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Transactive Modeling and Simulation Capabilities

NIST Transactive Energy Challenge Preparatory Workshop

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

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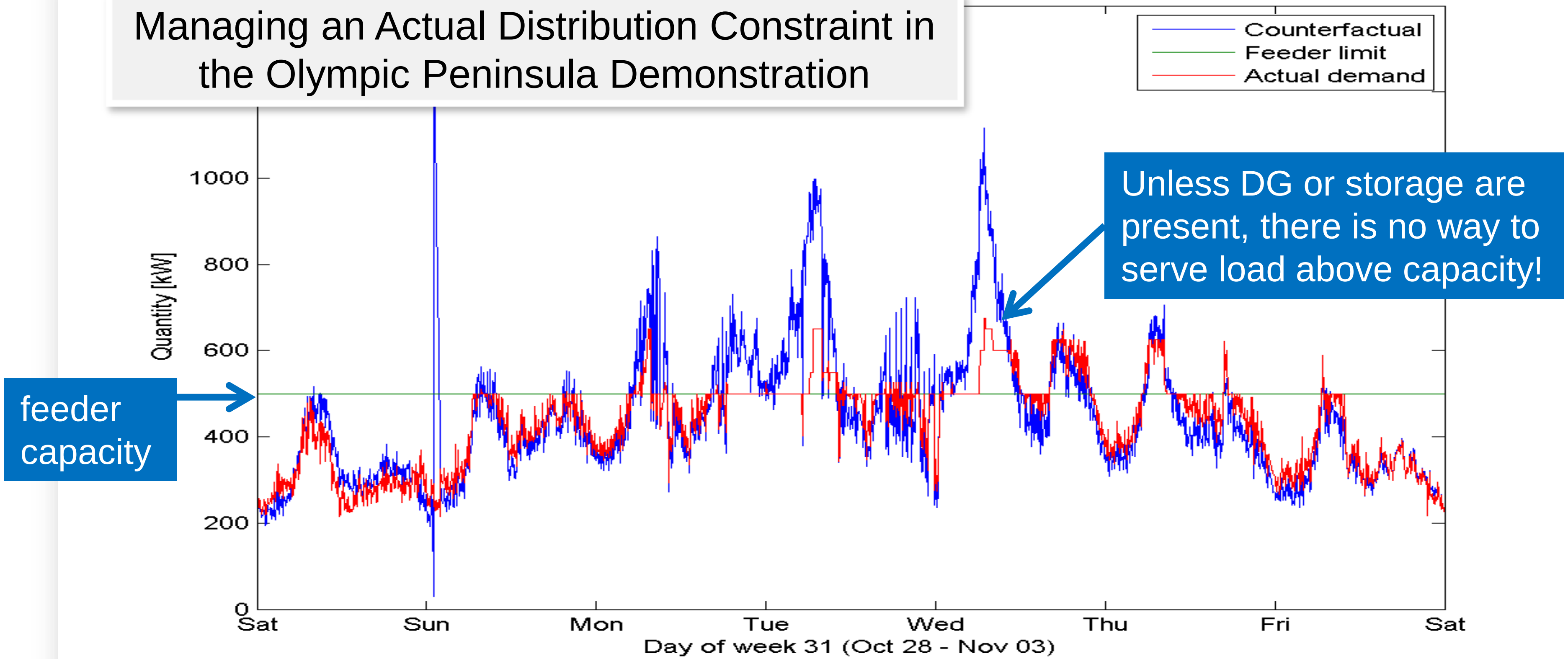
Managing an Actual Distribution Constraint in the Olympic Peninsula Demonstration



- 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

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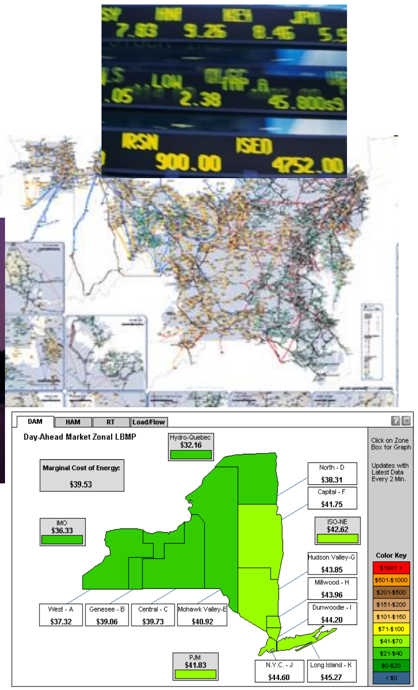
Unifies models of the key elements of a smart grid:

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

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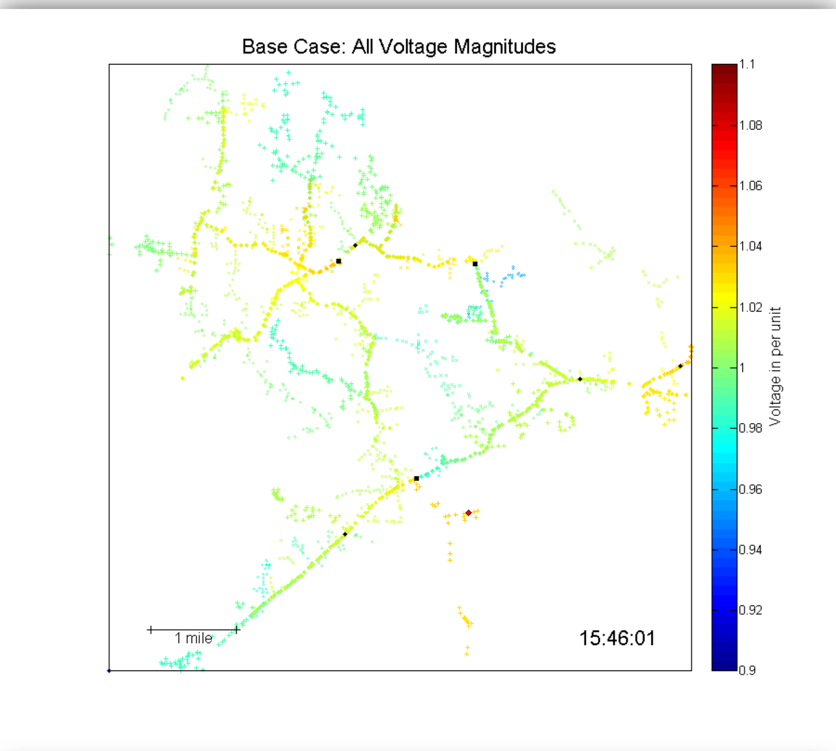
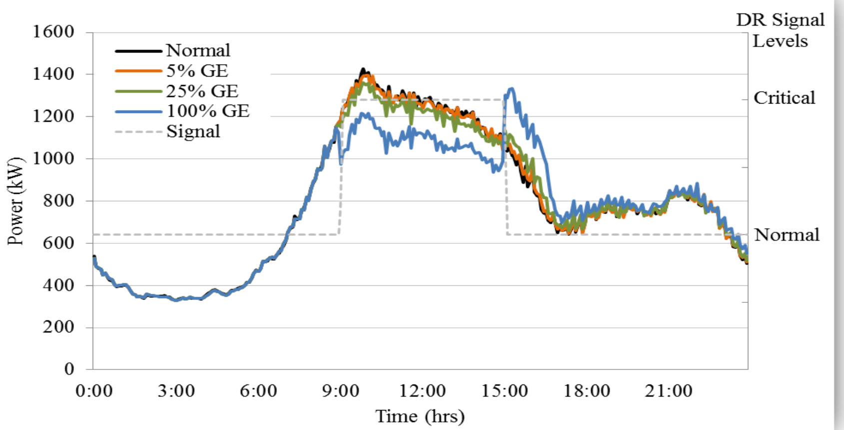
What GridLAB-D is:

- 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.

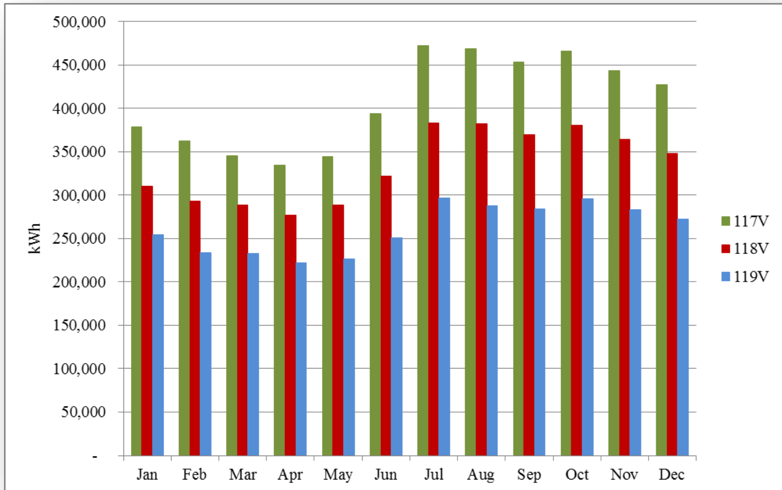


What GridLAB-D is not:

- 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:

AEP Ohio gridSMART® Demonstration Project
Real-Time Pricing Demonstration Analysis

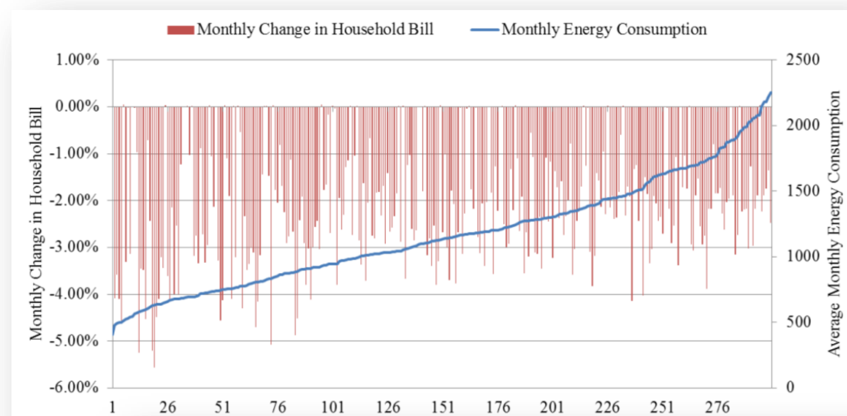


Table 2.3. Comparison of Monthly Wholesale Energy Costs for an Average Household ($)

	Monthly Wholesale Energy Cost Per Household ($)					
	June	July	August	September	Average	Per Day
Control	$43.93	$57.57	$42.58	$37.92	$45.50	$1.492
RTP_{da}	$42.80	$55.68	$41.69	$37.17	$44.34	$1.454
RTP_{da} Congested	$43.10	$56.55	$42.05	$37.44	$44.79	$1.470

Hardware in the Loop Testing and Power System Simulation of High Penetration Levels of PV

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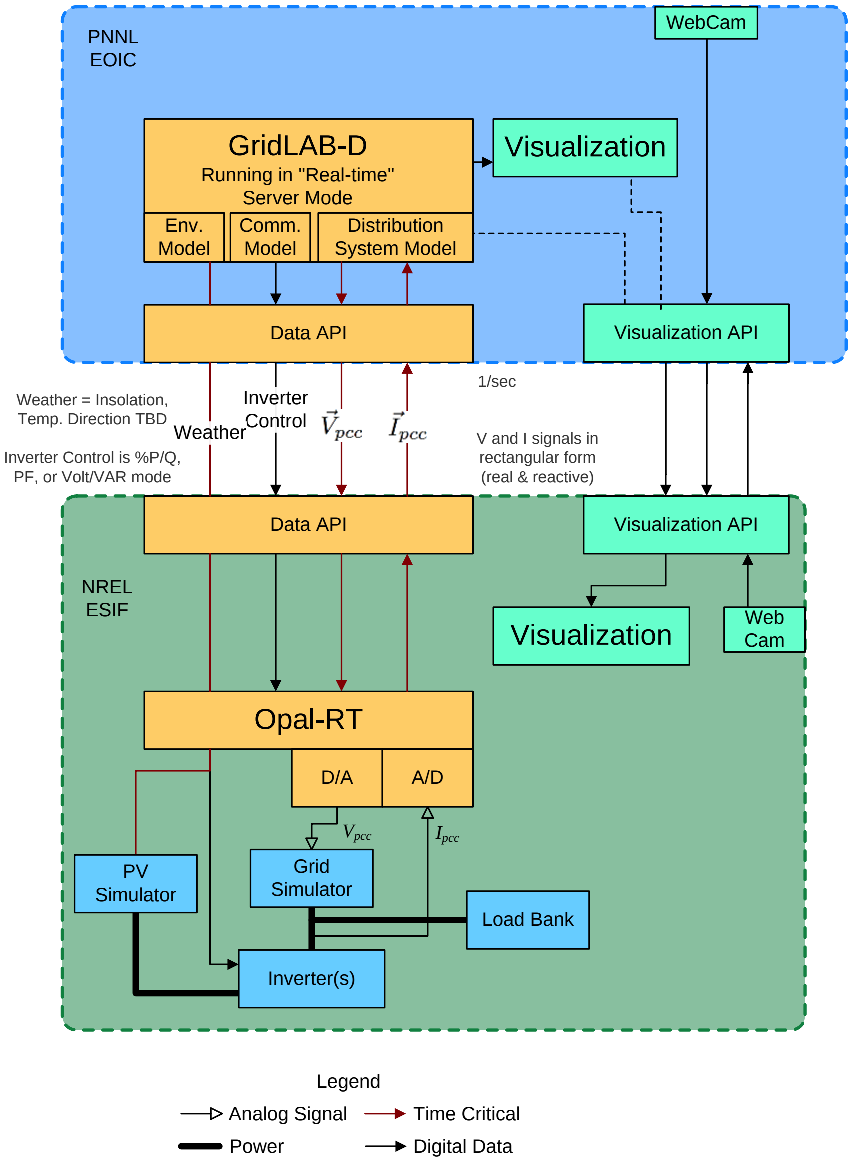
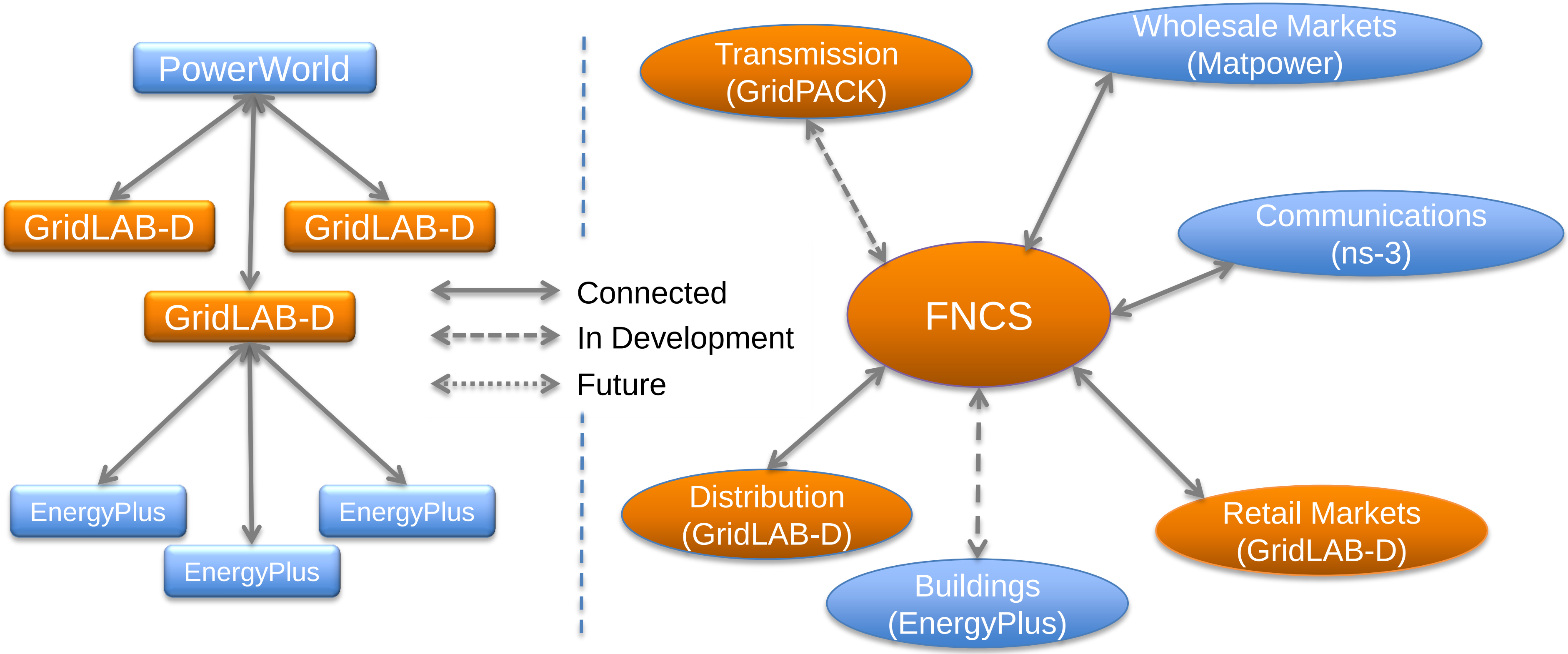
- A joint Hardware In the Loop (HIL) effort between PNNL and NREL using PNNL's EIOC and NREL's ESIF
- Hardware located in the ESIF is combined with system level software simulations in EIOC
  - PNNL: GridLAB-D running a time-series power system model
  - NREL: PV inverter hardware running with control 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



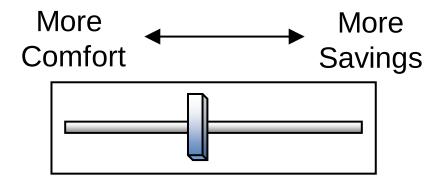
Scalability and Co-Simulation

- 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

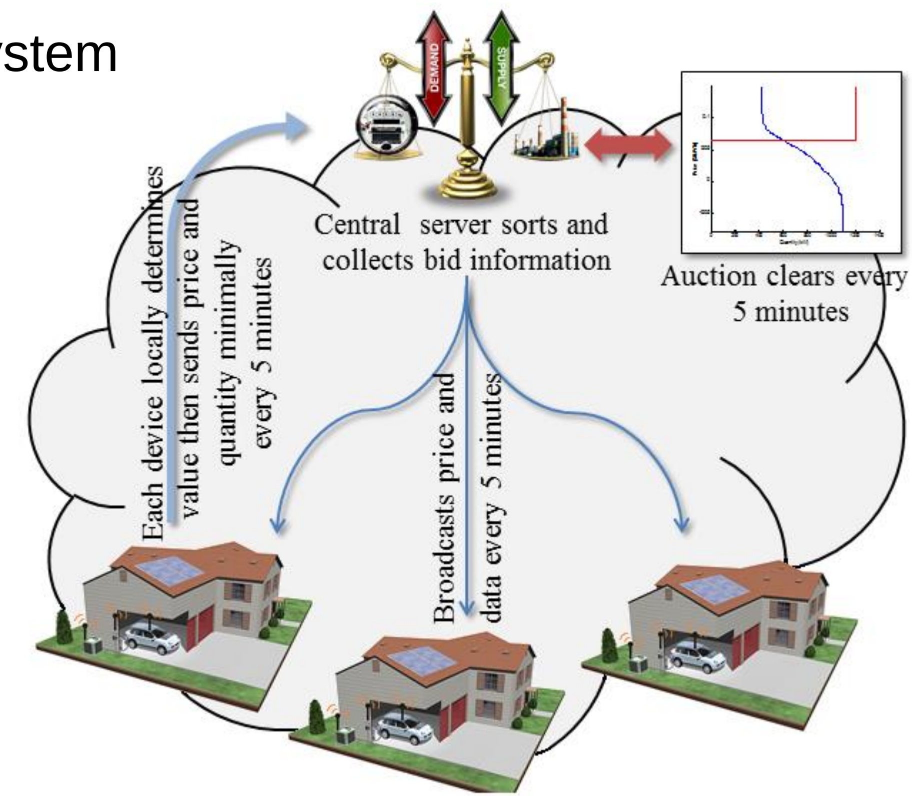


Demand Response/Real-Time Pricing Example

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

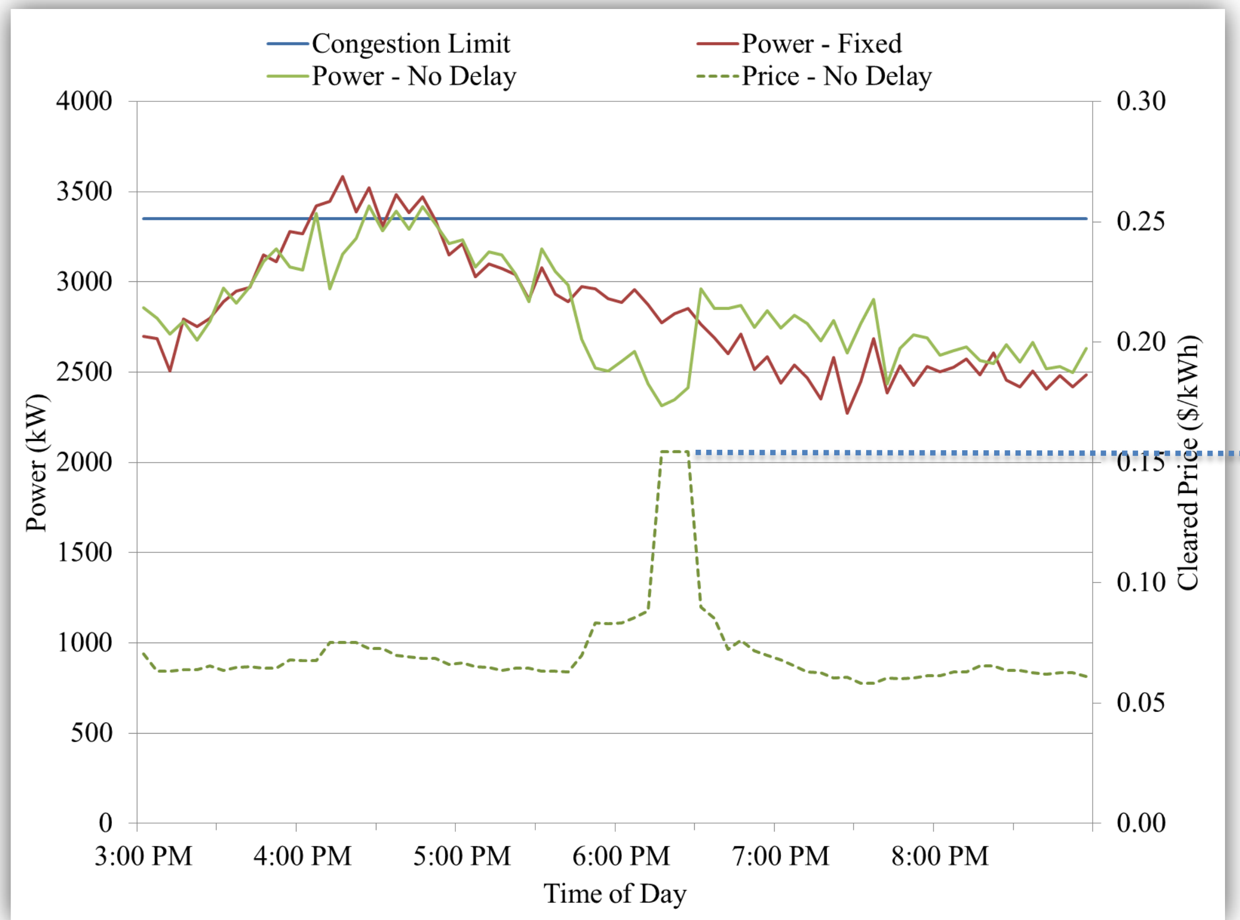


- Residential energy management system
  - Acts as a distributed agent to offer bids & respond to clearing prices
  - Consumer sets a preference for “savings” versus “comfort”
- Same system as discussed before (part of the AEP gridSMART® ARRA Demonstration)



Ideal result is…

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



~0.16 $/kWh

GridLAB-D

www.gridlabd.org

IEEE-13 node system with 900 residential loads simulated in GridLAB-D™

But what happens when including communication latency?

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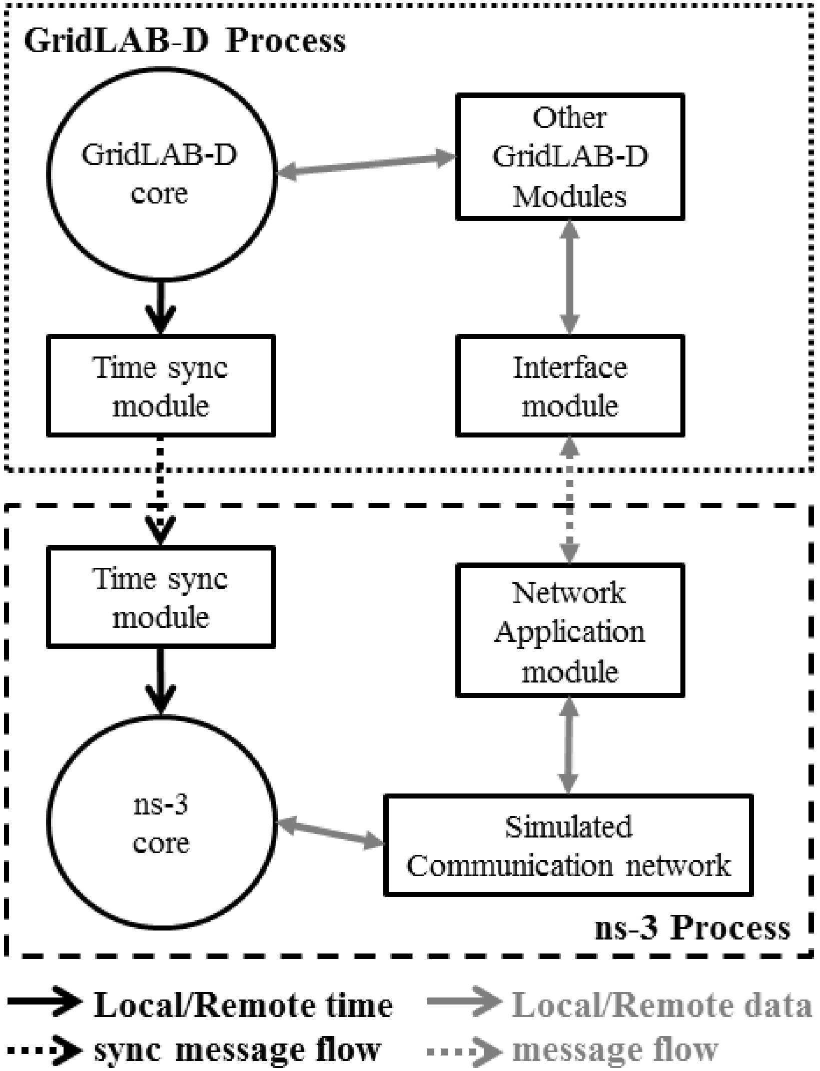
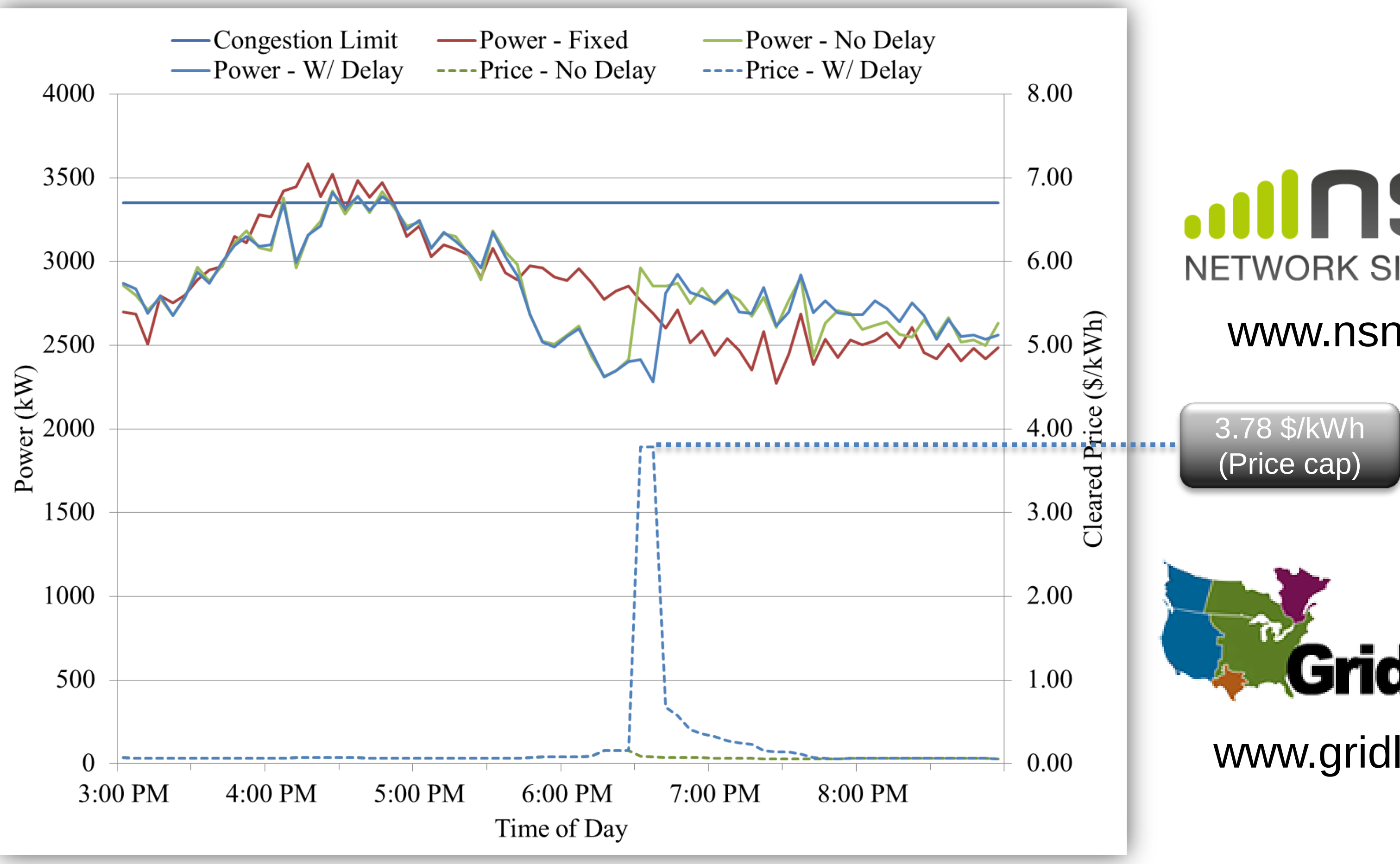
- IEEE-13 node model with 900 residential loads and controllers modeled in GridLAB-D
- Model was modified to work within FNCS framework
- An ns-3 communication network model was created (radial WIFI)
- EXTREME communication delays (for Wifi) were considered



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)



NETWORK SIMULATOR

www.nsnam.org

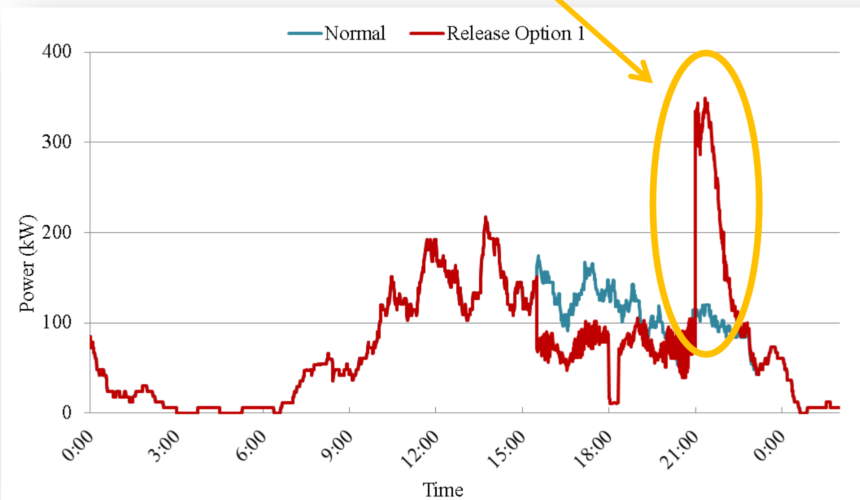
www.gridlabd.org

As simulated in GridLAB-D and ns-3

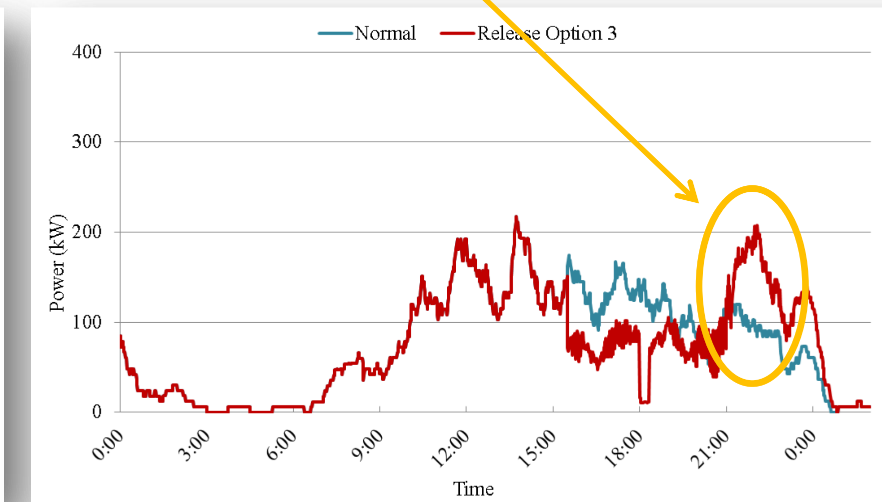
Back up slides

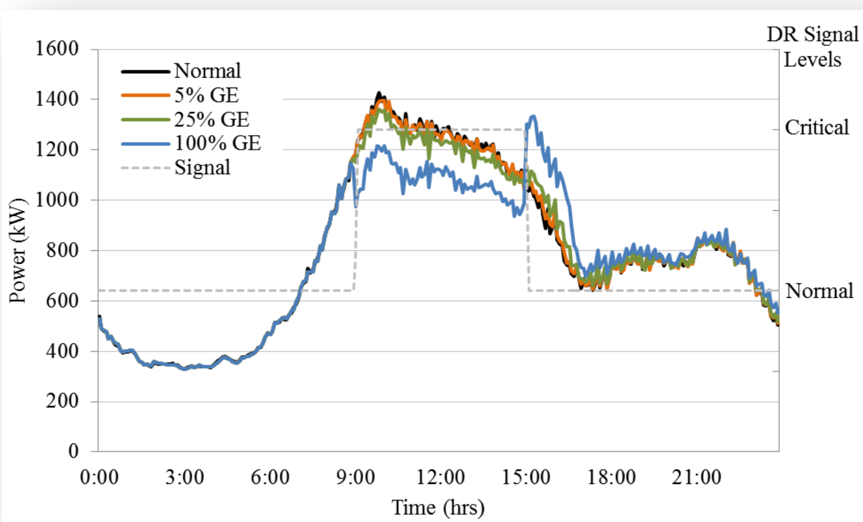
GE CRADA – Smart Appliance DR

Rebound



Mitigated with randomized "release" times



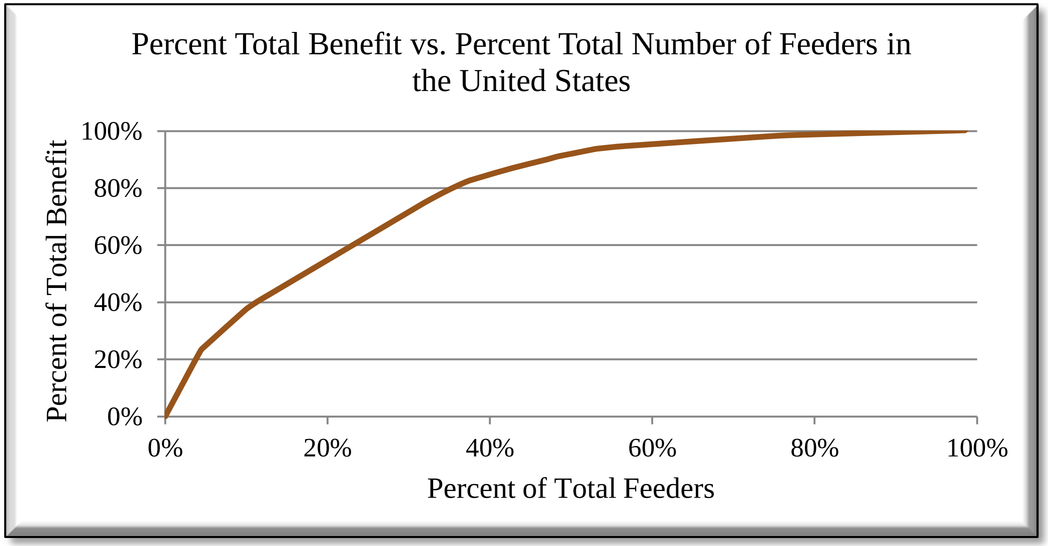


Lifetime savings for an average household by appliance in PJM.

	Average Lifetime of Appliance (years)	Lifetime Savings ($)
Clothes Dryer	14	$ 37.62
Clothes Washer	12	$ 27.88
Dishwasher	12	$ 39.61
Food Preparation	15	$ 3.72
Freezer	16	$ 13.08
HVAC	14	$ 201.07
Lights and Plugs	-	-
Refrigerator	14	$ 12.12
Water Heater	14	$ 137.31
Total	-	$ 472.41

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

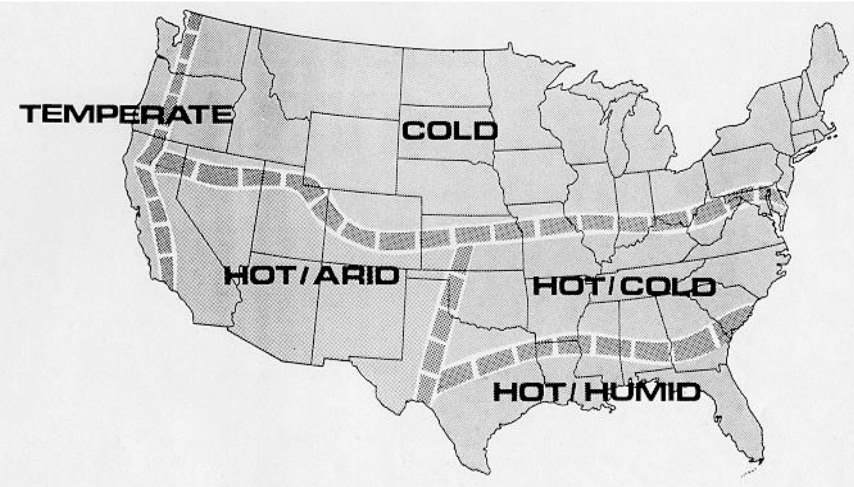


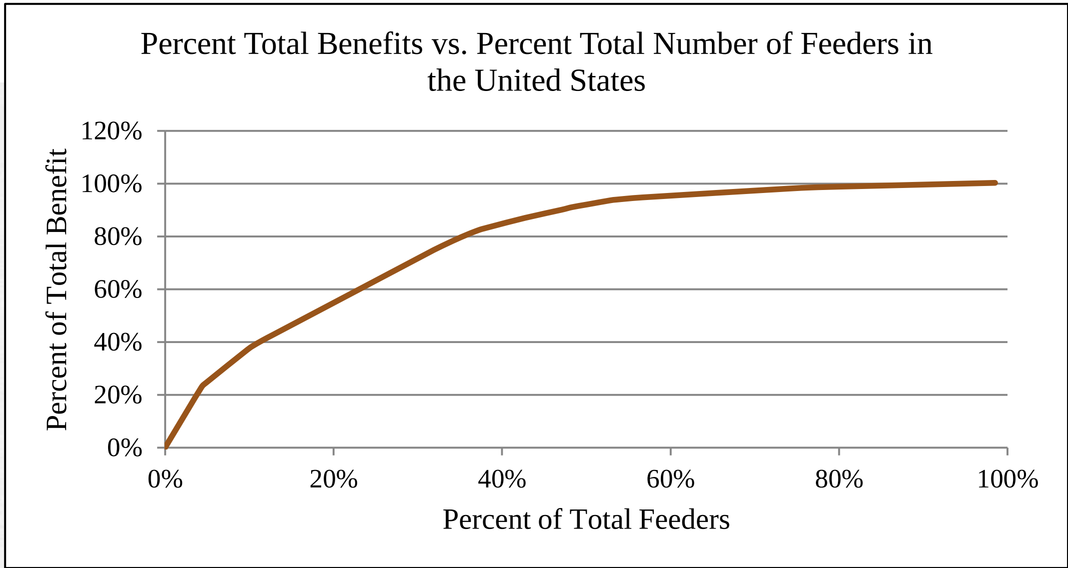
Distributed Resources

- 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

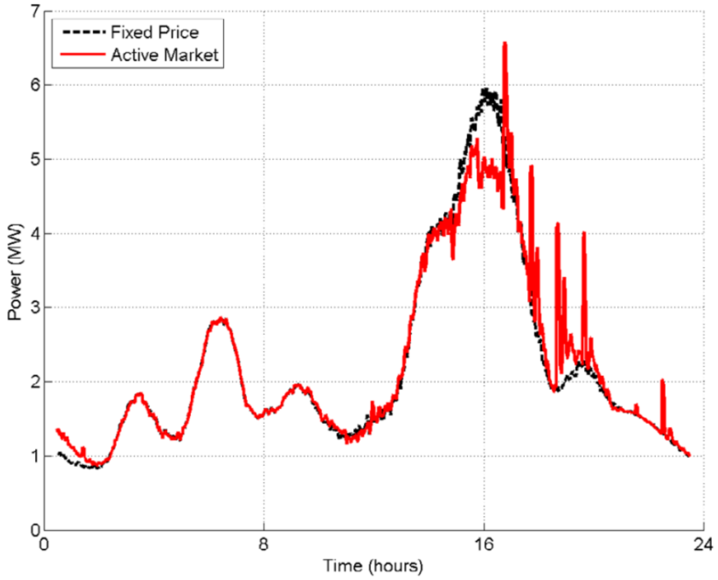
Conservation Voltage Reduction Analysis on a National Level

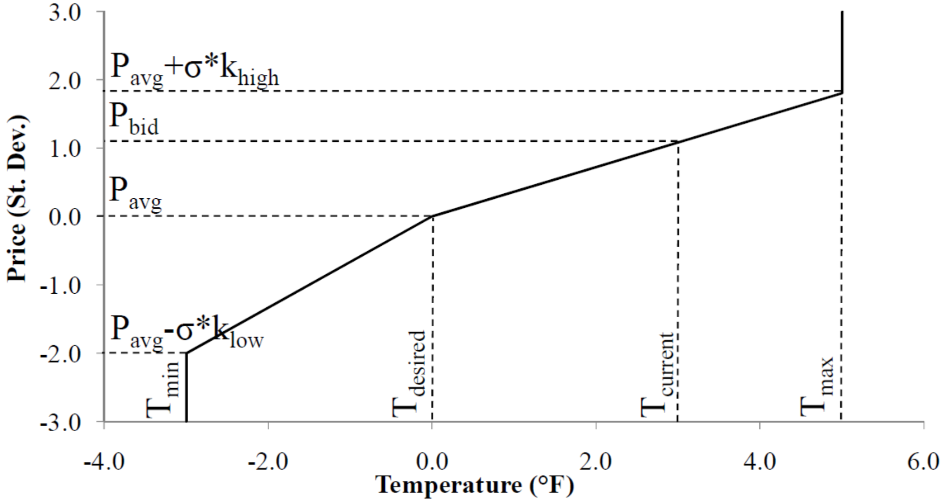
- Many empirical studies indicate a reduction in distribution system voltage reduces energy consumption.
  - How CVR achieves this energy reduction has been a topic of debate.
  - Using GridLAB-D it was possible to show the mechanism by which energy reduction is achieved.
- With an analytic basis for 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.

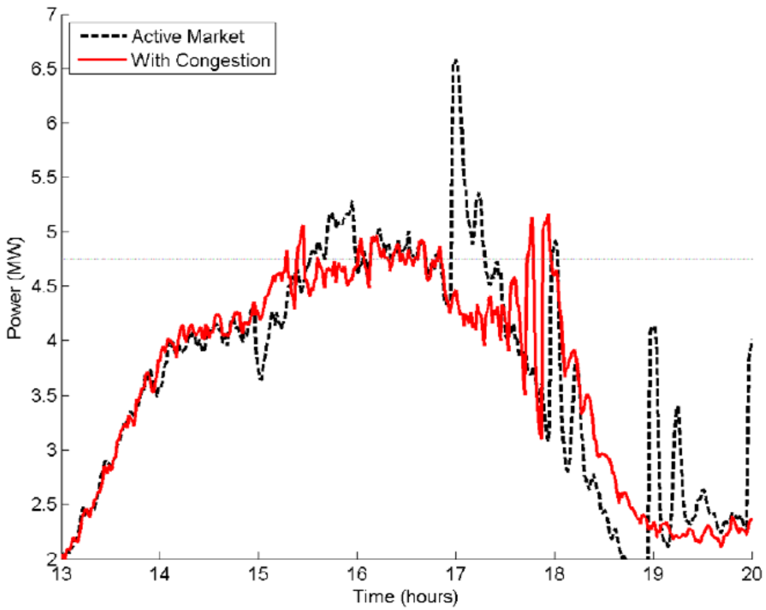


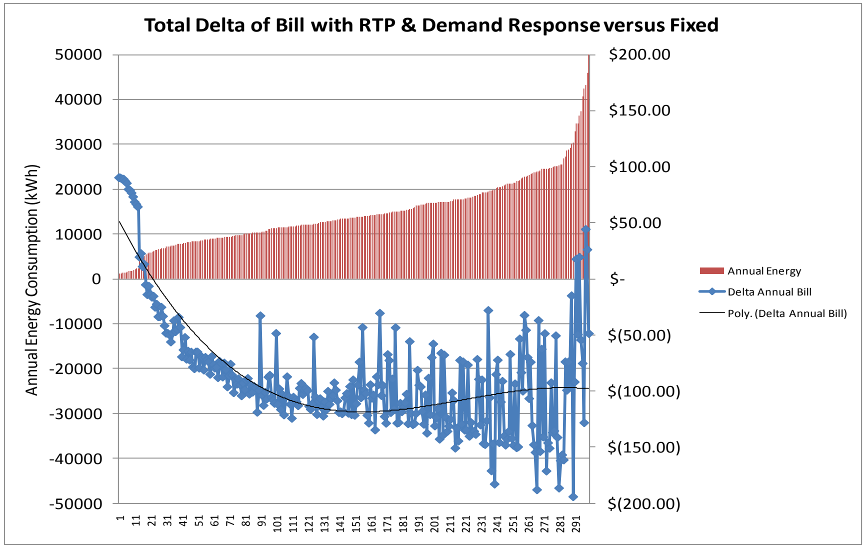


AEP gridSMART Demo









System Description

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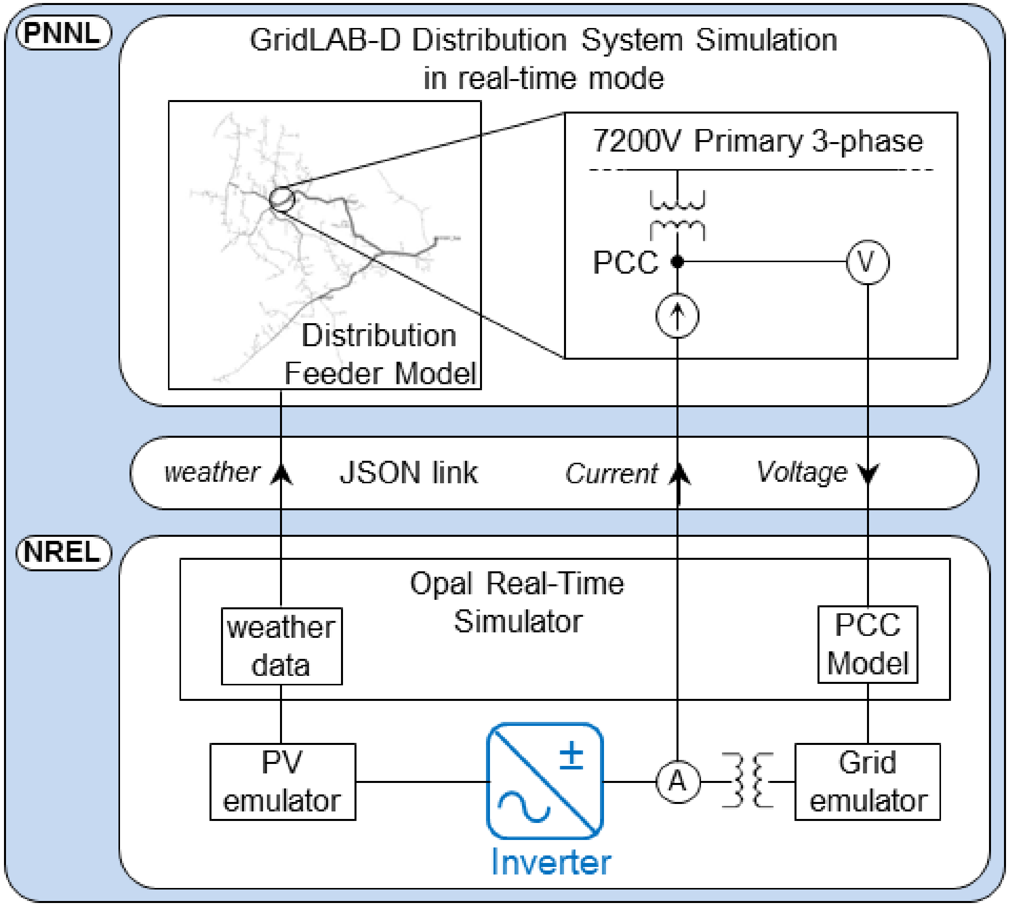
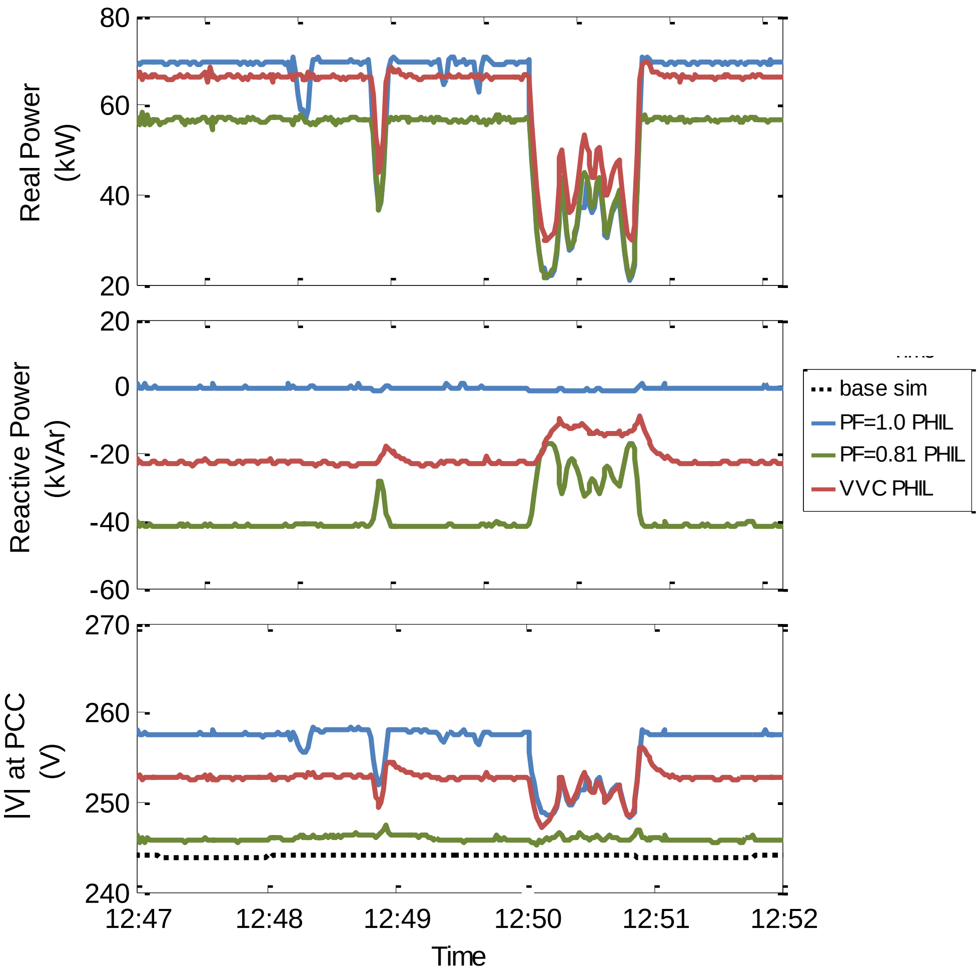
- Simulation of a distribution feeder in GridLAB-D
  - IEEE 123 node test feeder
  - IEEE 8500 node test feeder
- Robust, lightweight communication protocol
  - Complex *V*
  - Complex *I*
  - Weather model
- Hardware inverters at power, interacting with grid simulator and PV simulator
  - Single-phase 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