

Transaction-Based Operation of Resource Constrained Systems

– *TROPEC Transactive Energy Microgrid Controller* –

Volttron Technical Meeting
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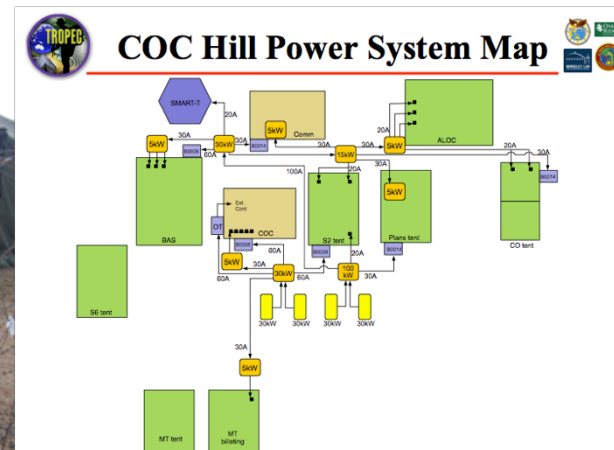
Objectives

- 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



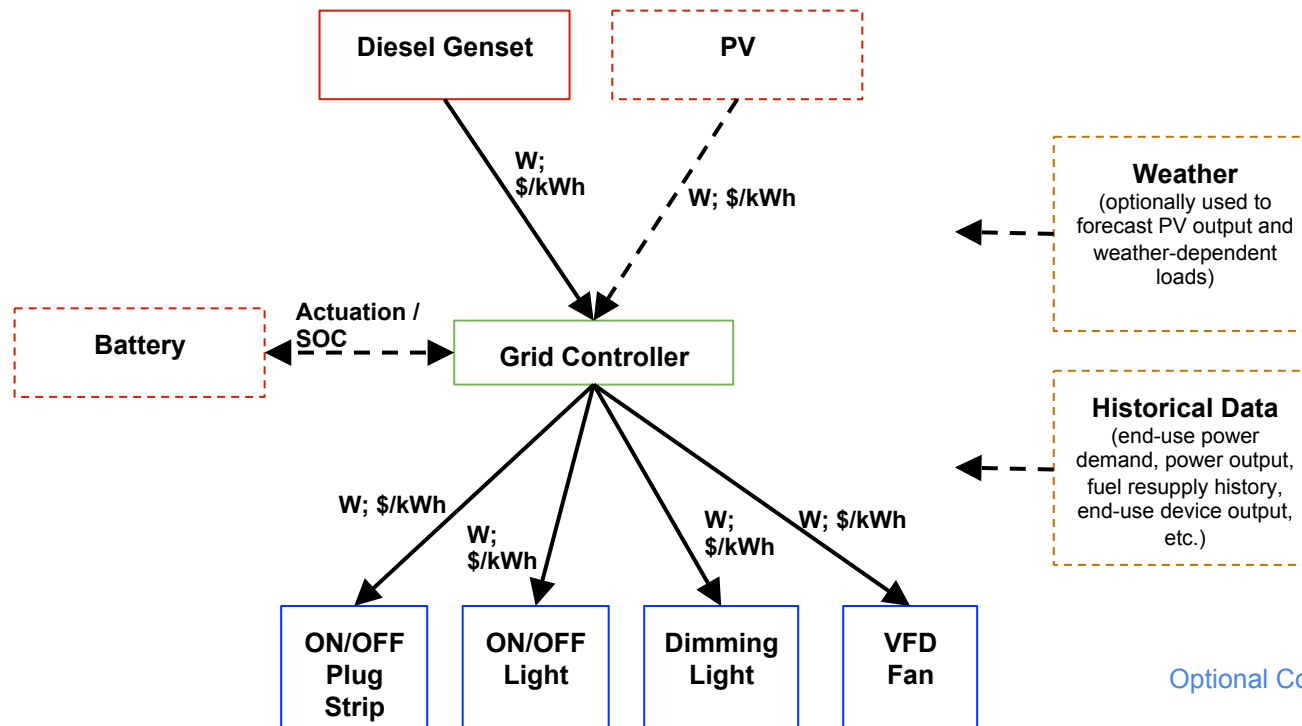
DoD & TROPEC Background

- 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



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



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

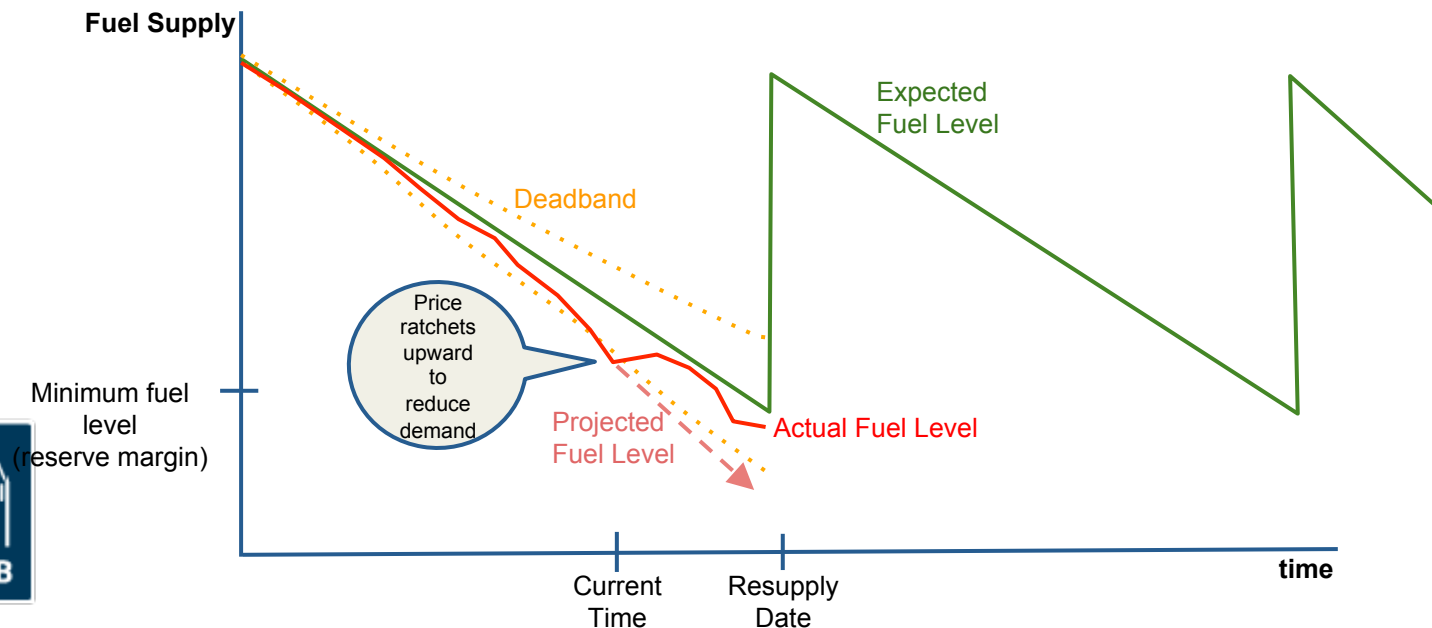


Civilian Applications

- 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

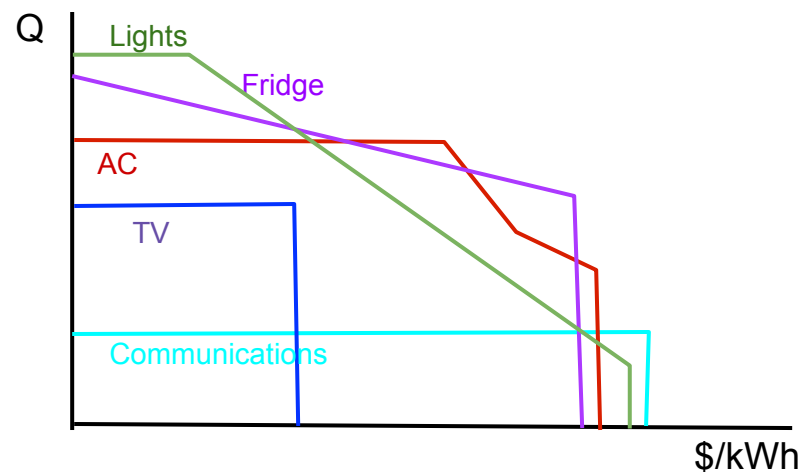


Civilian Applications

- 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



Civilian Applications

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



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

Representative TROPEC Electricity End-Use Loads

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

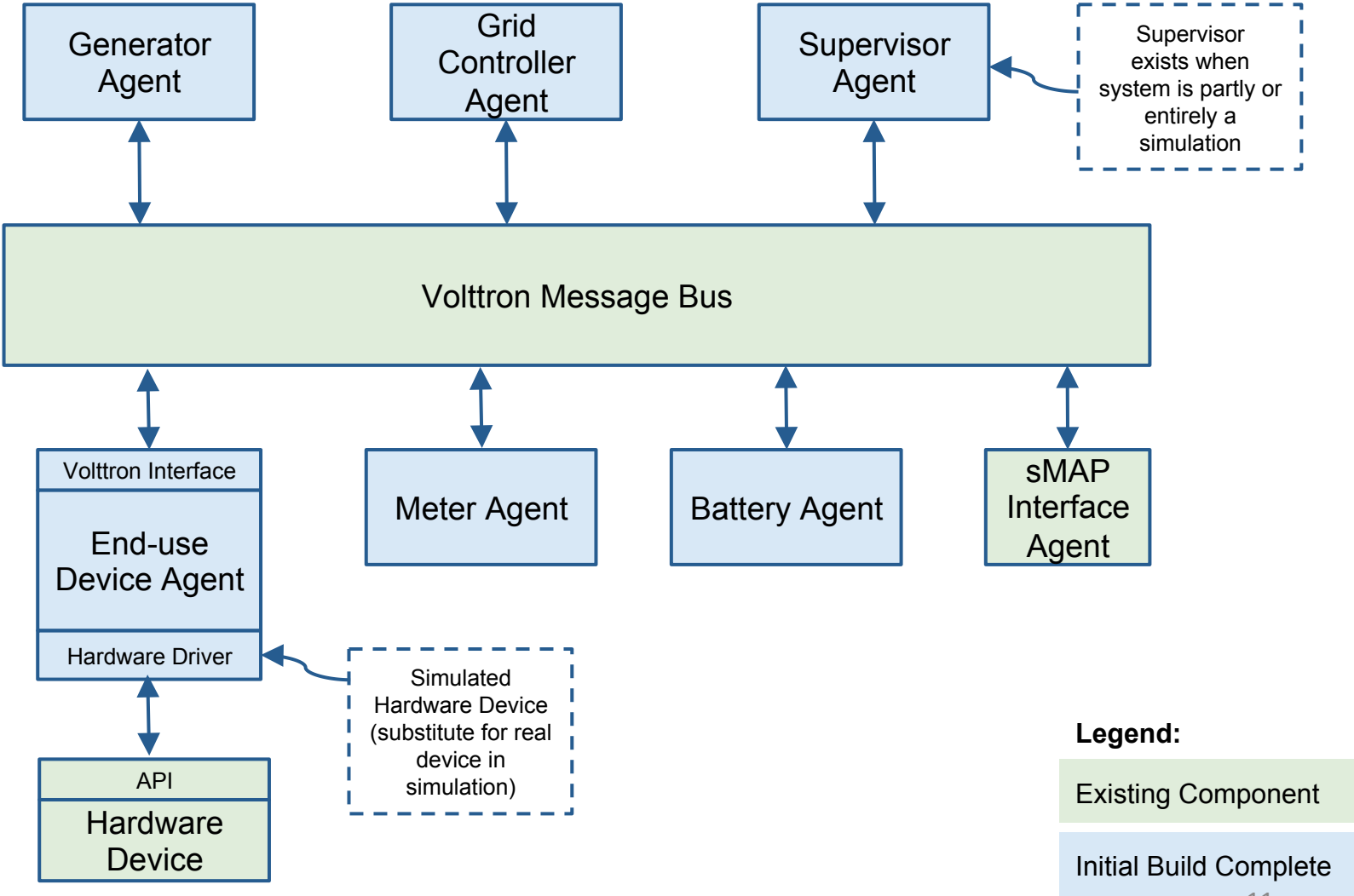


(Source: PB Boldak Data Analysis, 11/22/11; Expeditionary Energy Office E2O, NSWCCD, Unclassified)

- 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



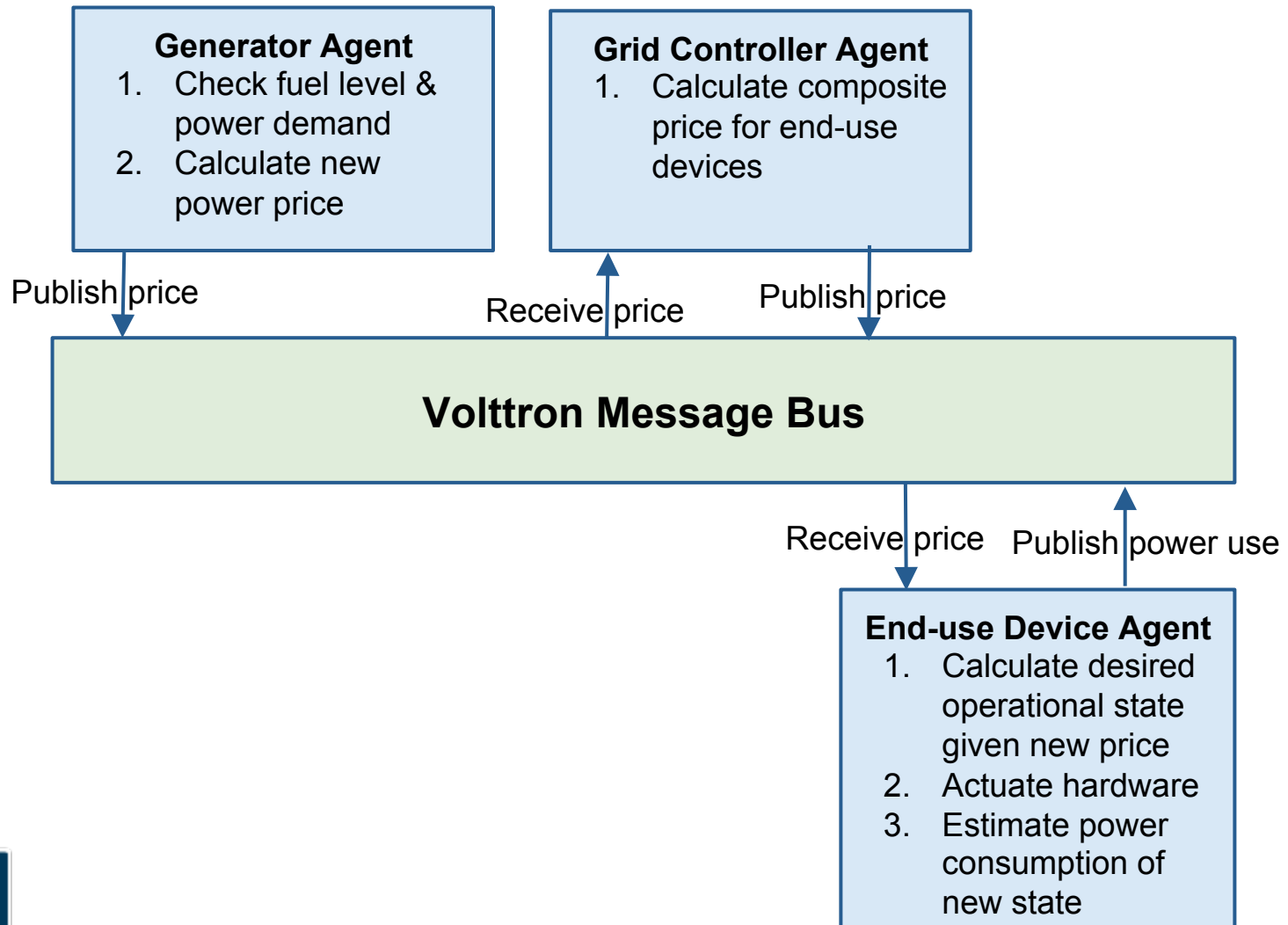
Software Platform Elements



Legend:

- Existing Component
- Initial Build Complete

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



Simulation Results – Web Dashboard

Configuration

Poll Interval
(Minutes):

Run Time
(days):

Initialize Simulation

Step Single

Run All

Status

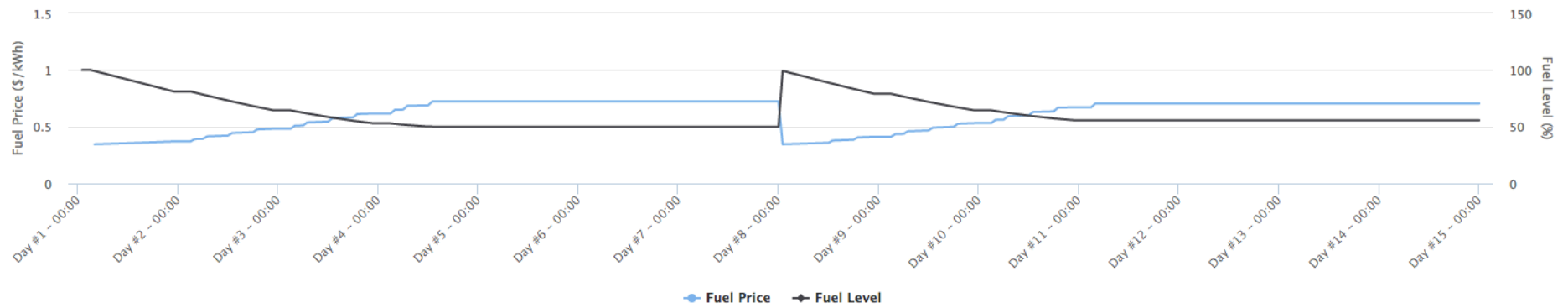
Current Time
(Seconds):

1209600

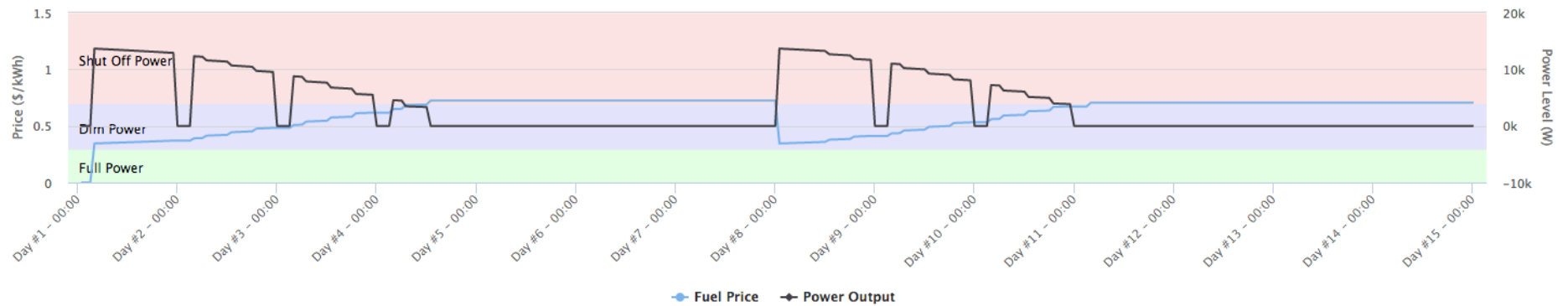
Progress:

100 %

Diesel Generator



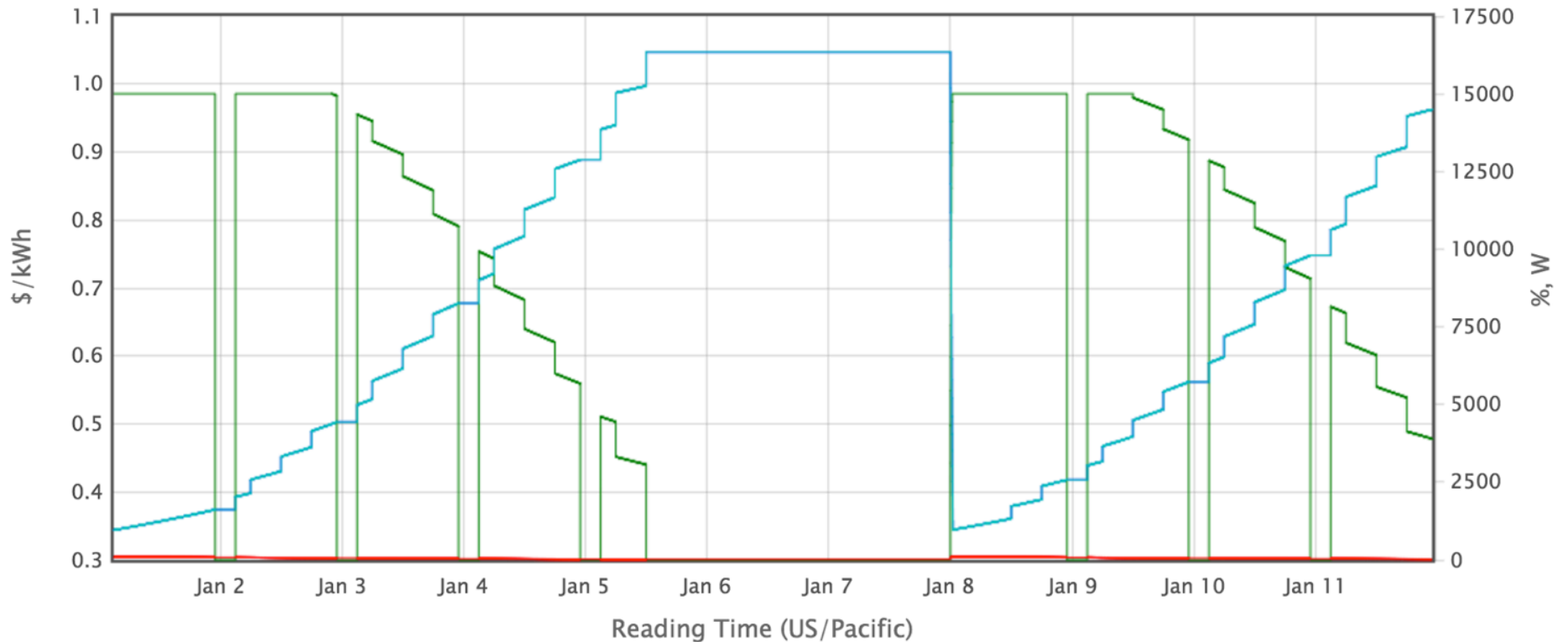
End-Use Device (Fan)



Simulation Results – sMAP Plotter

Anonymous user. [log in](#)

sMAP 2.0 Plotting Engine



Tuesday July 15, 2014 15:00:00 | Thursday July 16, 2015 15:00:00 | [now](#) | [reset](#) | [Select Streams](#) | [Plot](#) | [Clear](#)

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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

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



Future Enhancements

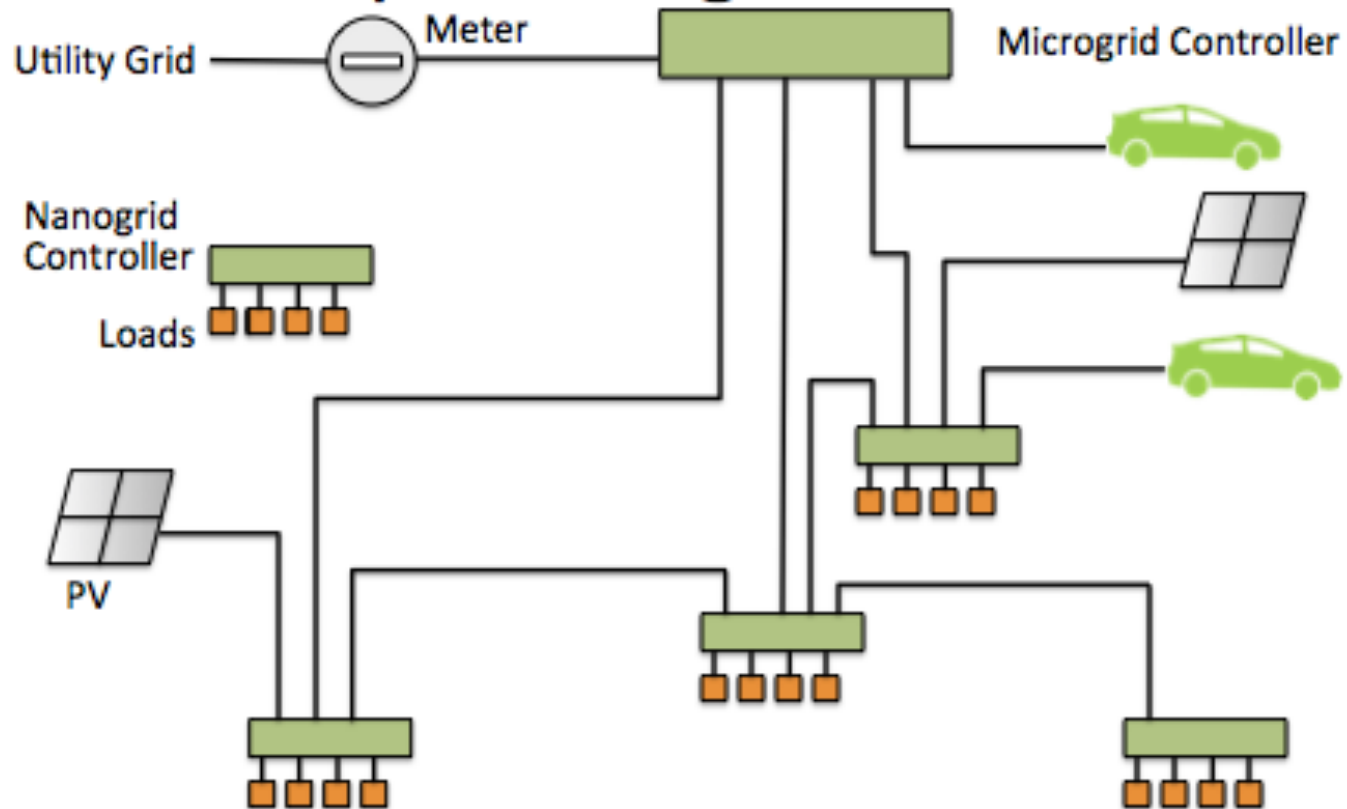
- Additional hardware elements:
 - Environmental Control Unit & other “real” military devices
 - PV generator
 - Battery
- Forecasting: implement more sophisticated price forecast method
- Load response: end-use devices respond based on forecasted needs
- Demonstrate in ORNL outdoor testbed
- Supply/demand 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

Future Vision: Local Power Distribution

Example local grid network



*All connections peer-to-peer and can be changed dynamically
Price is how devices know which way power should flow*