Optimization, Monitoring, and Control for Smart Grid Consumers

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Outline

- Energy efficiency example: Honeywell Novar
- Smart grid and commercial buildings
- Smart grid and industrial facilities
- Research underway: microgrid optimization
Novar Remote Energy Management Service

- Honeywell Novar keeps energy consumption and costs low for multi-site businesses and reduces peak loads for utilities
  - 6 gigawatts of load in customer sites under management in U.S.
- Novar multi-site customers include:
  - Walmart, Office Depot, Home Depot, Lowes
- Internet and standard protocols used for communication
- Typical results
  - 20-40% improvement in energy efficiency and maintenance costs
  - 10-20% reduction in peak use
- Analysis & Feedback
  - comparison between buildings
  - comparison to baseline and model
  - root cause analysis
  - specific suggestions

Secure cloud-based energy management
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U.S. energy consumption (all sources)

About 70% of the nation’s electricity consumption is in homes and buildings.

Building automation controls 66% of energy use in homes and buildings today—the smart grid will enable more.
Wide range of building energy costs

2003 Energy Expenditures per Sq. Ft. of Commercial Floorspace and per Building, by Building Type ($2006) (1)

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Per Building Per Square Foot</th>
<th>Per Building Per Square Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Service</td>
<td>4.54</td>
<td>25.3</td>
</tr>
<tr>
<td>Food Sales</td>
<td>4.36</td>
<td>24.2</td>
</tr>
<tr>
<td>Health Care</td>
<td>2.57</td>
<td>63.3</td>
</tr>
<tr>
<td>Public Order and Safety</td>
<td>1.93</td>
<td>29.8</td>
</tr>
<tr>
<td>Office</td>
<td>1.87</td>
<td>27.7</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>1.61</td>
<td>22.9</td>
</tr>
<tr>
<td>Lodging</td>
<td>1.60</td>
<td>57.3</td>
</tr>
</tbody>
</table>

http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.3.9

- Over an order-of-magnitude spread in energy costs, both on per-sq-foot and per-building bases, across types of commercial buildings

High diversity in construction and use of buildings
Various Daily Profiles …

... commerce

... two-shift manufacturing

... casino

... administration
Commercial buildings—smart grid complexities

- The energy used for “overhead” (HVAC / lighting / etc.) must be balanced with the energy used for “production,” or meaningful work in a facility
  - requires detailed knowledge of overhead and production loads
- Building codes must be followed (indoor air quality, energy efficiency, etc.)
  - specific operating conditions must be maintained
- Control schedules for commercial buildings must be designed with knowledge of weather, indoor conditions, expected occupancy, etc.
  - building should be “comfortable” just in time for first occupants but not any earlier
- Startup of loads (in occupied mode or after power failure) must be managed
  - e.g., electrical spikes cannot be tolerated
- Complete replacement of existing control systems typically not feasible
  - gateways used to interface with newer technologies
- Thermal / ice storage increasingly common for load shifting
  - requires knowledge of current and future cost of energy, weather information, current and future demand, existing storage capacity, etc.

*Domain knowledge essential for load management*
Building automation system example

- EBI Server
- Stations or Browsers
- Wireless Devices (Operations and Maintenance)
- Distributed System Architecture
  - Campus 2
  - Campus 3
- Casual Users
- MIS/Human Resources

**LAN**
- Honeywell Security Manager Server (Optional)
- Honeywell Building Manager Server (Optional)
- Honeywell Life Safety Manager Server (Optional)
- Honeywell Energy Manager Server
- Digital Video Manager (Optional)

**WAN**
- BACnet
- LON
- EIA
- Excel Life Safety Panel
- Modbus
- Wireless Ethernet
- Pulse Meters
- Intelligent Meters
- IP Cameras
- Analog Cameras

**Security Manager**
- Intrusion Panels
- CCTV
- Temperature

**Building Manager**
- Third Party Controllers

**Life Safety Manager**
- Third Party Controllers

**Energy Manager**
- Third Party Controllers

**Digital Video Manager**
- Third Party Controllers
Considerable variety in energy management functions in buildings. Function use depends significantly on type of business.

Increasing integration between facility-side and business-side systems/functions.

Figure 2.1. Surveyed Prevalence and Usage Rates for Selected EMCS Functions (from Lowry 2002)

C&I smart grid example: Johnson Controls (JCI) worked with Georgia Tech to implement a real-time-pricing controller for the campus. The BACnet-based JCI building automation system receives hour-ahead prices from Southern Company and adjusts temperature set points and boiler fuel source. Annual savings are estimated at $650K – $1M.

For more information: http://www.fire.nist.gov/bfrlpubs/build07/PDF/b07028.pdf
C&I smart grid example:
Honeywell Novar is the global leader in multisite energy management, with remote energy supervision of > 10,000 sites, including 65% of the top U.S. retailers (Walmart, Home Depot, Staples, Sam’s Club, ...). In the U.S., Novar manages over 6 GW of loads in commercial buildings.

For more information:  http://www.novar.com/
C&I smart grid example:
Ice Energy’s storage solution (Ice Bear) enables peak load reduction in commercial buildings through the generation of ice during off-peak times and the use of the ice for cooling during peak load. A controller and ESI are part of the Ice Bear product, which determines the energy source (the EMS controls the cooling demand). Condensing unit peak reduction of 94 – 98 per cent is routinely realized in commercial installations.

Courtesy of B. Parsonnet, Ice Energy
For more information:  [http://www.ice-energy.com/](http://www.ice-energy.com/)
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## Industrial sector—electricity use (U.S.)

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Total electricity used (10^6 kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals</td>
<td>207,107</td>
</tr>
<tr>
<td>Primary Metals</td>
<td>139,985</td>
</tr>
<tr>
<td>Paper</td>
<td>122,168</td>
</tr>
<tr>
<td>Food</td>
<td>78,003</td>
</tr>
<tr>
<td>Petroleum and Coal Products</td>
<td>60,149</td>
</tr>
<tr>
<td>Transportation Equipment</td>
<td>57,704</td>
</tr>
<tr>
<td>Plastics and Rubber Products</td>
<td>53,423</td>
</tr>
<tr>
<td>Nonmetallic Mineral Products</td>
<td>44,783</td>
</tr>
<tr>
<td>Fabricated Metal Products</td>
<td>42,238</td>
</tr>
<tr>
<td>Machinery</td>
<td>32,733</td>
</tr>
<tr>
<td>Wood Products</td>
<td>28,911</td>
</tr>
<tr>
<td>Computer and Electronic Products</td>
<td>27,542</td>
</tr>
<tr>
<td>Textile Mills</td>
<td>19,753</td>
</tr>
<tr>
<td>Beverage and Tobacco Products</td>
<td>17,562</td>
</tr>
<tr>
<td>Printing and Related Support</td>
<td>13,089</td>
</tr>
<tr>
<td>Electrical Equip., Appliances, and Components</td>
<td>12,870</td>
</tr>
</tbody>
</table>

(plus smaller contributors)

http://www.eia.doe.gov/emeu/mecs/mecs2006/pdf/Table11_1.pdf
Industry—smart grid complexities

• Industrial plants can be high consumers of electricity
  – up to 100s of MW at peak load and 100Ms of kWh annual consumption
  – Direct connection to transmission and distribution grids
• Large manufacturing facilities can have substantial on-site generation
  – U.S. industrial generation: 142 B kWh, about 15% of net electricity demand
  – sales and transfers offsite: 19 B kWh
• Automatic generation control (AGC) and ancillary services
  – large plants can play important roles for grid reliability and frequency regulation
• Industrial users have high interest in protection of usage data
  – load information is often highly confidential and competition-sensitive
• Manufacturing processes can be inflexible with respect to time
  – interdependencies in process must be respected, for performance and safety
• Many customers require dynamic pricing models for process optimization
  – forecasted pricing and special tariffs from utilities in many cases

Domain knowledge essential for load management
Distributed control system (DCS) example

- Hundreds of controllers
- Tens of thousands of field devices
- Hundreds of console stations
- Hundreds of third-party interfaces
- Hundreds of thousands of I/O points—millions soon?
- Tens of millions of lines of code
- Tens of thousands of processors
- Cyber and physical security
High-security network architecture

- Level 3.5 DMZ
  - Terminal Services Srv
  - PHDS Srv
  - OS Patch & Virus Protection
  - eServer

- Level 3 Advanced Control
  - DVM
  - PHD/S
  - BCK Srv
  - Domain Controller & IAS

- Level 2 Supervisory Control
  - PKS Srvs
  - ACE
  - ESF
  - ESC
  - DC

- Level 1 Process Control
  - C300 Controller
  - C200 Controller

- Level 4 Wireless DMZ
  - Business LAN

- Comm flow
  - L4 to L4
  - Limited L3.5 to L3.5
  - Very Limited L3.5 to L4
  - No Direct communications between L4 & L3
  - No Direct communications between L1 & L3, L2 or L4
  - Limited L2 to L2
  - Very Limited L2 to L3.5
  - L3 to L3
  - Very Limited L2 to L1
  - L1 to L1

- NON-FTE redundancy
  - Optional Router depending on PCN complexity (may connect directly to FW)

- FTE
  - Control Firewall Pair
  - NON-FTE redundancy
  - Limited L1 to L1

- FTE
  - Limited L1 to L3
  - Limited L2 to L1
New DOE smart grid cybersecurity award

- **Role-Based Access Control (RBAC)-Driven Least Privilege Architecture for Control Systems**
- Building upon previous DOE research, Honeywell will research, develop and commercialize an architecture for critical systems that limits each operator’s access and control privileges to the appropriate level for their job function.
- **Partners:** Univ. of Illinois, Idaho National Laboratory

**C&I smart grid example:**
Alcoa Power Generation, Inc. participates in the MISO wholesale market by providing regulation of up to 25 MW as an ancillary service through control of smelter loads at Alcoa’s Warwick Plant (Ind.). APGI is reimbursed for load modulation as if the energy was generated. Total facility load is 550 MW. More than 15 GW of regulation capability is available in U.S. industry. Additional capability exists for other ancillary services.

For more information:
C&I smart grid example:
A food manufacturer participates in a CAISO demand response program. Proposed day-ahead events are received from the utility. A person examines the production schedule to decide which (if any) manufacturing loads can be shed. The load shedding is enabled in the EMS for automatic execution based on further events the following day. The site receives utility compensation for participation based on actual meter readings compared to a baseline.
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Microgrid optimization schematic

- Supply-side and demand-side aspects
- Not limited to electric power—microgrid can include cogeneration units
- Key challenges include:
  - optimization formulation
  - load forecasting
- Versatile Energy Resource Allocation (VERA) tool (Honeywell Prague Lab)

- Which boilers to use? At which load?
- Schedules for devices: starts / stops
- To charge or to discharge storage?
- How much heat and power is needed from CHP?
- Temporal load reduction: when, how much?
- etc.
Supply-side microgrid problem (partial)

Minimize

$$\sum_{t=1}^{T} \left[ \sum_{i=1}^{N} \left[ X_{t,i} \cdot \left( f_i(p_{t,i}) + C_{i}^{\text{fixed}} \right) + C_{i}^{\text{start}} \max(X_{t,i} - X_{t-1,i}, 0) \right] + P_{t,u} R_{t}^{\text{sell}} \right]$$

s.t.

$$\sum_{i=1}^{N} P_{t,i} + P_{t,u} = D_t$$

$$P_{i,\min} X_{t,i} \leq P_{t,i} \leq P_{i,\max} X_{t,i}$$

$$P_{u,\min} \leq P_{t,u} \leq D_t$$

$$X_{t,i} \in \{0,1\}$$

$$X_{0,i} = X_{0,i}$$

MINLP problem, solved with a solution step ranging from 15 minutes to 1 hour.

- Indicator for $i$-th generator in operation
- Startup operating cost for $i$-th generator
- Cost for importing grid power at time $t$
- Fixed operating cost for $i$-th generator
- Variable cost for $i$-th generating asset at $t$
Forecasting for Effective Energy Management

**Inputs**
- Time of day
- Holiday
- Ambient temperature
- Wind velocity
- Humidity

**Demand Model**

**Predictions**
- Heating demand
- Cooling demand
- Electricity demand
- Steam demand
- ...

- Little first-principles understanding → statistical modes required
- Model form/structure varies with situation
- Need to take advantage of operational data as obtained
  → Data-centric local models
Data-centric modeling

Current state and its neighborhood (= past operating points similar to the current one)

... the dependency $Y = f(X_1, X_2)$ is much simpler in the local neighborhood than in the global context

Local regression models are built on-the-fly
Local Regression

Points in the neighborhood are weighted according to

**Kernel function**

\[ w = \exp \left( -\frac{3\sigma \, d^2}{2} \right) \]

**Distance function**

\[ d^2 = \sum_{i=1}^{N} \left( \frac{X_i^* - X_i}{h_i} \right)^2 \]

**Query point**

\[ x_0 \]

**Forecast**

\[ y \]

**Independent variable**

\[ x \]

(time of day)

**Bandwidth**

**Polynomial fit**

**Local neighborhood**
Energy Forecaster

Efficient energy load forecasting

Advanced reporting and administration

Basic demand analysis

Energy demand forecast 1-4 days ahead

Configuration wizard
VERA interface
Optimization Results (Combined Heat & Power)

Real-time prices

Forecasted demand

Power demand

Power price

Heat demand

Gas price

Steam demand

CASE I

Zero GT1 startup costs

CASE II

Non-zero GT1 startup costs

Gas turbine GT1 keeps running all day due to high start-up costs

5 – 20% reduction in energy consumption realized

Optimal resource allocation

Purchased power  Gas Turbine 1 generation  Gas Turbine 2 generation
VERA technology implementation

750-bed hospital in the Netherlands

Approximate energy costs: €1,200,000 per year

- hot water boiler
- 2 steam boilers
- Compressor and absorption chillers
- 2 gas combined heat and power units

Energy Forecaster + Optimizer installed in 2002, still in operation

Cost savings:

2003 € 75 000 (6%)
2004 € 90 000
2005 €151 000

Savings improve over time ... more data ⇒ better forecasting model
Demand-side formulation (partial)

Minimize \( \sum_{t=1}^{T} \left( R_t^{\text{sell}} P_{t,u} - R_t^{\text{buy}} P_{t,LG}^{\text{excess}} - R_t^{\text{buy}} P_{t,s}^{\text{grid}} \right) \)

subject to

\[ P_{t,u} + P_{t,LG}^{\text{cons}} + P_{t,s}^{\text{cons}} = L_t \]

\[ S_t = \max \{ \min \left[ S_{t-1} + P_{t,LG}^{\text{stored}} + P_{t,u}^{\text{stored}} - P_{t,s}^{\text{cons}} - P_{t,s}^{\text{grid}}, S_{\max} \right] , 0 \} \]

\[ \left( P_{t,LG}^{\text{stored}} + P_{t,u}^{\text{stored}} = 0 \right) \lor \left( P_{t,s}^{\text{cons}} + P_{t,s}^{\text{grid}} = 0 \right) \]

- \( R_t^{\text{sell}}, R_t^{\text{buy}} \): utility sell and buy rates at time \( t \)
- \( P_{t,u} \): utility-supplied power at time \( t \)
- \( P_{t,LG}^{\text{cons}}, P_{t,s}^{\text{cons}} \): locally generated and stored power consumed at time \( t \)
- \( P_{t,s}^{\text{grid}} \): stored power supplied to grid at time \( t \)
- \( P_{t,LG}^{\text{stored}}, P_{t,u}^{\text{stored}} \): locally generated and utility-supplied power used for storage at time \( t \)
- \( P_{t,LG}^{\text{excess}} \): excess production at time \( t \)
- \( L_t \): total load at time \( t \)
- \( S_t \): state of charge for storage at time \( t \)
Integrated Microgrid Optimization Problem

**SUPPLY SIDE**
- Wind
- Photovoltaics
- Cogeneration (CHP)
- Other sources – e.g. biomass

**DEMAND SIDE**
- Campuses
- Neighborhoods

**UTILITIES**
- Bulk electricity network

Optimization of generation, storage and consumption

- Generation forecast
- Load forecast
- System Optimization
  - Equipment schedules, fuel switching
  - Purchase or generate?
  - Optimum use of storage capacities

- Load management
  - Curtailable loads
  - Reschedulable loads
  - Critical loads

- Electric cars
  - Can be used as a temporal storage

- Demand response, dynamic pricing, buying green power
- Energy storage components
  - Batteries, fuel cells, hydrogen, thermal storage, etc.
Concluding remarks...

- 90+% of electricity generated is consumed in end-use facilities (in developed economies)
- Many successful applications today in commercial and industrial sectors
  - without smart meters
  - with available infrastructure (Internet, cellular, etc.)
  - ... but much more can be done
- Many common principles across all customer sectors, including residential
- Rich research opportunities for algorithmic research
  - microgrid optimization
  - integration of renewables, storage, PHEVs
  - cybersecurity, and integrated cyber/physical security
  - ...
