Transactive Modeling and Simulation Capabilities

NIST Transactive Energy Challenge Preparatory Workshop

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Early Transactive Experiment (2008): GridWise™ Olympic Peninsula Project

Managing an Actual Distribution Constraint in the Olympic Peninsula Demonstration

Unless DG or storage are present, there is no way to serve load above capacity!

- Using price signals, successfully:
  - Coordinated response of 100s of devices
  - Reduced bulk energy costs
  - Alleviated local constraints

But how do the results translate to other regions of the country?
To utilities with wholesale markets?
GridLAB-D: A Design Tool for a Smarter Grid

Unifies models of the key elements of a smart grid:

- **Power Systems**
- **Loads**
- **Markets**

- Smart grid analyses
  - field projects
  - technologies
  - control strategies
  - cost/benefits
- Time scale: sec. to years
- Open source
- Contributions from
  - government
  - industry
  - academia
- Vendors can add or extract own modules

GridLAB-D is an open-source, time-series simulation of all aspects of operating a smart grid, from the substation to end-use loads in unprecedented detail.

Simultaneously solves 1) power flow, 2) end use load behavior in 1000s of homes and devices, 3) retail markets, and 4) control systems.

**NEW**: Supported by newly established, industry-led User’s Association.

>45,000 downloads in 150 countries
What GridLAB-D Currently Can and Cannot Do

What GridLAB-D is:

- Performs time-series simulations.
- Captures midterm dynamic behavior (seconds to hours).
- Captures seasonal effects (days to years).
- Simulates control systems.
  - Individual device controls.
  - System level controls.

What GridLAB-D is not:

- Is not a power system specific tool.
- Is not suited for transmission only studies.
- Is not an “optimizer” (although it can receive inputs from an optimizer).
Field Studies: Validation & Verification

- Evaluated GE Coordinated Volt/VAR system on 8 AEP feeders
- Simulations predicted a 2.9% reduction in energy consumption (field results indicated 3.3% reduction)
- Has led to 4 follow-on CVR experiments with AEP (OH & OK)
- Represents intersection of building and grid technologies and shared benefits

- Developed transactive control system for AEP gridSMART® Demonstration

- Evaluated effects on consumer bills & potential for DR-related savings with RTP
  - Accepted as a retail RTP rate by Ohio PUC
  - Fairness across classes of energy users

- Comparison between simulated and observed results available in report:

<table>
<thead>
<tr>
<th>AEP Ohio gridSMART® Demonstration Project Real-Time Pricing Demonstration Analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.3. Comparison of Monthly Wholesale Energy Costs for an Average Household ($)</td>
<td></td>
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<tr>
<td></td>
<td>June</td>
</tr>
<tr>
<td>Control</td>
<td>$43.93</td>
</tr>
<tr>
<td>RTP&lt;sub&gt;10&lt;/sub&gt;</td>
<td>$42.80</td>
</tr>
<tr>
<td>RTP&lt;sub&gt;10&lt;/sub&gt; Congested</td>
<td>$43.10</td>
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</tbody>
</table>
A joint Hardware In the Loop (HIL) effort between PNNL and NREL using PNNL’s EIOC and NREL’s ESIF

Hardware located in the ESIF is combined with system level software simulations in EIOC
- PNNL: GridLAB-D running a time-series power system model
- NREL: PV inverter hardware running with control signal received from the GridLAB-D simulation

Communications between the two facilities is via the internet using JSON

Initial work focused on HIL with PV inverters
Scalability and Co-Simulation

- Co-simulation allows for expansion of capabilities with minimal investment
  - Allows for re-use of existing software AND models
  - Enables multi-scale modeling & simulation required for understanding transactive

- FNCS is a framework for integrating simulators across multiple domains
  - Framework for Network Co-Simulation (FNCS – pronounced like “Phoenix”)
  - Developed for HPC applications across multiple platforms

![Diagram of FNCS integration with various simulators such as GridLAB-D, PowerWorld, EnergyPlus, GridPACK, Matpower, GridLAB-D, EnergyPlus, GridLAB-D, GridLAB-D, and EnergyPlus.](attachment:image.png)
Demand Response/Real-Time Pricing Example

► RTP, double-auction, retail market
  ■ Market accepts demand and supply bids
  ■ Clears on five minute intervals
  ■ Designed to also manage capacity constraints at substation

► Residential energy management system
  ■ Acts as a distributed agent to offer bids & respond to clearing prices
  ■ Consumer sets a preference for “savings” versus “comfort”

► Same system as discussed before
  (part of the AEP gridSMART® ARRA Demonstration)
Ideal result is...

- Decreased wholesale energy costs
- Peak demand limited to feeder capacity

IEEE-13 node system with 900 residential loads simulated in GridLAB-D™
But what happens when including communication latency?

- IEEE-13 node model with 900 residential loads and controllers modeled in GridLAB-D
- Model was modified to work within FNCS framework
- An ns-3 communication network model was created (radial WIFI)
- EXTREME communication delays (for Wifi) were considered
But what happens when including communication latency?

Excessive communication delays during critical period caused an "accounting error" in auction (this was considered in Demo deployment)

As simulated in GridLAB-D and ns-3
Back up slides
GE CRADA – Smart Appliance DR

Rebound

Mitigated with randomized “release” times

Lifetime savings for an average household by appliance in PJM.

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Average Lifetime of Appliance (years)</th>
<th>Lifetime Savings ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clothes Dryer</td>
<td>14</td>
<td>$37.62</td>
</tr>
<tr>
<td>Clothes Washer</td>
<td>12</td>
<td>$27.88</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>12</td>
<td>$39.61</td>
</tr>
<tr>
<td>Food Preparation</td>
<td>15</td>
<td>$3.72</td>
</tr>
<tr>
<td>Freezer</td>
<td>16</td>
<td>$13.08</td>
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<tr>
<td>HVAC</td>
<td>14</td>
<td>$201.07</td>
</tr>
<tr>
<td>Lights and Plugs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>14</td>
<td>$12.12</td>
</tr>
<tr>
<td>Water Heater</td>
<td>14</td>
<td>$137.31</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-</strong></td>
<td><strong>$472.41</strong></td>
</tr>
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</table>
Evaluation of SGIG Grants – Potential Impacts of Primary Technologies

► Distribution automation benefits
  ■ Volt-VAR optimization (annual energy saved) 2% – 4%
  ■ Reclosers & sectionalizers (SAIDI improved) 2% – 70%
  ■ Distribution & outage management systems (SAIDI improved) 7% – 17%
  ■ Fault detection, identification, & restoration (SAIDI improved) 21% – 77%

► Demand response
  ■ Instantaneous load reductions 25% – 50%
  ■ Sustainable (e.g. 6-hour) load reductions 15% – 20%

► Thermal storage (commercial buildings)
  ■ Peak load reduction @ 10% penetration: up to 5%

► Residential photovoltaic generation
  ■ 3 kW- 5 kW each, 0% – 6% penetration (0.1% - 3% annual energy saved)
  ■ Low penetration: losses generally decreased
  ■ High penetrations, deployed in an uncoordinated manner, can increase system losses
Distributed Resources

► Residential Buildings
  ▪ Agent-based, thermal model (ETP)
  ▪ Controllable for Demand Response applications (i.e., price responsive thermostats)
  ▪ Controllable appliance models (i.e., DLC water heater)

► Single-Zone Office and Retail Buildings
  ▪ Connection to EnergyPlus for more advanced models

► Distributed Generation / Storage
  ▪ Photovoltaics, Wind Turbines, Diesel, Batteries, Inverters, PHEVs, Thermal Energy Storage
  ▪ Agent-based control and market bidding strategies

► Real-Time Energy Markets
  ▪ Built to represent all aspects of a retail transactive market
Many empirical studies indicate a reduction in distribution system voltage reduces energy consumption.

- How CVR achieves this energy reduction has been a topic of debate.
- Using GridLAB-D it was possible to show the mechanism by which energy reduction is achieved.

With an analytic basis for analysis it was possible to extrapolate these results to a national level.

When extrapolated to a national level a complete deployment of CVR provides a 3.0% reduction in annual energy consumption for the electricity sector.

80% of this benefit can be achieved if deployed on 40% of feeders, a 2.4% reduction.
AEP gridSMART Demo
System Description

- Simulation of a distribution feeder in GridLAB-D
  - IEEE 123 node test feeder
  - IEEE 8500 node test feeder

- Robust, lightweight communication protocol
  - Complex $V$
  - Complex $I$
  - Weather model

- Hardware inverters at power, interacting with grid simulator and PV simulator
  - Single-phase inverters
  - Three-phase inverter
Effect of Inverter Control Mode on PCC Voltage

- Single-phase inverter embedded in IEEE 8500 node test feeder at PCC on secondary system
- 5-minute period with cloud transient
- Inverter control modes compared
  - Base case, no PV
  - PV injects active power (PF = 1.0)
  - PV injects active power and absorbs reactive power at PF = 0.81
  - PV with active Volt/VAr control (VVC)
PV & EV

- PV models in cooperation with NREL
- HECO study: high penetration solar led to significant voltage variations
  - Control of real power loads was ineffective for voltage control – low load resource
  - Inverter technology with four-quadrant control was effective but limited by standards
  - Additional insight into inverter control is necessary with respect to revised standards
- Coordination of EV charging can reduce transformer overloading, increase renewable integration, and benefit both distribution AND transmission goals
- Develop rapid, cost-effective interconnection studies for PV
- MECO FY13: benefits / impacts of decentralized vs. centralized battery storage