Herrick Laboratories PURDUE UNIVERSITY

2016 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

A VOLTTRON-Based System for Providing Ancillary Services with Residential Building Loads

Xin Jin, Ph.D.

Buildings and Thermal Systems Center

National Renewable Energy Laboratory

Intelligent Building Operations (IBO) Workshop
Purdue University, West Lafayette, Indiana
July 10, 2016

PURDUE UNIVERSITY

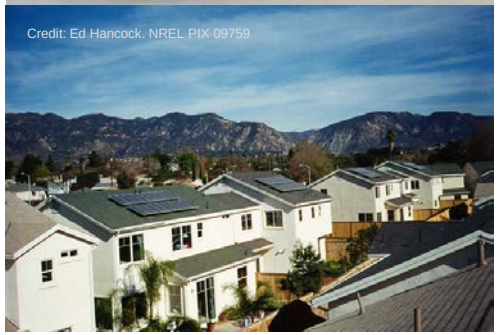
C H P B Center for High Performance Buildings at Purdue

University of Colorado Boulder

NREL/PR-5500-66730

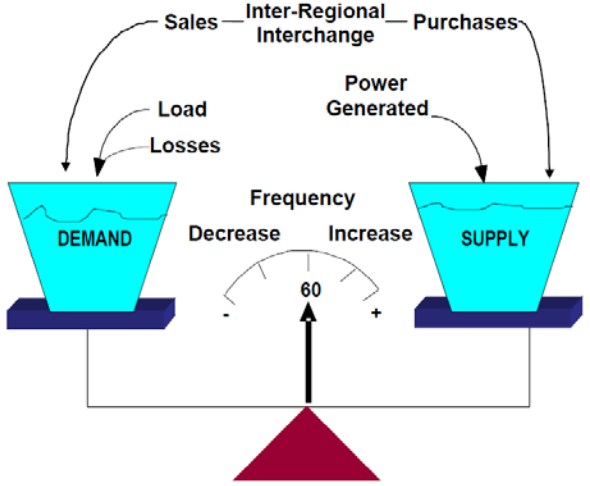
Ancillary Services

- Ancillary services support a stable balance between generation and load in power systems.
- Demand response (DR) for ancillary services:
  - » May provide superior response to generators
  - » Different from traditional DR
  - » Technical requirements are more challenging in terms of speed and accuracy.
- Pilot studies leverage demand-side resources
  - » commercial building: HVAC systems
  - » electric vehicle: charging and discharging
  - » residential building: very few



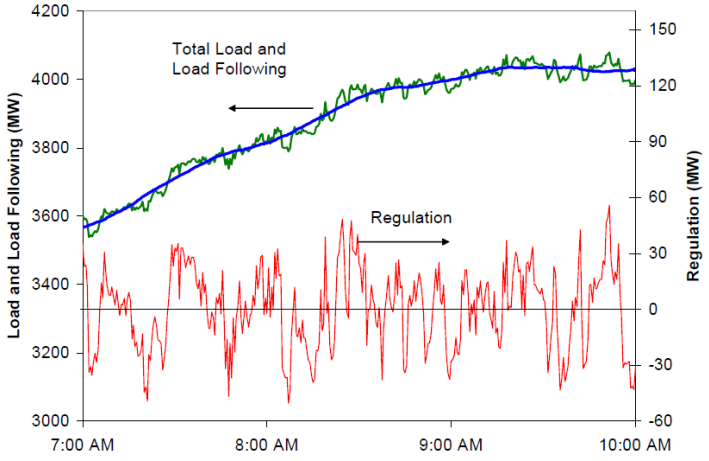
Frequency Regulation

- A service for maintaining the system frequency by balancing supply and demand in the grid
- Generally considered a higher value service than other ancillary services
- Also more challenging due to the constraint of short response time



Generation/Demand Balance

Source: NERC: balancing and frequency control. Figure 3a.



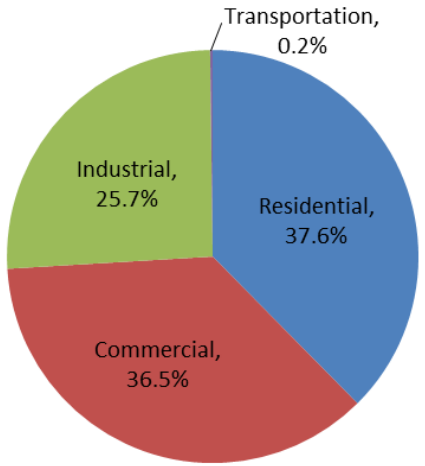
Compensating minute-scale fluctuations in load and generation

Source: B.J. Kirby. Frequency Regulation Basics and Trends. ORNL/TM-2004/291. Figure 4.

Residential Building Loads

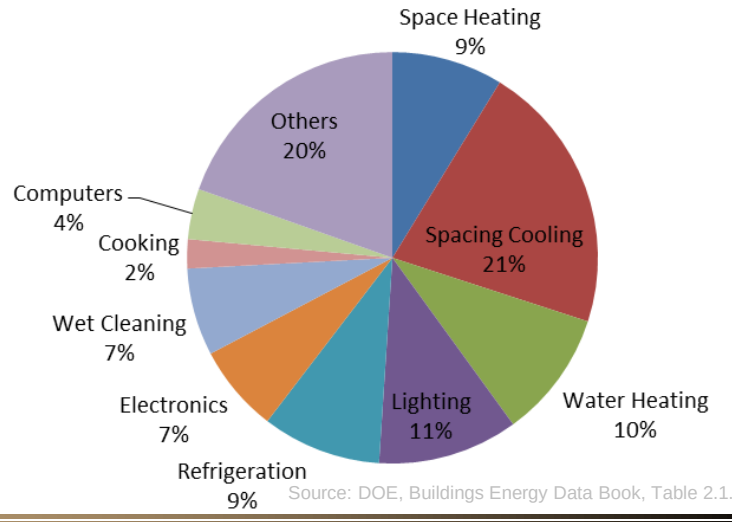
- The residential building sector accounts for 38% of the total U.S. electricity use.
- Many residential building loads are flexible and could be curtailed or shifted at the request of the grid.
- Residential building loads represent a largely untapped resource for providing ancillary services.
- However, there are many barriers that prevent residential loads from being widely used for ancillary services.

U.S. Electricity Consumption by Sector (2015)



Source: EIA, Electric Power Monthly, Table 5.1.

U.S. Residential Electricity Consumption by End Use (2015)



Source: DOE, Buildings Energy Data Book, Table 2.1.5.

Technical Barriers

- Residential loads are relatively small and need to be aggregated to provide an impactful grid service resource.
- Most residential end-use devices lack the communication capabilities with the grid.
- “Connected” residential devices have emerged to overcome the communication barrier.
- These connected devices have introduced a new interoperability challenge due to the existence of numerous standards and communication protocols.


Credit: Bethany Sparn. NREL PIX 25545

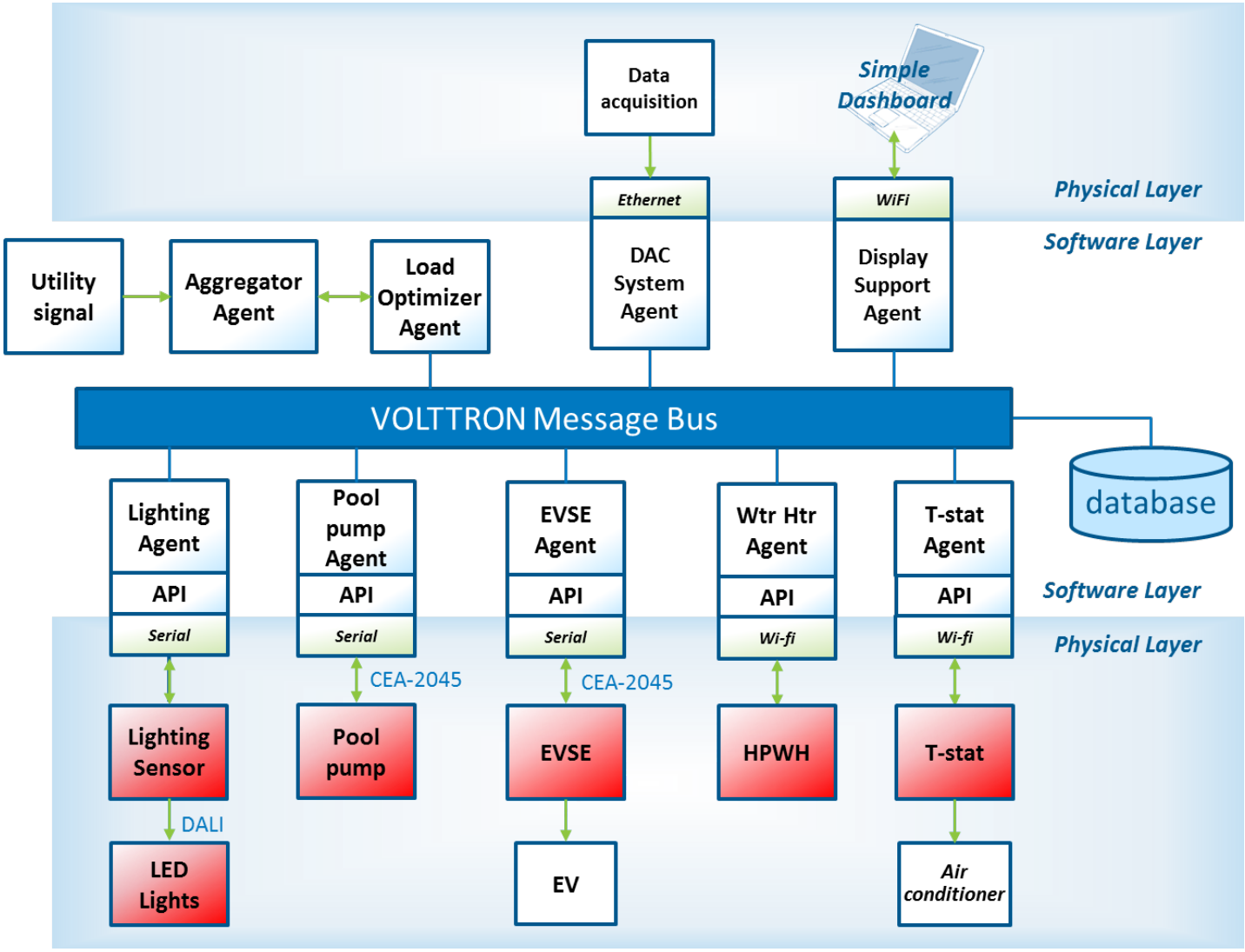

Credit: Bethany Sparn. NREL PIX 25541

VOLTTRON™

- An application platform (e.g., Android, iOS) for distributed sensing and control applications
- Not a protocol but rather a platform for implementing protocols as applications
- Ideal for equipment interoperability
  - » Open source and non-proprietary
  - » Flexible and extensible for developers to work with devices and external resources
  - » Existing drivers for building equipment
    - – Standard-based: Modbus, BACnet, OpenADR, CEA-2045
    - – Proprietary (access via APIs): thermostat, light control, etc.

Source: DOE BTO 2015 VOLTTRON Meeting

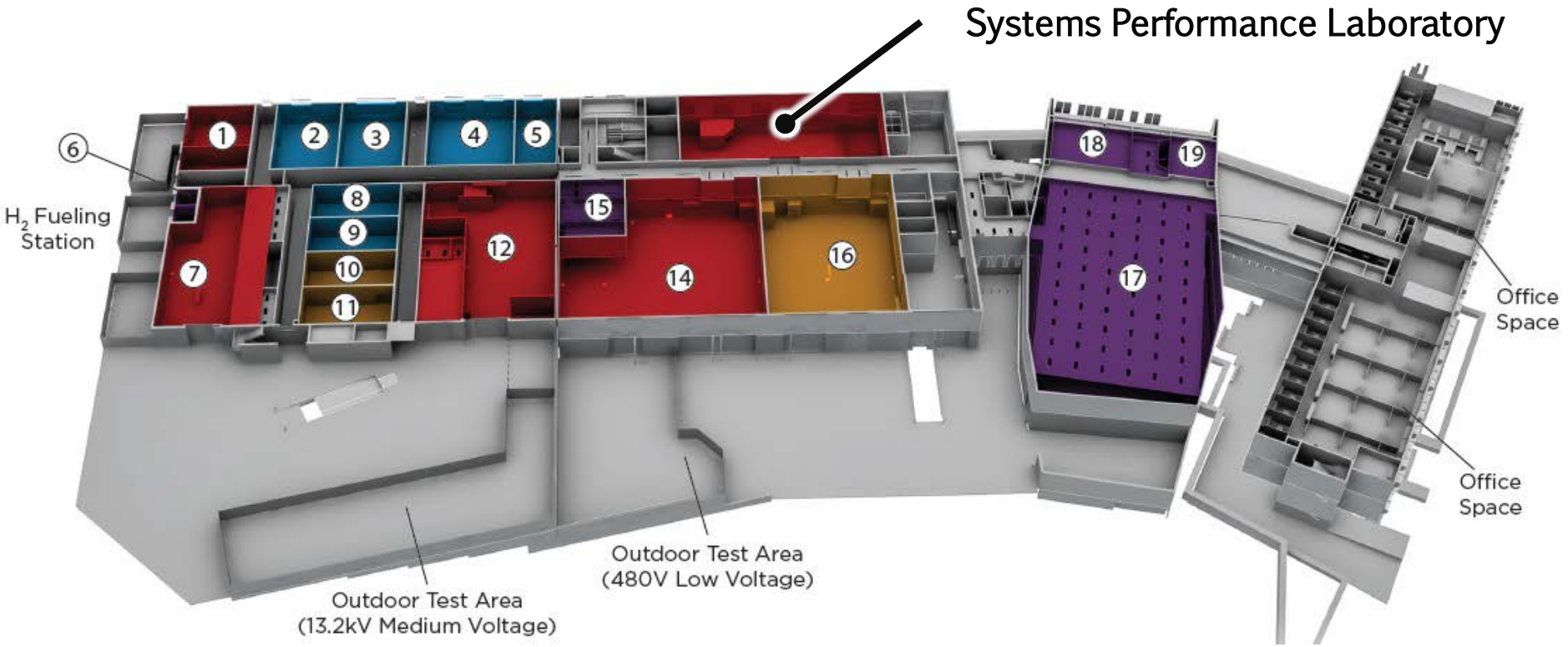
Layout of VOLTTRON Infrastructure



VOLTTRON Deployment in ESIF

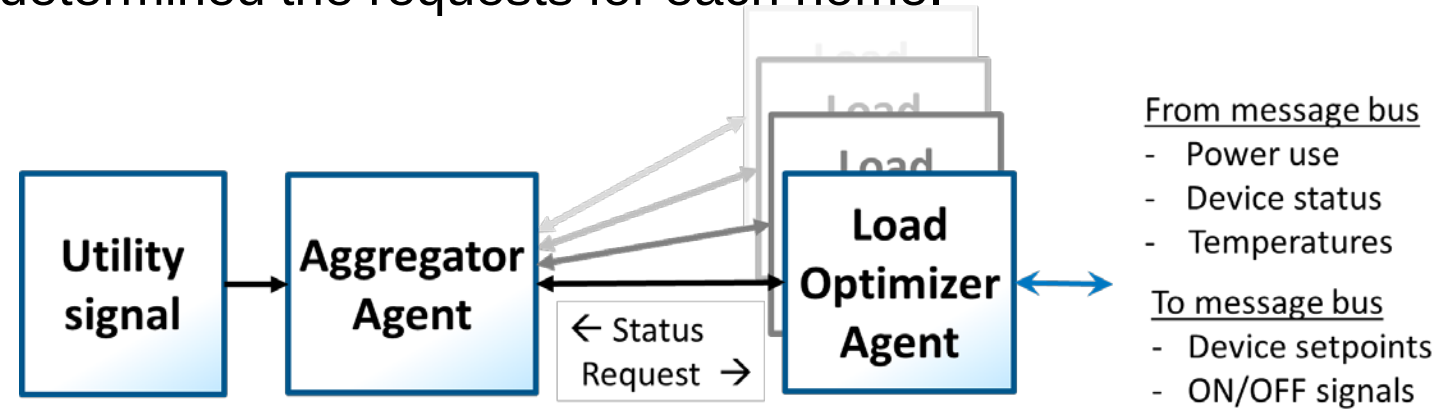
NREL's Energy Systems Integration Facility (ESIF):

- 2014 Laboratory of the Year named by the R&D Magazines
- A first-of-its-kind research user facility: an ultra-energy efficient workplace, one of the most energy-efficient HPC data centers, and sophisticated high-bay lab spaces

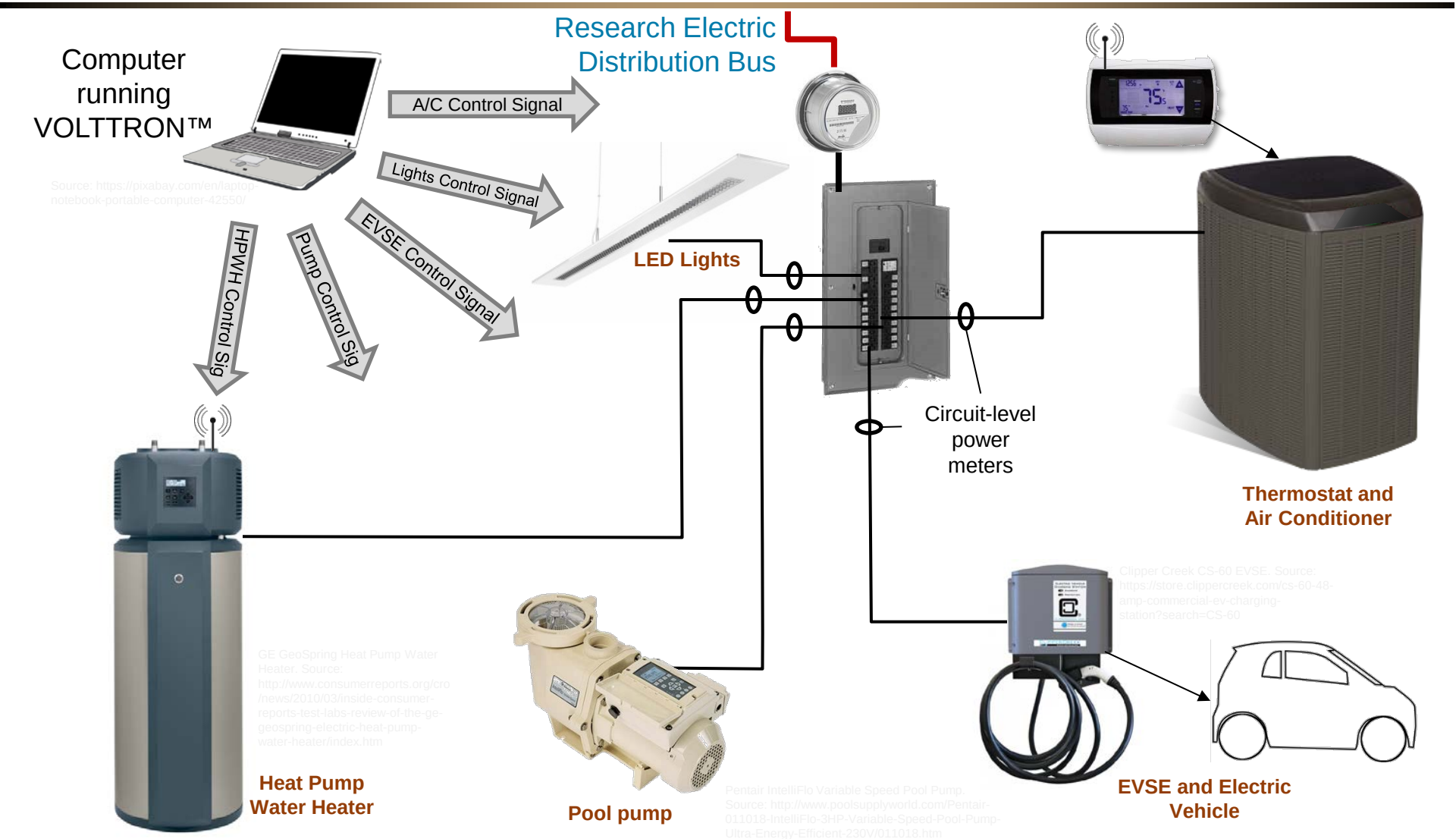


Frequency Regulation Use Case

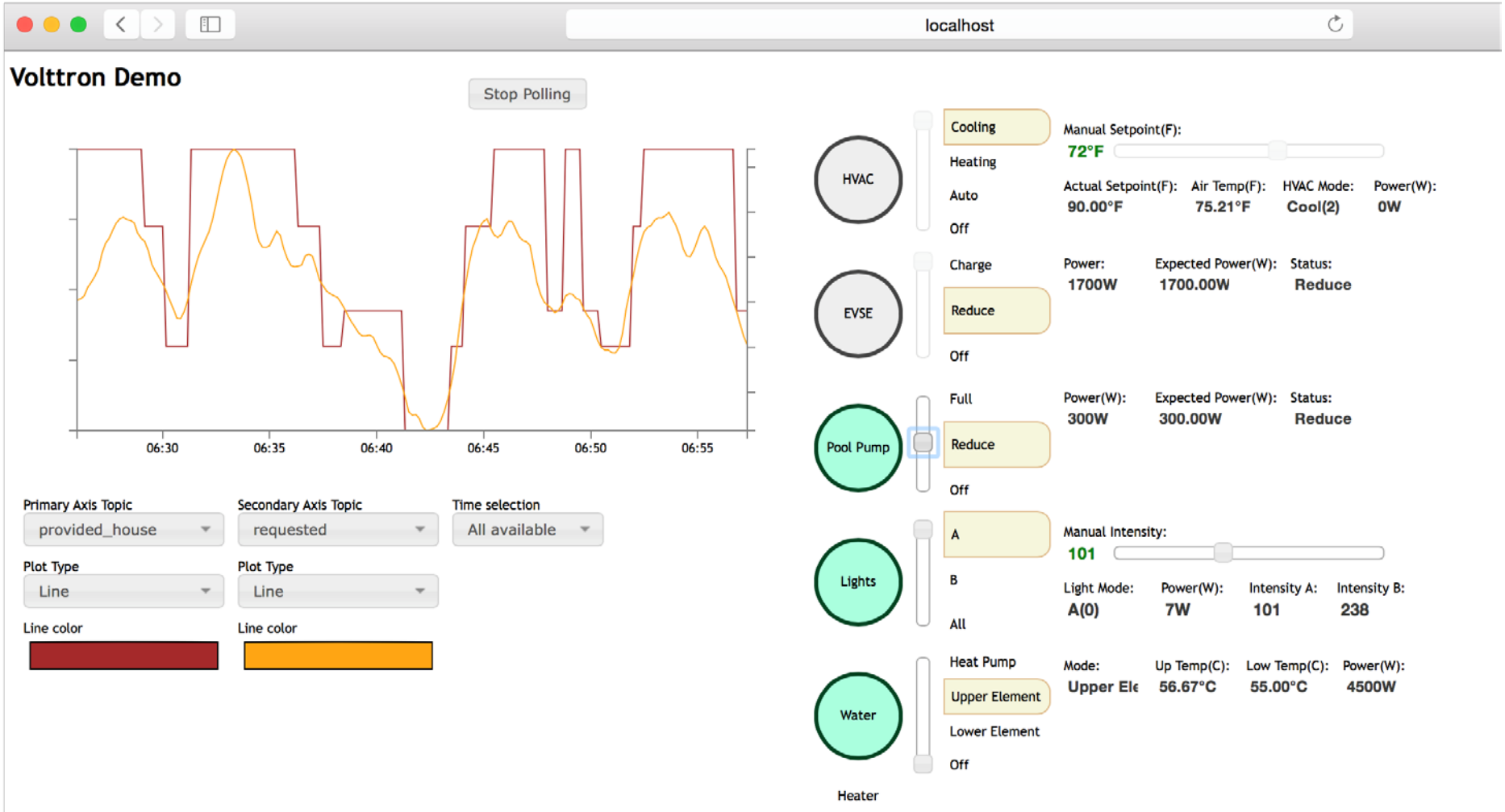
- We examined residential appliances' ability to provide regulation services and used the connected appliances in the System Performance Laboratory at the ESIF.
- An actual regulation signal from PJM Interconnection (a regional transmission organization) in July 2013 was used.
- Each home communicated their available demand response capacities to the aggregator.
- The aggregator agent sampled the signal every 10 seconds and determined the requests for each home.



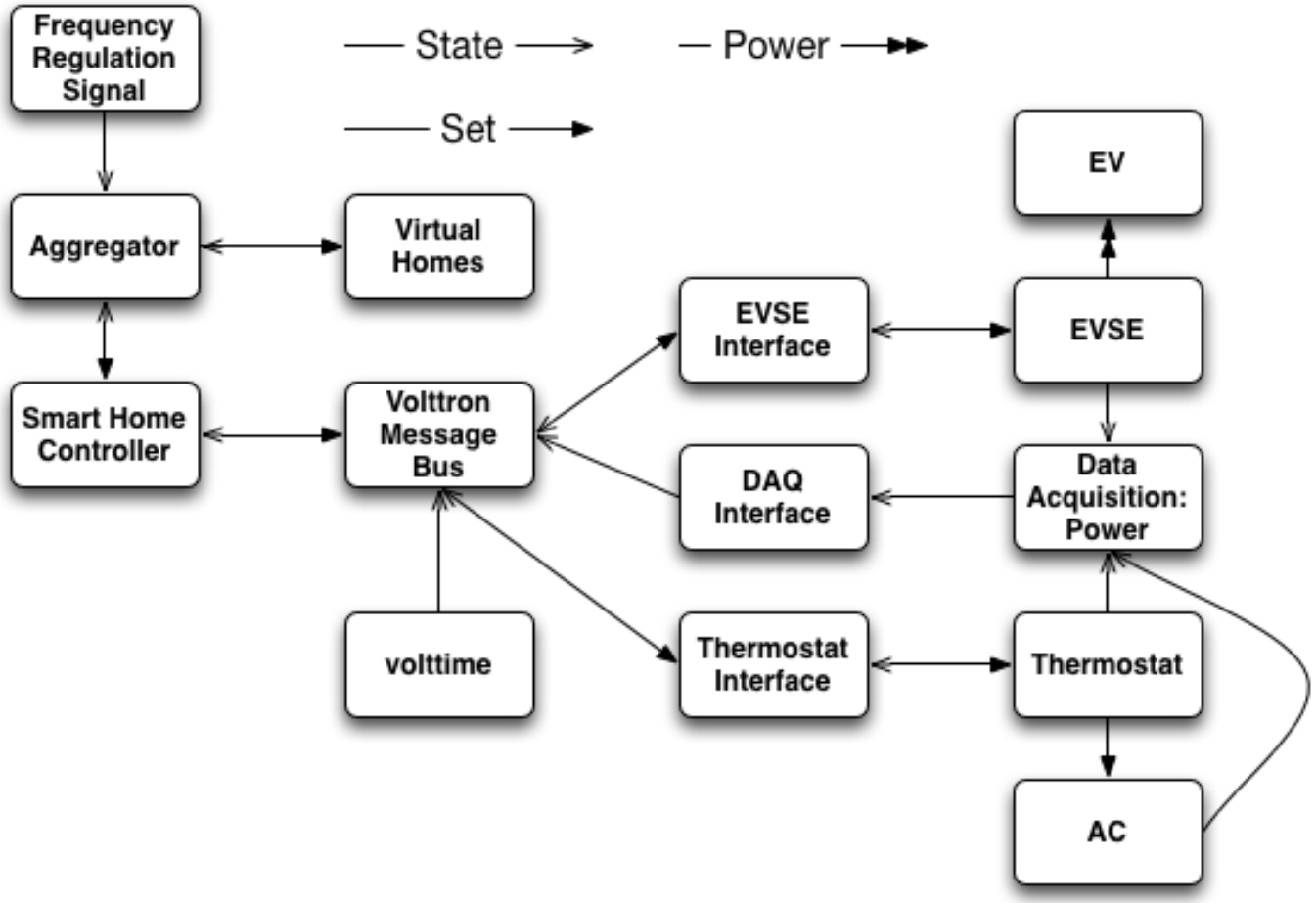
Communication and Hardware



VOLTTRON Dashboard

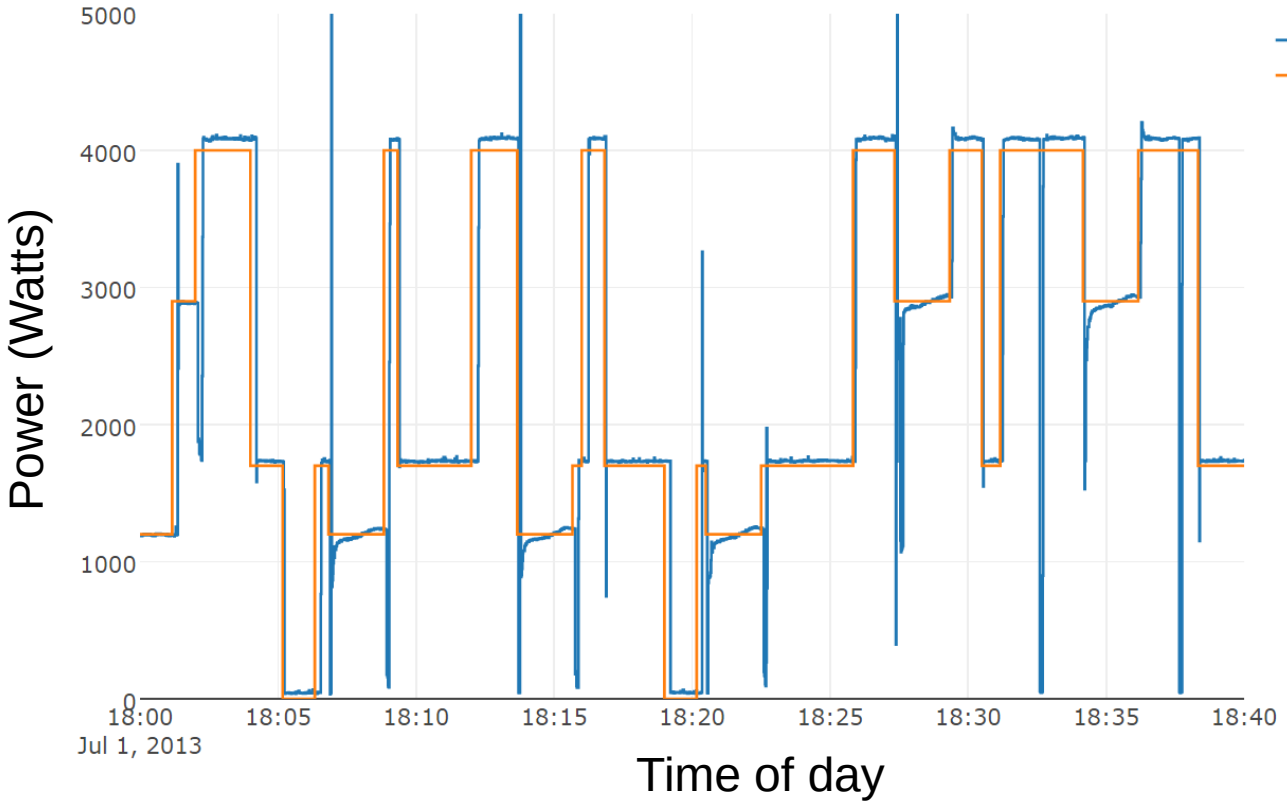


Hardware-in-the-Loop Architecture



- One laboratory home and 20 virtual homes were used in the HIL experiment.
- Each home was equipped with an HVAC unit and an EVSE unit.

Responding to an Aggregator Signal



HVAC Load:

- About 1.2 kW

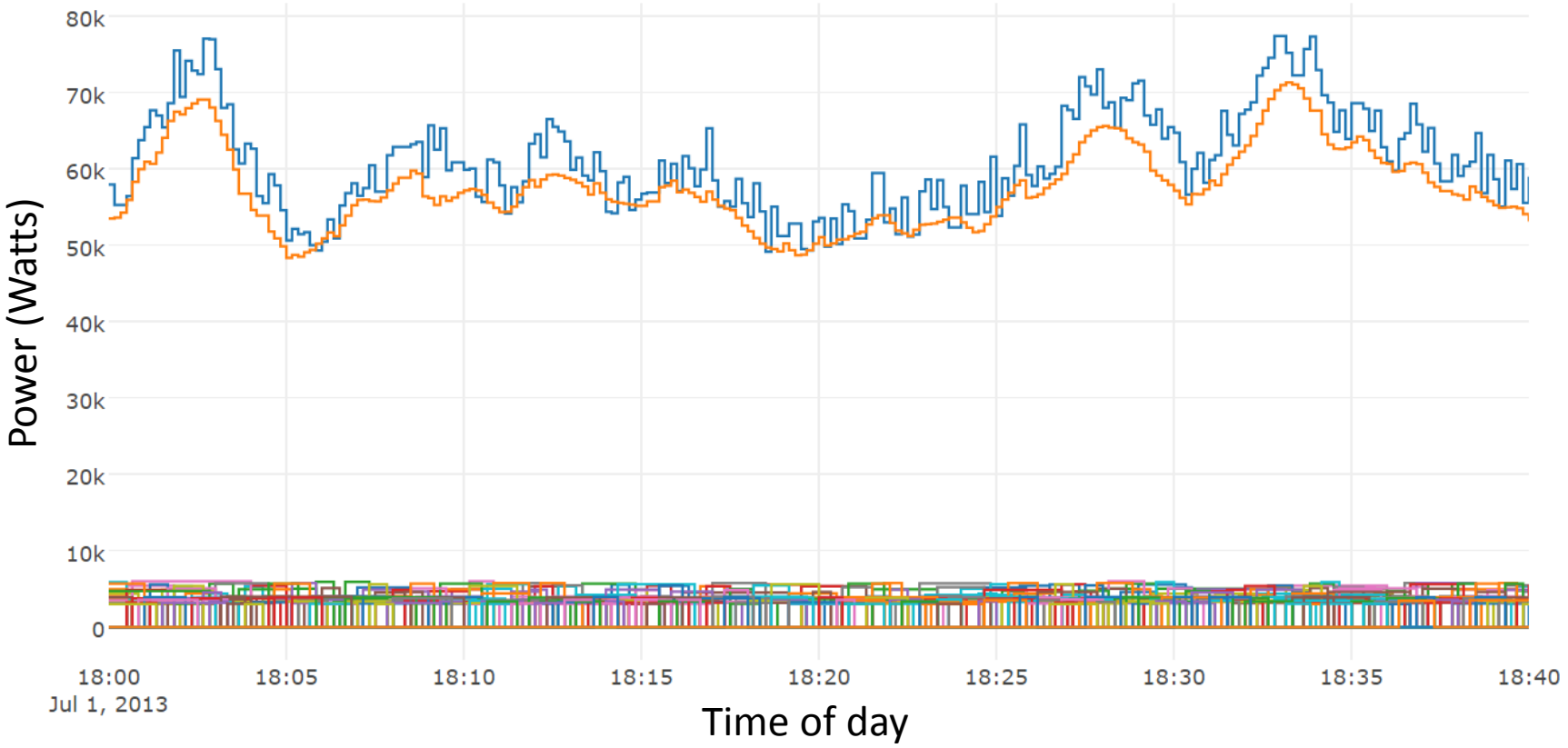
EV Charging Load:

- Full-rate: 4.1 kW
- Curtailed rate: 1.6 kW
- Standby: <0.1 kW

Test home's response signal from aggregator and delivered response

During the frequency regulation demonstration, a signal was sent to the individual lab home requesting a certain amount of regulation from that specific home. The home responded by turning on and off the air conditioner and electric vehicle charger. Measured power for these two devices is shown with the blue line.

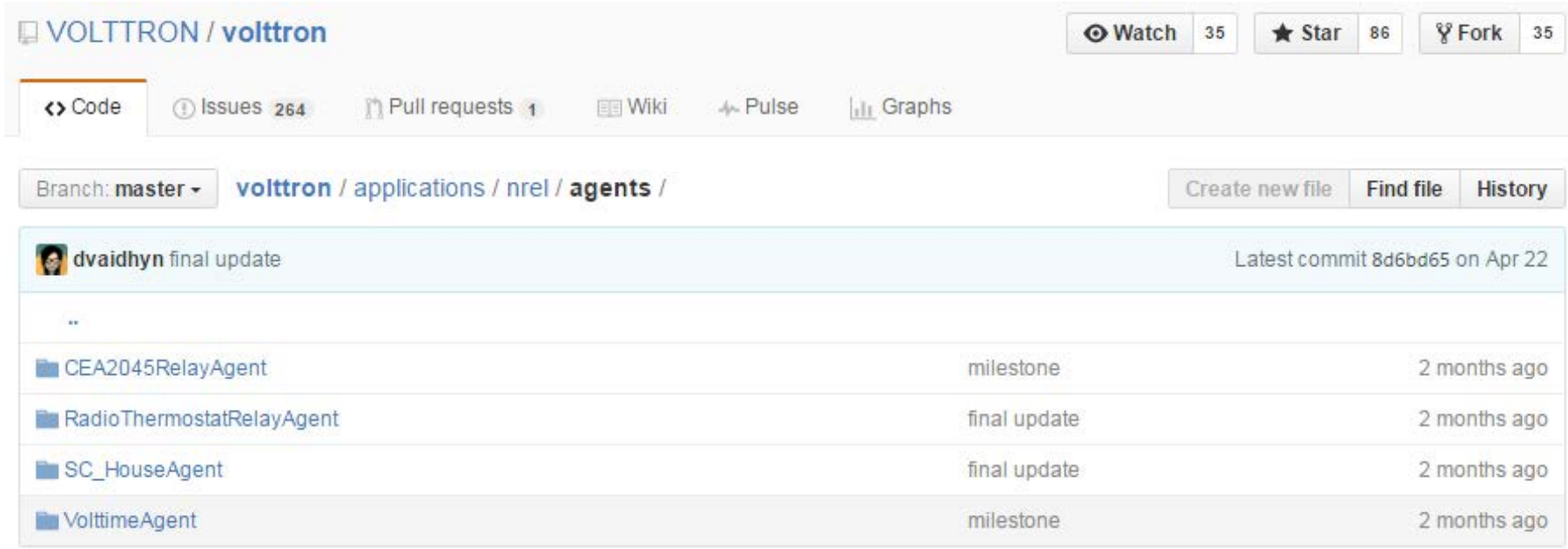
Aggregated Response



Aggregated response from 1 home's physical appliances, plus 20 simulated houses during demonstration

As the lab home was being controlled, many loads from simulated houses were controlled to match the actual frequency regulation signal (orange line). The lab home devices plus all the devices in the simulated homes are controlled so that their cumulative power (blue line) follows the frequency regulation signal. The simulated devices are shown at the bottom of the figure, roughly fifty 3-5 kW on/off loads.

Contributed VOLTTRON Agents



- The CEA-2045 and Radio Thermostat agents are now part of the VOLTTRON core distribution.
- SC_HouseAgent: an example of how to use these two agents
- VolttimeAgent: an agent for synchronizing time among multiple agents

Summary

- Residential loads are capable of providing fast time-scale ancillary services via aggregation.
- Manufacturers should be more open about their APIs.
- Responsiveness of loads is affected by hardware constraints, which can limit their ability to provide ancillary services.
- Equipment with variable speed/power control provides more options compared to the simple on/off loads.
- Other important factors to consider: equipment health, user comfort/convenience, resource availability, etc.

Acknowledgement

- This work was funded by Department of Energy Building Technologies Office under the Grid Connected Functionality project.
- Team members who also contributed to the project: Dane Christensen (PI), Deepthi Vaidhynathan, Kyri Baker, Jason Woods, Bethany Sparn, Wesley Jones, Mike Simpson, Harry Sorensen, and Monte Lunacek.

Thank You!

Xin Jin

xin.jin@nrel.gov