# GridLAB-D
# Smart Grid Simulation

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For more information see www.gridlabd.org

# Overview

- What is GridLAB-D?
- How is GridLAB-D different?
- How does GridLAB-D work?
- Why use GridLAB-D?
- Examples of analysis results

GridLAB-D

# A Unique Tool for Designing and Studying Smart Grids

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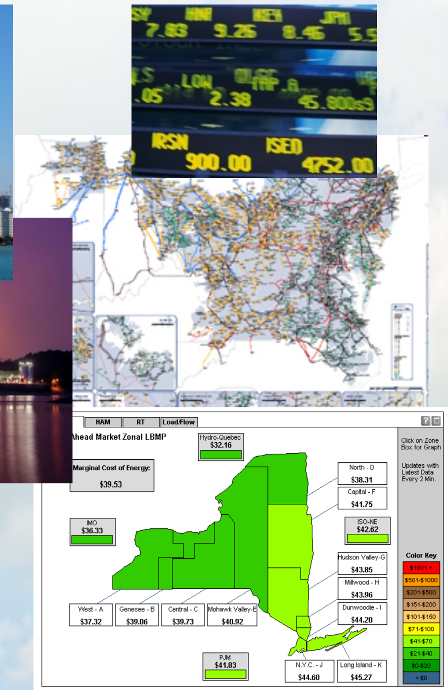
## *Unifies models of the key elements of a smart grid:*

### *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 a DOE-funded, open–source, time-series simulation of all aspects of operating a smart grid from the substation level down to loads in unprecedented detail

➢ Simultaneously solves:
- Unbalanced, 3-phase power flow (radial or network), w/explicit control strategies
- End use load physics, voltage-dependency, behavior & control in 1000s of buildings.
- Double-auction retail supply/demand markets

# Unifying Multiple Discipline

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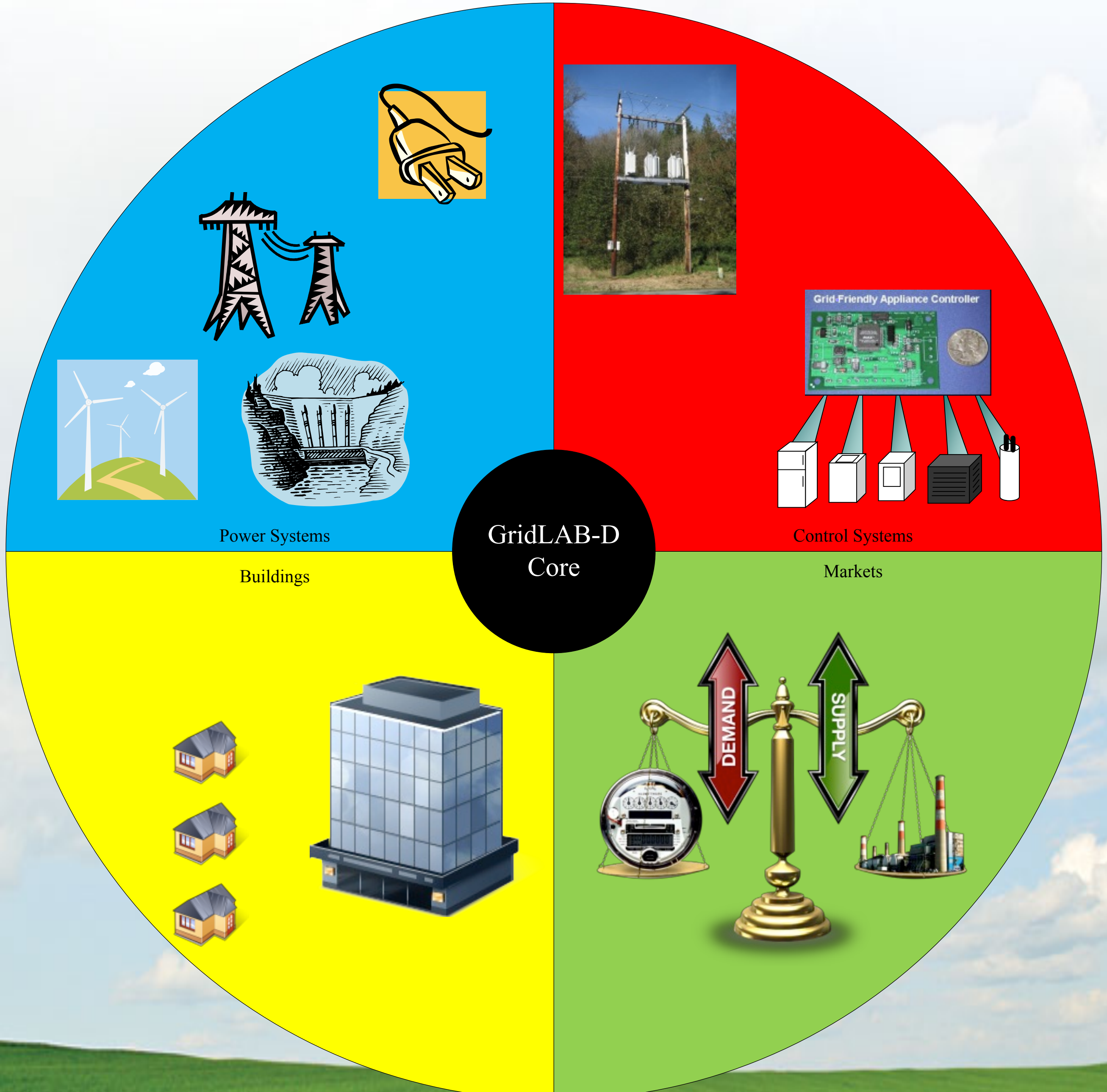


# Comparison of Simulation Methods

## Conventional Methods

- System dynamics
  - Series of interacting feedback loops (focus on rates)
- Dynamic systems
  - State model w/physical meaning (focus on states)
- Discrete Event
  - Queuing models of entities (focus on events)

## Agent-based Method

- Complex bottom-up models
- Focus on behaviors and relationships of many entities
- Agents placed in environments
- Agents can be endowed with a wide range of behaviors
  - No restrictions on agent behaviors or outcomes
- Relationships can be arbitrary
  - No restrictions on what information is used by agents or when information is transferred

# Method Strengths & Weaknesses

## Conventional Simulations

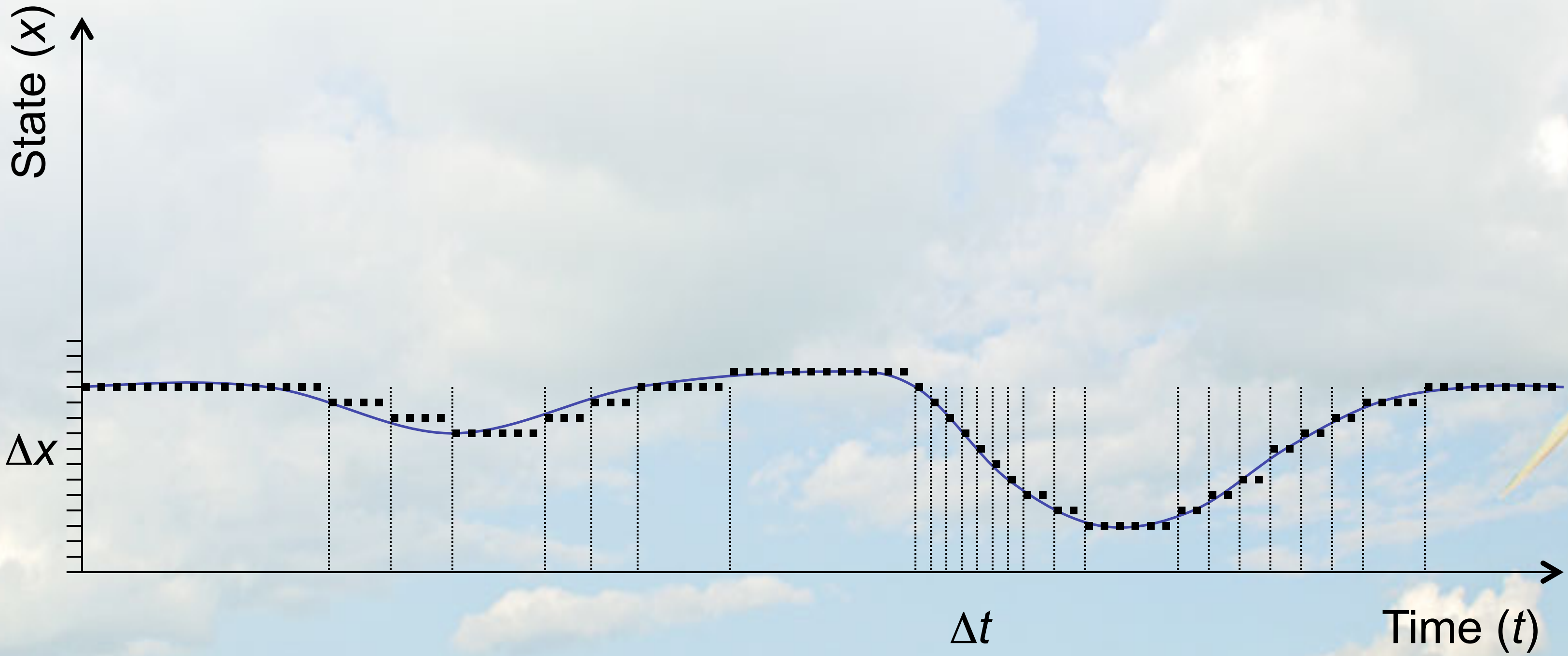
- Advantages
  - Very easy to validate analytically
  - Often computationally efficient
  - Distinct steady state/dynamic sol.
- Disadvantages
  - Requires solvable set of equations
  - Homogeneous solution often difficult to modify/update/improve
  - Essentially incompatible with each other
  - Difficult to integrate with other models
  - Can be difficult to scale
  - Typically domain specific solution

## Agent-based Simulations

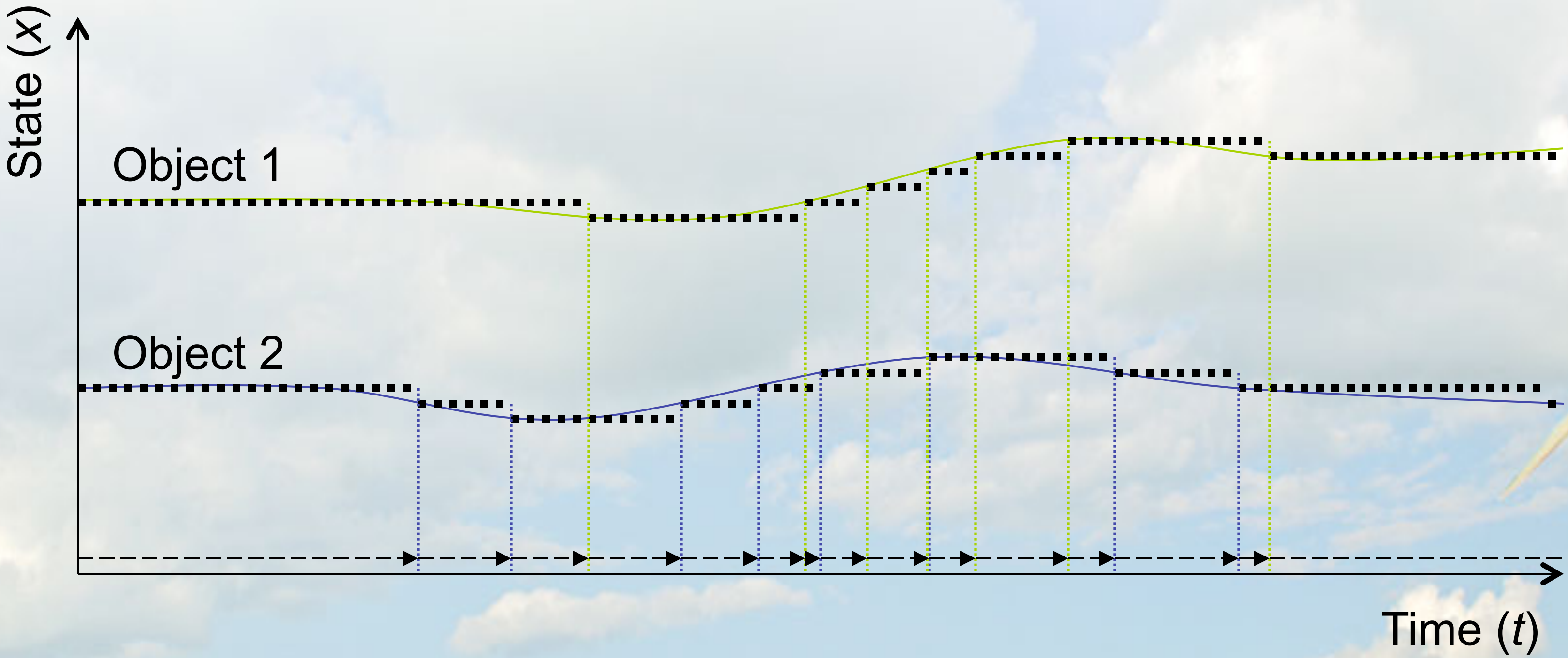
- Advantages
  - Very general approach
  - Domain-independent solver
  - Outcome is emergent
  - Quasi-steady/dynamic
  - Scales quite well
  - Local conventional models
  - Allows multi-disciplinary models
- Disadvantages
  - Very detailed models needed
  - Massive data I/O requirements
  - Very difficult to validate
  - Requires multi-disciplinary teams

# GridLAB-D Core Solver

*Determines a time-series of steady states of resolution Δx with variable time-step of resolution Δt*



# Each object can influence time



# High Fidelity Integration

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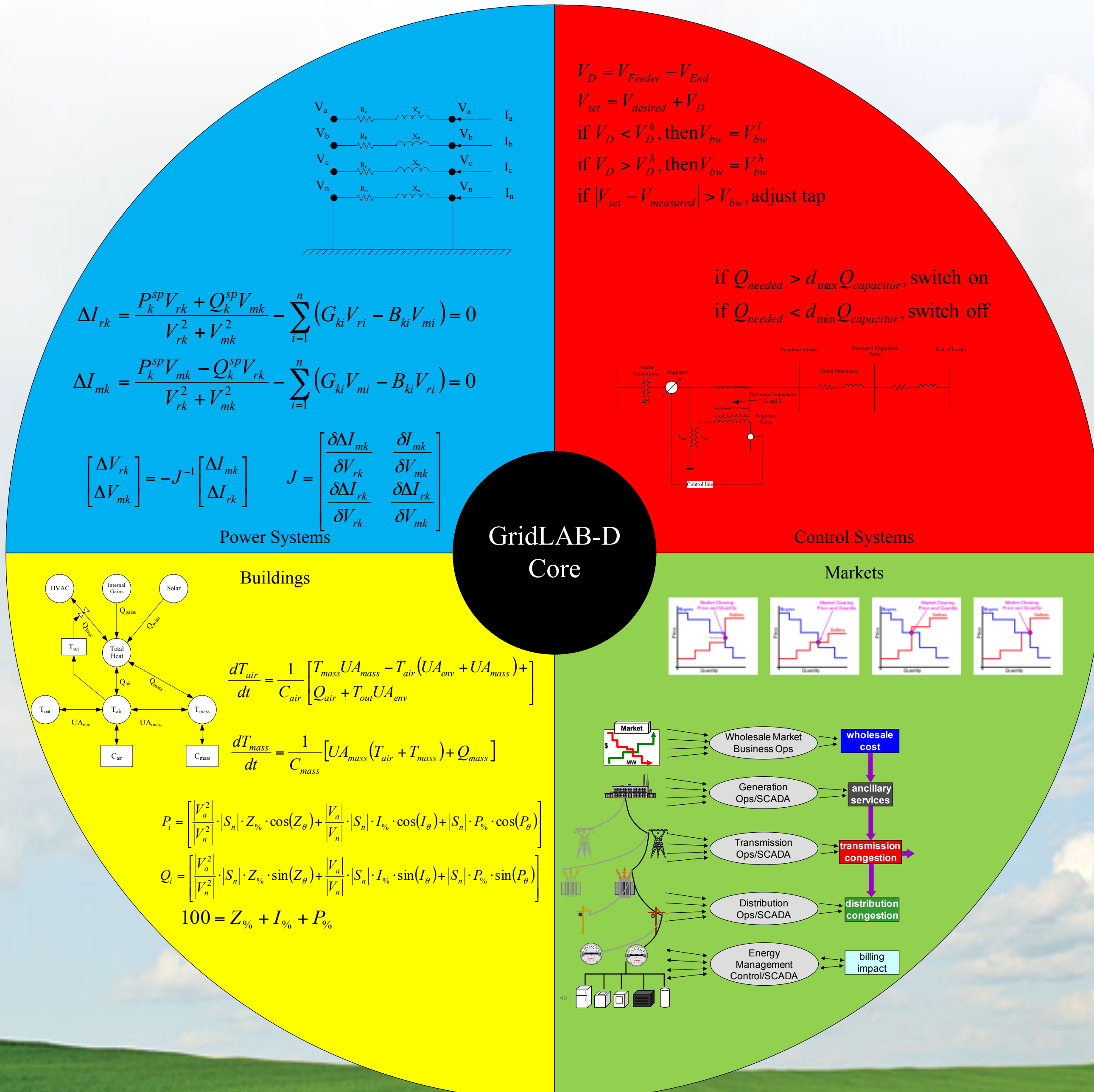
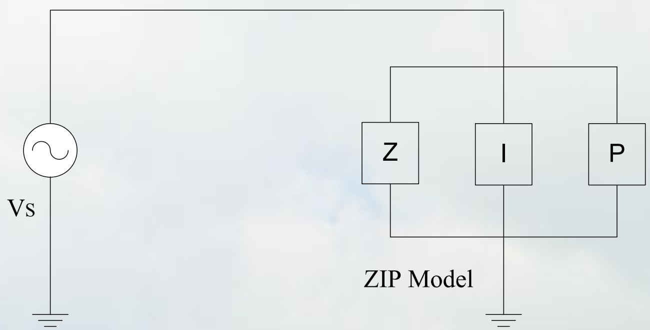


# Electric Systems

- Full-featured steady-state powerflow solvers
  - Forward-backsweep and Newton-Raphson
- Focus is currently on distribution systems
  - 3Φ unbalanced distribution system modeling
  - Theoretically capable of transmission (but not used)
- High-performance implementation
  - Quasi-steady: last solution used to find next
  - Parallelization used depends on solver
- Dynamic solver coming soon

# Buildings and Appliances

## Static ZIP Models

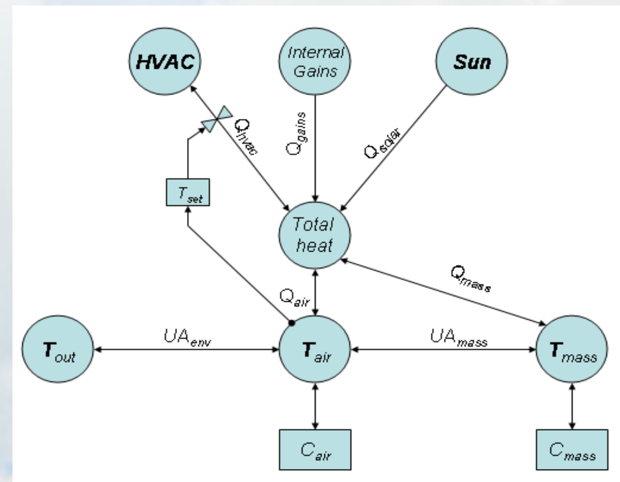



$$P_i = \left[ \frac{|V_a^2|}{|V_n^2|} \cdot |S_n| \cdot Z_{\%} \cdot \cos(Z_\theta) + \frac{|V_a|}{|V_n|} \cdot |S_n| \cdot I_{\%} \cdot \cos(I_\theta) + |S_n| \cdot P_{\%} \cdot \cos(P_\theta) \right]$$

$$Q_i = \left[ \frac{|V_a^2|}{|V_n^2|} \cdot |S_n| \cdot Z_{\%} \cdot \sin(Z_\theta) + \frac{|V_a|}{|V_n|} \cdot |S_n| \cdot I_{\%} \cdot \sin(I_\theta) + |S_n| \cdot P_{\%} \cdot \sin(P_\theta) \right]$$

$$1 = Z_{\%} + I_{\%} + P_{\%}$$

## Dynamic Load Models




$$\frac{dT_{air}}{dt} = \frac{1}{C_{air}} \left[ T_{mass} UA_{mass} - T_{air} \left( UA_{env} + UA_{mass} \right) + Q_{air} + T_{out} UA_{env} \right]$$

$$\frac{dT_{mass}}{dt} = \frac{1}{C_{mass}} \left[ UA_{mass} \left( T_{air} + T_{mass} \right) + Q_{mass} \right]$$

# Power Markets

- Double auction
  – Retail real-time pricing
- General bidding controller
  – Thermostatic controls
  – Generation/storage control
- Retail market integration with AMES (Iowa State University)

# Many other capabilities

- Appliance control and demand response
- Communication systems
- Reliability analysis
- Feeder reconfiguration
- Distribution automation
- Distributed generation
- Thermal storage
- PHEV charging
- Fault current analysis & protection coordination
- Telemetry (data collection/analysis)
- Interoperability (Excel/Matlab/Java/ODBC)

# Current Activities

- Commercial buildings
- Bulk generators
- Wholesale power markets
- Optimization
- Telecommunications protocols
- Renewable generation models
- Unit commitment/economic dispatch
- Subsecond/transient simulation

# Prototypical Feeders

- Set of distribution feeder models
  - Representative of North American systems.
- Openly available
  - Derived from 575 actual feeders at 151 substations.
- 17 utilities contributed data.
  - 5 PUDs, 4 MUNs, 7 IOUs, 1 REA
- Used to extrapolate results to national level
  - Can also be done on a smaller regional scale

# Studies Completed to Date

## Government & Industry

- Demand Response Business Case (NRECA)
- National Conservation Voltage Reduction Study (DOE)
- Columbus Ohio CVR Study (GE)
- Appliance Control CRADA (GE/DOE)
- ARRA SGIG Technology Impacts Analysis (DOE)
  - Renewable Integration
  - Distribution Automation
  - Demand Response
  - Energy Storage
- ARRA AEP gridSmart SGDP

## Academic

- Courses that use GridLAB-D
  - University of Washington
  - Washington University
  - CalTech
- Master's Theses
  - Demand Response (DTU)
- PhD Dissertations
  - Unit Commitment/Economic Dispatch (Stanford)
  - Renewable Integration (UVic)
  - Distribution Automation (ISU)

# Studies Considered, Proposed or Active/In Progress

## Government/Industry

- National Lab Studies
  - Advanced controls (PNNL)
  - HPC (LANL)
  - Microgrids (PNNL)
  - Renewables (NREL)
  - Telecommunications (PNNL)
  - Transmission/dynamics (PNNL)
- Other smart grid studies
  - Denmark, Australia, New Zealand, California, Pacific Northwest, New Jersey

## Academic

- Optimization (Stanford)
- Wind integration (UVic)
- Distribution automation (WSU)
- Wholesale market impacts (Iowa State)

# National Conservation Voltage Reduction Study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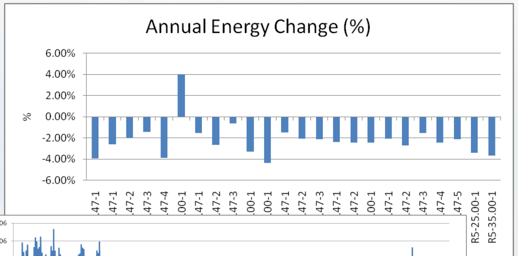
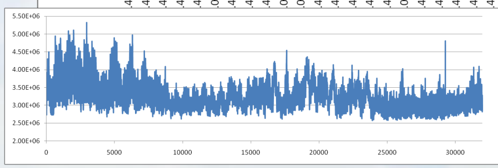
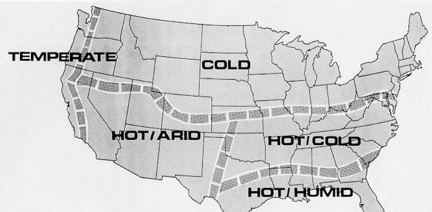
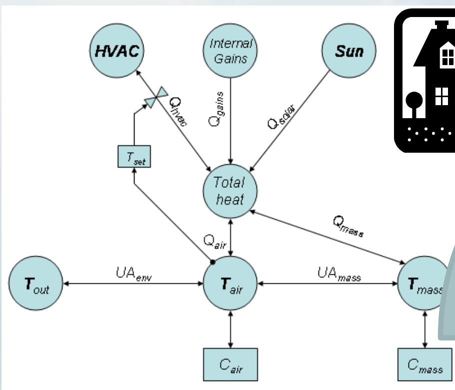
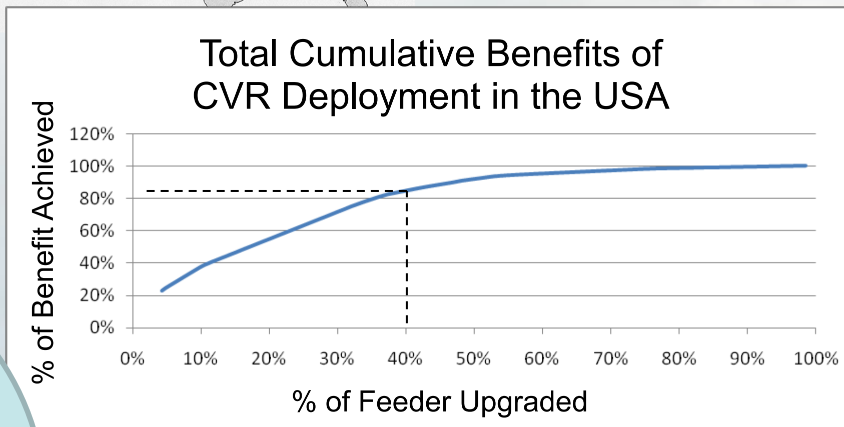



| Region | Feeder | kV | # of feeders | % within a region |
|---|---|---|---|---|
| Region 1 | R1-12.47-1 | 12.5 | 2,200 | 20.56% |
| | R1-12.47-2 | 12.47 | 2,500 | 23.36% |
| | R1-12.47-3 | 12.47 | 2,000 | 18.69% |
| | R1-12.47-4 | 12.47 | 1,800 | 16.82% |
| | R1-25.00-1 | 24.9 | 1,200 | 11.21% |
| | GC-12.47-1 | 12.47 | 1,000 | 9.35% |
| Region 2 | R2-12.47-1 | 12.47 | 3,500 | 18.72% |
| | R2-12.47-2 | 12.47 | 3,200 | 17.11% |
| | R2-12.47-3 | 12.47 | 3,000 | 16.04% |
| | R2-25.00-1 | 24.9 | 3,500 | 18.72% |
| | R2-35.00-1 | 34.5 | 4,000 | 21.39% |
| | GC-12.47-1 | 12.47 | 1,500 | 8.02% |
| Region 3 | R3-12.47-1 | 12.47 | 1,500 | 30.00% |
| | R3-12.47-2 | 12.47 | 1,500 | 30.00% |
| | R3-12.47-3 | 12.47 | 1,000 | 20.00% |
| | GC-12.47-1 | 12.47 | 1,000 | 20.00% |
| Region 4 | R4-12.47-1 | 13.8 | 14,000 | 33.14% |
| | R4-12.47-2 | 12.5 | 15,000 | 35.50% |
| | R4-25.00-1 | 24.9 | 12,500 | 29.59% |
| | GC-12.47-1 | 12.47 | 750 | 1.78% |
| Region 5 | R5-12.47-1 | 13.8 | 400 | 8.79% |
| | R5-12.47-2 | 12.47 | 600 | 13.19% |
| | R5-12.47-3 | 13.8 | 650 | 14.29% |
| | R5-12.47-4 | 12.47 | 500 | 10.99% |
| | [illegible] | 12.47 | [illegible] | 9.89% |
| | [illegible]-25.00-1 | 22.9 | 450 | [illegible] |
| | R5-35.00-1 | 34.5 | 500 | [illegible] |
| | GC-12.47-1 | 12.47 | 1,000 | [illegible] |

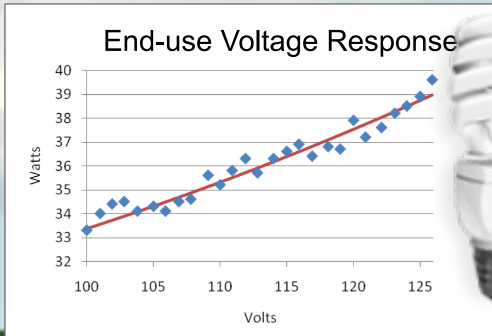



## GridLAB-D

**25 feeders x 1 minute over 1 year x 2 cases**

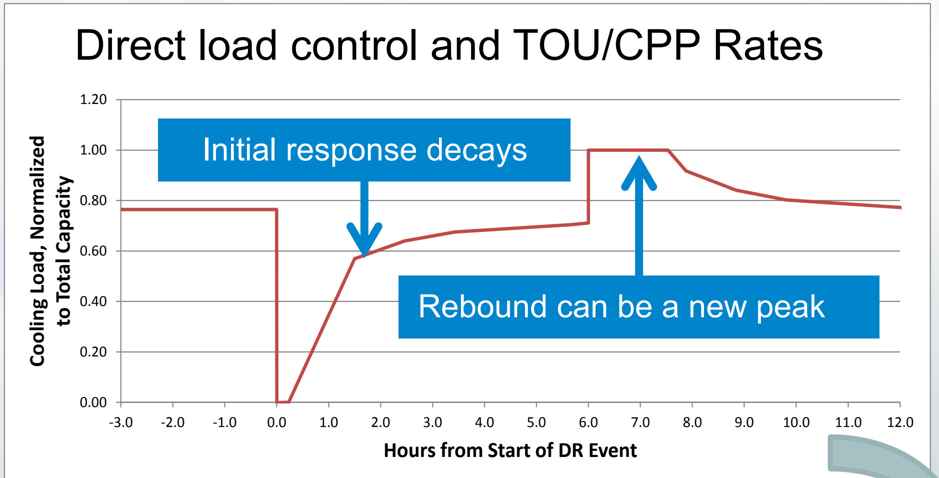



## Keys Results:

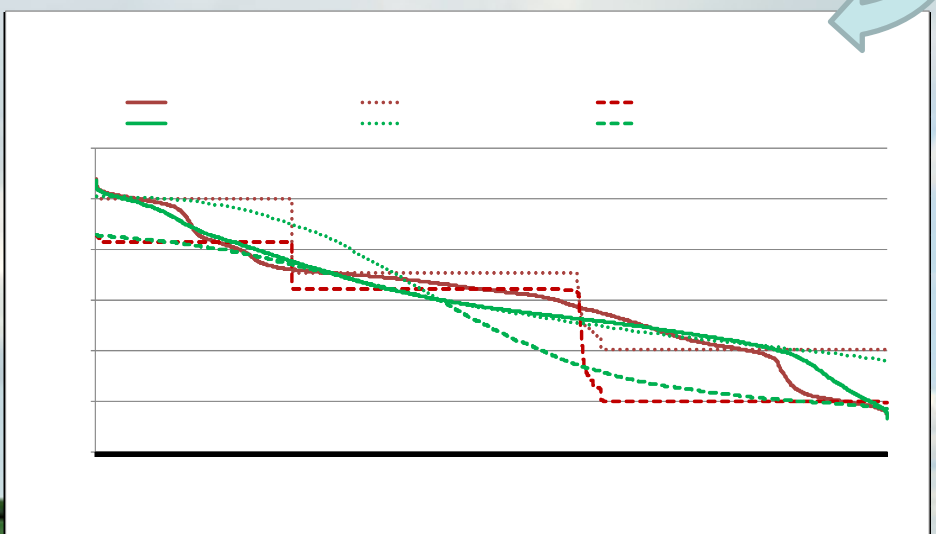
1. **Peak load reductions between 0.5% and 3%**
2. **Benefits vary widely depending on feeder, etc.**
3. **100% deployment saves ~3% national energy**
4. **40% deployment saves ~2.4% national energy**


Ref: **Evaluation of Conservation Voltage Reduction on a National Level**
Schneider, K.P., Fuller, J.C., Tuffner, F., Singh, R.
*Pacific Northwest National Laboratory report for the US Department of Energy, 2010*

# Demand Response Business Case Study




## GridLAB-D: Calibrated residential & Commercial building load models



| Customer Billing: Fixed_A vs. RTP_A | | | | |
|---|---|---|---|---|
| Month | Average Bill ($) | | Average Consumption | |
| | Fixed_A | RTP_A | Fixed_A | RTP_A |
| 1 | $ 88.45 | $ 85.95 | 1,078 | 1,079 |
| 2 | $ 84.45 | $ 80.14 | 1,019 | 1,018 |
| 3 | $ 98.47 | $ 95.46 | 1,226 | 1,208 |
| 4 | $ 106.86 | $ 113.66 | 1,233 | 1,207 |
| 5 | $ 139.91 | $ 136.68 | 1,654 | 1,630 |
| 6 | $ 160.05 | $ 153.49 | 1,911 | 1,869 |
| 7 | $ 193.47 | $ 201.91 | 2,336 | 2,307 |
| 8 | $ 193.44 | $ 231.09 | 2,336 | 2,322 |
| 9 | $ 126.09 | $ 94.11 | 1,478 | 1,462 |
| 10 | $ 102.06 | $ 77.38 | 1,279 | 1,266 |
| 11 | $ 87.00 | $ 73.17 | 1,057 | 1,053 |
| 12 | $ 89.81 | $ 88.54 | 1,098 | 1,098 |
| Annual | $ 1,470.07 | $ 1,431.58 | 17,705 | 17,519 |
| Sum (N=($)) | $ 145,537 | $ 141,726 | 1,752,817 | 1,734,424 |

**Key results:**

1. **Single family homes offer most returns (16% reduction)**
2. **New construction less costly**
3. **All competitive with coal**
4. **Existing commercial not competitive with CT**
5. **Comfort/billing impacts minimal**

# ARRA SGIG Impact Study

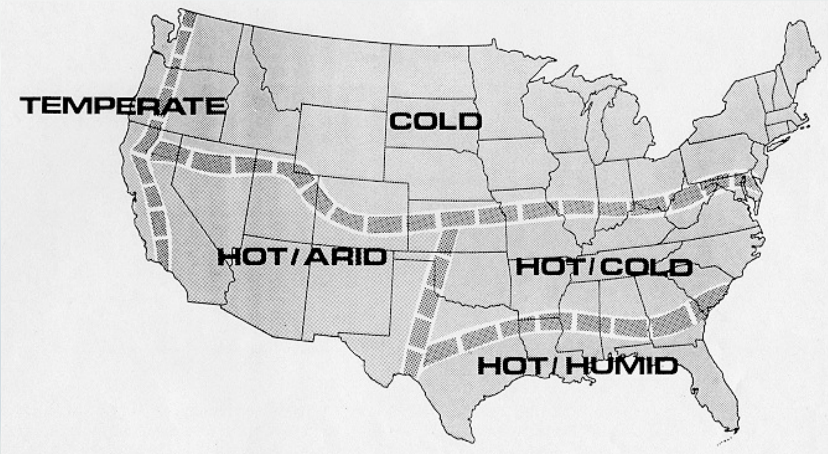
- **Quantify <u>technical potential</u> of ARRA SGIG**
  - Federal money invested: ~$3.4 billion
  - Total investment including industry co-funding: ~$8.2 billion
- **Deployment/data collection/analysis >5 years**
  - Grant recipients not <u>required</u> to report impact/benefits
- **GridLAB-D can estimate SGIG technology impacts**
  - Gives DOE preview/forecast of SGIG impacts
  - Opportunity to validate GridLAB-D results with actual results

# Common SGIG Technologies

- **Distribution Automation (52 grants)**
  - Capacitor and Regulator Automation
  - Fault Detection, Isolation, and Recovery/Reconfiguration (FDIR)
  - Conservation Voltage Reduction (CVR)
- **Demand Response (65 grants)**
  - Time-of-Use (TOU) and Critical Peak Pricing (CPP)
  - User interface technologies (HEMs, Smart Thermostats, etc.)
  - Direct Load Control (DLC)
- **Renewable Integration (12 grants)**
  - Distributed Solar Photovoltaic
  - Distributed Wind Generation
- **Energy Storage (13 grants)**
  - Thermal Energy Storage (Ice Bear®)
  - Plug-In Hybrid Electric Vehicles (PHEV – with WSU-TC)

# Simulation Models Used

- **Annual simulations of Taxonomy Feeders**




- 25 feeder models
- One-minute time-steps
- Regionalized to extrapolate national level impacts

- **Technologies individually compared with base case**
  - Over 400 annual simulations completed
  - Large quantities of data produced and analyzed
  - Cluster computation resources used

# Benefit Metrics

- **DOE Smart Grid Impact Metrics used**
  - Customer Electricity Usage ($ & kWh)
  - Peak Load Reduction
  - System Losses
  - Reliability Indices (SAIDI, SAIFI, CAIDI, MAIFI)
  - Component Loading and Overloads
  - Generator Capacity Factors and Emissions ($CO_2$, $NO_x$, $SO_x$)
  - Distributed Resources and Renewable Energy Supplied
  - Component Switching Operations
- **Excludes job creation & market innovation metrics**

# Potential Impacts of SGIG 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 (annual energy saved): — 0.1% – 3%
  - Low penetration: — losses generally decreased
  - High penetrations, uncoordinated deployment: — can increase system losses

# AEP Smart Grid Demo Project

# Where to Get More Information

- Main website: www.gridlabd.org
- SourceForge main page:
  - http://sourceforge.net/projects/gridlab-d/
- Downloads site:
  - https://sourceforge.net/projects/gridlab-d/files/
- Documentation site:
  - http://sourceforge.net/apps/mediawiki/gridlab-d/index.php?title=Main_Page
- List of technical papers:
  - http://sourceforge.net/apps/mediawiki/gridlab-d/index.php?title=Related_Papers
- Bug reporting site:
  - http://sourceforge.net/apps/trac/gridlab-d/
- User forum site:
  - http://sourceforge.net/projects/gridlab-d/forums

# GridLAB-D Project Contacts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