A Brief Introduction to Renewable Energy and the Smart Grid

Seattle City Light

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Power Engineering is Sexy Again

Why the New Interest in Power Engineering?

• Renewable Energy
• Smart Grid
• Electric Vehicles
• Service to society
Renewable Energy

- Physics tells us that energy cannot be created or destroyed, but only converted from one form to another
- Technically, there is no such thing as renewable energy
- “Renewable Energy” is a bit of a misnomer

Renewable Energy

- Renewable energy are energy flows which are replenished at the same (or greater) rate than they are used over the timescale considered
Renewable Energy

• What we commonly consider renewable resources come from only three origins
  - Solar Radiation
  - Heat from the Earth
  - Gravity

Solar Radiation

• The Sun’s solar radiation is responsible for:
  - Solar
  - Biomass (photosynthesis)
  - Hydro (evaporation)
  - Wind (uneven heating of the atmosphere)
  - Wave (a result of wind)
Solar Radiation

• Sun provides 5.4 YJ/yr (yotta joules: $1 \times 10^{24}$ J) to Earth’s atmosphere
• Approx 30% is deflected back into space
• Remaining 3.8 YJ is approximately 10,000 times the amount of energy used by fossil and nuclear fuels per year

Solar Radiation

• Solar radiation also drives wind, waves and photosynthesis
  ▪ Wind and waves: 11.17 ZJ/yr (zetta joule: $1 \times 10^{21}$ J)
  ▪ Photosynthesis: 1.26 ZJ/yr
Heat from the Earth

• Interior of the Earth is at a high temperature
• Causes:
  ▪ Decay of radioactive material
  ▪ Residual heat from the formation of the Earth
• Note: scientists’ knowledge of the core of the Earth is limited

Heat from the Earth

• We can only harness the heat that makes it way to the crust (5-50 km depth)
• Approximately 4 ZJ of energy stored as water or steam at depths of 10km
• Pockets of heat can be used to drive steam turbines in geothermal plants
Gravity

- Potential energy
- Gravity from the moon and Sun cause tides (mostly the moon)
- Approx. 93.6 EJ/yr (exajoule: $1 \times 10^{18}$ J)
- Result is a very gradual slowing down of the Earth (not on any appreciable timescale)
- Tidal action can be harnessed by tidal generators

Harnessing Renewable Energy

- Enough renewable energy present to more than fulfill mankind’s energy appetite
- How well are we doing at harnessing it?
Harnessing Renewable Energy

• In 2008: 4,119 TWh (tera watt hours) of electrical energy was generated
• Less than 10% (372 TWh) is from renewable resources

Harnessing Renewable Energy

• Match the source to its share of the renewable energy generated

<table>
<thead>
<tr>
<th>Source</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>67%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>15%</td>
</tr>
<tr>
<td>Hydro (conventional)</td>
<td>4%</td>
</tr>
<tr>
<td>Solar/PV</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Wind</td>
<td>14%</td>
</tr>
</tbody>
</table>
Harnessing Renewable Energy

- Match the source to its share of the renewable energy generated

- Biomass: 67%
- Geothermal: 15%
- Hydro (conventional): 4%
- Solar/PV: <1%
- Wind: 14%

Note: Tidal, wave and others are not utilized on any appreciable scale
Harnessing Renewable Energy

Dependent on amount of snow/rain each year

TOP 5 STATES WITH THE MOST INSTALLED WIND CAPACITY
Washington State
1,964 MW
California
2,793 MW
Iowa
3,670 MW
Texas
9,727 MW
Wind turbines convert kinetic energy in the wind into electrical energy.

Kinetic Energy of mass of air \( \frac{1}{2} m v^2 = \frac{1}{2} A \rho \ell v^2 \)

Power Extracted \( \frac{1}{2} C_p A \rho v^3 \)
performance coefficient < 59% (Betz Limit), closer to 40%
can vary seasonally and geographically by 10%

\[ P_T = \frac{1}{2} C_P \rho v^3 \]

area swept by rotor

cubic relationship

Bigger is Better

2.5 MW
2.0 MW
1.5 MW
1.0 MW

80 m
54 m
How do we measure performance?

Capacity Factor: \( \frac{\text{actual energy production}}{\text{maximum energy production}} \)
Most wind plants have annual capacity factors between 25% and 40%.
Location, Location, Location

U.S. Wind Map at 80m

Based on 5-min readings from the BPA SCADA system for points 45588, 79687
Balancing Authority Load in Red, Wind Generation in Blue; Installed Wind Capacity=1469 MW
BPA Technical Operations: Roy Ellis (roylellis@bpa.gov)
Windy areas are far from load
For More Information on Wind Energy

- www.awea.org
- www.eia.doe.gov/fuelrenewable.html
- www.windaction.org/
Why the New Interest in Power Engineering?

- Renewable Energy
- Smart Grid
- Electric Vehicles
- Service to society

Is the existing grid dumb?
The Smart Grid is...

A common theme in the various definitions of the Smart Grid is the increased interaction of the power system with communication networks and information technologies to supply electrical energy in a more reliable, efficient, secure, and environmentally neutral manner.
A Smart Grid should be able to:

1. develop, store, send and receive digital information through one or a combination of devices and technologies.

2. develop, store, send and receive digital information to or from a computer or other control device.

3. measure, monitor and report electricity use and power quality characteristics.

4. sense and localize disruptions on the grid and communicate such information for reliability and security purposes.
A Smart Grid should be able to:

(5) detect, prevent, communicate with regard to, respond to, or recover from system security threats.

(6) have any appliance or machine to respond to signals, measurements, or communications automatically or in a manner programmed by its owner or operator.

(7) use digital information to operate functionalities on the electric utility without human interaction.

(8) use digital controls to manage and modify electricity demand, enable congestion management, assist in voltage control, provide operating reserves, and provide frequency regulation.
Customer Domain

- Service Provider
- Operations
- Distribution
- Markets

Building / Commercial
- Meter
- Solar Generation
- Multi-Dwelling

Thermal Storage

Solar

Distributed Wind

Co-Generation

Electric Vehicle

Automation

Thermostat

Industrial Gateway

Lighting

Industrial Processes

Sub-Metered

Home

Gateway (EOG)

Appliances

Smart Grid Technologies

- Smart Appliances
  - Two-way communication
    - Zigbee, powerline communication (PLC)
  - Remotely controllable
  - Owner-programmable
Smart Grid Technologies

- Home Area Network (HAN)
  - Communication between smart appliances and controller
  - Interfaces with smart meter

Smart Grid Technologies

- Advanced Metering Infrastructure (AMI) with Smart Meters
  - Two-way communication with utility
  - Real-time energy usage
  - Time-dependent price signals
  - Power quality characteristics
  - Control signals
Consumer Empowerment

- Consumers can respond to price signals
- Known as Demand Response
- Examples:
  - laundry done at night to avoid high prices
  - informed comfort versus cost tradeoff decisions for air conditioning, etc.

Enhanced Asset Utilization

- Price-sensitive demand could result in reshaped load profile
- Better utilization of assets
Smart Grid Domains

Distribution Domain
Smart Grid Technologies

- Automated substation/distribution devices
  - Transformers
  - Capacitor banks
  - Switches
  - Sectionalizers
- Remote power-harvesting sensors
- Control of distributed generation

Smart Grid Domains
Smart Grid Technologies

- Phasor Measurement Units (PMU)
  - Voltage magnitude and phase measurement
  - Rely on GPS technology to synchronize several PMU readings, leading to enhanced knowledge of system state
Smart Grid Technologies

- Remote power-harvesting sensors
- Video sagometers
  - Detect when transmission lines are overloaded
  - Dynamic line ratings

The Smart Grid is a Work in Progress

- Standards
- Legislation
- Pilot Projects
Smart Grid Case Studies

• +100 projects funded by Federal Government
  ▪ Xcel Energy—SmartGrid City
  ▪ GridWise™ Demonstration Project

SmartGridCity—Boulder, CO

• Started in 2008
• +20,000 smart metered customers
• Smart Grid infrastructure
  • Communication
  • Sensing
  • Automation
SmartGridCity—Boulder, CO

• It's so smart that the number of customer-voltage complaints — about either surges or drops — went from 70 in 2007 to zero so far this year.
• It's so smart that it identified a transformer that was overloaded and needed to be replaced — before it got fried.

Source: Mark Jaffe, Boulder's SmartGridCity brings Xcel up to speed on electric picture, The Denver Post, Sept. 9, 2009.

SmartGridCity—Boulder, CO

• Original Project Cost: $15.3 million
• Revised Project Cost: $42.1 million
• Only 43% of residents have meters
• Tried to pass on costs through rate increase
• Trouble in installing communication network due to...
GridWise™ Demonstration Project

- Pacific Northwest National Laboratories and regional utilities and industry
- Olympic Peninsula of Washington State
- March 2006 through March 2007
- Tested smart appliance technology and demand-response of customers
GridWise™ Demonstration Project

- Key Results and Findings:
  - Showed feasibility of internet-based coordination of customer demand response
  - Peak load reduced by 15%
  - High customer adoption rate if the human interface is made simple
  - 10% reduction on electricity bills
  - Regulatory rather than technical barriers are most significant

Observations

- What is the business case?
- Customer benefits are poorly quantified
- Electricity is relatively inexpensive and people will pay for convenience
- Customers resent being treated like lab rats
- Smart Grid is not only Smart Meters!
- Working with regulators is key
IEEE Smart Grid

- Cross-society effort
- Transactions on Smart Grid launched June 2010
- IEEE Smart Grid web portal

http://smartgrid.ieee.org/

Questions?
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