment.

For years, the big criticism of alternative energy was cost: It was too expensive and therefore of little interest.

In contrast, coal-fired generation produced 49.7% of U.S. electricity supplies in 2005, followed by nuclear power at 19.3%, natural gas at 19.1% and hydropower at 6.5% and oil-fired generators at 2.5%.
Where Should U.S. Energy R&D Be Focused?

- Electrochemical: 25%
- Improved natural gas efficiency: 28%
- Biofuel genetic development: 28%
- Improved petroleum efficiency: 30%
- Hydroelectric: 33%
- Biofuel feedstock improvement: 38%
- Biofuel process improvements: 38%
- Hydrogen fuel sources: 41%
- Improved coal efficiency: 42%
- Tidal: 47%
- Nuclear, fusion: 47%
- Geothermal: 50%
- Nuclear, fission: 50%
- Fuel cell: 54%
- Solar, thermal: 61%
- Solar, wind: 70%
- Solar, photovoltaic: 74%
Fig 5. Software components of the reference design meter. Each of the tasks is called by a central task wheel without pre-emption. Higher priority tasks occur earlier in the task list and thus get an earlier chance at processor cycles. The message board facilitates inter-task notifications, as depicted by bold arrows in the diagram.
Fig. 6. Message processing in the electric meter reference design. Inbound messages are assembled, decoded and processed; outbound messages are formatted and built by separate tasks that communicate with one another using a message board.
The Cost of Power

States served by Bonneville Power Administration enjoy cheaper retail electricity rates than most other states. The Ice Harbor Lock and Dam (right) on the lower Snake River near Burbank, Wash., is one of 31 dams operated by Bonneville. Below, a sampling of 2005 rates:

<table>
<thead>
<tr>
<th>STATES SERVED BY BONNEVILLE POWER ADMINISTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
</tr>
<tr>
<td>Massachusetts</td>
</tr>
<tr>
<td>California</td>
</tr>
<tr>
<td>Texas</td>
</tr>
<tr>
<td>Florida</td>
</tr>
<tr>
<td><strong>Colorado</strong></td>
</tr>
<tr>
<td>Minnesota</td>
</tr>
<tr>
<td>Oregon</td>
</tr>
<tr>
<td>Washington</td>
</tr>
<tr>
<td>Idaho</td>
</tr>
</tbody>
</table>

National average: 8.09

Source: U.S. Department of Energy
Plugged In
Where some technology companies are building data centers to take advantage of low energy costs.

<table>
<thead>
<tr>
<th>COMPANY/LOCATION</th>
<th>ESTIMATED ENERGY COST, cents per kilowatt-hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yahoo Wenatchee, Wash.</td>
<td>1.8</td>
</tr>
<tr>
<td>Microsoft Quincy, Wash.</td>
<td>2.9</td>
</tr>
<tr>
<td>Yahoo Quincy, Wash.</td>
<td>2.9</td>
</tr>
<tr>
<td>Google The Dalles, Ore.</td>
<td>3.4</td>
</tr>
<tr>
<td>Firms also eyeing Austin, Texas</td>
<td>5.0</td>
</tr>
</tbody>
</table>

*For all industries, charged by full-service providers, 2004

Source: Energy Information Administration
Power Fluctuation
Price volatility in the energy trading markets is making them more attractive—and more risky—to Wall Street firms and hedge funds. Nymex-traded futures prices in three markets.

<table>
<thead>
<tr>
<th></th>
<th>Electricity</th>
<th>Natural gas</th>
<th>Crude oil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$120 per megawatt</td>
<td>$16 per million BTUs</td>
<td>$80 per barrel</td>
</tr>
<tr>
<td></td>
<td>105</td>
<td>14</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>

*Monthly peak electricity futures

Sources: Reuters via WSJ Market Data Group; Thomson Datastream
Energy Hogs

Heating accounts for the biggest chunk of a typical residential utility bill

- Appliances and lighting: 34%
- Space heating: 34%
- Water heating: 13%
- Electric A/C: 11%
- Refrigerator: 8%

Peak Demand prices $0.20

CA cap: 1$ per kWh home
4 $ per kWh industry

January: 8.3 cents, up 11.6% from year earlier

Jumping Juice
Average retail price of electricity for all sectors, in cents per kilowatt hour
Powering That Fancy TV

You may love that new plasma TV—until you get your energy bill. Here's how the price tag compares to a few other appliances:

50" Plasma TV: $130 Per Year

Refrigerator: $60 Per Year

(Price based on 12 cents per kilowatt hour. Assumes TV is on for about 5 hours per day.)
Mix of sources
Hydrocarbons
Hydro $H_2O$flow

U.S. Energy Sources in 2010

- Domestic Oil
- Nuclear
- Hydro
- Other
- Imported Oil
- Natural Gas
- Coal

Source: U.S. Department of Energy

Lutions. But some advocate con-

ider prices via
Run of the River (Low Head) Hydro
**Heavy Lifting**

Venezuela and Canada jump to the top of the oil patch when extra-heavy reserves are counted along with conventional sources. In billions of barrels:

- Venezuela*
- Saudi Arabia
- Canada
- Iran
- Iraq
- Kuwait
- Abu Dhabi
- Russia
- Libya
- Nigeria

*Amount of extra-heavy oil in Venezuela is a rough estimate only.

*Sources: BIP PLC, Oil & Gas Journal, Alberta Energy and Utilities Board, Canada's National Energy Board.*
Key Supplier

Top U.S. imports of crude oil and products by country of origin, January 2006

<table>
<thead>
<tr>
<th>Country</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>71.6 million</td>
</tr>
<tr>
<td>Mexico</td>
<td>55.7 million</td>
</tr>
<tr>
<td>Venezuela</td>
<td>47.7 million</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>42.4 million</td>
</tr>
<tr>
<td>Nigeria</td>
<td>36.8 million</td>
</tr>
<tr>
<td>Algeria</td>
<td>22.1 million</td>
</tr>
<tr>
<td>Iraq</td>
<td>16.5 million</td>
</tr>
<tr>
<td>Angola</td>
<td>13.4 million</td>
</tr>
<tr>
<td>Ecuador</td>
<td>11.8 million</td>
</tr>
</tbody>
</table>

Source: Energy Information Administration
Figure 2. Predictions indicate that the peak and subsequent decline in world oil production will probably occur within the next few decades. The data here are based on optimistic estimates that place the oil reserve at 2248–3896 billion barrels. Just how soon the peak will occur depends on annual population growth rates and increases in demand. The given ranges account for uncertainty in predicting the future: For each estimate of projected growth in demand for petroleum—0, 1%, or 2%—there exists a 95% chance that the peak will occur by the year on the left-hand end of the range and a 5% chance that it may occur as late as the year on the right-hand end. (Data from ref. 4.)
Safety in Numbers

Total U.S. coal production
1.2 billion short tons

Total coal-mining fatalities

*As of May 31, 2006.
Sources: U.S. Department of Energy, Energy Information Administration; Mine Safety and Health Administration
Barrels and Lumps

The U.S. has 27% of the world’s coal reserves and just over 2% of oil reserves. Global proved reserves, measured by energy output:

**Oil:** 6,958 quadrillion BTUs

- U.S.: 153
- Americas, ex. U.S.: 808
- Africa: 646
- Asia-Pacific: 230
- Europe and Eurasia: 817

**Coal:** 20,797 quadrillion BTUs

- Africa and the Middle East: 1,161
- U.S.: 5,643
- Europe, Eurasia: 6,568
- Americas, ex. U.S.: 633
- Asia-Pacific: 6,792

Source: BP Statistical Review of World Energy 2006
From Coal to Oil

One method for creating a synthetic alternative to crude oil:

Coal is placed in a chamber and heated with oxygen and steam, creating a synthetic gas or syngas. A byproduct of this process is carbon dioxide.

The gas is then placed in a Fischer-Tropsch reactor where heat and pressure convert it into liquid hydrocarbons.

This liquid can be sent to a refinery and made into fuels such as gasoline or diesel.

Source: WSJ research
### Power Play

Nuclear power as percentage of domestic electricity production among the Group of Eight leading nations, in 2003.

<table>
<thead>
<tr>
<th>Country</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>78%</td>
</tr>
<tr>
<td>Germany</td>
<td>28</td>
</tr>
<tr>
<td>Japan</td>
<td>23</td>
</tr>
<tr>
<td>U.K.</td>
<td>22</td>
</tr>
<tr>
<td>U.S.</td>
<td>19</td>
</tr>
<tr>
<td>Russia</td>
<td>16</td>
</tr>
<tr>
<td>Canada</td>
<td>13</td>
</tr>
<tr>
<td>Italy</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: International Energy Agency
Generating stations

Technologies: Nuclear -- Fusion

- The sun
- No commercial fusion reactors today
Generating stations

Technologies: Nuclear – Fission
Boiling Water Reactor (BWR)
  • radioactive steam in the turbine
  • uses enriched uranium
### WHO DOES ENRICHMENT?

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>CAPACITY, MTSWU*</th>
<th>PERCENTAGE, WORLDWIDE</th>
<th>TECHNOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>15 000</td>
<td>31.5</td>
<td>Centrifuge</td>
</tr>
<tr>
<td>United States</td>
<td>11 300</td>
<td>23.7</td>
<td>Diffusion</td>
</tr>
<tr>
<td>France</td>
<td>10 800</td>
<td>22.7</td>
<td>Diffusion</td>
</tr>
<tr>
<td>England, Germany, &amp; Netherlands**</td>
<td>8 300</td>
<td>17.5</td>
<td>Centrifuge</td>
</tr>
<tr>
<td>Japan</td>
<td>1 050</td>
<td>2.2</td>
<td>Centrifuge</td>
</tr>
<tr>
<td>China</td>
<td>1 000</td>
<td>2.1</td>
<td>Centrifuge</td>
</tr>
<tr>
<td>Brazil</td>
<td>120</td>
<td>0.3</td>
<td>Centrifuge</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>47 570</strong></td>
<td><strong>100</strong></td>
<td></td>
</tr>
</tbody>
</table>

* Metric ton separative work units per year for commercial-scale facilities operational and under construction.
** The three countries operate enrichment facilities through the Urenco consortium.

Source: IAEA Nuclear Fuel Cycle Information System, January 2006

### WHERE IS THE URANIUM?

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>1000S OF METRIC TONS OF URANIUM*</th>
<th>PERCENTAGE, WORLDWIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>989</td>
<td>28</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>561</td>
<td>16</td>
</tr>
<tr>
<td>Canada</td>
<td>438</td>
<td>12</td>
</tr>
<tr>
<td>South Africa</td>
<td>299</td>
<td>8</td>
</tr>
<tr>
<td>Niger</td>
<td>228</td>
<td>6</td>
</tr>
<tr>
<td>Namibia</td>
<td>213</td>
<td>6</td>
</tr>
<tr>
<td>Russia</td>
<td>158</td>
<td>5</td>
</tr>
<tr>
<td>Brazil</td>
<td>143</td>
<td>4</td>
</tr>
<tr>
<td>United States</td>
<td>102</td>
<td>3</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>91</td>
<td>3</td>
</tr>
<tr>
<td>Other countries</td>
<td>315</td>
<td>9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3 537</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

* Assured plus inferred resources recoverable at a cost of less than US $80 per kilogram as of 1 January 2003.
Generating stations

Technologies: Nuclear – Fission
Pressurized Water Reactor (PWR)

- radioactive superheated water makes clean steam in steam generator
- uses enriched uranium
URANIUM PRICES HAVE SPIKED BEFORE

Source: UXC.com
Help Wanted

Plans to build more nuclear-power plants in several countries threaten to strain the supply of expertise.

Nuclear power generation capacity by nation, in thousands of megawatts

- **South Africa**
- **India**
- **Taiwan**
- **China**
- **UK**
- **South Korea**
- **Russia**
- **Japan**
- **France**
- **U.S.**

**Legend:**
- Operational
- In construction
- Planned
- Proposed

Source: World Nuclear Association
Generating stations

Technologies: Nuclear

- Fusion
- Fission
  - Boiling Water Reactor (BWR)
  - Pressurized Water Reactor (PWR)
  - Heavy Water Reactor (PHWR)
Generating stations

Technologies: Nuclear – Fission
Pressurized Heavy Water Reactor (PHWR)

- PWR that uses heavy water ($D_2O$; $D = \text{deuterium isotope or heavy hydrogen}$)
- uses natural uranium
Generating stations

Technologies: Nuclear

- Fusion
- Fission
  - Boiling Water Reactor (BWR)
  - Pressurized Water Reactor (PWR)
  - Heavy Water Reactor (PHWR)
Generating stations

Technologies: Nuclear -- Fusion

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- radioactive superheated water makes clean steam in steam generator
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Generating stations

Technologies: Nuclear – Fission
Pressurized Heavy Water Reactor (PHWR)

- PWR that uses heavy water ($D_2O$; $D =$ deuterium isotope or heavy hydrogen)
- uses natural uranium
3M Co.'s composite-reinforced cable
On the Run

Change in futures prices over the past two years

Source: Thomson Datastream
Fig. 1. Rising copper costs are a factor when optimizing magnetic components for low cost.
Figure 2. HTS wires. First-generation commercially available HTS wires are a composite of silver or silver alloy and filaments of Bi$_{1.8}$Pb$_{0.3}$Sr$_2$Ca$_2$Cu$_3$O$_{10}$ or BSCCO-2223. (Courtesy of American Superconductor Corp.)
Some Important Characteristics of Ultracapacitors and Other Similar Energy Storage Devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Company</th>
<th>Energy density</th>
<th>Power density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial ultracapacitors</td>
<td>Maxwell/Montena</td>
<td>3.11 Wh/kg</td>
<td>0.8 kW/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.2 Wh/L</td>
<td>1.1 kW/L</td>
</tr>
<tr>
<td></td>
<td>Ness, Korea</td>
<td>4.1 Wh/kg</td>
<td>1.2 kW/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0 Wh/L</td>
<td>1.45 kW/L</td>
</tr>
<tr>
<td>Laboratory devices</td>
<td>Okamura Lab,</td>
<td>High power</td>
<td></td>
</tr>
<tr>
<td>(future products)</td>
<td>Japan Nanogate</td>
<td>model</td>
<td></td>
</tr>
<tr>
<td></td>
<td>capacitors</td>
<td>27 Wh/kg</td>
<td>8 kW/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 Wh/L</td>
<td>12 kW/L</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High energy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>model</td>
<td>model</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 Wh/kg</td>
<td>0.54 W/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>85 Wh/L</td>
<td>0.76 kW/L</td>
</tr>
<tr>
<td></td>
<td>Telcordia</td>
<td>10.5 Wh/kg</td>
<td>0.47 kW/kg</td>
</tr>
<tr>
<td></td>
<td>Asymmetrical</td>
<td></td>
<td>4.2 kW/kg</td>
</tr>
<tr>
<td></td>
<td>cells</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \eta = \frac{\text{discharge energy}}{\text{charge energy}} \]

\[ \eta > 95\% \text{ at power density of 1 kW/kg} \]

**Energy Loss** (self-discharge):
- 10% after >300 hours, 20% after >1000 hours

**Commercial Availability:**
- The largest single cell:
  - Operational voltage: 2.7 V,
  - Capacitance: 5000 F,
  - Resistance: 0.19 Ω, Energy storage: 18 kJ
- The capacitor module:
  - Operational voltage: 42 V,
  - Capacitance: 145 F,
  - Energy storage: 128 kJ

**Cost:**
- Current cost: ~0.05 Wh/$
- USDoE's future goal: >2 Wh/$
## Backup Juice

Some distributed-energy resources available commercially:

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>HOW IT WORKS</th>
<th>SIZE RANGE</th>
<th>FUEL TYPE</th>
<th>EFFICIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microturbines</td>
<td>Small combustion turbines that generate electricity</td>
<td>25 kW to 500 kW</td>
<td>Natural gas, hydrogen, propane, diesel</td>
<td>20% to 30%</td>
</tr>
<tr>
<td>Combustion Turbines</td>
<td>Energy is extracted from the high-pressure, high-velocity gas flowing from the combustion chamber</td>
<td>500kW to 25MW</td>
<td>Natural gas, liquid fuels</td>
<td>20% to 45% depending on size</td>
</tr>
<tr>
<td>Reciprocating Engines</td>
<td>A reciprocating, or internal-combustion, engine converts the energy contained in a fuel into mechanical power</td>
<td>5 kW to 7 MW</td>
<td>Natural gas, diesel, landfill gas, digester gas*</td>
<td>25% to 45%</td>
</tr>
<tr>
<td>Fuel Cells (phosphoric acid fuel cells)</td>
<td>A fuel cell is similar to a battery in that an electrochemical reaction is used to create current</td>
<td>100 kW to 200 kW</td>
<td>Natural gas, landfill gas, digester gas*, propane</td>
<td>36% to 42%</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>Solar cells convert sunlight directly into electricity</td>
<td>Less than 1kW to 100 kW</td>
<td>Sunlight</td>
<td>5% to 15%</td>
</tr>
<tr>
<td>Wind</td>
<td>A turbine with fan blades harnesses the wind to generate electricity</td>
<td>Several kW to 5 MW</td>
<td>Wind</td>
<td>20% to 40%</td>
</tr>
</tbody>
</table>

Source: California Energy Commission

*Digester gas is from sewage treatment*
Some broadband-over-power-line installations cause harmful interference to licensed stations, and these cases are being pursued...with the FCC

—Paul L. Rinaldo
Chapter 29  Transmission and Distribution Solid-State Controllers

This pioneering chapter discusses the current state of the electronic control of large blocks of ac power. This has been made possible by the development of IGBTs and GTOs that can switch large currents at high voltages. The chapter reveals how the reactance of a line can be reduced by series compensation and how this enables the control of power flow (Section 29.1 and 29.2). It also shows how capacitors and inductors can be replaced by electronic converters that create either lagging or leading reactive power by switching alone. This remarkable achievement is having repercussions throughout the power industry (Section 29.3).

As an example of what is happening, you are invited to read Section 29.6 that describes a 20 MW frequency converter that has absolutely no moving parts. Then read on in Section 29.5 that discusses a unified power flow controller (UPFC) that can electronically modify the phase-shift and magnitude of an injected voltage and thereby control the magnitude and direction of active and reactive power flow between two interconnected regions.
Chapter 30  Harmonics

Industrial and commercial enterprises, government and private institutions, as well as electrical utilities are becoming increasingly aware of distortion and the quality of electric power. The main problem is the effect of harmonics on electrical equipment and distribution systems. Harmonics are becoming very important because they are generated by electronic drives, computers and other switching devices that are being installed everywhere.

This important chapter explains the origin of harmonics and their effects. It shows that harmonics are always created by non-linear loads. Thus, when a perfect sine wave of voltage or current is applied to a load that contains linear and non-linear elements, the latter will always generate harmonic voltages and currents.

In effect, a non-linear load behaves like a frequency converter. It converts a portion of the fundamental power it absorbs into harmonic power. One striking example of a non-linear load is a simple switch that opens and closes periodically. The switch absorbs power at the fundamental frequency and converts it into harmonic power of many different frequencies.
Another important feature is that a periodic switch can either absorb or deliver reactive power at the *fundamental* frequency. This makes it possible to simulate the properties of capacitors and inductors by using an appropriate switching procedure.

The book reveals a simple method of analyzing a distorted wave. It helps the student get a better grasp of the meaning of harmonics. The method is based on Fourier series, but in a very user-friendly way. Software on harmonic analysis is available that yields an immediate solution. However, students find it more interesting when they actively participate in the harmonic-solving procedure. In this regard, a spreadsheet is easy to set up and the computation is straightforward. Problems toward the end of the chapter were solved this way.

Although this chapter appears at the end of the book, it may be referred to whenever the need arises.
Chapter 26  Distribution of Electrical Energy

The distribution of electric power covers all systems operating roughly between 120 V single-phase, and 69 kV, 3-phase. This chapter describes the equipment used to transport, regulate, protect, interrupt and transform electric power for use by the ultimate consumer. Also covered are the important questions of grounding and the safety measures needed to prevent electric shocks (Sections 26.18 to 26.22).

Chapter 27  The Cost of Electricity

Everyone is interested in the cost of electricity. The basic elements that make up an electricity bill are presented here, together with the reasons that justify the various tariff structures.
Chapter 25 Transmission of Electrical Energy

Transmission is the term used whenever electric power is carried over high-voltage (HV) and extra-high-voltage (EHV) lines. In the same style as the previous chapter on generation, this chapter highlights the essential features of transmission, using simple mathematics. A transmission line is composed of a string of $L$, $R$, $C$ components that determine its power-handling capacity and voltage regulation. The effect of these components is explained in simple terms by making use of phasor diagrams. Another topic of interest is the so-called BIL of electrical apparatus, a term that describes its tolerance level to lightning strokes and switching transients (Sections 25.10 to 25.12).
late 1800's

"WHAT WILL HE GROW TO?"

late 1900's Telecom internet
Figure 1. World population growth since the 13th century.
A Bird’s Eye View

- Generating stations – make power
- Loads – use power
- Bulk transmission system – move power to the distribution system
- Distribution system – move power to the loads
A Bird’s Eye View

Central Power Stations
Gen
Gen
Gen

Bulk Transmission system

Load

Large Industrial

Distributed Generation

Gen
Gen

Distribution system

Load

Industrial

Load

Residential

Commercial
578 MW Steam Turbine/Generator
Generating stations

Technologies: Fossil Fueled
- boiler/steam turbine
  - coal
  - oil
  - gas
- Combustion turbine
  - gas
  - oil
  - coal gasification
Figure 3. The electric grid is the high-voltage system that connects power generators to consumers through the power-delivery system. Power stations generate medium voltages that are stepped up so that electricity can be efficiently transmitted. Step-down transformers (not all of which are shown in the figure) decrease the voltages delivered to consumers.
Figure 4. Rotating machines.
This schematic shows a cut-away view of a rotating machine with HTS rotor and copper armature coils. The rotor coils are cooled by helium gas or liquid neon. Racetrack-shaped rotor coils are made of HTS wire that operates at around 30 K and 2 T. The armature coils connect to the outside electrical circuit. Like the rotor coils, they are racetrack-shaped. The armature coils, though, have a more complex nested configuration; they face the rotor coils around the cylindrical periphery of the rotor.