Transaction-Based Operation of Resource Constrained Systems

– TROPEC Transactive Energy Microgrid Controller –

Volttron Technical Meeting
July 24, 2015

Rich Brown, Bruce Nordman, Stephen Czarnecki, Mike Spears, Anna Liao, Michael Von Hippel, Mary Ann Piette

Lawrence Berkeley National Laboratory

BERKELEY LAB

Funded by DOE/EERE, DoD/TROPEC

Objectives

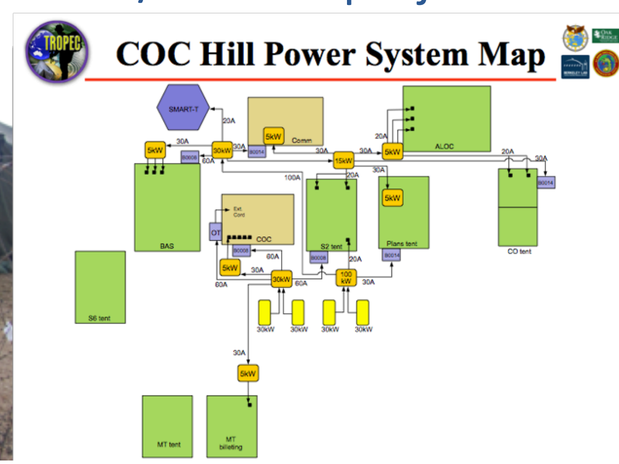
- Integrate representative contingency-base load and generation assets into transactional network
- Demonstrate operation of microgrid using transactional network to:
  - –Publish a power price that varies according to energy resource availability and efficiency (e.g., fuel supply)
  - –Adjust end-use device consumption according to local power price and value of services each device provides
  - –Maximize end-use service delivered "utility," subject to energy and capacity available from generation and storage resources.
- Emphasis on energy management; capacity management is secondary goal
- Demonstration should use hardware components where feasible

BERKELEY LAB

DoD & TROPEC Background

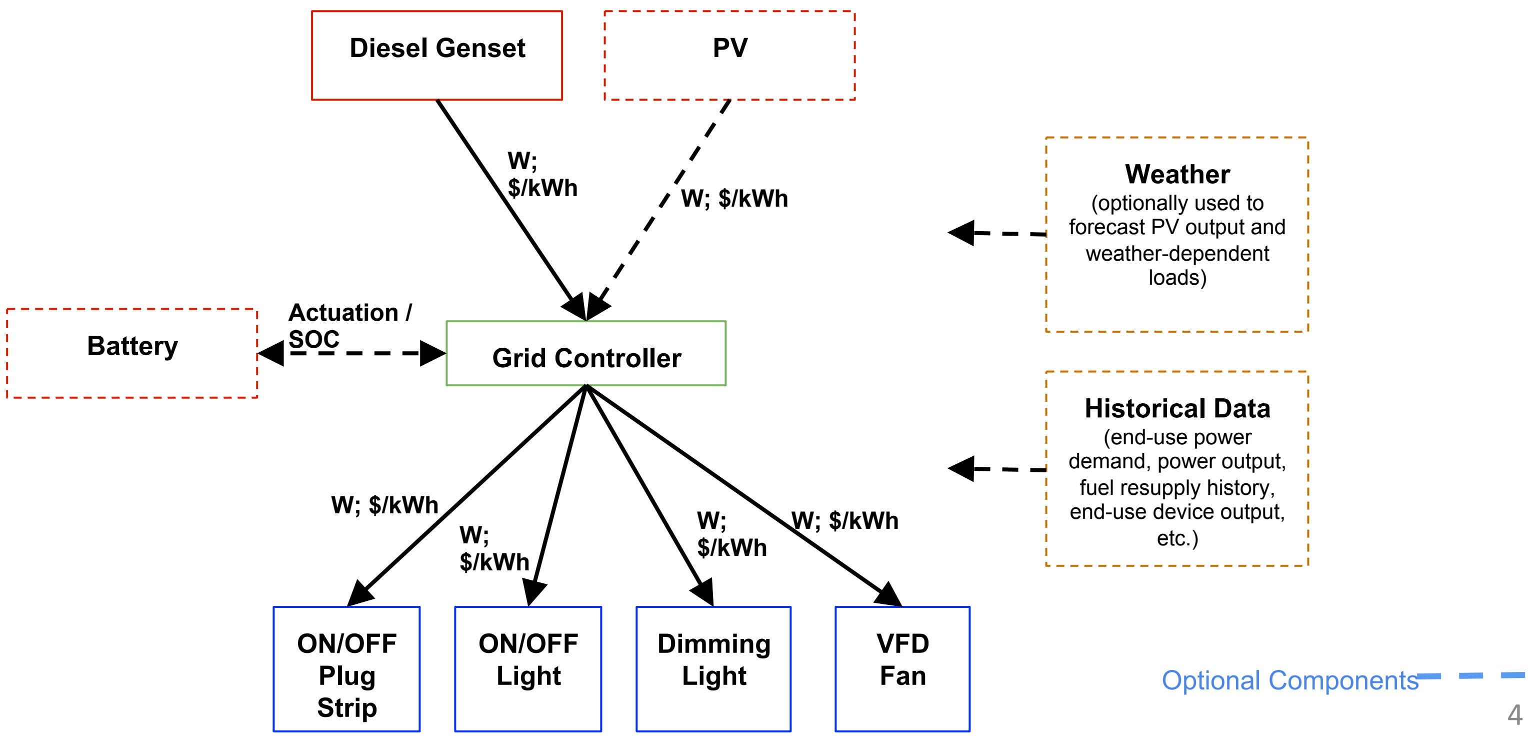
- DoD is largest energy user in Federal govt., mostly "operational"
- Contingency (or forward operating) bases are significant energy users; fuel supply-lines create operational vulnerabilities
- DoD investing in energy security: efficiency, microgrids, renewables
- TROPEC is part of this initiative:
  - –Identify and assess innovative technologies to reduce and manage energy use on contingency bases
  - –Partners: U.S. Pacific Command, NAVFAC, ORNL, LBNL
  - –Dual-use technologies: Military/Civilian
- Transactive Energy Microgrid is joint BTO/TROPEC project

BERKELEY LAB



Microgrid Control Concept

- Price of electricity used to manage energy, balance supply & demand
- Supply assets (generators, battery) publish prices based on energy scarcity
- Grid controller publishes price to end-use devices to balance available supply and demand
- End-use devices adjust load based on local price and device-specific demand elasticity curves (or "functions" where demand is not continuous)



More Concepts and Assumptions

- Each entity is **autonomous**: decides how to operate based on environmental inputs and power price
- **Event-based** system: computation and communication triggered by events
  - –No system-wide fixed time step; individual entities may have fixed time steps internally
  - –In Volttron, events initiated through pub/sub message bus
- Devices are **cooperative**: never consume more than their power budget
- System has **sufficient generator capacity** to always meet combined power needs of end-use devices (like today's base camps)
  - –Diesel generator has hardware controller to balance instantaneous supply and demand
  - –Batteries may be present to better balance supply and demand, increase generator efficiency, store excess PV, allow non-fossil operation when no PV generation

BERKELEY LAB

Generator Controller

- Monitors part-load efficiency and energy supply available for given generating asset and publishes corresponding power price
- Controller does hourly/daily energy management, not real-time load balancing (assume generator has hardware controller for that)
- Generator controller has variants for each supply type: Diesel genset, PV
  - Diesel genset controller is the only supply source in our basic configuration
  - PV controller (optional) mainly provides forecasting of PV supply
- Implemented as Volttron agents

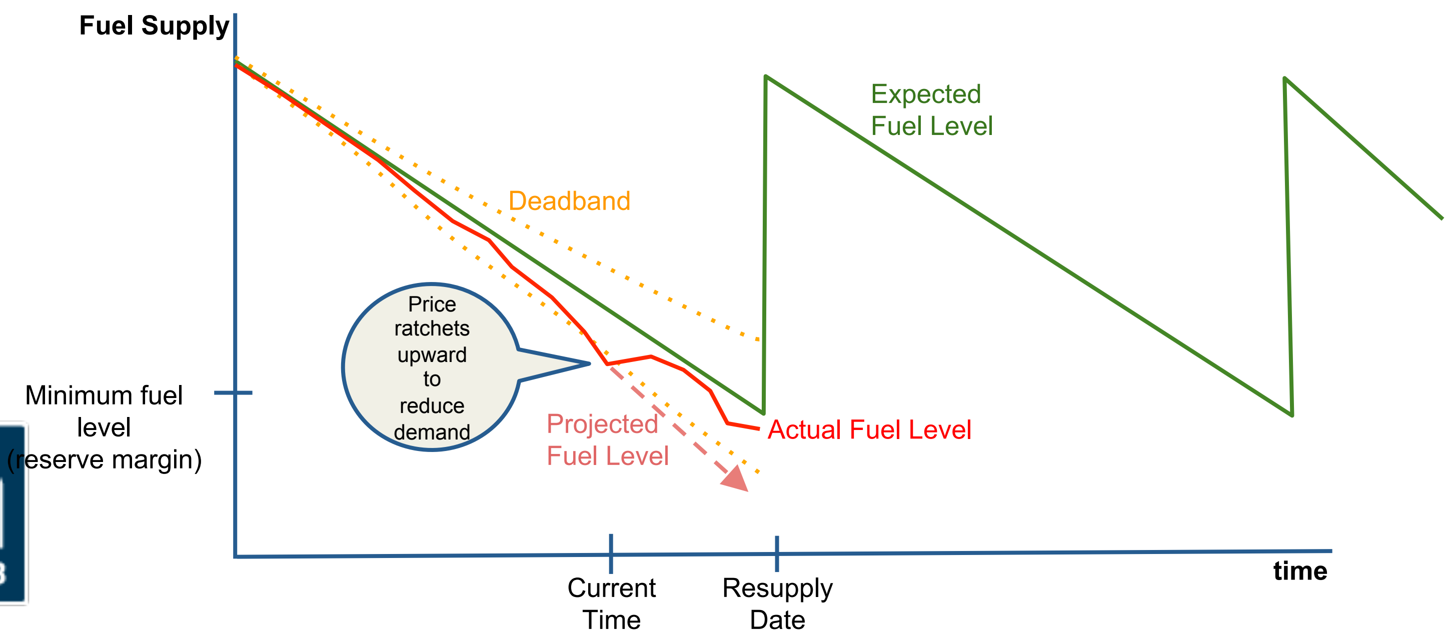
BERKELEY LAB

Civilian Applications

- Managing fuel supplies for critical facilities running on backup power
- Management of building microgrids - any building type

Diesel Genset Controller

- Calculates price at each time step based on:
  - fuel supply remaining
  - expected fuel resupply date
  - minimum allowable fuel supply (reserve margin)
  - current fuel burn rate
- Price starts at “normal” baseline then adjusted upward when projected fuel level on resupply date falls below the reserve margin (outside deadband)



Grid Controller

- Grid controller provides system-wide balancing of supply and demand
- Controller sets local price sent to end-use loads, based on:
  - Availability of supply (as reflected in prices published by generators)
  - Expected load
- Operates on variable time step: event-based
- Controller publishes current and forecast prices
  - Forecast period adjustable (e.g., hour ahead, day ahead)
  - Price forecast method initially very simple
- Grid controller directly controls battery charge/discharge to buffer generator
- Prices published to Volttron message bus; subscribed by all end-use loads

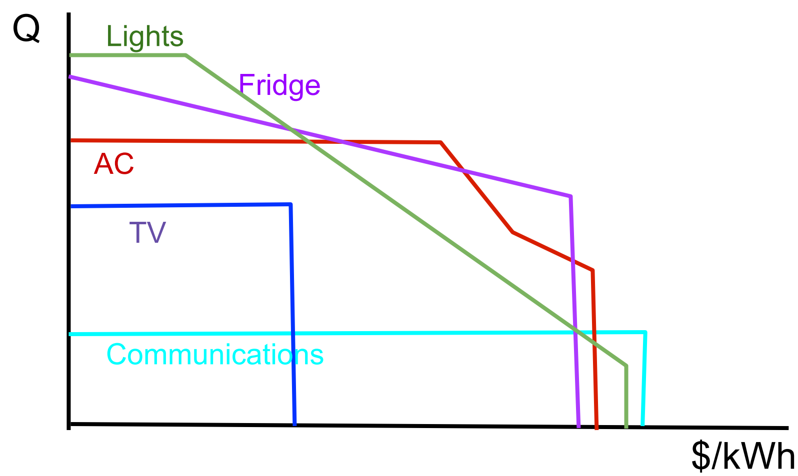
BERKELEY LAB

Civilian Applications

- Integration of renewables and storage in buildings
- Management of tenant energy budgets in leased buildings

End-Use Device Agents

- Monitor local energy price and device operational goals, adjust device load
- Devices start with typical operating schedule to ensure loads vary over time
- Variants for each device type, to control unique attributes of that device
- Priority and flexibility of end-use devices represented in “demand elasticity curve” or demand function (may be continuous or not, depending on device)
  - High priority devices (e.g., communications) curtail only at very high prices
  - Shape of curve indicates device control flexibility (e.g., dimming lights)
  - User specifies functions to reflect their priorities and control modes



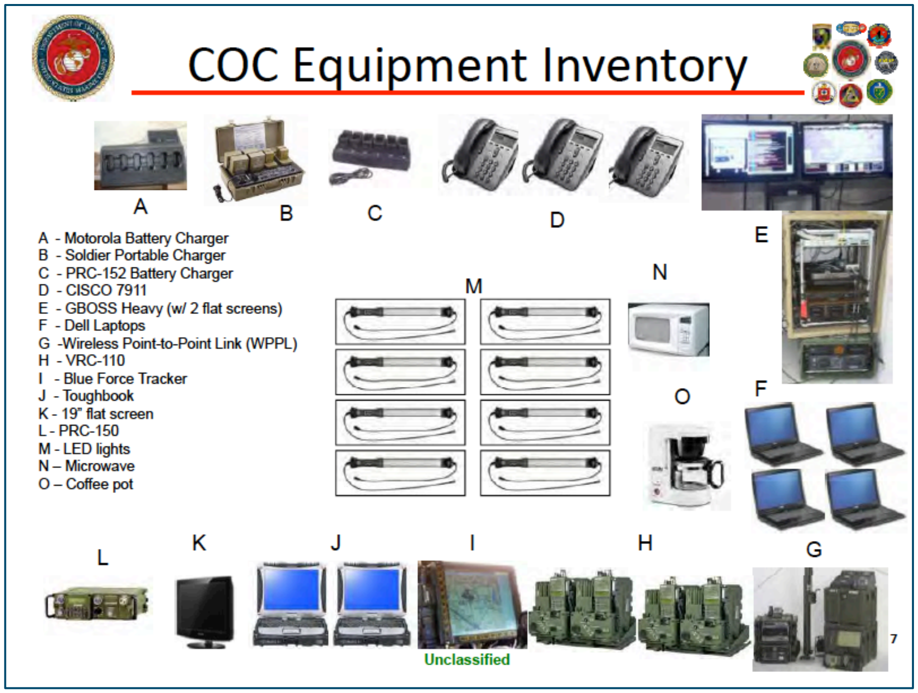
End-use Device Demand Elasticity Curves as Function of Power Price

Civilian Applications
- Price-based Auto-DR in buildings
- Management of tenant energy budgets in leased buildings

BERKELEY LAB

Representative TROPEC Electricity End-Use Loads

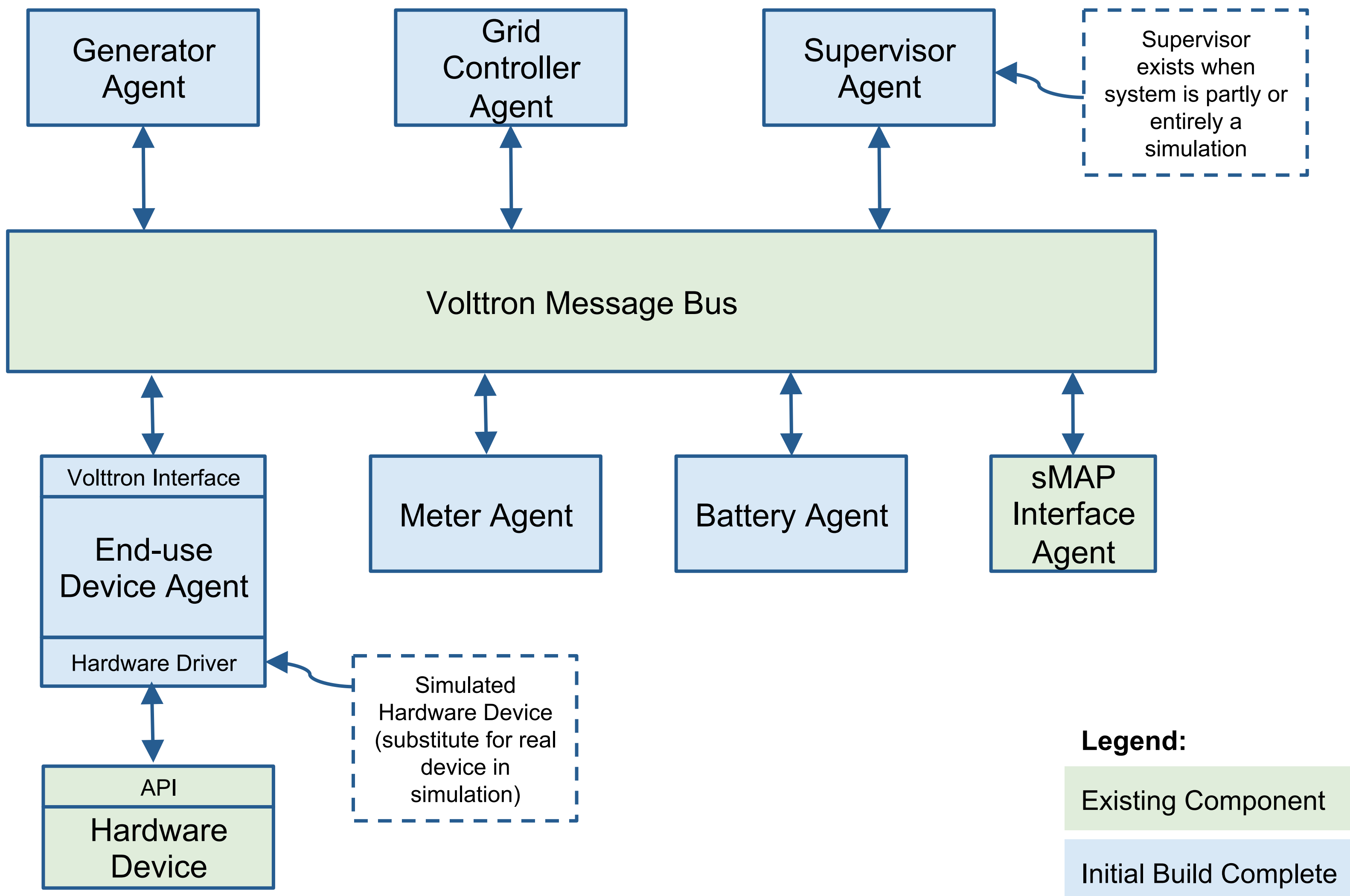
Use representative civilian equipment for proof-of-concept test (basic set of equipment in red, optional in green)



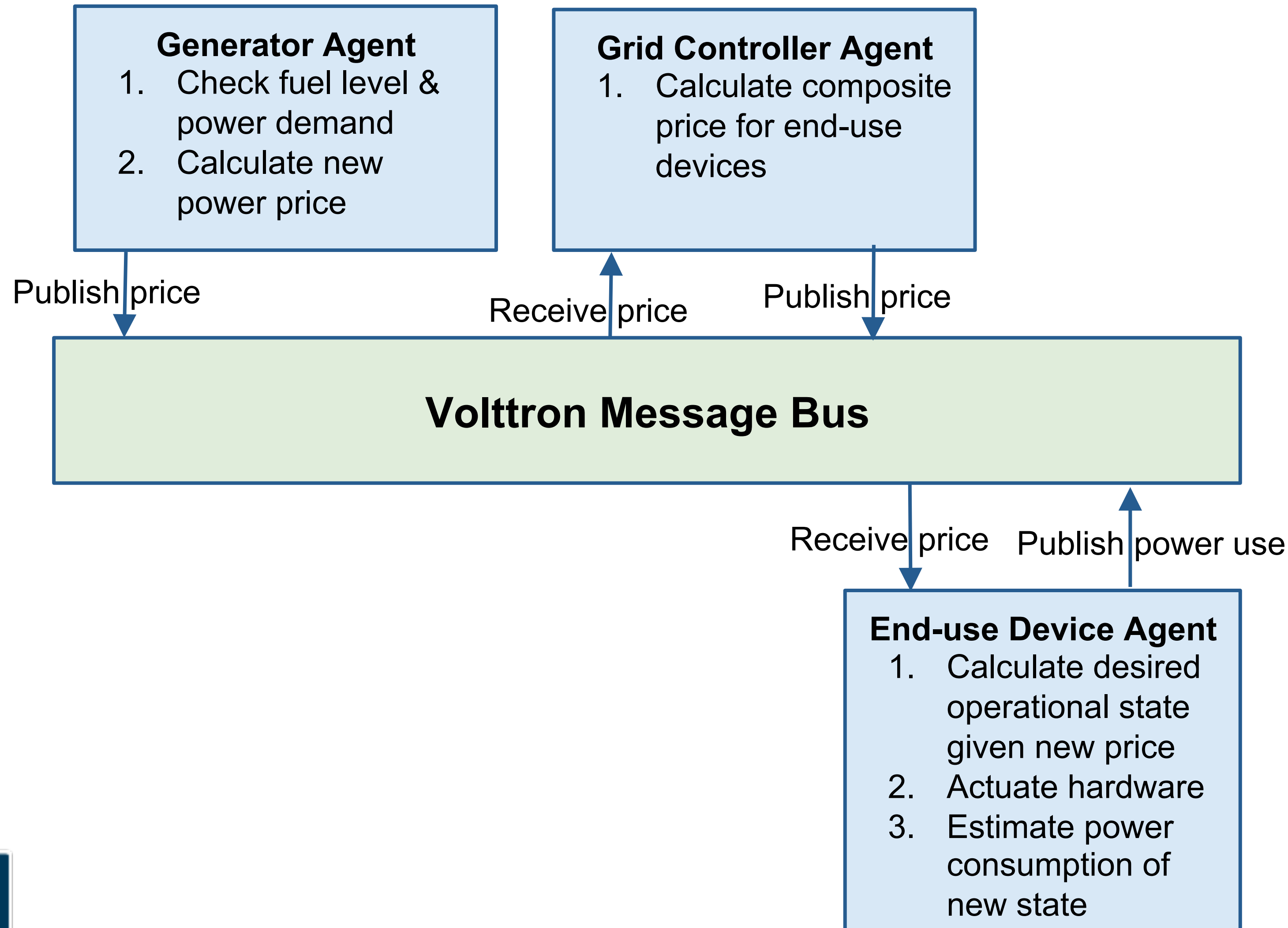
(Source: PB Boldak Data Analysis, 11/22/11; Expeditionary Energy Office E2O, NSWCCD, Unclassified)

- Cooling & Heating - Environmental Control Unit (ECU)
- Fan: variable speed
- Lighting: dimming fixture
- Motorola battery charger
- Soldier portable charger
- PRC-152 Battery charger
- Telephone handsets (CISCO 7911)
- Microwave
- GBOSS Heavy (with 2 flat screens)
- Dell laptops
- Wireless point-to-point link (WPPL)
- VRC-110
- Blue Force tracker
- Toughbook
- 19” flat screen monitor
- PRC-150
- Coffee pot: switched outlet

Software Platform Elements



Event Handling Example in Volttron

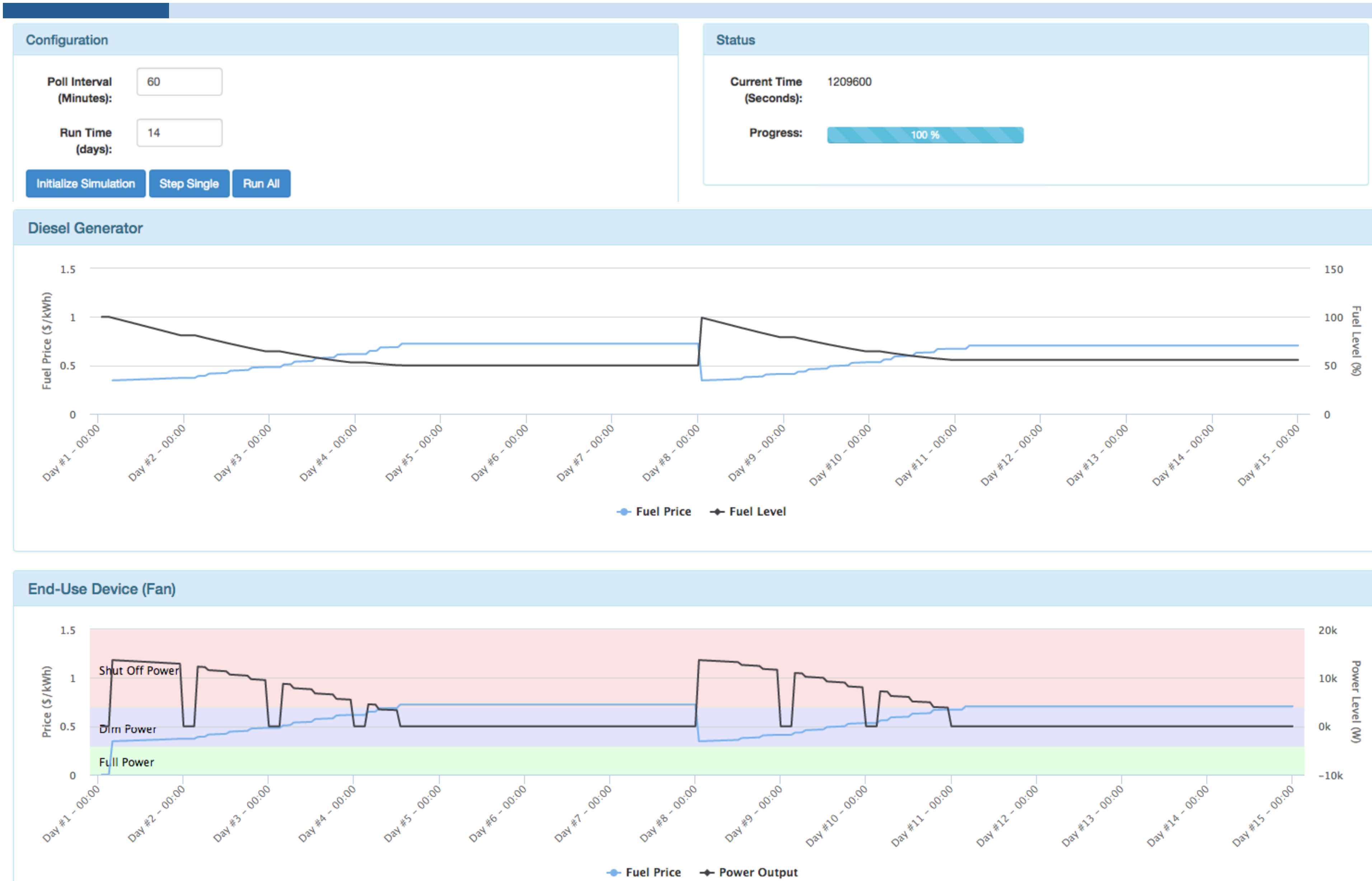


Equipment Simulation

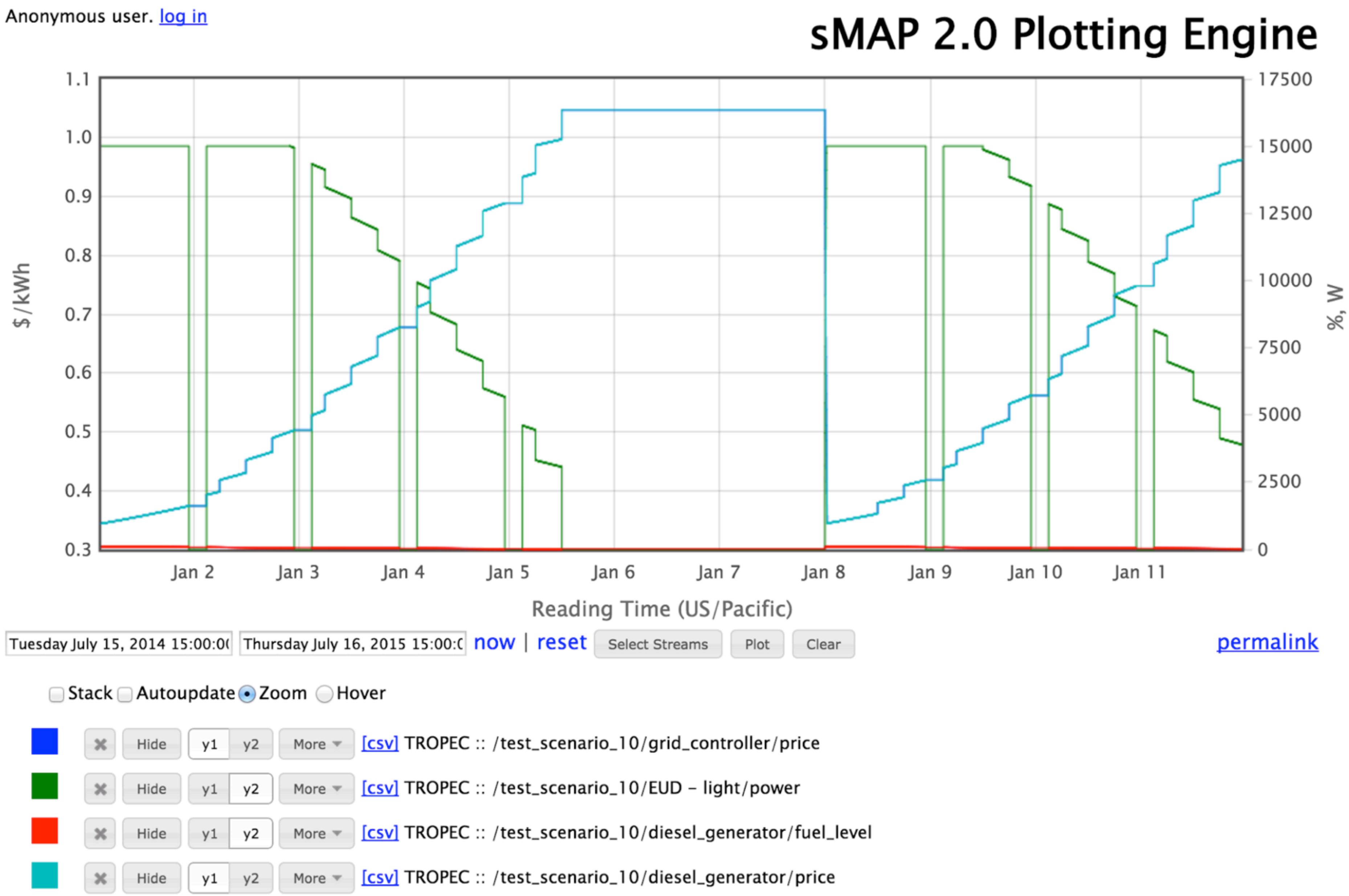
- Software agents initially tested in framework that simulates hardware
  - Supervisor agent manages simulation, creates simulated time
  - Supervisor tracks next event for each entity in system, “fast forwards” time between events (Discrete Event Simulation)
- Simulated devices have same network control interface as real devices
- Device power consumption estimated from measuring actual device
- Generator fuel consumption estimated using specific-consumption curve (gallons of fuel per hour, as function of power output)
- Benefits of simulation:
  - Test many different configurations, algorithms, and elasticity curves
  - Run (much) faster than real-time; quick analysis of many options
  - May be useful for testing other Volttron agents in the future

BERKELEY LAB

Simulation Results – Web Dashboard



Simulation Results – sMAP Plotter



Benchtop Hardware Demonstration

- Install real end-use devices to be controlled by the Volttron agents
- Hardware proof-of-concept testing verifies:
  - Devices can respond on timescales required
  - Devices can operate in stable manner (e.g., lights don't flicker, unplugging one device doesn't adversely affect the others, etc.)
  - Demand functions calibrated properly – correct price response
- Hardware testing also important to create compelling demo for DoD
- Continue with simulated genset and meter grid power to keep track of actual power supplied to end-use devices
  - "Virtual" fuel resupply through software
  - PV and battery also simulated initially

Civilian Applications

- Integration of common devices (lighting, computers, fans, etc.) into a Volttron network

BERKELEY LAB

Add-on TROPEC Assessment

- DoD TROPEC "laboratory assessment" of DOE-developed technology
- Goal: make demonstration more relevant to DoD context
  - Additional end-use loads (would like to include air conditioner, since that is the largest load at a base camp)
  - Input from PACOM on realistic demand elasticity curves (priorities)
- Demonstrate two scenarios:
  - Base case: fuel resupplied on expected schedule
  - Test case: fuel resupply delayed X days
  - Performance Metric: # of extra days of operation from stretching fuel supply using load management capability of transactional network

BERKELEY LAB

Future Enhancements

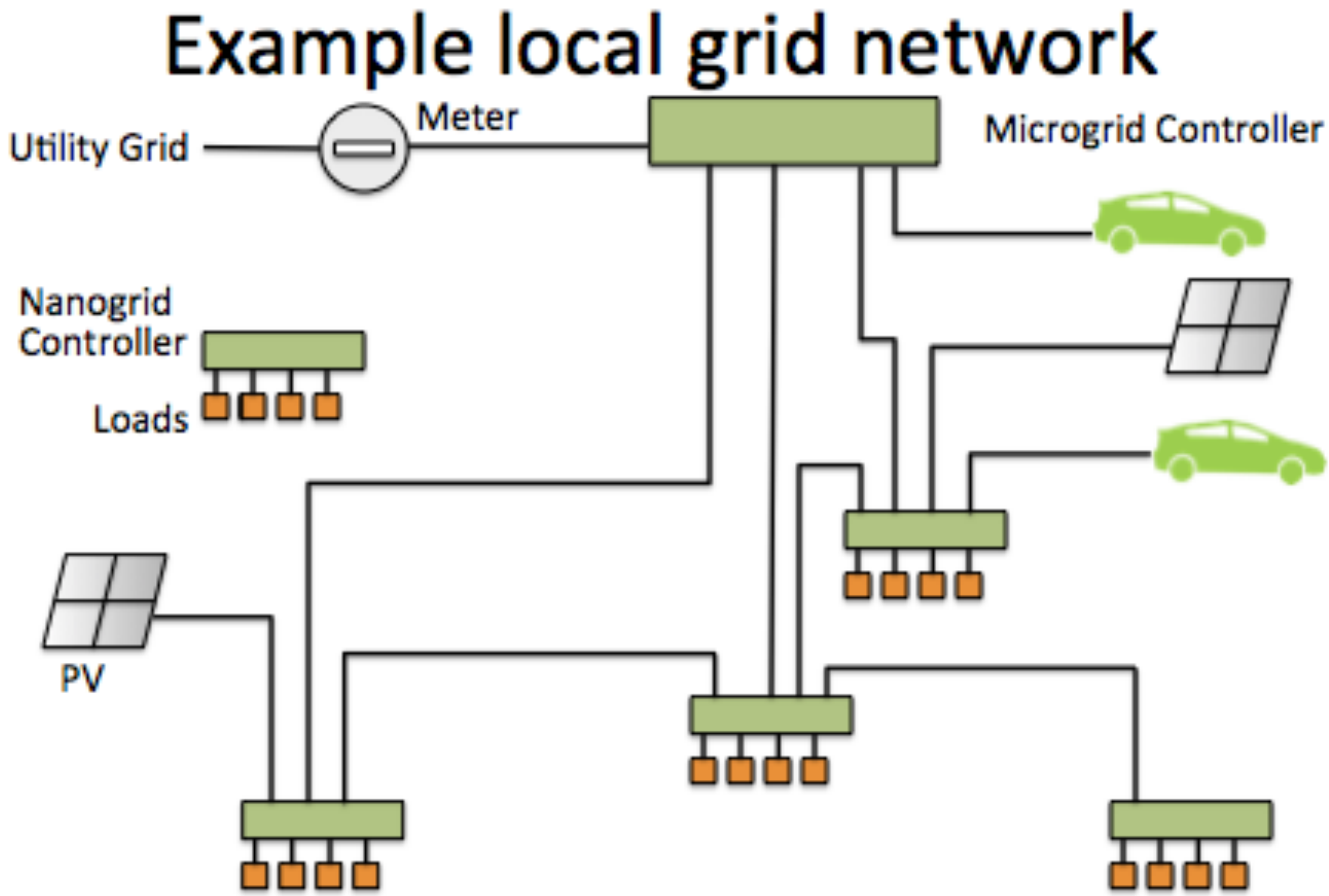
- Additional hardware elements:
  - Environmental Control Unit & other "real" military devices
  - PV generator
  - Battery
- Forecasting: implement more sophisticated price forecast method
- Load response: end-use devices respond based on forecasted needs
- Demonstrate in ORNL outdoor testbed
- Supply/demand balancing: grid controller modifies price to avoid projected *capacity* shortfall (as opposed to *energy* shortfall)
- Integration with hardware microgrid controller
- Apply controller to workstation control (CBERD)

Civilian Applications

- Managing fuel supplies for critical facilities running on backup power
- Management of building microgrids

BERKELEY LAB

Future Vision: Local Power Distribution



All connections peer-to-peer and can be changed dynamically

Price is how devices know which way power should flow

BERKELEY LAB