OAK RIDGE National Laboratory

Ongoing VOLTTRON Projects at Oak Ridge National Laboratory

Michael Starke, PhD

Electric Energy Systems Integration Group

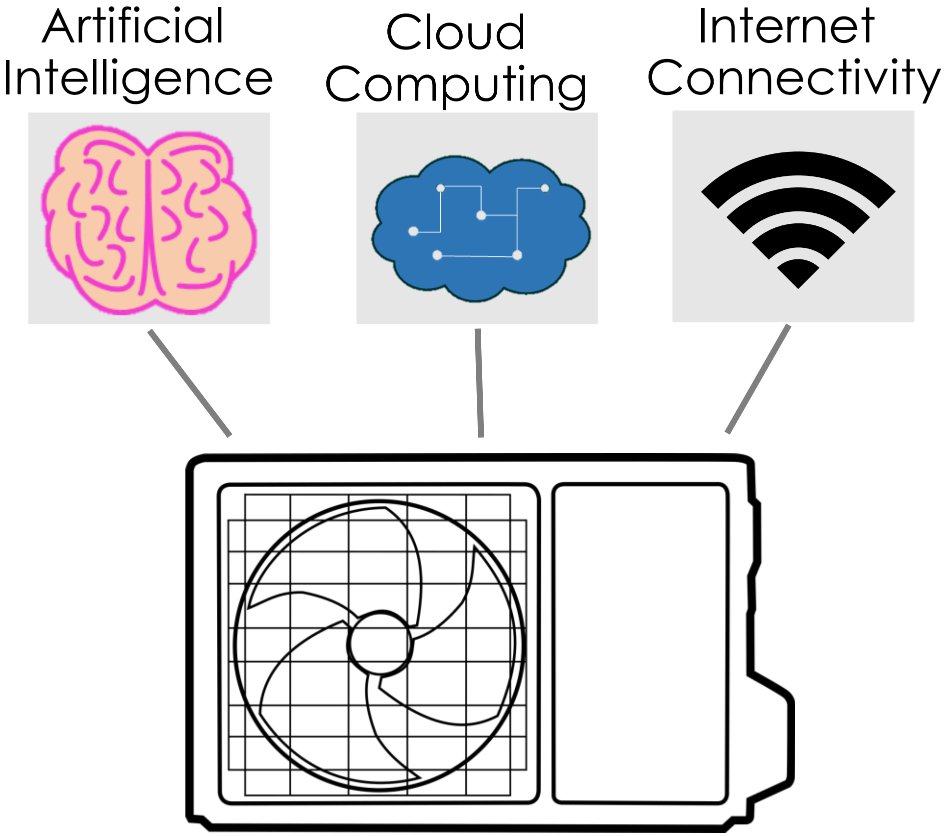
Oak Ridge National Laboratory

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

VOLTTRON Implementation

- Projects:
  - Utilized as software layers to support power electronic integration and intelligence.
  - Used to perform neighborhood level optimization and control.
- Primary Applications:
  - Inter/external communication of systems
  - Provides agent platform for multiple parallel program operations



VOLTTRON™
Devices | Data | Decisions

Neighborhood Projects

Southern Company:
Utility provider, host of developed software, API developer, historian.

Oak Ridge National Laboratory:
Transactive platform architect, optimization, data evaluator, dashboard

Alabama Power: Centralized

Rheem: Water Heater and Device API provider
Carrier: HVAC and Device API provider

MICROGRID:
Samsung: Energy Storage
PowerSecure: Power Electronics and Integration
ORNL: Microgrid Controller

Georgia Power: Decentralized

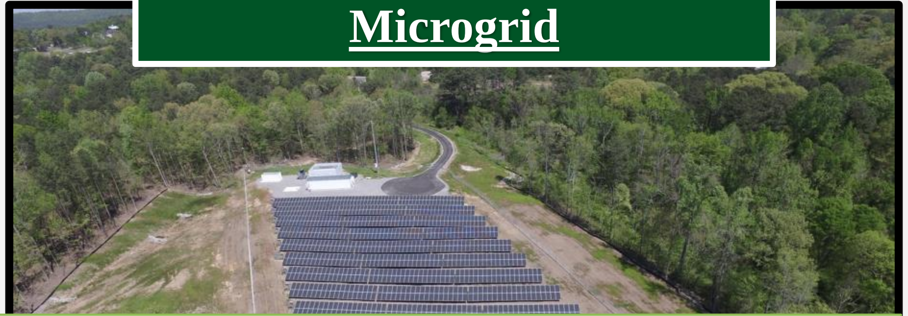
AoSmith: Water Heater provider
SkyCentrics: Water Heater API
Lennox: HVAC provider
Ecobee: HVAC API provider
Delta: Power Electronics System and API
LG Chem: Energy Storage Provider
eMotor Works: EV Charger

Connected Communities in Alabama

Alabama Power: Neighborhood

62 Residential Buildings

Alabama Power: Microgrid



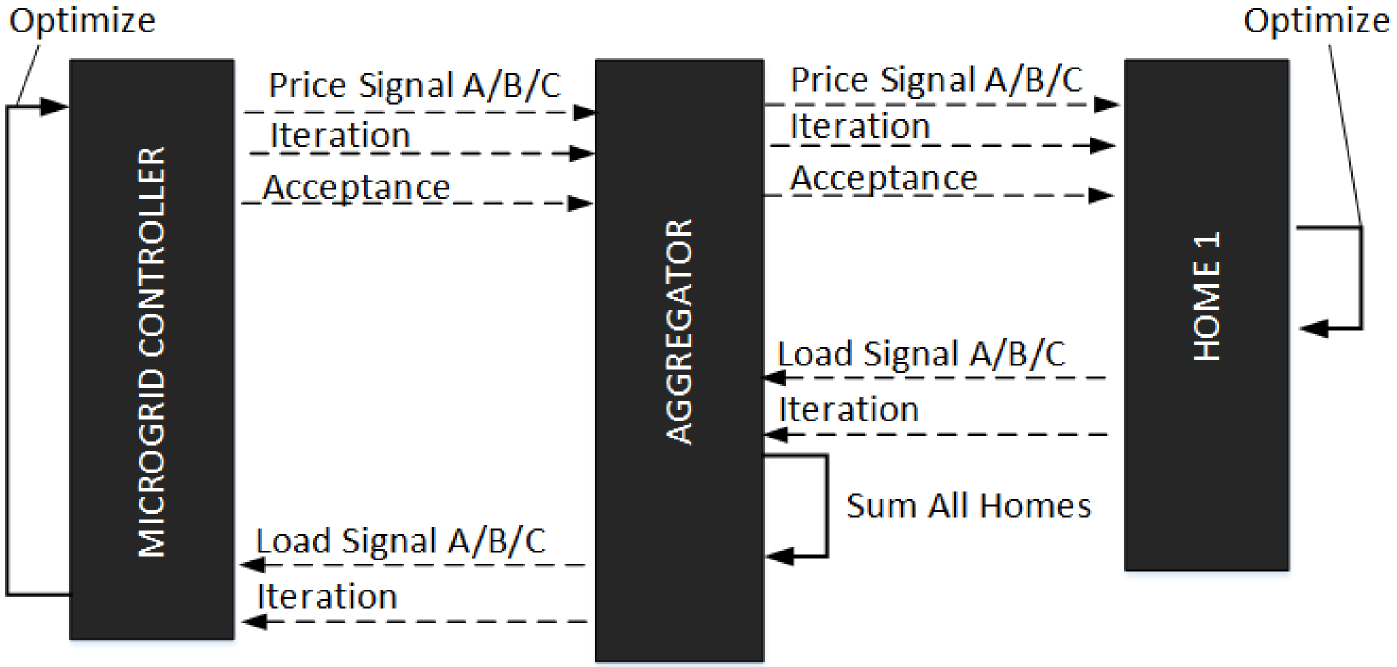
PV System: 420kW
Energy Storage System: 250kW, 681kWh
Generator: 400kW

Alabama Power: Timeline

- October 2017: Construction began
- December 2017: Entire Microgrid Completed
- May 2018: Entire Neighborhood Completed
- August 2018: Deployment of Full Neighborhood Water Heater Control
- October 2018: Deployment of Full Neighborhood HVAC Control
- November 2018: Integration of CSEISMIC Price Signal as Driver
- February 2019: Started running alternating on and off weekly against different study use cases.

Approach: General Transactive (Alabama Centralized)

- Microgrid controller and VOLTTRON 'negotiate/transact' a load/price
- Microgrid controller optimizes resources and creates 24-hour pricing offer.
- VOLTTRON allocates price signals to resources (loads) which optimize and provide total load projection
- This process iterates until Microgrid controller meets minimum convergence criteria.

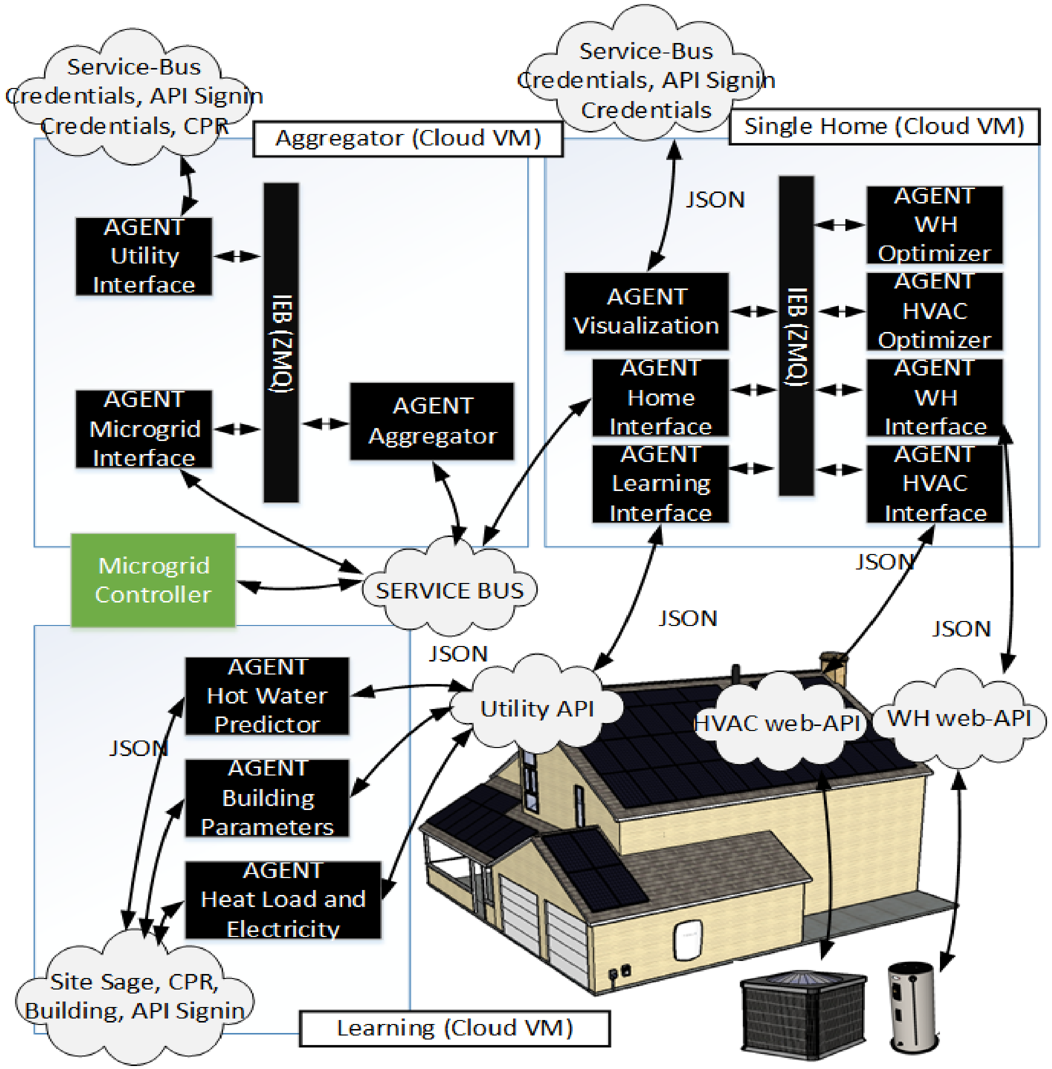


REF: M. Starke, J. Munk, H. Zandi, T. Kuruganti, H. Buckberry, J. Hall, J. Leverette, "Agent-Based System for Transactive Control of Smart Residential Neighborhoods," IEEE Power and Energy General Meeting, 2019.

Approach – Agent Framework (Alabama, Centralized)

Agent based framework to support autonomous integration and negotiation of load resources with a microgrid controller.

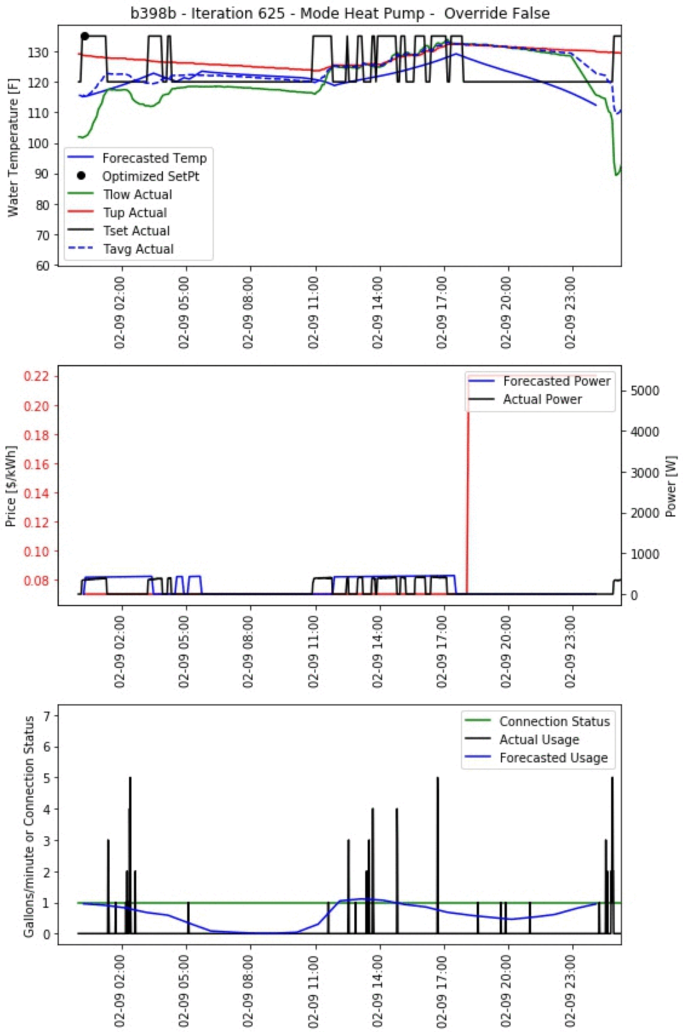
Agent	Purpose
Home Interface	Data Pass through and collector of optimization and electrical consumption projections for Aggregator agent
HVAC Interface	Translates HVAC decisions and status to vendor API
Water Heater Interface	Translates Water Heater decisions and status to vendor API
HVAC Optimizer	Utilizes building specifications, forecasted weather data, building parameter data, price forecast, and HVAC status data to optimally schedule HVAC and provide expected electrical consumption.
Water Heater Optimizer	Utilizes predicted water consumption, price forecast, and Water Heater status data to optimally schedule Water Heater and provide expected electrical consumption.
SoCoInterface	Pulls data from Southern Company API which includes weather, building specifications, historical load measurements by circuit, device credentials, and historical data.
Learning	Utilizes data collected from SoCo stored data to perform predictions on hot water usage, internal heat loads, building parameters, etc.

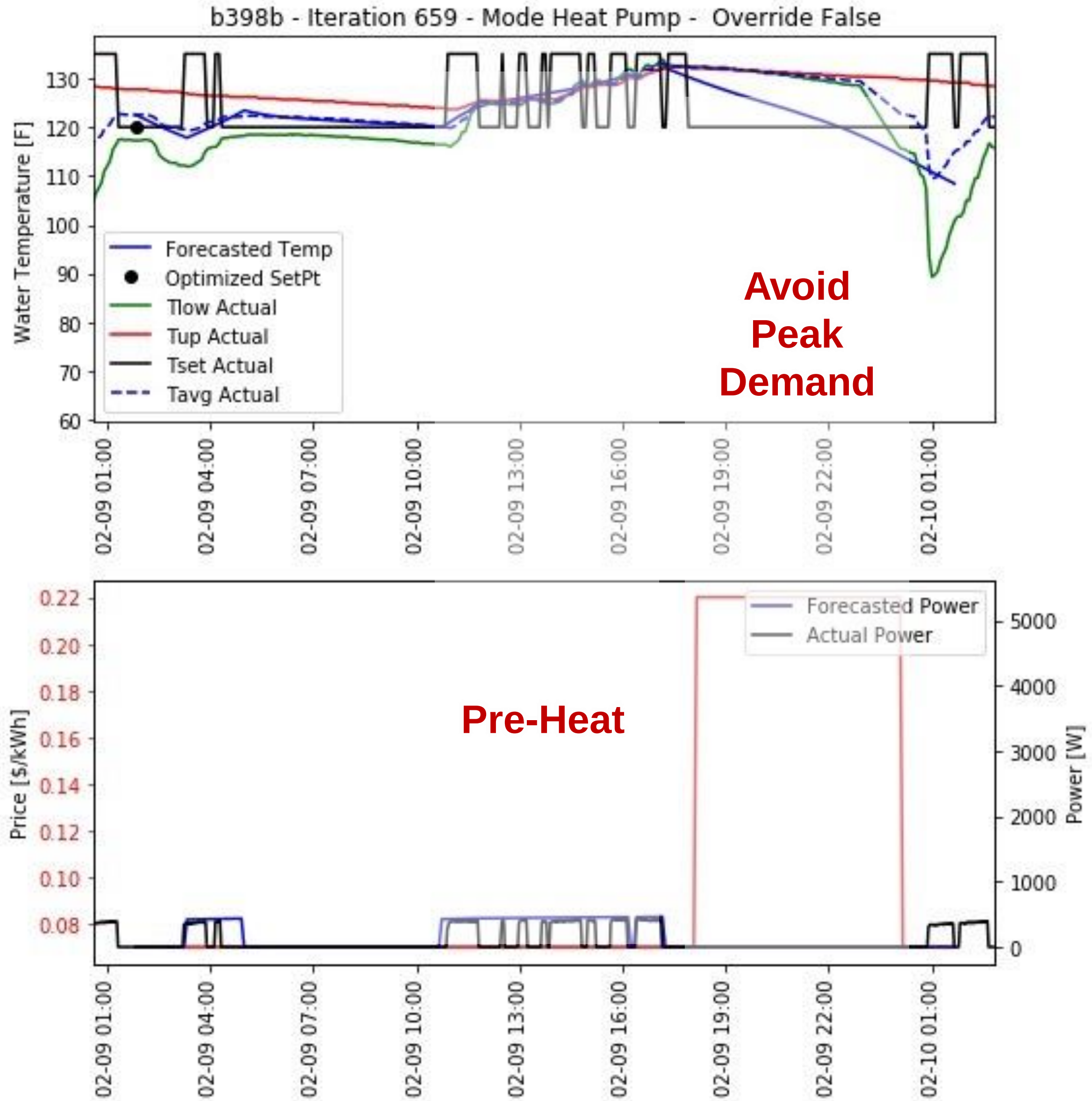


REF: Helia Zandi, Michael Starke, Jeffrey Munk, Teja Kuruganti, James Leverette and Jens Gregor, "An Automatic Learning Framework for Smart Residential Communities," 3rd International Conference on Smart Grid and Smart Cities, June 2019
REF: M. Starke, J. Munk, H. Zandi, T. Kuruganti, H. Buckberry, J. Hall, J. Leverette, "Agent-Based System for Transactive Control of Smart Residential Neighborhoods," IEEE Power and Energy General Meeting, 2019.

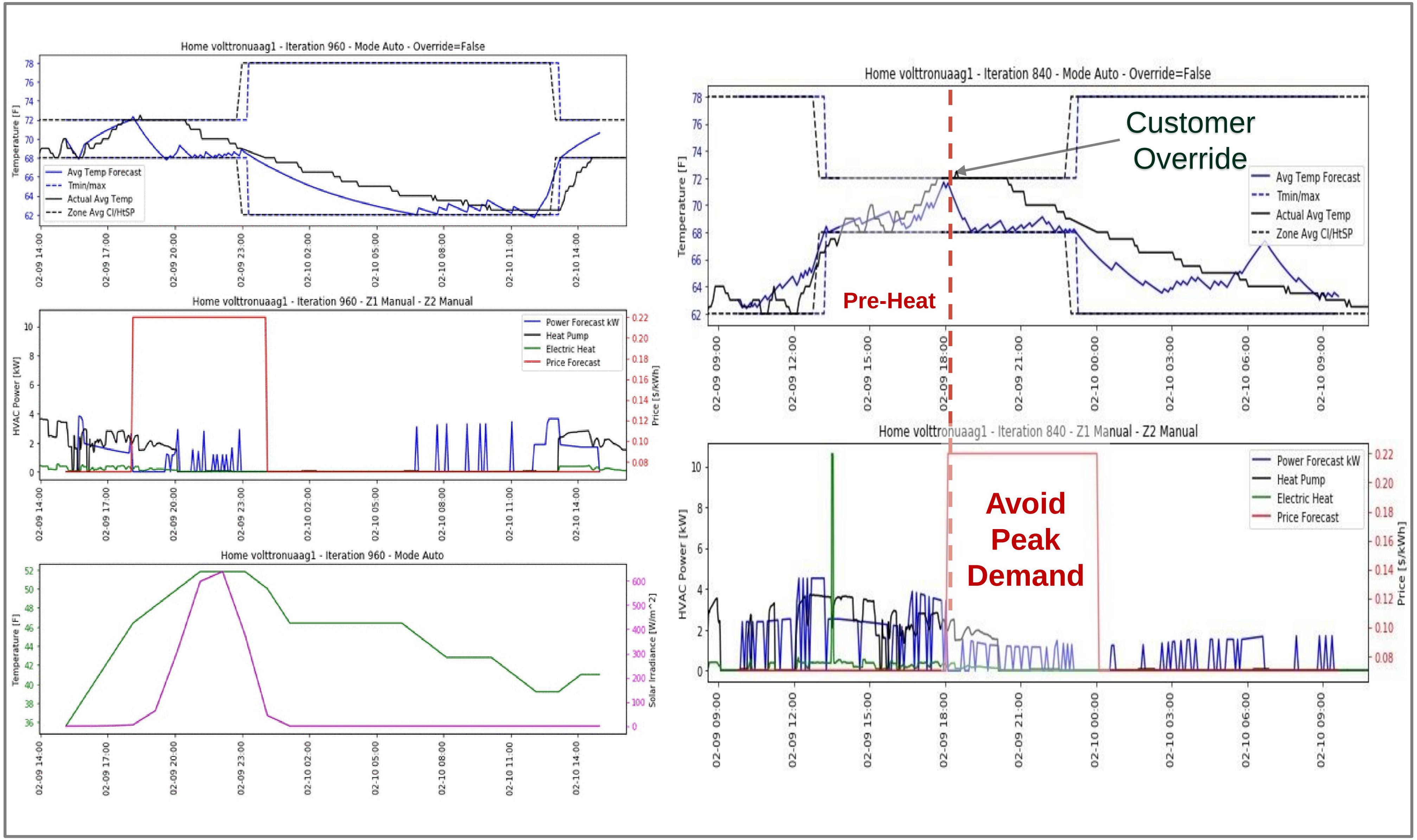
Oak Ridge National Laboratory

WATER HEATER CONTROLS





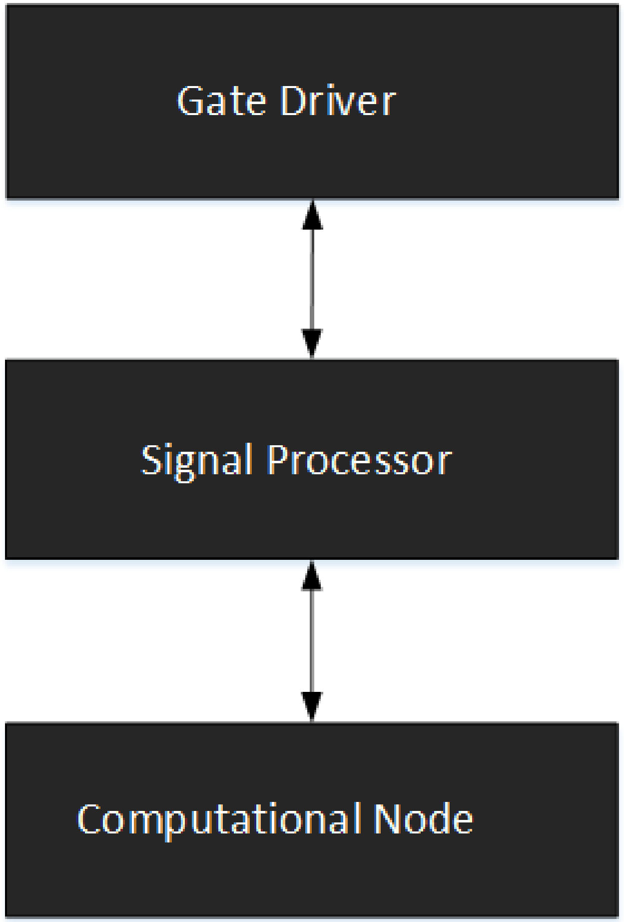
HVAC CONTROLS



Power Electronic System Layers

ORNL-Developed Universal Inverter Interface

ORNL-Developed Commercialized DSP Controller Employing Ethernet Port

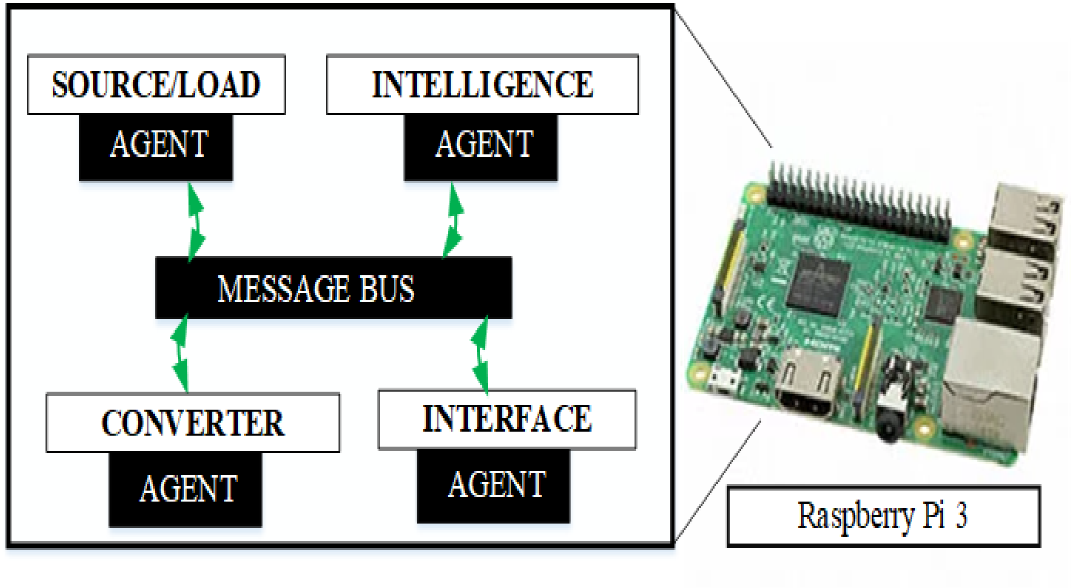


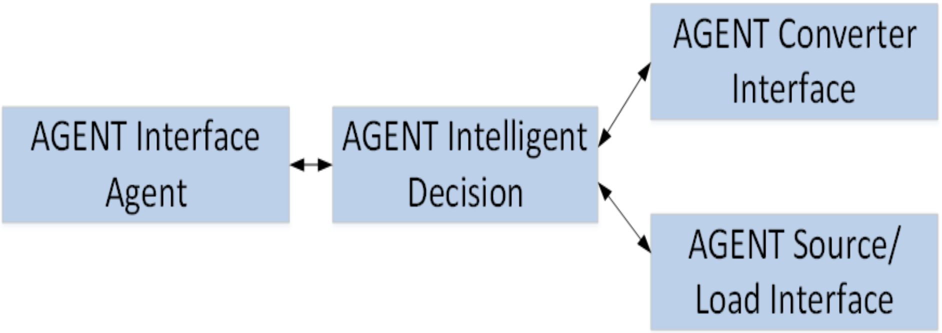
Responsible for actuating the semiconductors

Utilizes local measurements and input from computation node to issue reference signals; responsible for synchronization, control, and automatic fault detection.

Decision making for overall converter functionality based on outside input;

Computer Layer (Agent Framework)



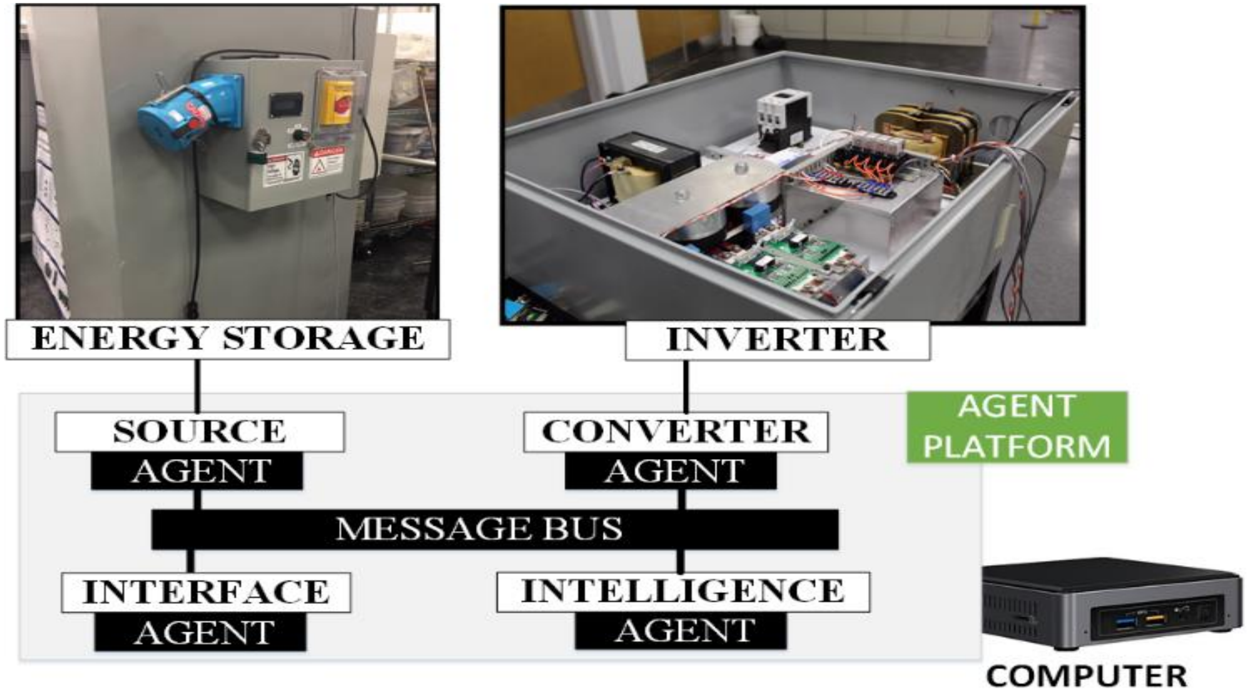


Agent	Purpose
Converter	Communicates with the PEC, sends control, receives status and data, and converts the data to communicate over a local message bus for sharing with other agents.
Source/Load	Communicates to the source or load interface, sends control, receives status and data, and converts the data to communicate over a local message bus for sharing with other agents.
Interface	Communicates to the outside, sends status information, receives either control commands or transactive signal references, and converts data to communicate over a local message bus for sharing with other agents.
Intelligence	**System Decision Making:** • **Orchestrate sub-systems** • **Provide intelligent decision making** • **Utilize optimization**

Orchestrate Sub-systems

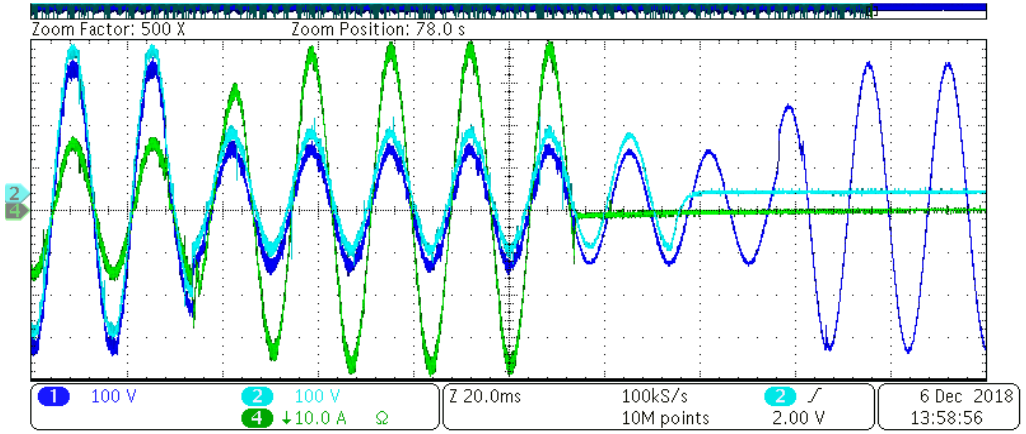
Physical Hardware

- Energy storage is a secondary use system with Nissan Leaf (Spiers New Technologies)
- Inverter (ORNL developed inverter)

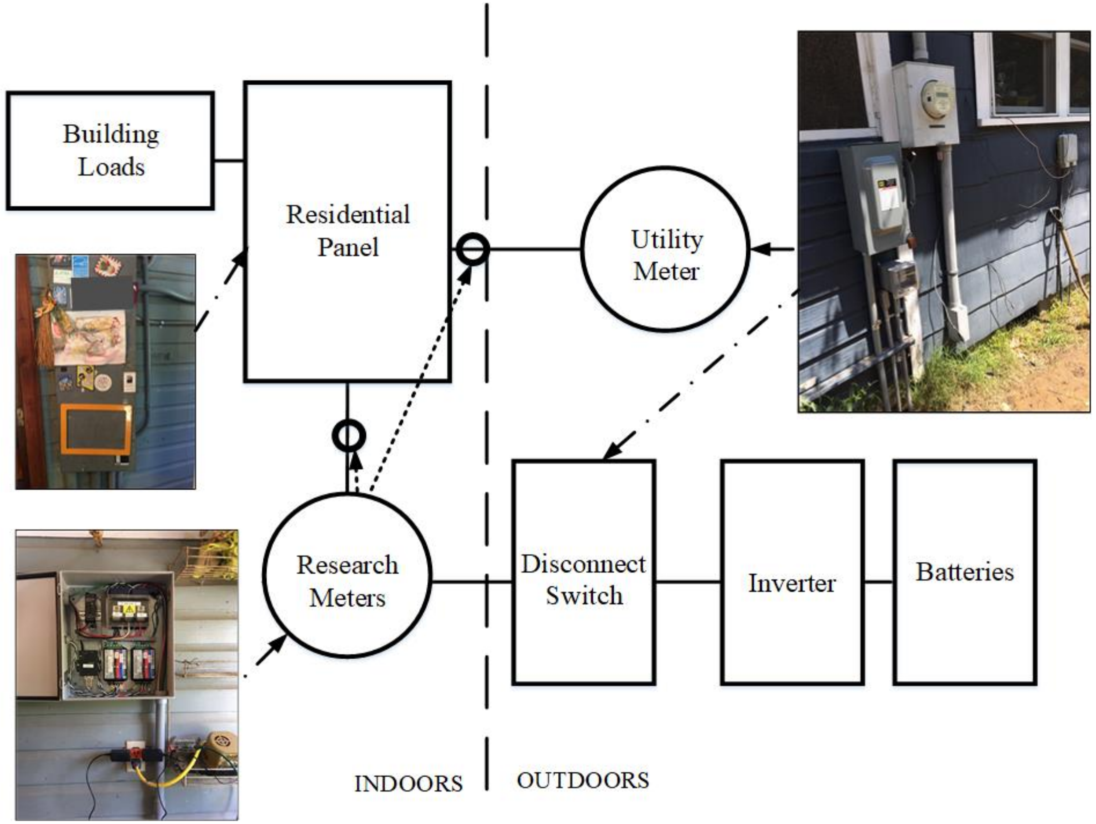


REF: M. Starke, R. Zeng, S. Zheng, M. Smith, M. Chinthavali, Z. Wang, B. Dean, L.M. Tolbert, "A Multi-Agent System Concept for Rapid Energy Storage Development," IEEE Innovative Smart Grid Technologies, 2019.

Fault Protection



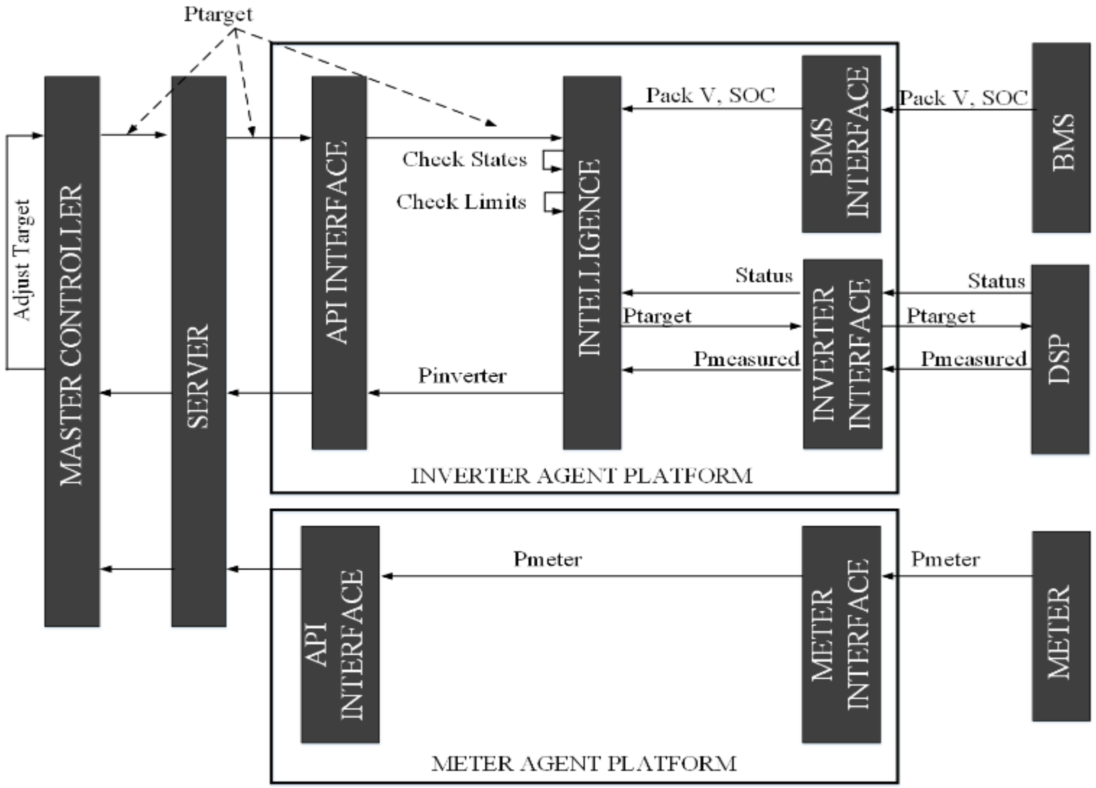
Deployment of Technology



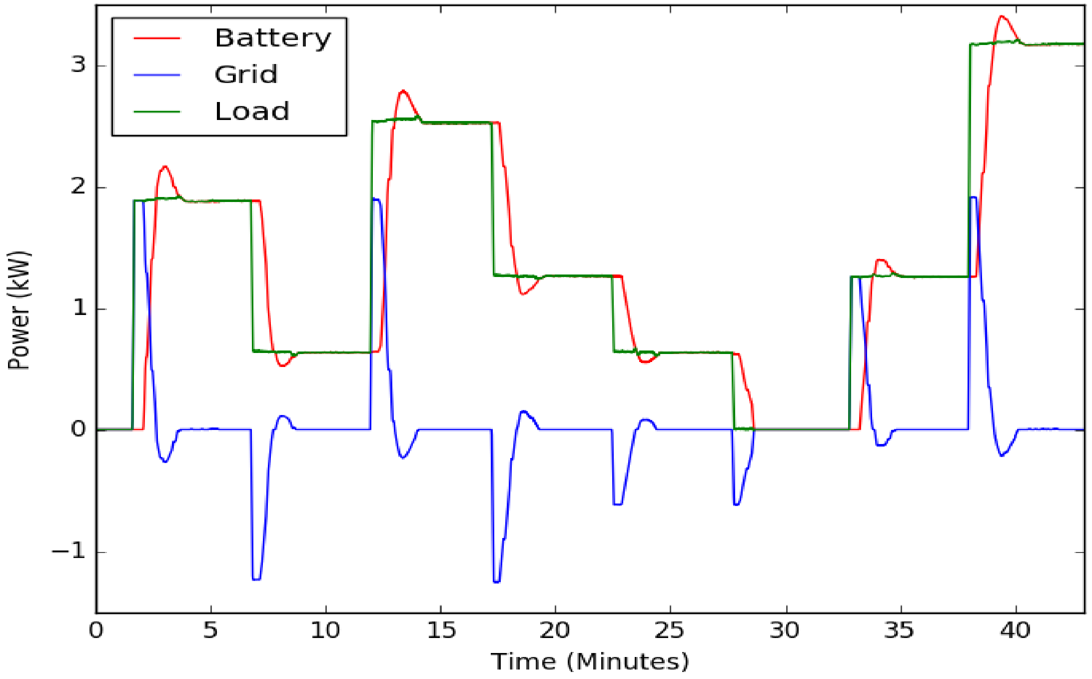
REF: Michael Starke, Madhu Chinthavali, Zeng Rong, Zheng Sheng, Steven Campbell, Mitch Smith, Ben Dean, Residential (secondary use batteries based) energy storage system with modular software and hardware power electronic interfaces, Energy Conversion Congress and Expo, 2019.

Added Tweaks For Economic Gains

Communication/Agent Framework



Closed Loop Control to Negate Net Load

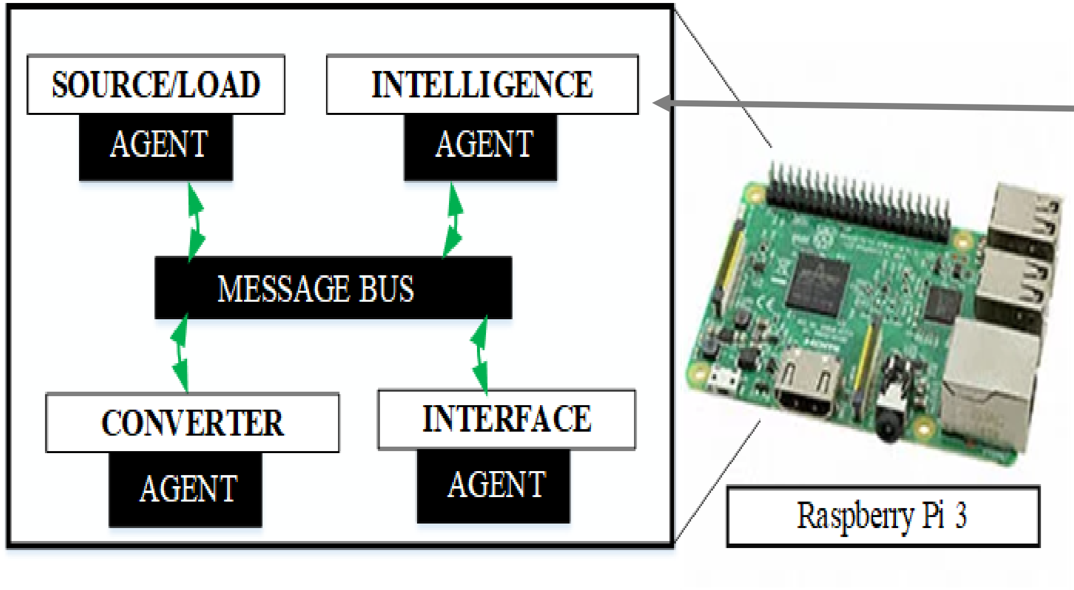


Michael Starke, Madhu Chinthavali, Zeng Rong, Zheng Sheng, Steven Campbell, Mitch Smith, Ben Dean, Residential (secondary use batteries based) energy storage system with modular software and hardware power electronic interfaces, Energy Conversion Congress and Expo, 2019.

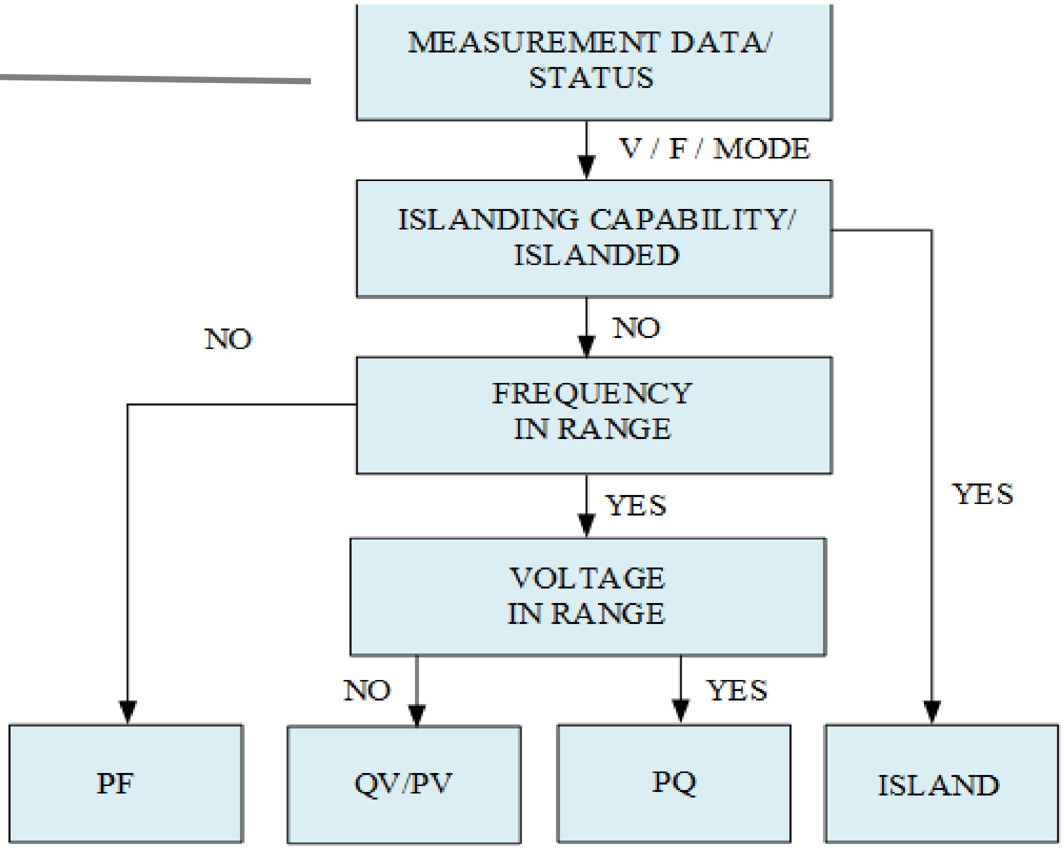
Provide intelligent decision making

Decision Making

- Allow inverter to automatically decide operational modes based on current measured conditions.



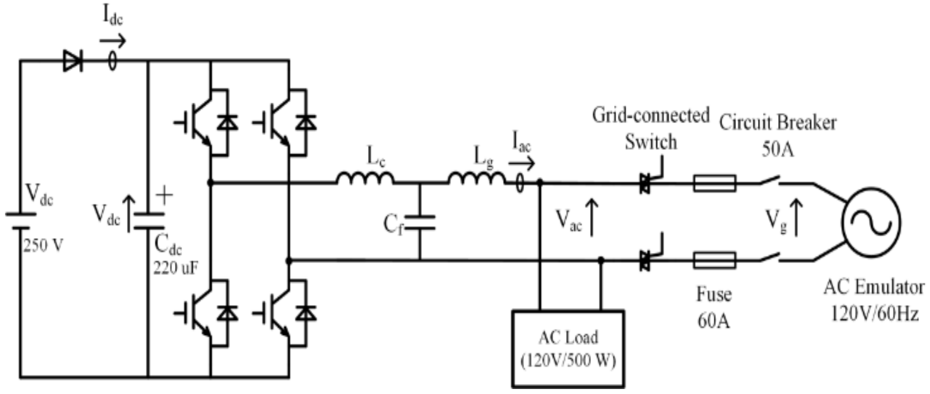
Intelligence Layer

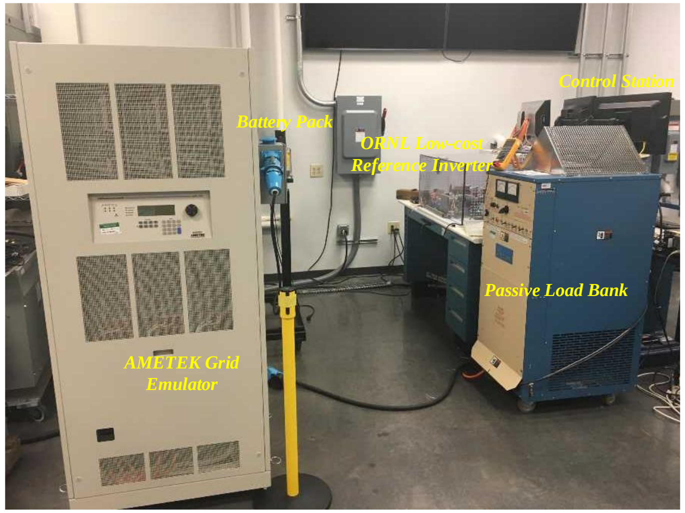


Michael Starke, Madhu Chinthavali, Chris Winstead, Z. Sheng, Steven Campbell, Rong Zeng, Teja Kuruganti, Yaosuo Xue, Chuck Thomas, Networked Control and Optimization for Widescale Integration of Power Electronic Devices in Residential Homes, Energy Conversion Congress and Expo, 2019.

Provide intelligent decision making

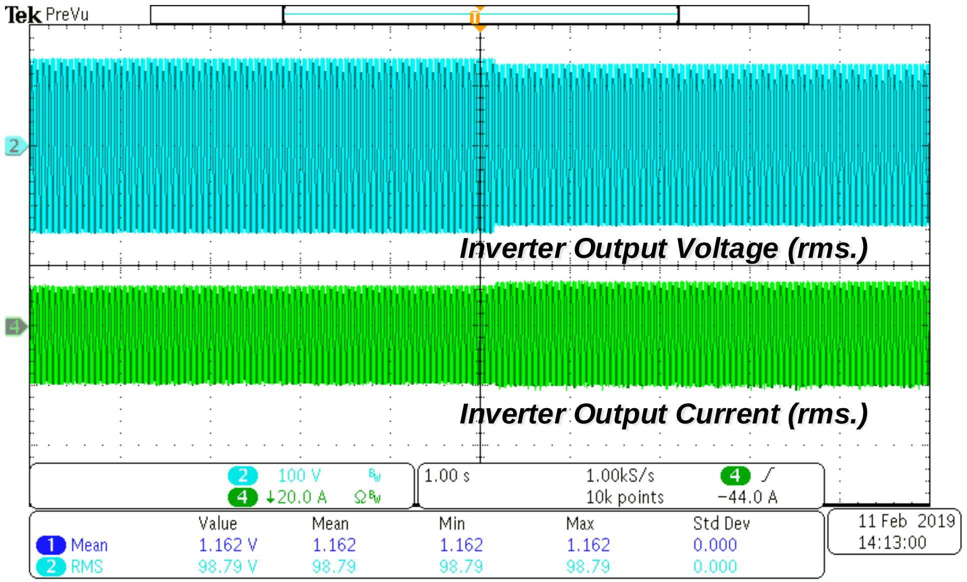
Function	Role of proposed hybrid interface
Grid-tied operation	Adaptive grid voltage tracking
PQ/PV/FQ mode	Power flow management
Islanding operation	Reconstruct a virtual grid
Anti-islanding protection	Seamless mode transfer through islanding detection
Fault ride through	Fault tolerant control





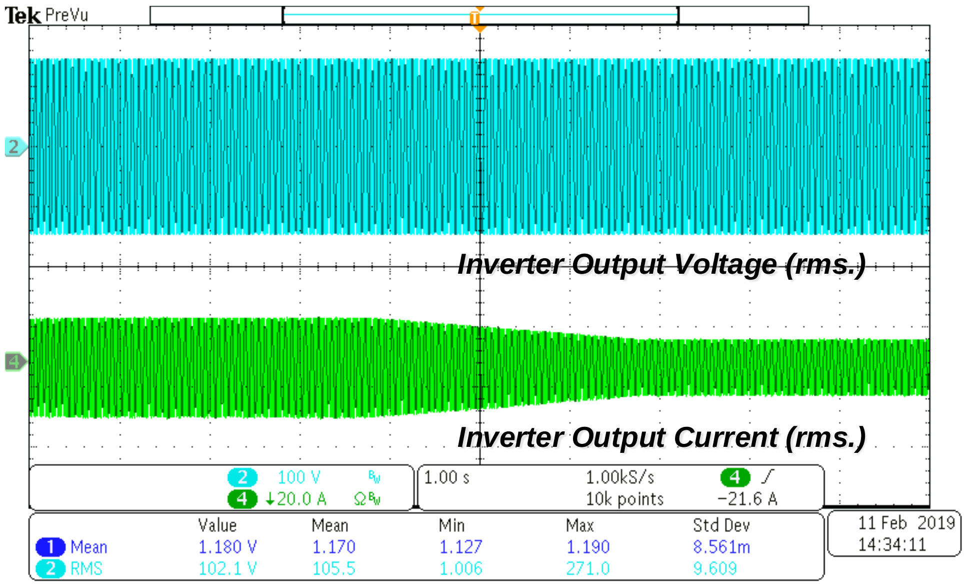
Voltage Drop Causes Automatic Change in Mode: Transition from PQ to QV (automatically increases power)

PQ to PV Transition



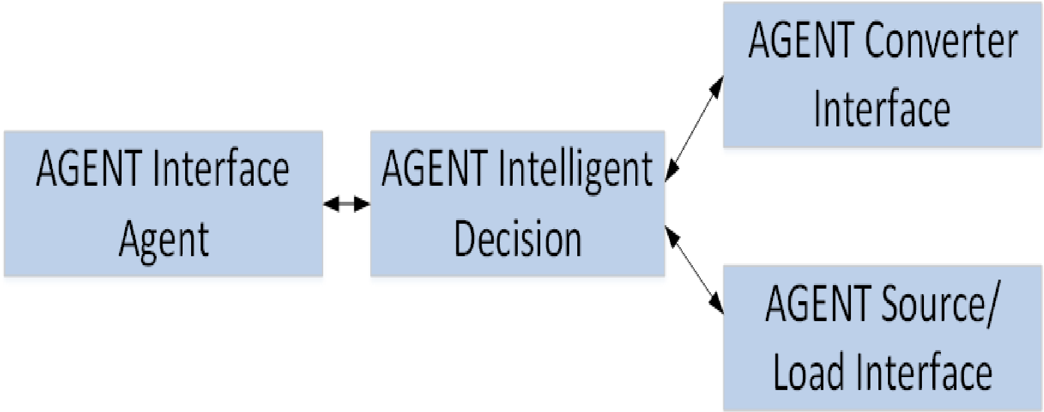
Frequency Increase Causes Automatic Change in Mode: Transition from PQ to PF (automatically decreases power)

PQ to PF Transition

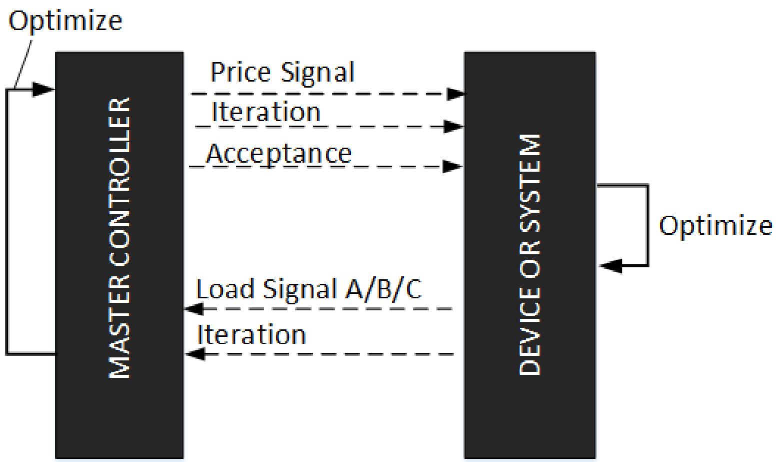


Michael Starke, Madhu Chinthavali, Chris Winstead, Z. Sheng, Steven Campbell, Rong Zeng, Teja Kuruganti, Yaosuo Xue, Chuck Thomas, Networked Control and Optimization for Widescale Integration of Power Electronic Devices in Residential Homes, Energy Conversion Congress and Expo, 2019.

Utilize Optimization: Economic / Transactive Capabilities



Intelligence Layer:
- Optimization of asset against economic signal.



Objective

$$min(W_P \sum_{t=0}^{T} P_t^{ES} * \rho_t + (W_{SOC} \sum_{t=0}^{T} SOC_t^{aux}))$$

Constraints

$$SOC_{t+1} \geq SOC_t + \left(P_t^c \eta - \frac{P_t^d}{\eta} - P_t^{loss}\right) \Delta t / E_t$$

Battery Model

$$P_{min}^c b_t^c \leq P_t^c \leq P_{max}^c b_t^c$$

$$P_{min}^d b_t^d \leq P_t^d \leq P_{max}^d b_t^d$$

Power limits for battery system

$$b_t^c + b_t^d \leq 1$$

Binary charge/discharge

$$SOC_t^{aux} \geq 0$$

$$SOC_t^{aux} \geq SOC_t - SOC_{max}$$

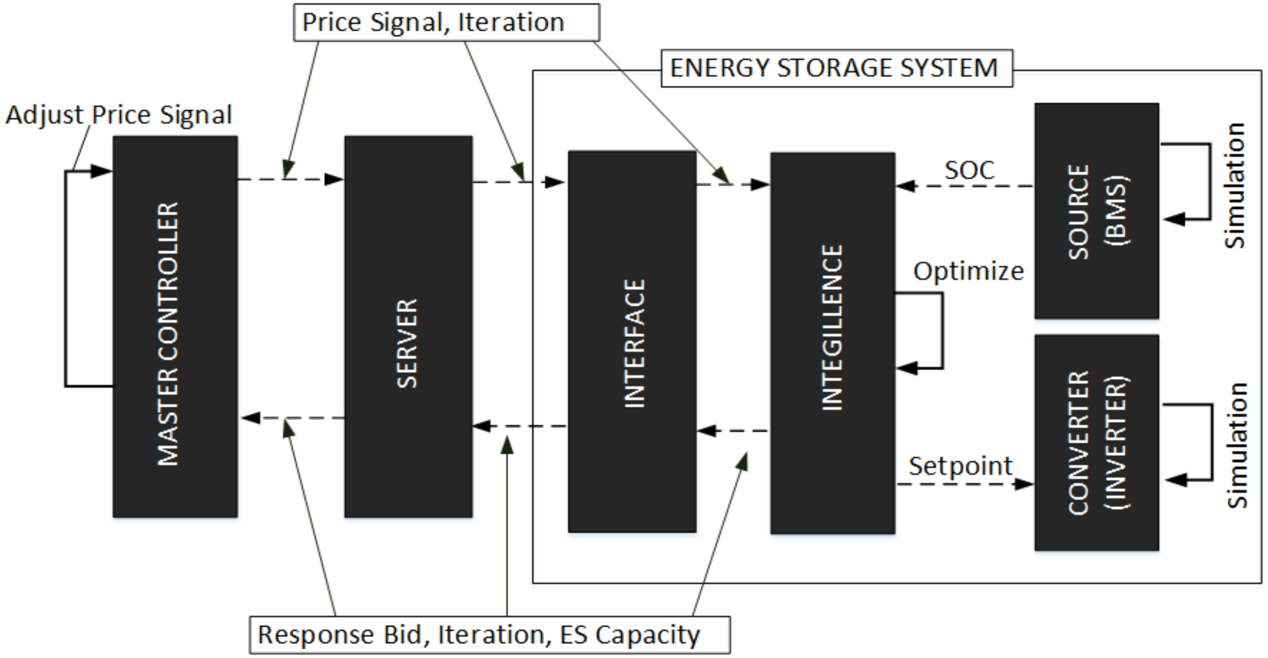
$$SOC_t^{aux} \geq SOC_{min} - SOC_t$$

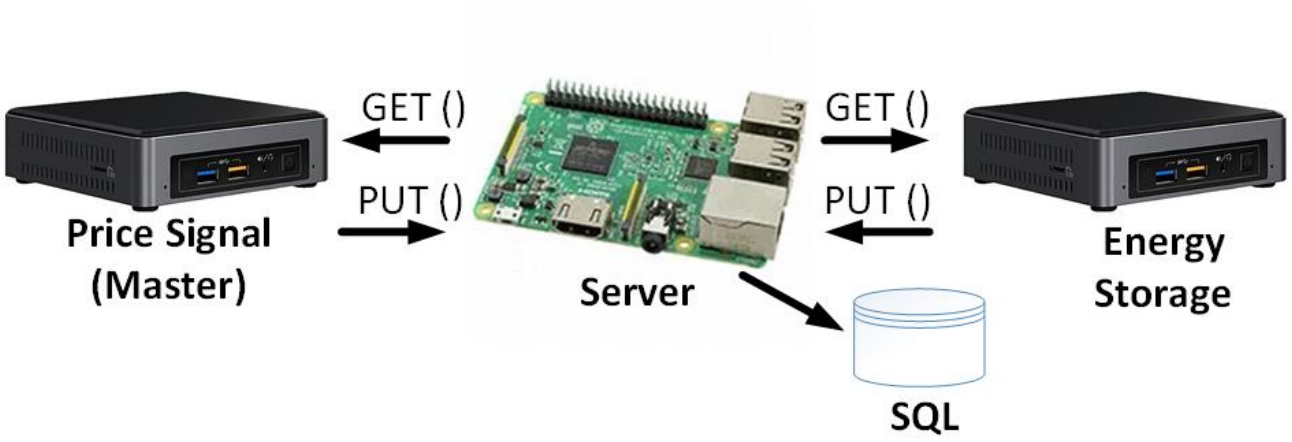
Soft constraints for state of charge

System Setup and Demonstration

<u>Demonstration Setup :</u>

- Used Models to perform long-runs.
- Agent Framework does not change from hardware implementation.
- Data is saved at the server. (All ES data is also posted to the server along with transactive negotiation).

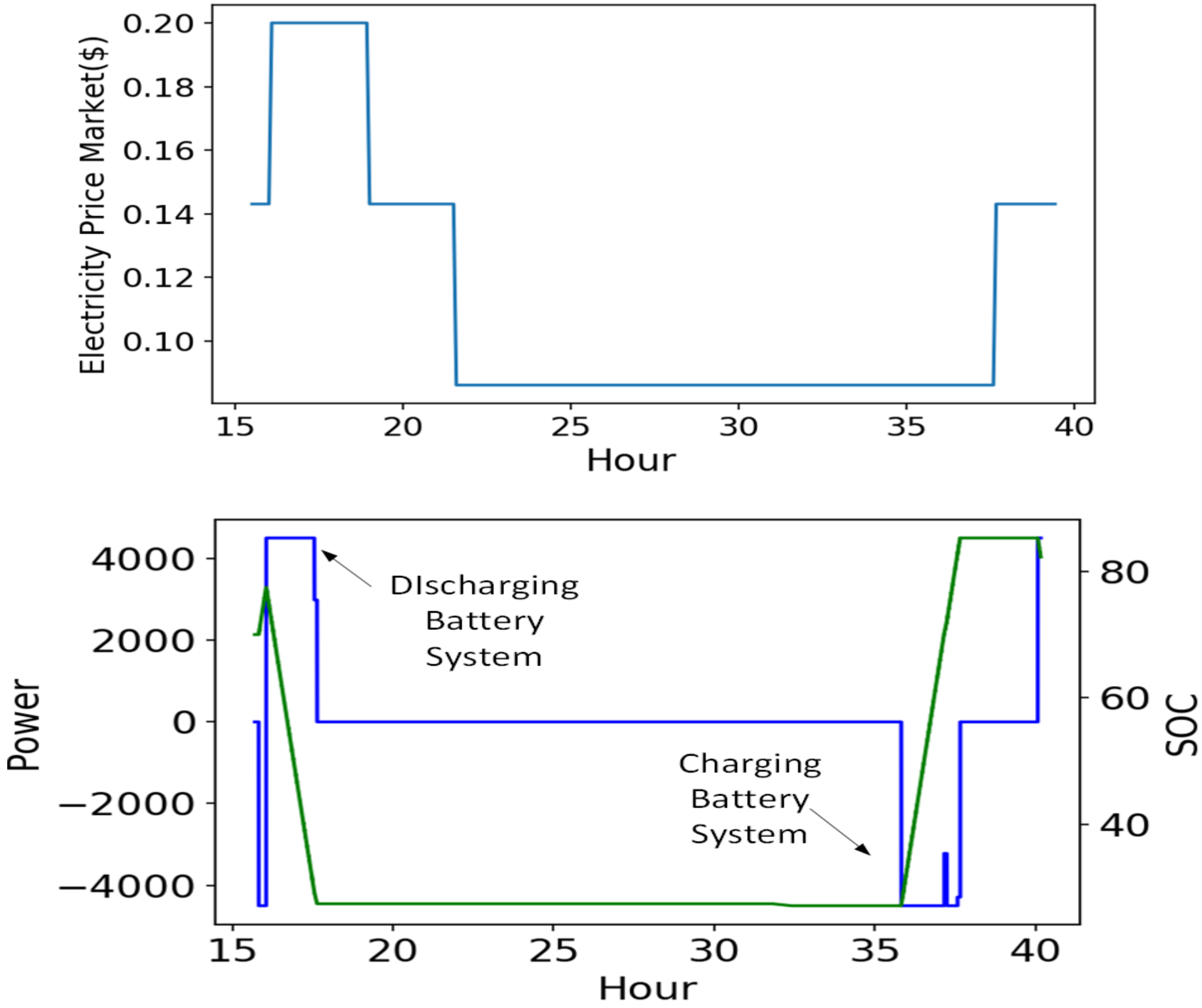




Transactive Energy Storage System

<u>Results:</u>

- Energy storage system self optimizes to dispatch according to economic signal.



Questions?

Michael Starke, PhD
Electric Energy Systems Integration Group
starkemr@ornl.gov