A Networking Approach to the Smart Grid

S. Keshav

Joint work with Prof. Catherine Rosenberg, ECE, UW

All images courtesy Wikipedia, unless otherwise specified
Outline

- What is the grid?
- Why the smart grid?
- Challenges
- ISS4E
- Overview of projects
What is the grid?
Constraints

- Nearly uncontrolled demand
- Generation is complex, diverse, sometimes inflexible
- Reliability
- Almost no storage
Problems...
Estimated U.S. Energy Use in 2008: ∼99.2 Quads

Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant “heat rate.” The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527
“15% of the generating capacity in Massachusetts is needed fewer than 88 hours per year”

Philip Giudice, Commissioner, Massachusetts Department of Energy, Nov. 30, 2009
Energy price volatility

Monthly U.S. Natural Gas Wellhead Price

From US EIA http://eia.doe.gov
Energy security

World map showing top 10 Oil Reserves Countries

<table>
<thead>
<tr>
<th>Oil Reserves</th>
<th>Billions of Barrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Saudi Arabia</td>
<td>261.8</td>
</tr>
<tr>
<td>2. Canada</td>
<td>180.0</td>
</tr>
<tr>
<td>3. Iraq</td>
<td>112.5</td>
</tr>
<tr>
<td>4. U.A.E</td>
<td>97.8</td>
</tr>
<tr>
<td>5. Kuwait</td>
<td>96.5</td>
</tr>
<tr>
<td>6. Iran</td>
<td>89.7</td>
</tr>
<tr>
<td>7. Venezuela</td>
<td>77.8</td>
</tr>
<tr>
<td>8. Russia</td>
<td>60.0</td>
</tr>
<tr>
<td>9. Libya</td>
<td>29.5</td>
</tr>
<tr>
<td>10. Nigeria</td>
<td>24.0</td>
</tr>
</tbody>
</table>

Map not to scale.
Copyright © 2006 Compare Infobase Limited

From mapsofworld.com
6 Cascading failures
7 Metering?
EVs
9 Lead times
Facts...

• If the grid were just 5% more efficient
  – equivalent to permanently eliminating the fuel and greenhouse gas emissions from 53 million cars.

• If every American household replaced just one incandescent bulb with CFL
  – would conserve enough energy to light 3 million homes

http://www.oe.energy.gov/
### Facts

<table>
<thead>
<tr>
<th>TWh generated (2008 est.)</th>
<th>Daily kWh/capita (2008 est.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 4,369</td>
<td>39.25</td>
</tr>
<tr>
<td>China 3,457</td>
<td>7.04</td>
</tr>
<tr>
<td>India 830</td>
<td>2.02</td>
</tr>
<tr>
<td>Canada 651</td>
<td>51.50</td>
</tr>
</tbody>
</table>
Great opportunities!
The smart grid
New technologies

- Demand management
- Data collection
- Distributed and renewable generation
- Ubiquitous Communication
- EVs
- Storage
Challenges

Bi-directional energy flows

Renewables
- millions
- non-disspatchable
- intermittent

Consumer incentivization

Exploiting elastic loads

Reliable communication
- sensors

Storage
A relatively static, predictable, stable system with inelastic loads and a few points of control

A highly dynamic system with elastic loads and millions of points of control

A paradigm shift
Beyond green networking

• Internet concepts and technologies can be used to smarten and green the grid
Similarities

- Vast
- Historically similar
  - bottom up + top down
Similarities

- Both match geographically distributed demands with distributed generation
United States transmission grid
Source: FEMA
Similarities

- Heterogeneous
- Critical to society
- Ossified
• Hierarchical
  – mesh-like core designed for high capacity
  – tree-like access network
A mid-size ISP

By R. Govindan et al
Kansas Electrical Transmission Grid
Similarities

- Simple API

The Internet hourglass

Applications: Web, FTP, Mail, News, Video, Audio, ping, kazaa

Transport protocols: TCP, SCTP, UDP, ICMP

IP

Ethernet, 802.1, Power lines, ATM, Optical, Satellite, Bluetooth

Image courtesy David Alderson, Caltech
Differences

- Electricity has no **headers**
  - no type
  - no destination
Differences

• Primarily one-way vs. primarily two-way flows
Differences

- Electricity loads are predictable
Differences

- Grid has practically no storage
  - Batteries not quite the same as DRAM!
  - $500/KWh
ISS4E vision

To apply our expertise in Information Systems and Sciences to find innovative solutions to problems in energy systems.

4 faculty
4 Master’s
4 PhDs
1 postdoc position
Focal point at UW for research in energy studies

- More than 70 faculty members with graduate students and postdoctoral fellows working as multi-disciplinary research teams

- Research areas:
  - Renewable Energy
  - Storage & Transport
  - Conversion Technologies
  - Emission Management
  - Power System Optimization
  - Sustainable Energy Policy
  - Conservation, Demand Mgmt, Energy Efficiency
  - Green Auto Powertrain
  - ISS4E

WISE
Lab facilities

- Sensors for building monitoring
- Smart power strips for home monitoring and control
- ENVI systems for home energy data collection
- Custom-built wireless sensors for solar panel monitoring
Data-driven approach
Fine grained (6 sec)

24 homes

1 year

Figure 3: Load measurements from houses in three classes for one week with busy hours marked by vertical lines.
Other datasets

- appliance energy use (SmartA, IBM)
- commercial building energy use over 2-4 years (Pulse)
- taxi driving records (Cabspotting)
- car fleet records (CrossChasm)
- electricity prices (IESO, UK, India)
- weather records
- ...

Measure
Markov models for home energy use
Other models

- appliance elasticity model
- transformer loading model
- aggregate electricity load model
- EV fleet charging model
- data center load model
- grid regulation model
- storage sizing model
- …
Use teletraffic theory to analyze effect of storage on distribution networks

- Considers trade-off between access latency, electricity cost and carbon footprint
- Can reduce more than 10% carbon emission for free

- Can further reduce carbon emission by 30%

FORTE finds an optimal upgrade plan for distributed datacenters.
Effect of storage in the home
Other analysis

- effect of smart appliances on peak energy
- regulation services provided by fleet charging
- benefit of EVs to taxi fleets
- effect of smartphones on user behaviour modification
- solar cell anomaly detection
- …
Design

Controller

Broadcast

House

PHEV

Lateral
Design
Other control mechanisms

- fleet charging control
- home storage control
- CDN request routing and data placement
- ...

Design
Gridlab-D for detailed grid simulation
Smartphone-based application architecture

HomeOS
(Microsoft Research)
Home in the Sky

Virtual Home

Real Home

Computer

Smartphone
Prototype system for solar panel anomaly detection
Conclusions

• The next decade will decide the grid of 2120
• Internet ~= Grid
• 40 years of Internet research {could, should, may} help
• Rich area for research
More information

http://blizzard.cs.uwaterloo.cs/iss4e