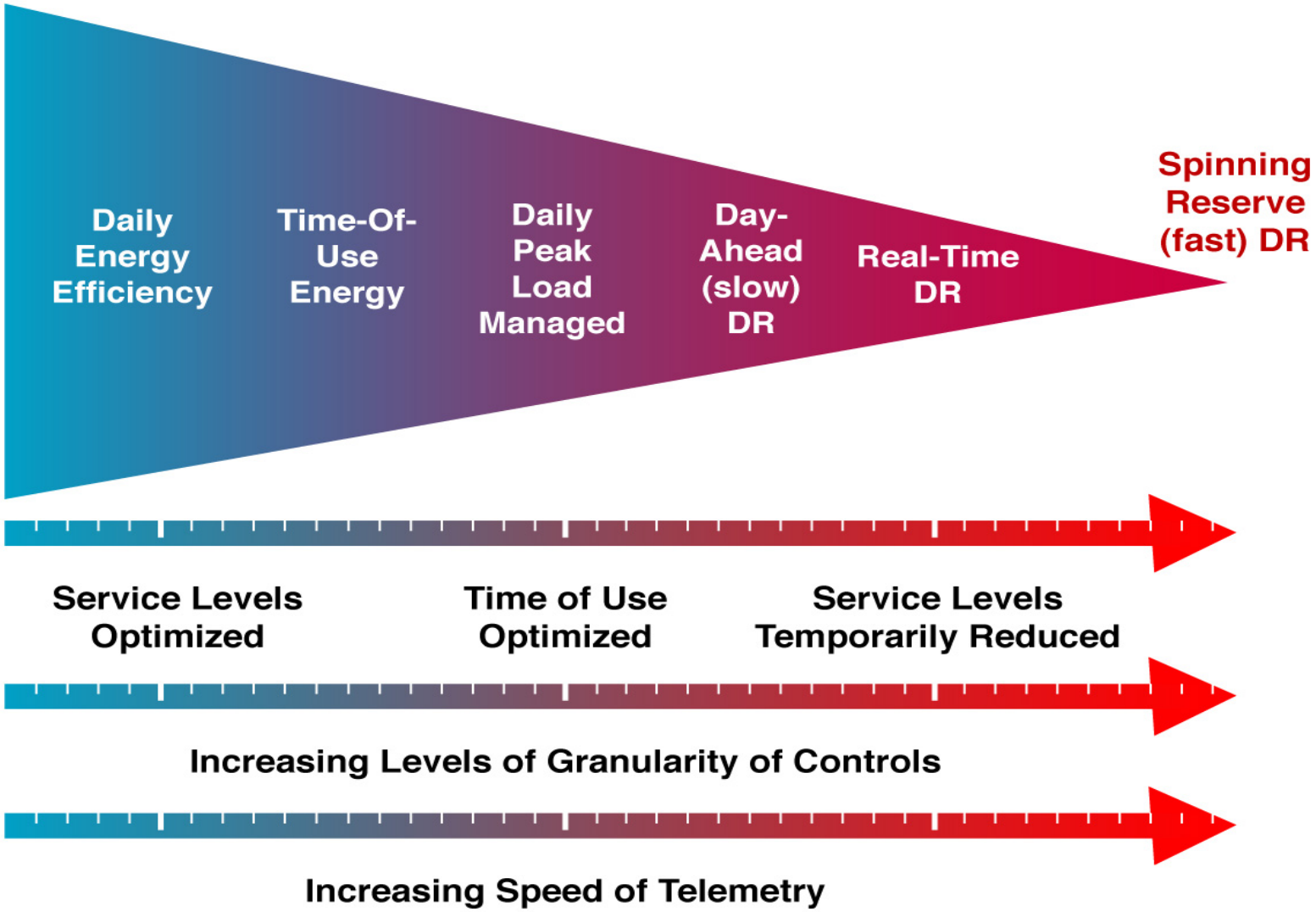
Presentation Outline

- Motivation and Introduction
- Objectives
- Synchronous Reserve Test
- Regulation Tests
  - Speed of Response
  - Accuracy
  - Latency
- Energy Impacts of AS
- AS Value in PJM
- Conclusions

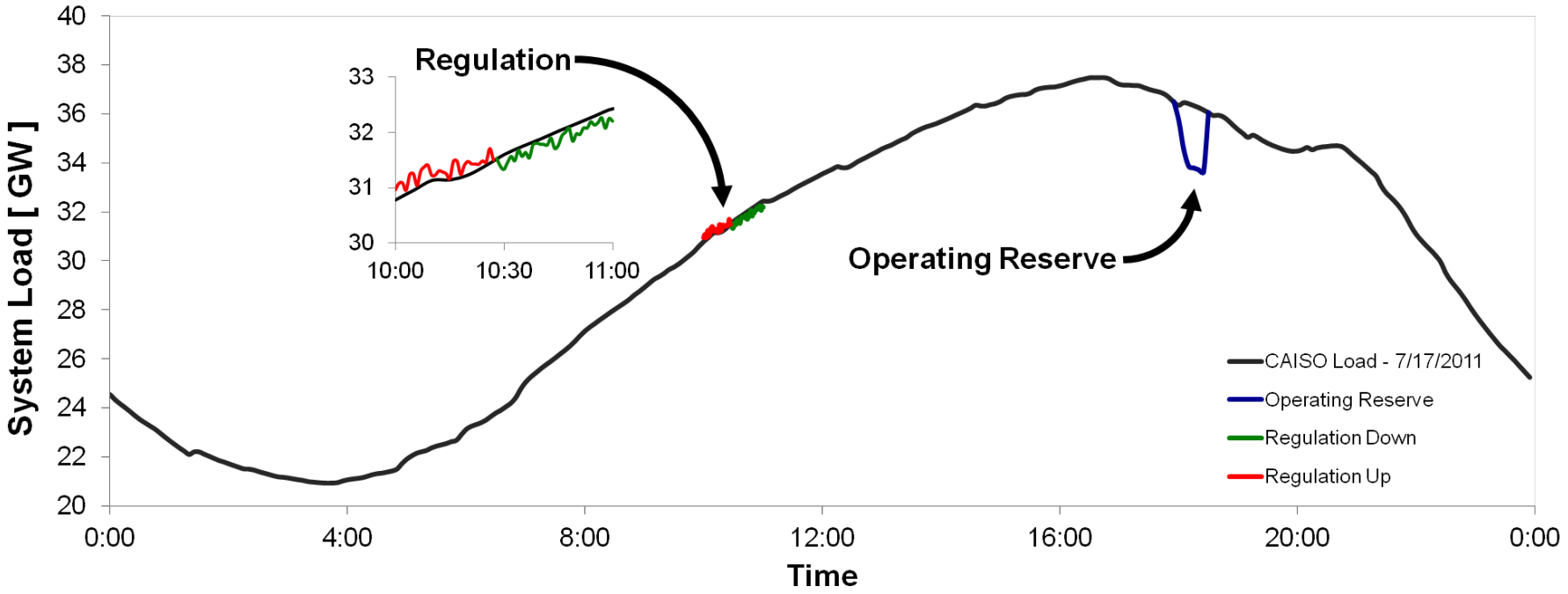
Linking Energy Efficiency and DR



Motivation

- Increased uncertainty in the electricity system:
  - Variable Renewable Generation
  - Electric Vehicles
  - May drive need for ramping and additional ancillary services procurement by system operators (Helman 2010)
- FERC rules (2008, 2011, 2012) to open markets to new resources, reduce uncertainty, and establish incentives for fast and accurate performance

Background - Ancillary Services



Operating Reserves respond when a contingency event occurs to restore balance.

- respond within 10 minutes
- event duration typically 10-30 minutes
- Includes Synchronous and Non-Synchronous

Regulation rectifies small discrepancies between load and 5-minute real time dispatch

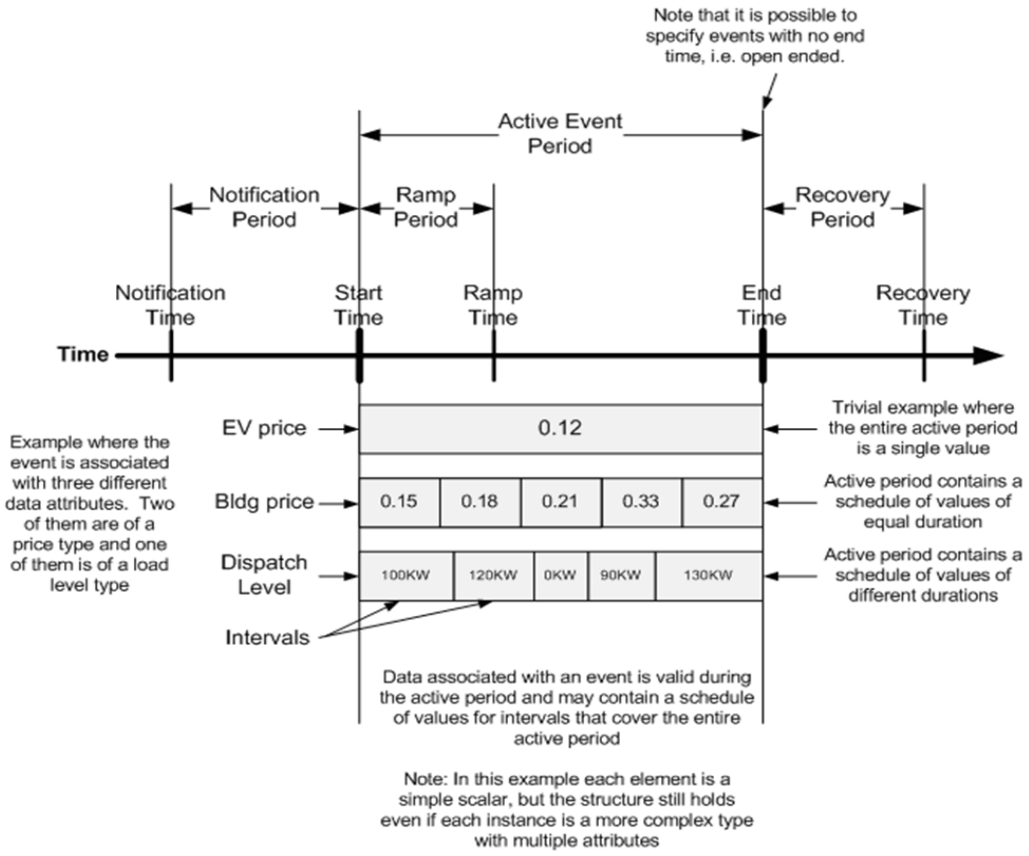
- receives an operating point instruction and responds within 4 seconds
- Theoretically energy neutral, although not in practice

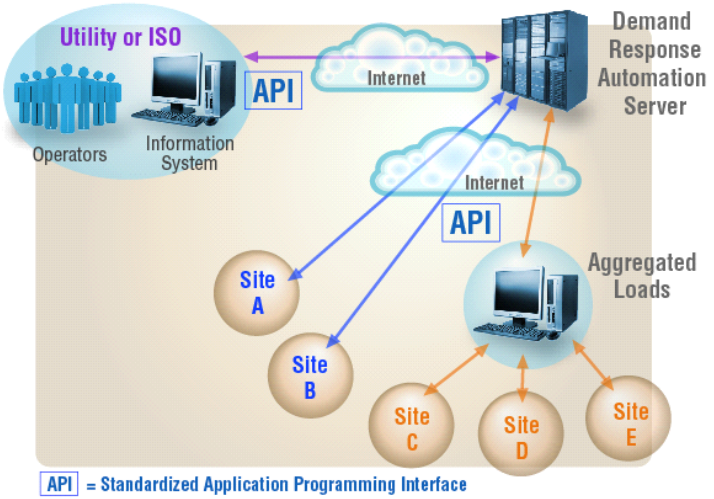
Why DR? Why Commercial Buildings?

- Qualities of DR resources provide some system benefits:
  - Very fast (extremely high ramp rates)
  - Cheap to operate (likely price takers)
  - Statistical reliability (property of large numbers of small resources)
  - Fast to market (very few siting/permitting issues)
- Commercial Building loads make up 36% of electricity load in the US
- Commercial Buildings have advanced control
- First cost can be high without standardized, interoperable communications paths

Introduction to OpenADR

- OpenADR 2.0 is a new national standard information exchange model for demand response automation

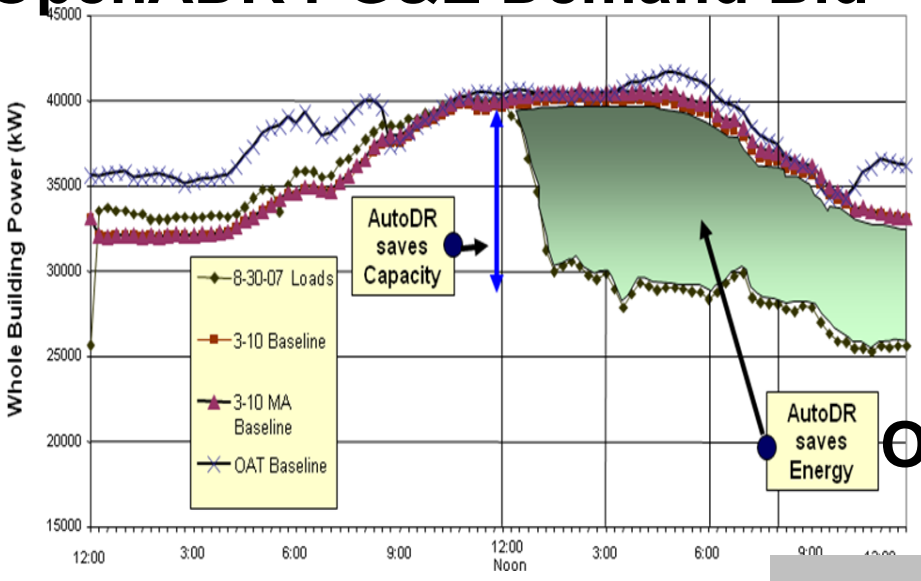




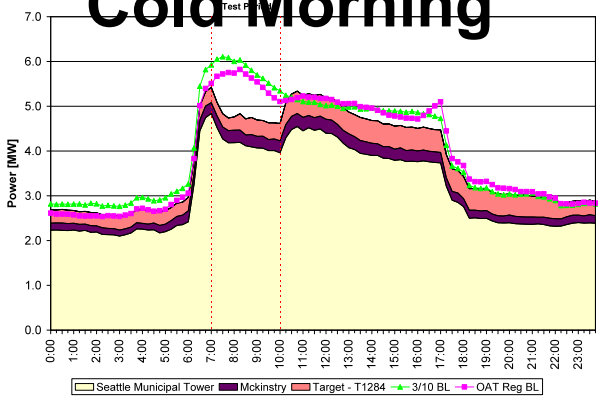
- Transport agnostic
- Basic (2.0a) and Advanced (2.0b) data profiles
- 2.0b satisfies all real-time communication requirements for ancillary services

Historic focus on Seasonal Grid Stress

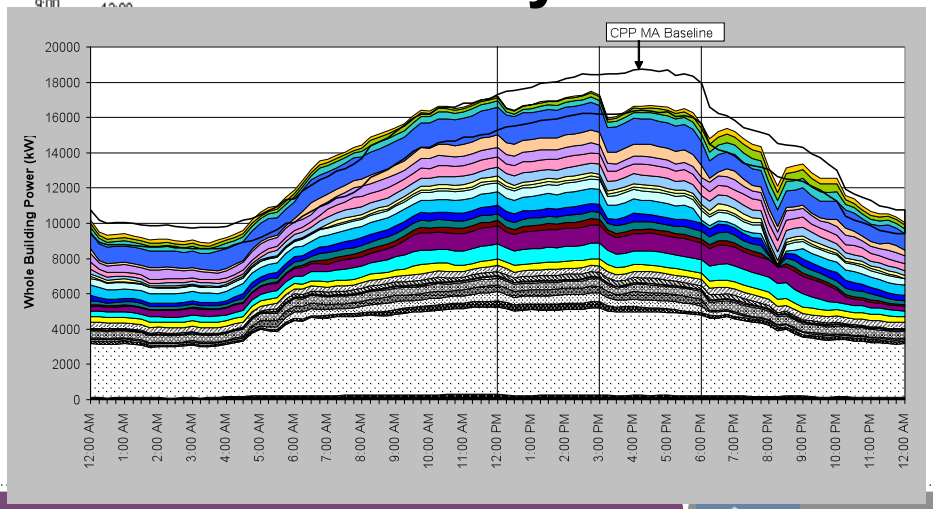
OpenADR PG&E Demand Bid



OpenADR Northwest Test on Cold Morning



OpenADR Cumulative Shed in July 2008

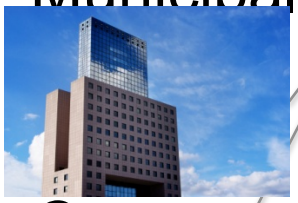


Tech Potential of DR and Dispatch Models

LOADS

Residentia

Municipal

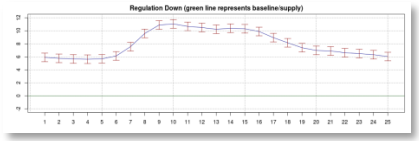


Commercial

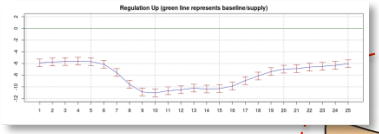
Agricultural

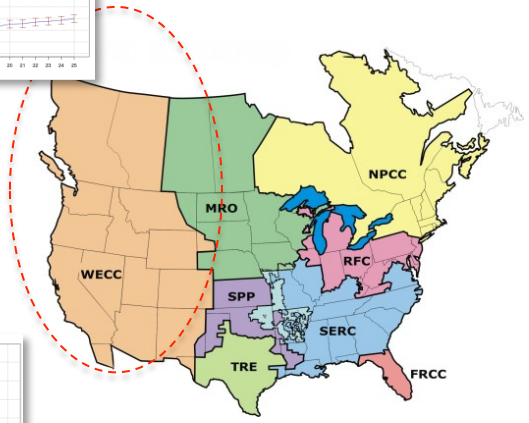
Response Parameters
Flexibility range (reg up, reg down, both)
Speed of Response
Store, Shift or Shed
Load response to products
Size of Response
Controllable
Sizing of Resource
Min and max daily consumption requirements
Cycling Rate Impacts (wear/tear)
Impacts on Overall Response
Rebound/Recovery Issues
Charge/Discharge
Independence
How to Predict
Predictable or Variable (daily, seasonal, geographic)
Time or Operational dependence
How it Participates
Individual or Aggregated

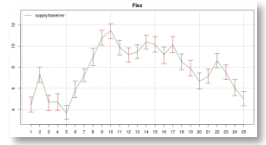
ANCILLARY SERVICES PRODUCTS

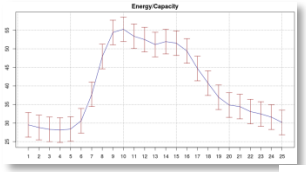


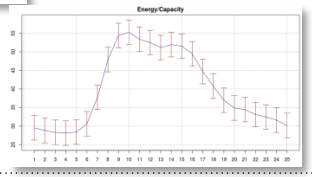
MODELS





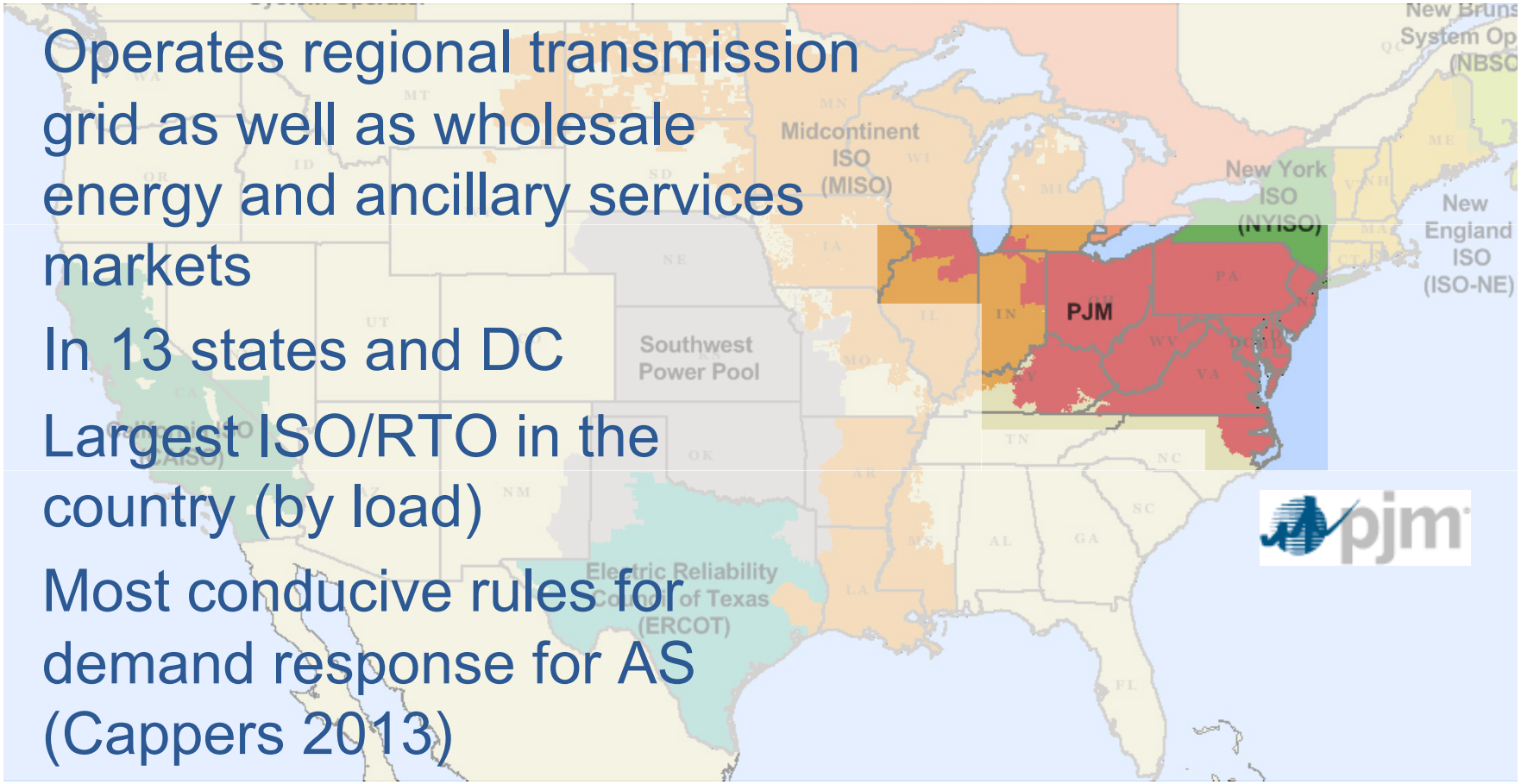






Background - PJM

- PJM is a Regional Transmission Organization (RTO)
- Operates regional transmission grid as well as wholesale energy and ancillary services markets
- In 13 states and DC
- Largest ISO/RTO in the country (by load)
- Most conducive rules for demand response for AS (Cappers 2013)



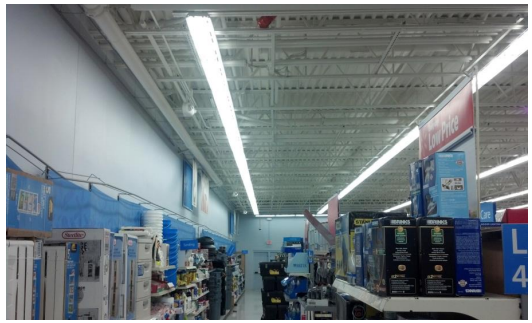
Source: FERC.gov

Project Objectives

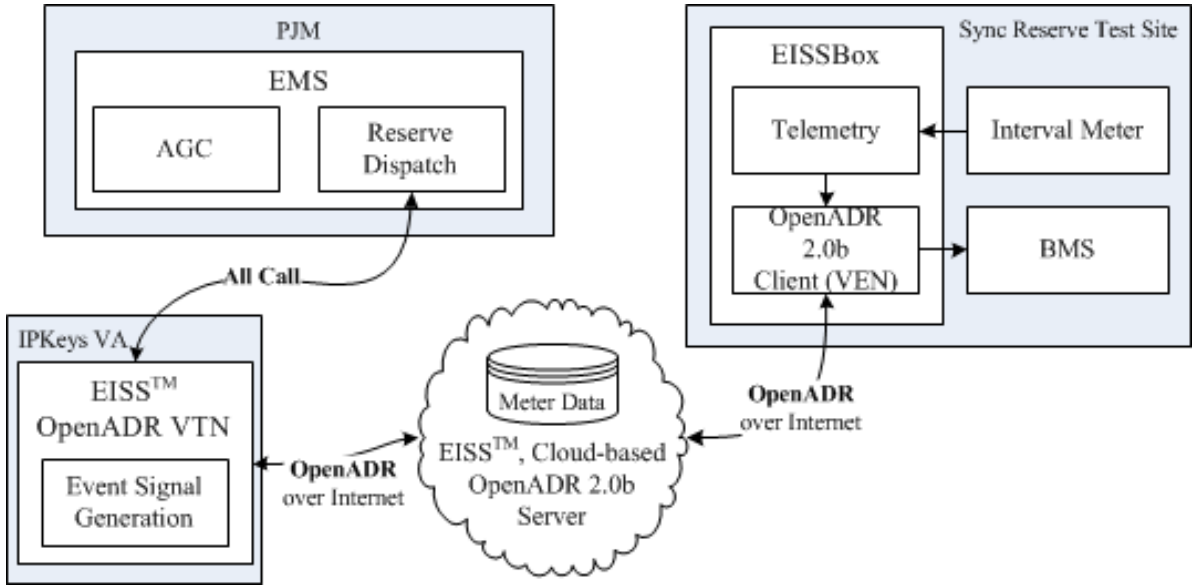
- Demonstrate OpenADR-enabled building load response satisfy requirements of ancillary services
- Quantify OpenADR architectural latencies with a variety of communications pathways
- Examine response speed and accuracy of building end-uses for ancillary services applications

Synchronous Reserve Demo - Site

- HVAC and Lighting in a big box retail through central building energy management system control
- Walmart Store in Quakertown, PA
- BMS – Honeywell Novar
- Metering – Schneider M820
- Control actions:
  - HVAC thru setpoint adjustment
  - Lighting thru 1/3 shed of perimeter lights

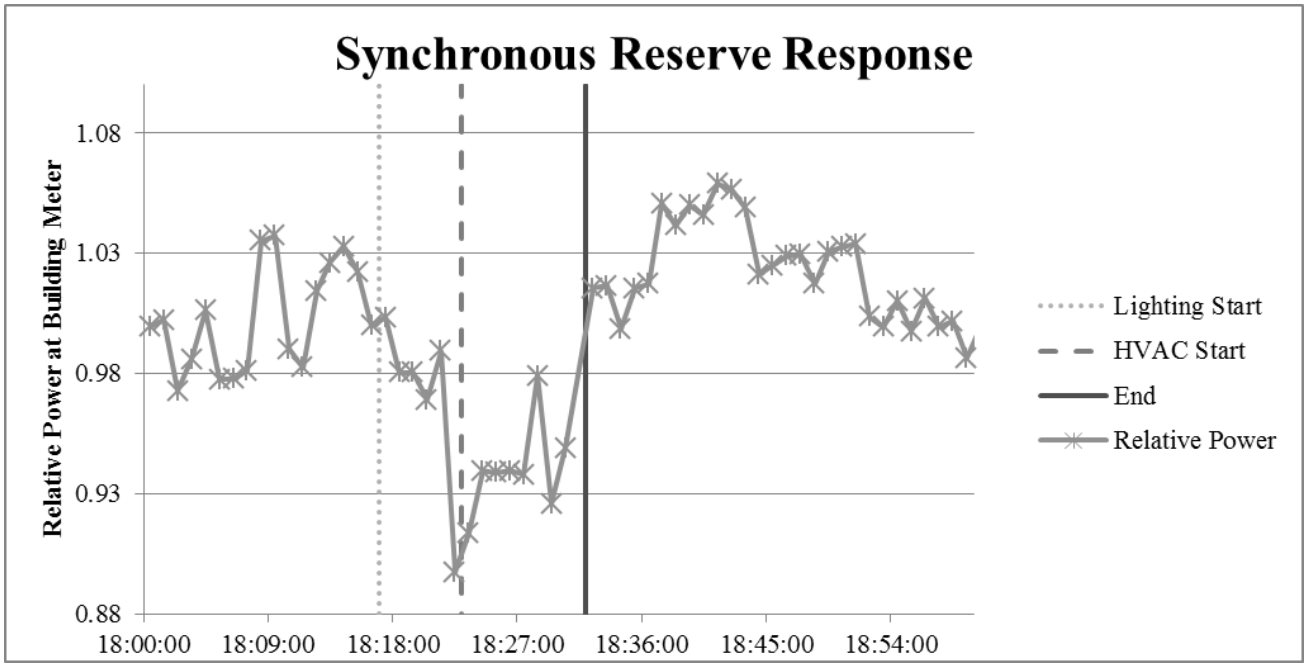


Synchronous Reserve Demo – Comm. Architecture



- Client polled using http every 20 seconds
- Client connected via cellular network
- Testing with new PJM automated M2M signaling next month

Synchronous Reserve Demo - Response

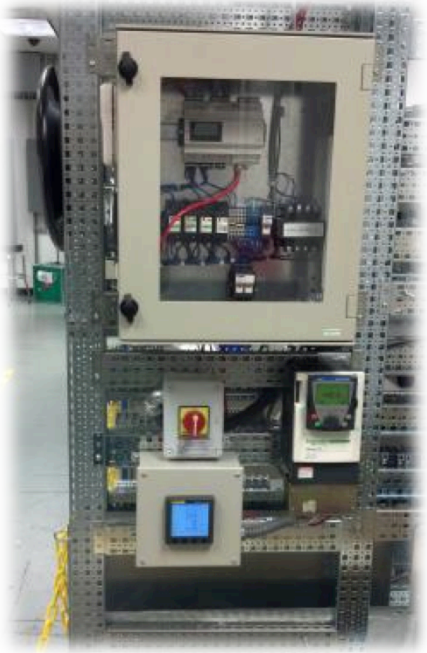


Loads successfully responded to synchronous reserve tests

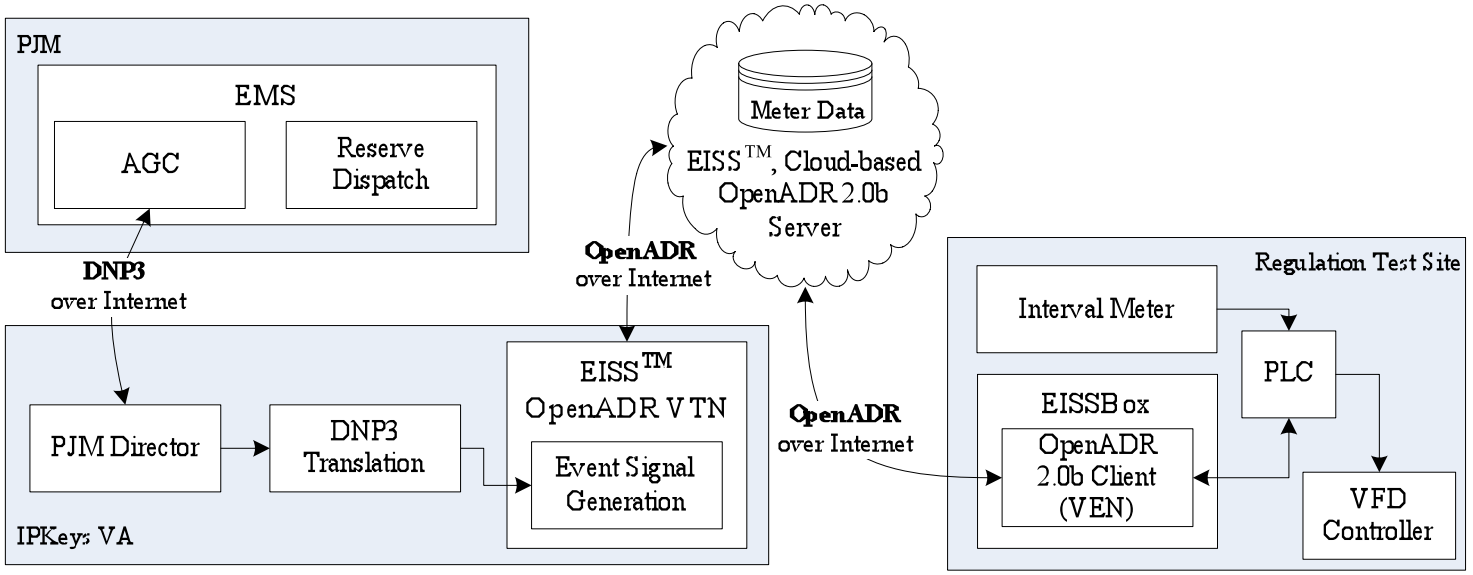
- Lighting response ~2% within 2 minutes
- HVAC response ~ 4% immediately or preemptively (?)
- Load response achieved without noticeable rebound

Regulation Demonstration - Site

- A heat pump cooling a small laboratory space was retrofitted with a VFD on supply fan
- Schneider Electric's VFD laboratory in Knightdale, NC
- Connected to VFD through PLC
- Telemetry – Schneider M820
- Controls:
  - 0.5 Hz frequency adjustments
  - Frequency range: 55 and 65 Hz.

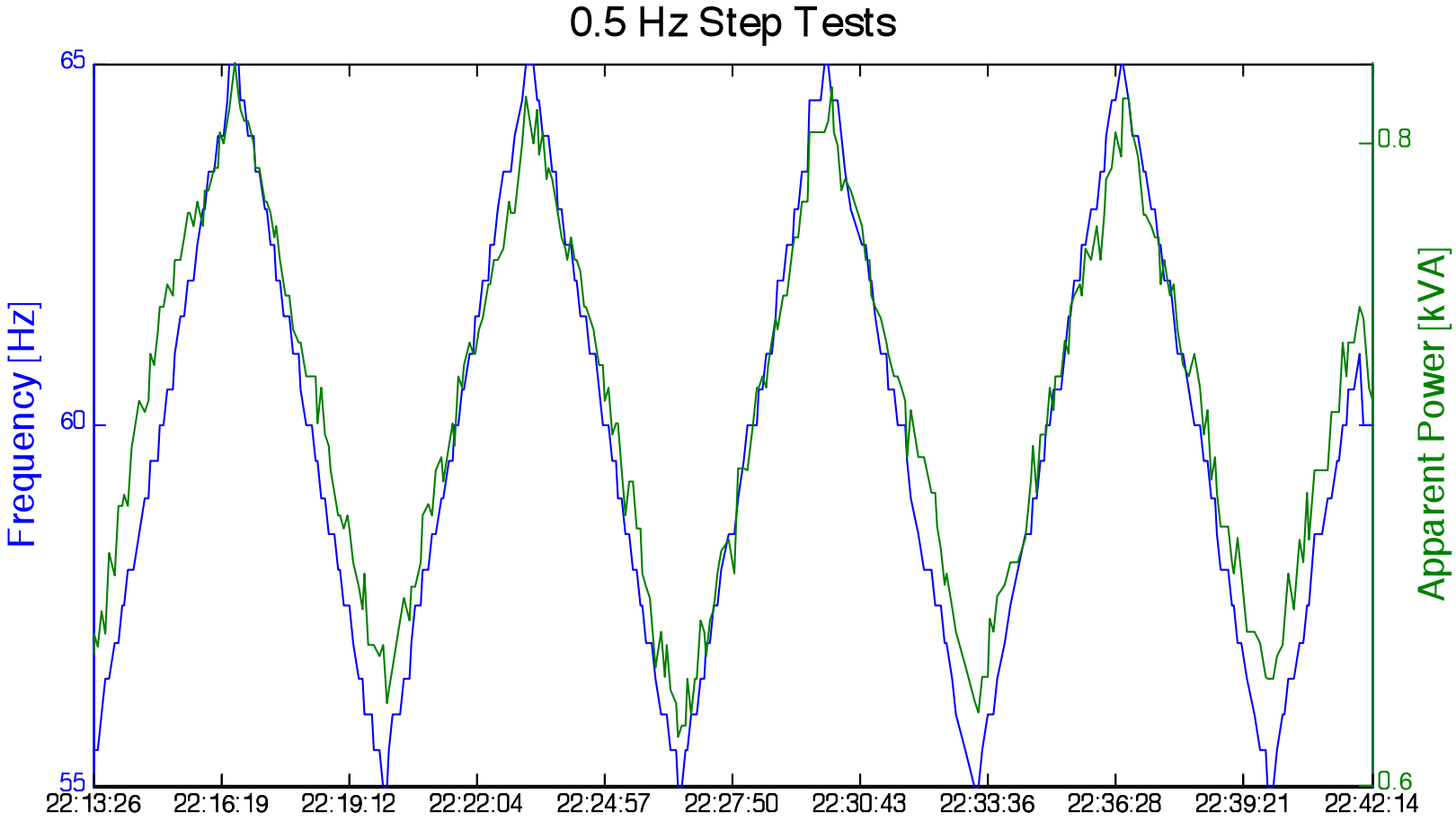


Regulation Demonstration – Comm. Architecture



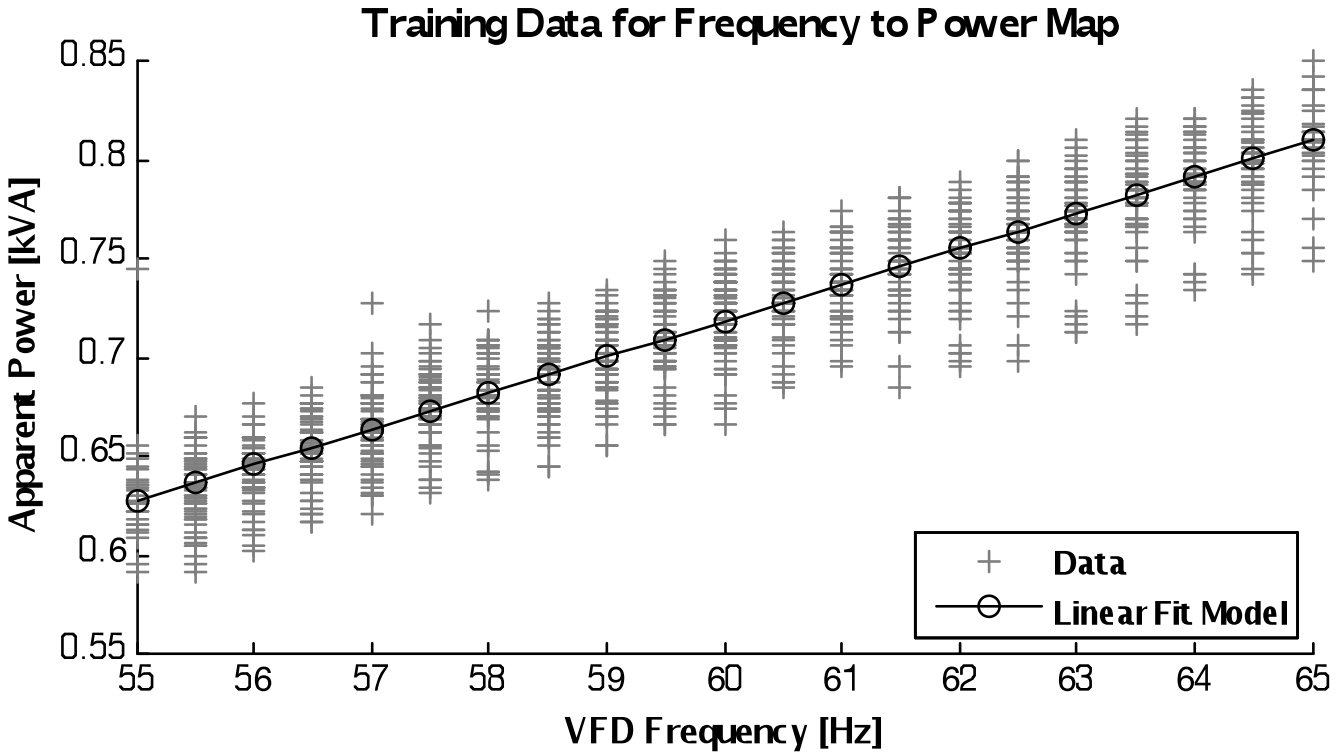
- Signals pushed to client via XMPP
- Wired internet connection
- At the time of tests, connection with PJM not established

Mapping frequency to power



Step tests were repeated on different days at different times to characterize system

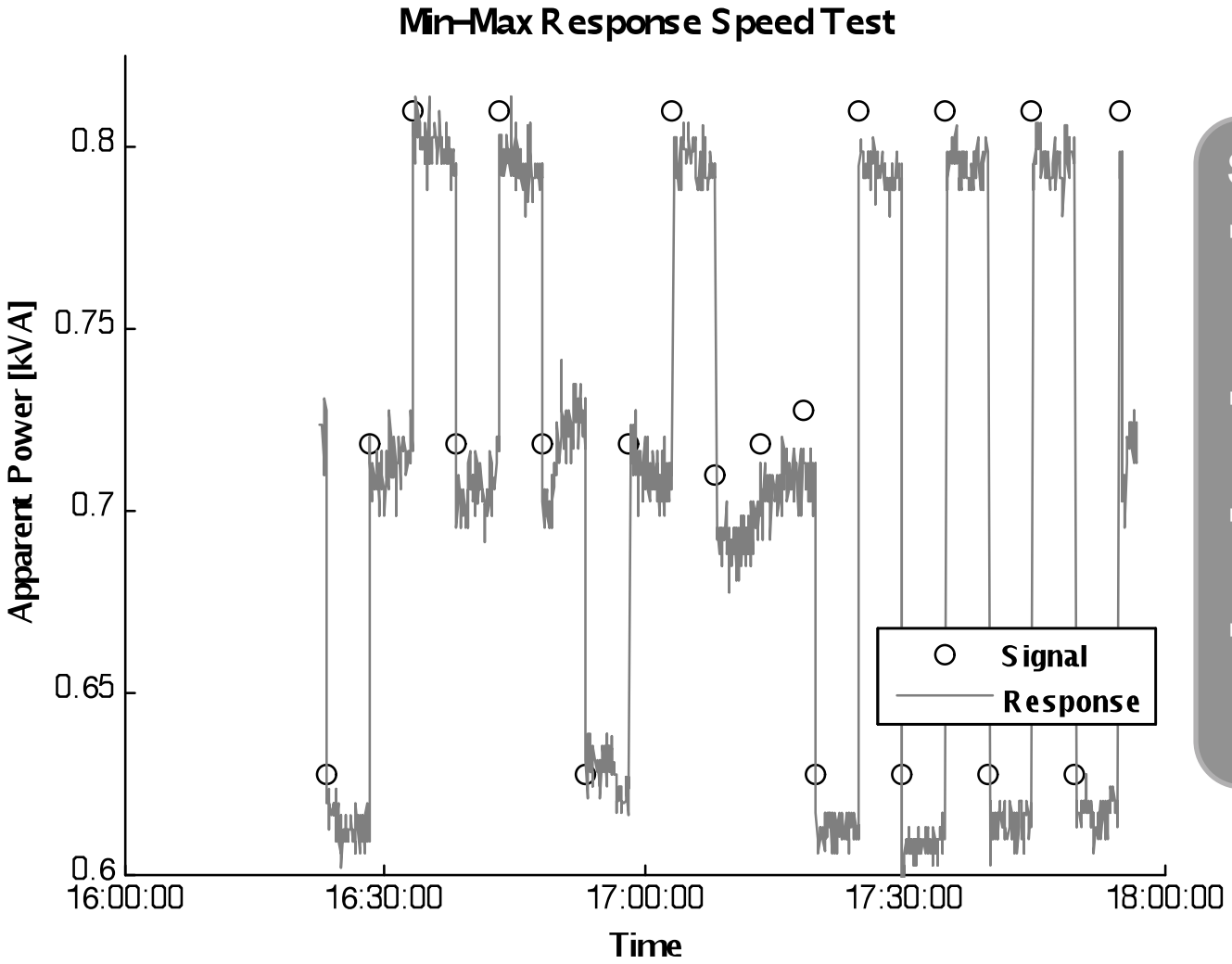
Frequency 2



Linear model appropriate between frequency and apparent power

- Linear expression: AP = 0.018*freq-0.371 [kVA]
- RMSE = 0.019 kVA
- Load too small for power factor measurement – no real power

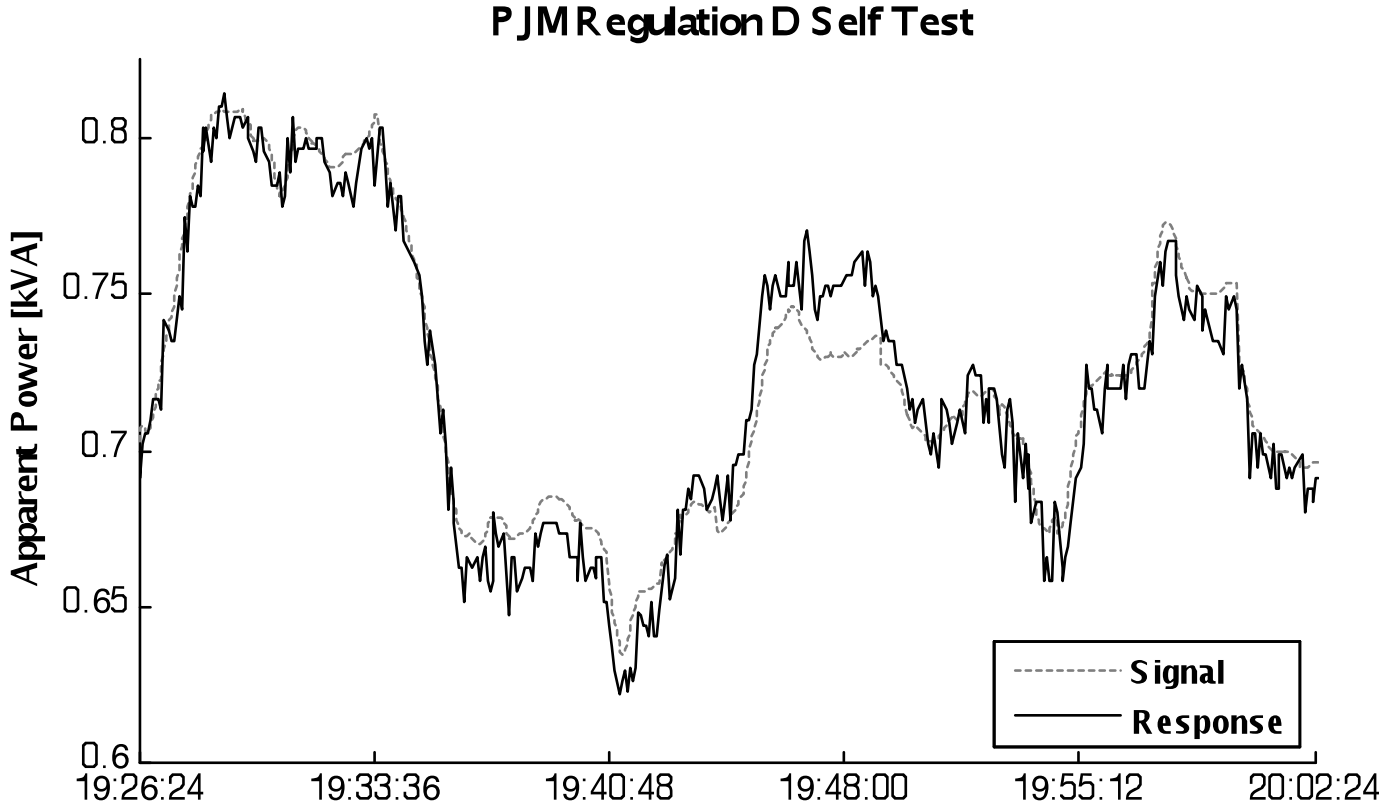
Response Speed Test



Speed of Response

- Large step changes are held for five minutes
- Average response time = 4.7 seconds
- Range 2.3 – 7.2 seconds
- ~ 4 seconds between meter reads

Accuracy of Response



Accurate response to 40 min dynamic regulation self-test signal

- Using PJM's precision metric (2014) achieves 90% accurate
- Despite rounding response to 0.5 Hz steps
- PJM expects 10 second lag in response

Communications Latencies

- Using data from all tests, Latency Statistics:

Number of signals sent	1538
Number of signals received	1495
Signals lost	43
Minimum latency [s]	0.01
25th percentile latency [s]	0.29
Median latency [s]	0.44
75th percentile latency [s]	1.04
Maximum latency [s]	10.21
Average latency [s]	0.99

- PJM expects 10 second lag in response
- Calculated latency plus response time is less than 10 seconds in most cases.

Energy Impacts of AS

- Synchronous Reserve Energy Impacts
  - Based on historical reserve calls (2009-2013)
  - Average duration: 11 minutes
  - Average events per year: 31
  - Probability of an event occurring in any hour: 0.4%
- Regulation Energy Impacts
  - Based on one month data (Dec 2012-Jan 2013)

Time Horizon	Energy Generation [kWh/kW]			
	Average	Std Dev	Min	Max
5 min	-0.0004	0.019	-0.083	0.083
15 min	-0.0013	0.026	-0.212	0.178
1 hour	-0.0054	0.043	-0.253	0.285

➢ **Ancillary services have less energy impact than typical DR (100 hrs, 2-4 hrs per call)**

Value of AS in PJM

- DR qualifies as a Tier 2 synchronous reserve in PJM
- Tier 2 reserves require an opportunity cost to provide reserves
- Tier 2 reserves are rarely required (more than 50% of the time have no value)
- Regulation much more valuable at an average of $17/kW-mo (fully participating), $2.2/kW-mo in Sync

Table: Market Clearing Price for AS in PJM in 2013

Units = [$/MW-h]	Average	Std Dev	Min	Max	MCP = $0
MCP for Synchronous Reserve*	3.06	8.63	0.00	210.07	54.0%
MCP for Capacity (Regulation)	24.02	28.74	0.00	756.05	0.1%
MCP for Performance (Regulation)	4.12	2.52	0.00	29.14	2.5%

* For Mid Atlantic Reserve Zone

Conclusion / Next Steps

- Individual end uses in commercial buildings can satisfy performance requirements of AS products in PJM
- Energy impacts from providing services in PJM are minimal
- OpenADR 2.0b enabled devices are suitable for AS provision with product time requirements
- Future Work:
  - Demonstrating VFD control for regulation as an integrated solution in BMS
  - Coordinating control of multiple building loads to achieve aggregate regulation response

Acknowledgements

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    - Joe Callis
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