PNNL-SA-91644

Pacific Northwest
SMART GRID
DEMONSTRATION PROJECT

Transactive Control in the Pacific Northwest Smart Grid Demonstration

Presentation for:
Trustworthy Cyber Infrastructure for the Power Grid -TCIPG
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Challenges & Opportunities Facing the Power Grid

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The challenges we face are significant …

- Increase asset utilization
- Integrate renewables and low-carbon sources
- Maintain and increase reliability
- Keep costs as low as possible
- Accommodate potential electrification of transportation (& other end uses)

So is the opportunity presented by smart grid …

- Fully engage <u>all</u> resources at <u>all</u> levels of the system to meet these challenges: the fundamental purpose of transactive control & coordination
  - Coordinate new distributed smart grid assets (demand response, distributed generation & storage)
  - Seamlessly integrate their use in conjunction with traditional grid assets

Managing Stochasticity of Loads & Renewables

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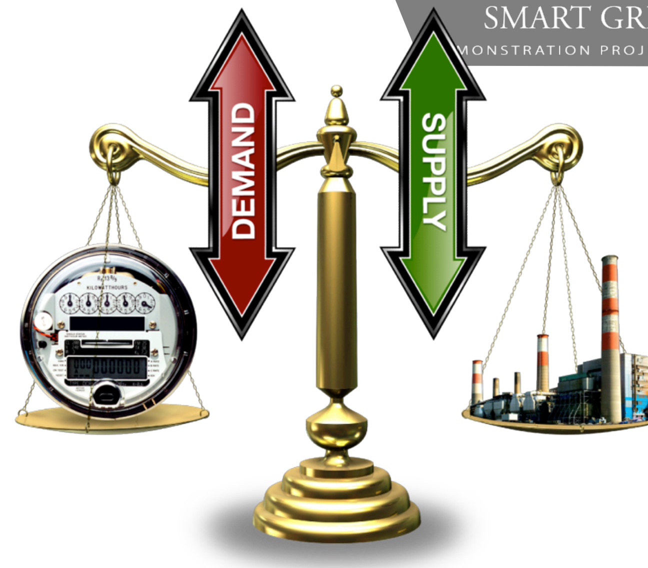
- Historically, the power grid:
  - had deterministic control of supply assets
  - responded to varying & stochastic fluctuations from demand
- With renewables, it is now variable & stochastic on both sides



Transactive control & coordination

- Coordinates operation of distributed assets to meet multiple generation, transmission, & distribution objectives
- Manages controllable assets at the distribution level to mitigate load variability & that of supply-side as well

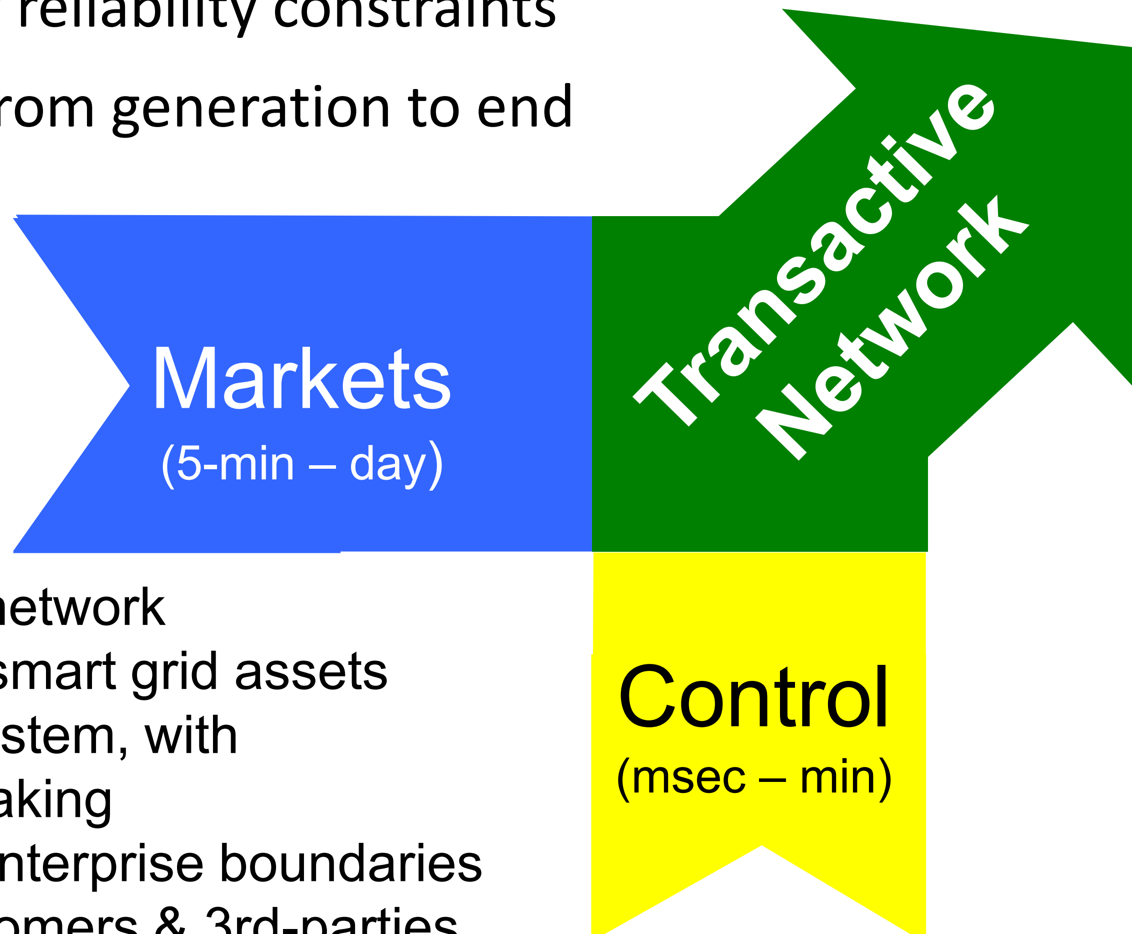
Definition of Transactive Control & Coordination (TC2)

Transactive control & coordination (TC2)

Uses economic or market-like constructs …

- to manage generation, consumption, & flow of electric power including reliability constraints
- by coordinating assets from generation to end use.

- TC2 blends elements power markets and energy control systems



- To form a transactive network
- organizing millions of smart grid assets
- into a virtual control system, with distributed decision making
- that respects natural enterprise boundaries between the grid, customers & 3rd-parties.

TC2 Nodes, Feedback & Incentive Signals

- Uses local conditions and global information to make local control decisions at points (nodes) where the flow of power can be affected.
- Nodes indicate their response to the network
  - In the form of a *feedback signal* as a forecast of their projected net flow of electricity (production, delivery, or consumption)
  - As a function of the *incentive signal* from the node(s) that serve them
- Node can then set the incentive signal with precision to obtain the desired response from nodes they serve
- Node's responsiveness is voluntary (set by the node owner)
- Node's response will be typically be automated by considering local needs vs. the incentive signal and reflected in the feedback signal

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What Problems or Issues is Transactive Control and Coordination Designed to Address?

Principal Challenges Addressed by TC2

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Principal Challenge	Approach
▶ Centralized optimization is unworkable ■ *for such large numbers of controllable assets, e.g. ~10^9 for full demand response participation*	▶ Distributed approach with self-organizing, self-optimizing properties of market-like constructs
▶ Interoperability	▶ Simple information protocol, common between all nodes at all levels of system: *quantity, price or value, & time*
▶ Privacy & security ■ *due to sensitivity of the data required by centralized techniques*	▶ Minimizes risks & sensitivities by limiting content of data exchange to simple transactions
▶ Scalability	▶ Self-similar at all scales in the grid ▶ Common paradigm for control & communication among nodes of all types ▶ Ratio of supply node to served nodes to ~10^3

Principal Challenges Addressed by TC2 (cont.)

Principal Challenge	Approach
▶ Level playing field for all assets of all types: ■ *existing infrastructure & new distributed assets of all types*	▶ Market-like construct provides equal opportunity for all assets ▶ Selects lowest cost, most willing assets to "get the job done"
▶ Maintain customer autonomy ■ *"Act locally but think globally"*	▶ Incentive-based construct maintains free will ■ *customers & 3rd-parties fully control their assets* ■ *yet collaborate (and get paid for it)*
▶ Achieving multiple objectives with assets needed to be cost effective	▶ Allows (but does not require) distribution utility to act as natural aggregation point ■ *addressing local constraints while representing their capabilities to the bulk grid*
▶ Stability & controllability	▶ Feedback provides predictable, smooth, stable response from distributed assets ▶ Creates what is effectively closed loop control needed by grid operators

Links All Values/Benefits in Multi-Objective Control

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Long-term objective for TC2 is to simultaneously achieve combined benefits

- Reduce peak loads (minimize new capacity, maximize asset utilization) – generation, transmission, & distribution
- Minimize wholesale prices/production costs
- Reduce transmission congestion costs
- Provide stabilizing services on dynamically-constrained transmission lines to free up capacity for renewables
- Provide ancillary services, ramping, & balancing (especially in light of renewables)
- Managing distribution voltages in light of rapid fluctuations in rooftop solar PV system output

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Transactive Control & Coordination in the Pacific Northwest Smart Grid Demonstration Project

Pacific Northwest Demonstration Project

What:

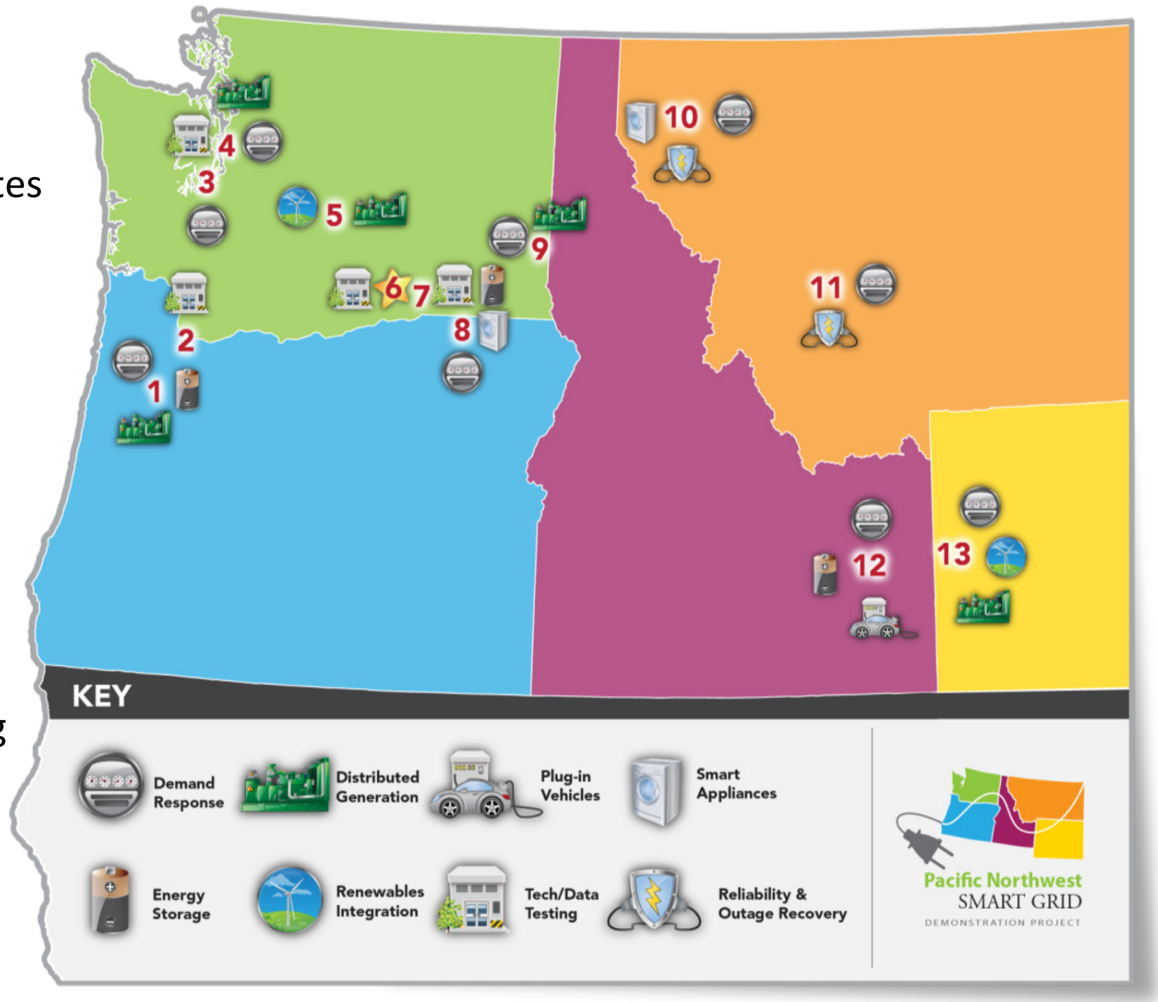
- $178M, ARRA-funded, 5-year demonstration
- 60,000 metered customers in 5 states

Why:

- Quantify costs and benefits
- Develop communications protocol
- Develop standards
- Facilitate integration of wind and other renewables

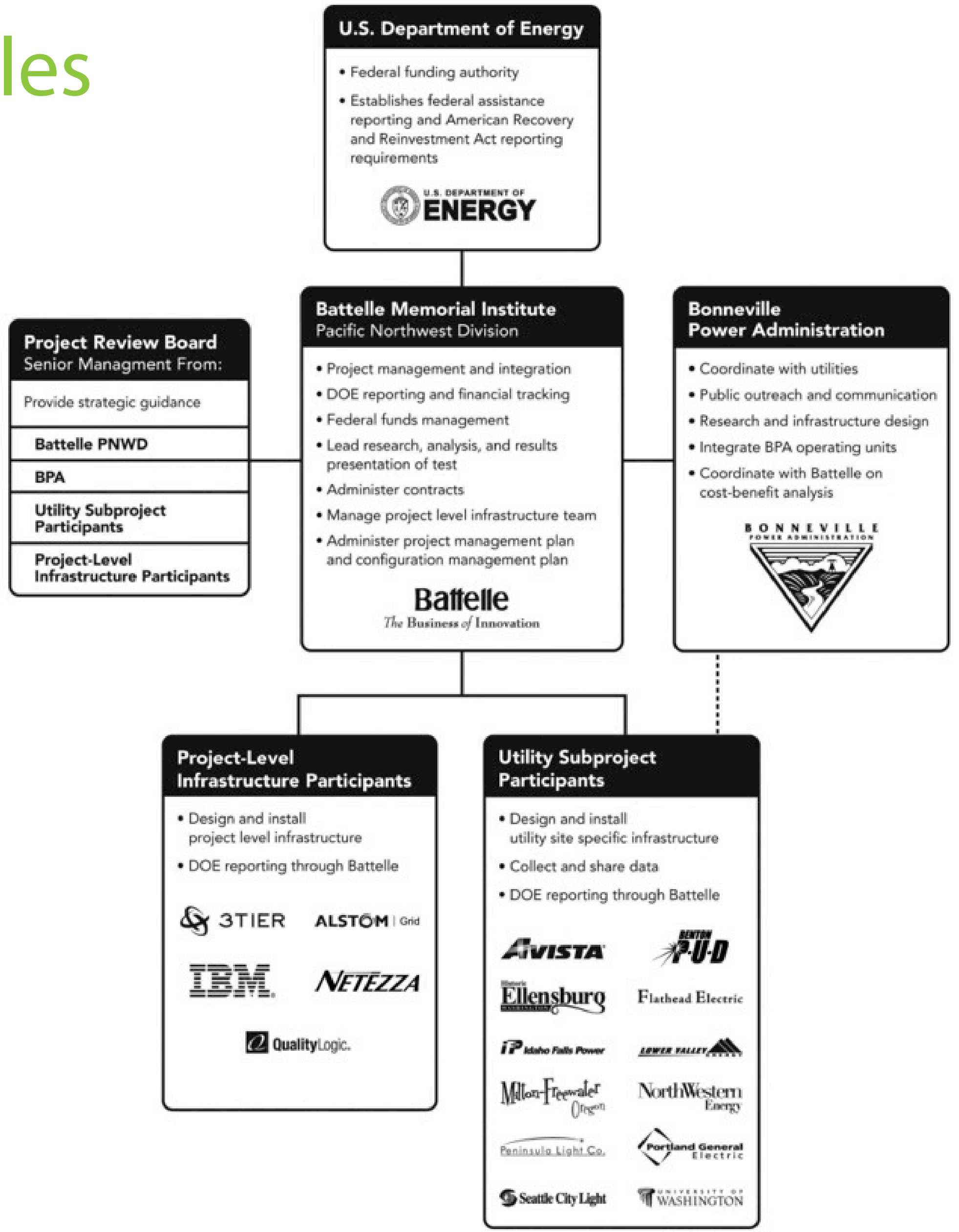
Who:

Led by Battelle and partners including BPA, 11 utilities, 2 universities, and 5 vendors



Project Structure / Roles

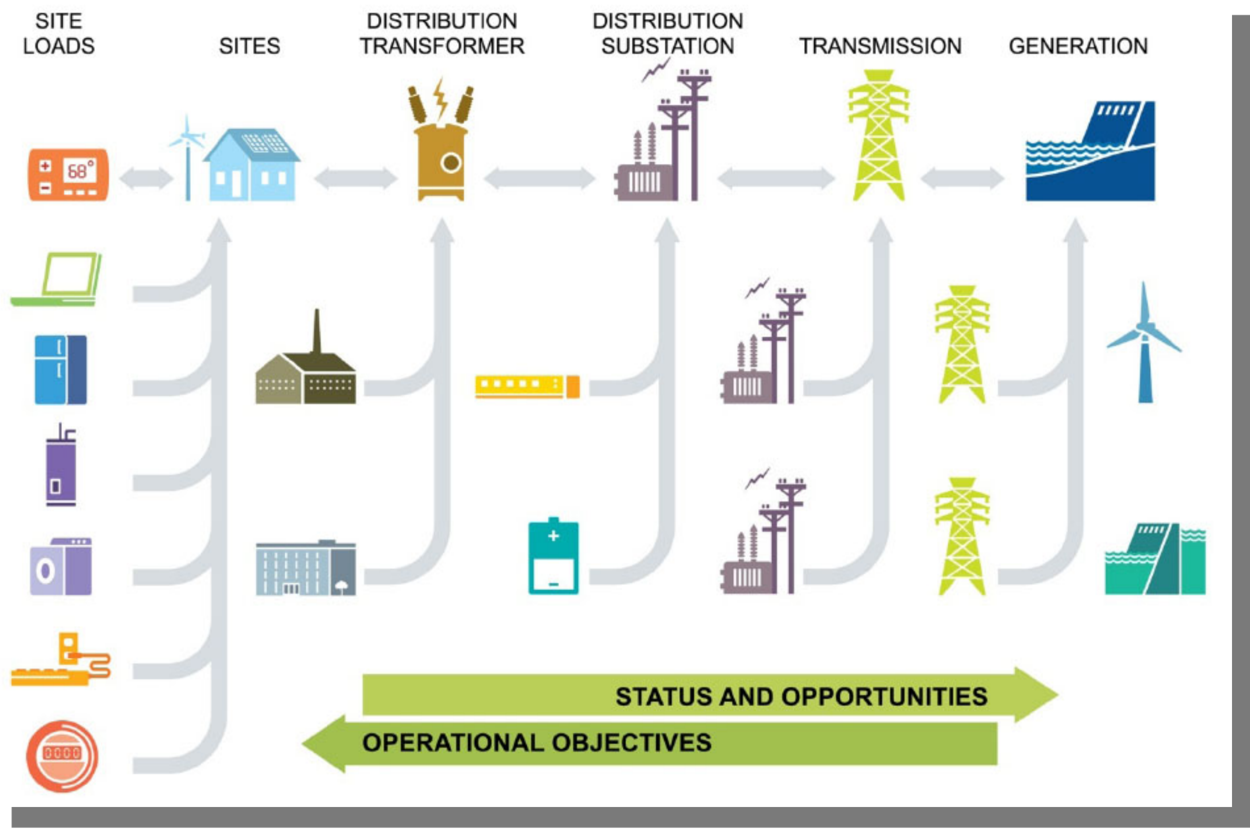
- Battelle Memorial Institute, Pacific Northwest Division
- Bonneville Power Administration
- 11 utilities (and University of Washington) and their vendors
- 5 technology infrastructure partners



Project Basics

Operational objectives

- Manage peak demand
- Facilitate renewable resources
- Address constrained resources
- Improve system reliability and efficiency
- Select economical resources (optimize the system)



Aggregation of Power and Signals Occurs Through a Hierarchy of Interfaces

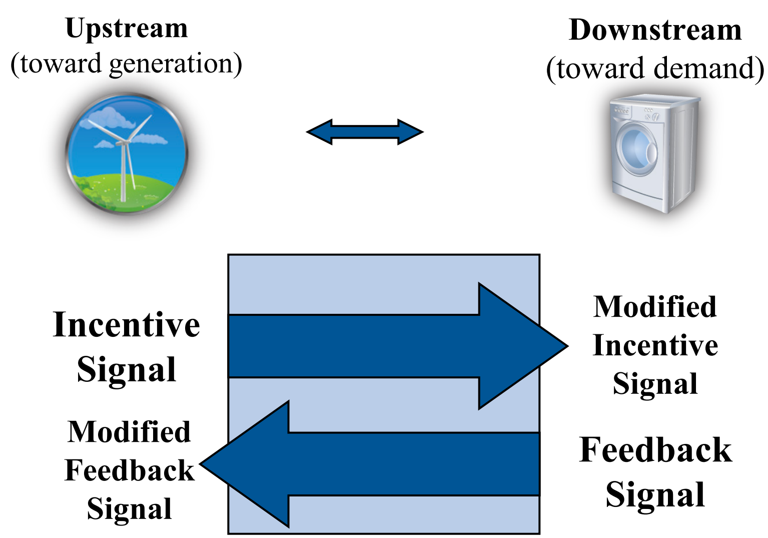
Transactive Control 101

What is it?

- Transactive control is a distributed method for coordinating responsive grid assets wherever they may reside in the power system.

Incentive and feedback signals

- The incentive signal sends a synthetic price forecast to electricity assets
- The feedback signal sends a consumption pattern in response to the incentive.



An Incentive Signal

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Predict and share a dynamic, price-like signal—the unit cost of energy needed to supply demand at this node using the least costly local generation resources and imported energy. May include

- Fuel cost (consider wind vs. fossil vs. hydropower generation)
- Amortized infrastructure cost
- Cost impacts of capacity constraints
- Existing costs from rates, markets, demand charges, etc.
- Green preferences?
- Profit?
- Etc.

Example "Resource Functions": Wind farm, fossil generation, hydropower, demand charges, transmission constraint, infrastructure, transactive energy, imported energy

A Feedback Signal

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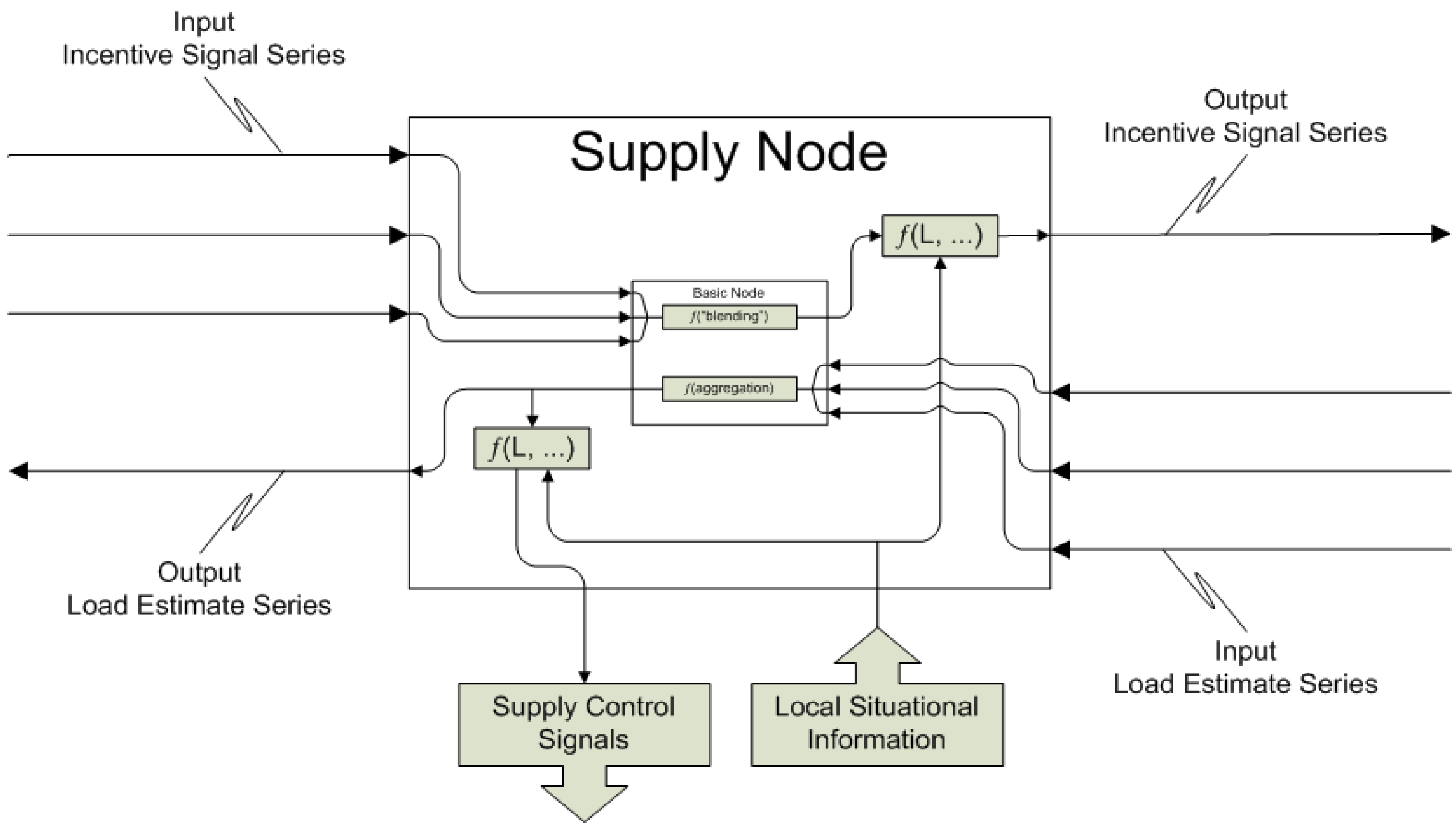
Predict and send dynamic feedback signal—power predicted between this node and a neighbor node based on local price-like signal and other local conditions. May include

- Inelastic and elastic load components
- Weather impacts (e.g., ambient temperature, wind, insolation)
- Occupancy impacts
- Energy storage control
- Local practices, policies, and preferences
- Effects of demand response actions
- Customer preferences
- Predicted behavioral responses (e.g., to portals or in-home displays)
- Real-time, time-of-use, or event-driven demand responses alike
- Distributed generation

Example "Load Functions": Battery storage, bulk inelastic load, building thermostats, water heaters, dynamic voltage control, portals / in-home displays

Transactive Node Inputs & Outputs



The system is distributed, predictive, scalable, and its signals track the energy that it represents.

Transactive Control – Electric Vehicle Charging Example

Simple Example – Local Electric Vehicle Charging

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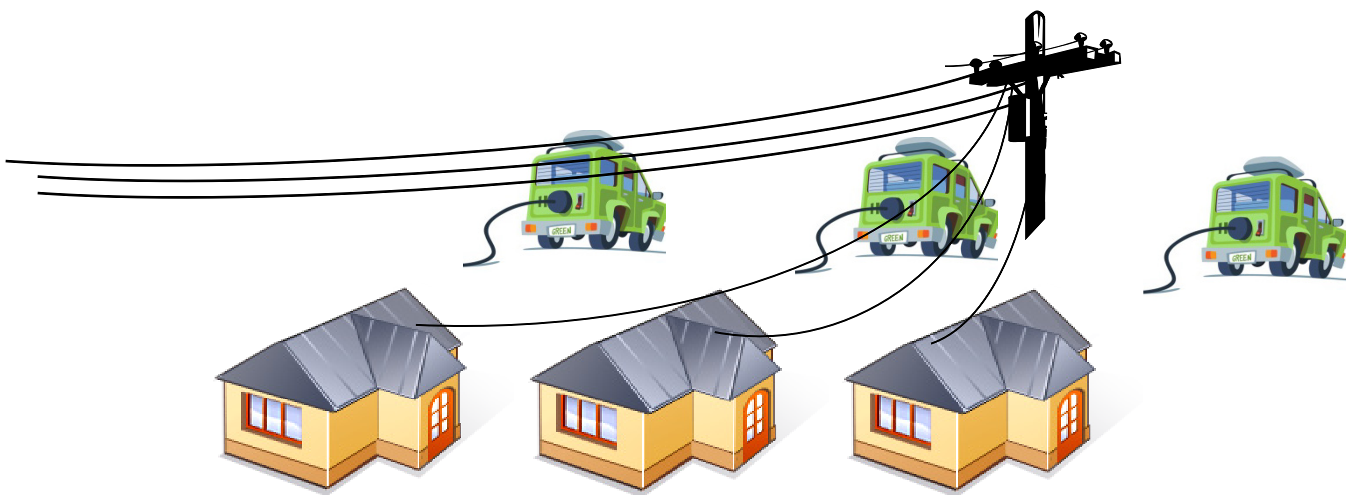
- Imagine the following situation:
  - Three neighbors with electric vehicles and different charging strategies
  - All three fed by same distribution transformer
  - All three come home and want to do a fast charge at the same time!
- Problem – transformer is overloaded if all three fast charge at the same time
- Transactive control solution –
  - Transformer sees in feedback signal that all three plan to fast charge
  - Transformer raises value of incentive signal during planned charging time to reflect decreased transformer life
  - Smart chargers and transformer "negotiate" through TIS and TFS until an acceptable solution is found

Our Example

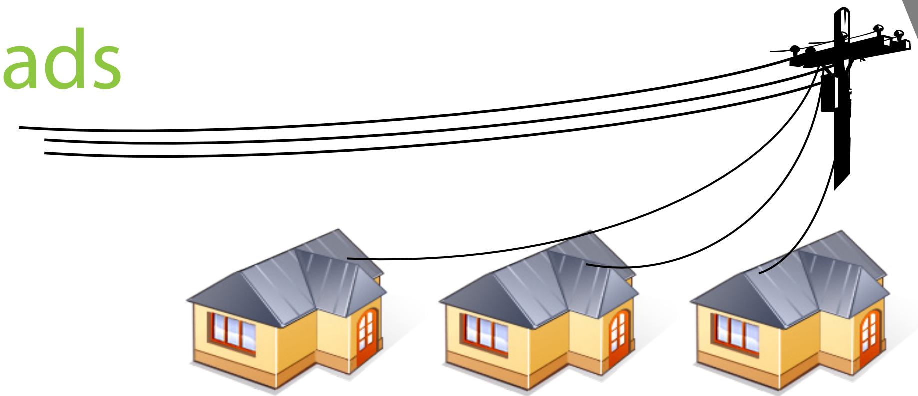


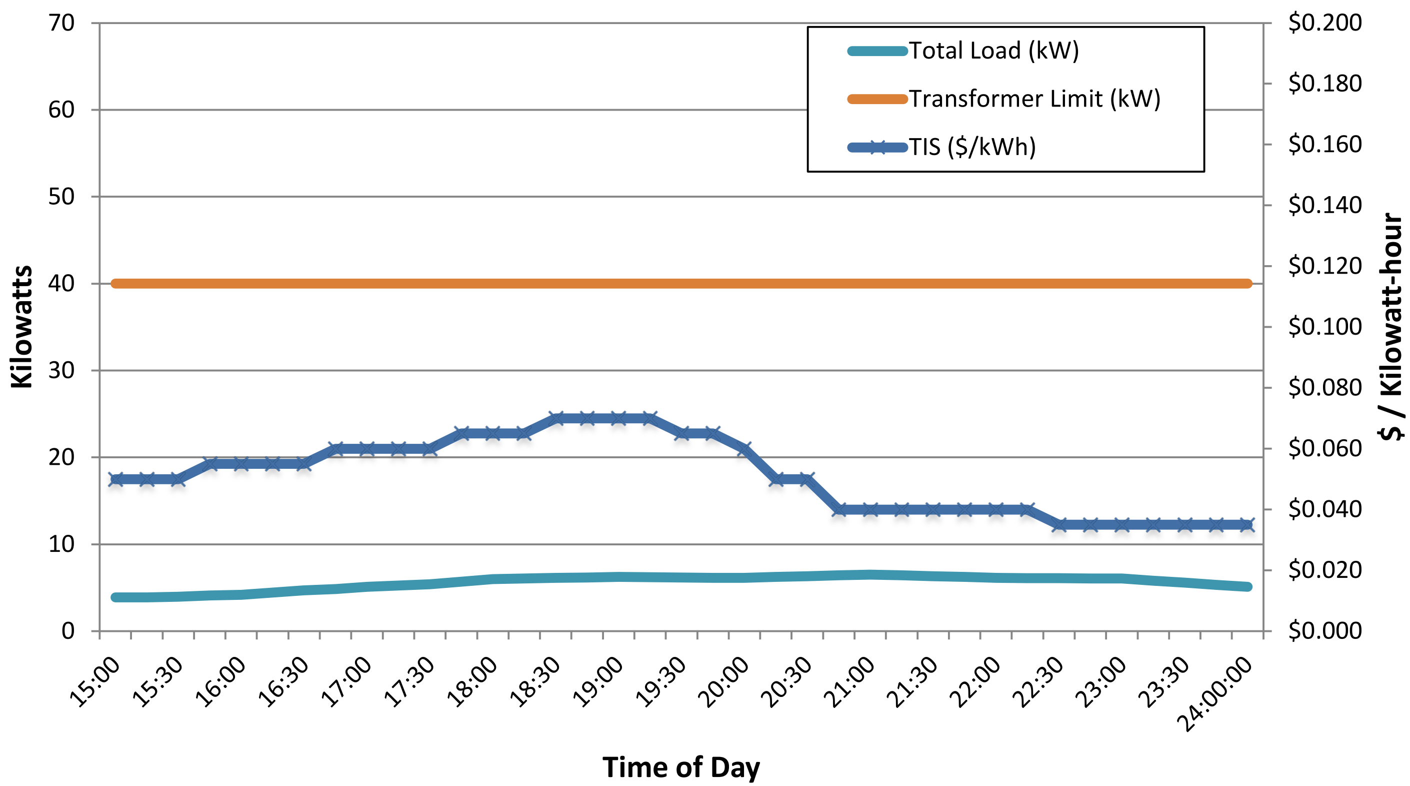
House 1:
I’m flexible

House 2:
I want it now!

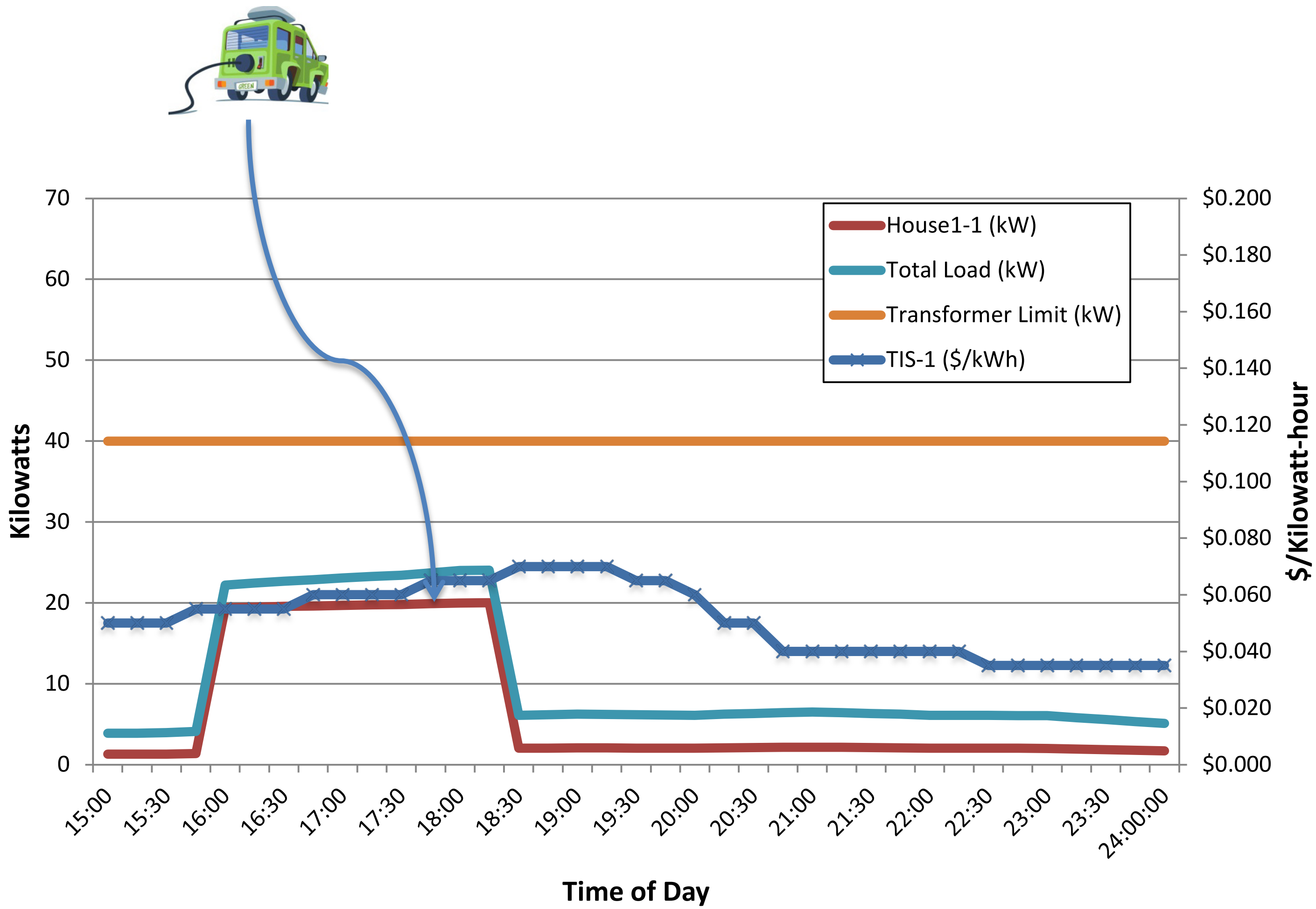
House 3:
I’m a bargain hunter

Start – house loads

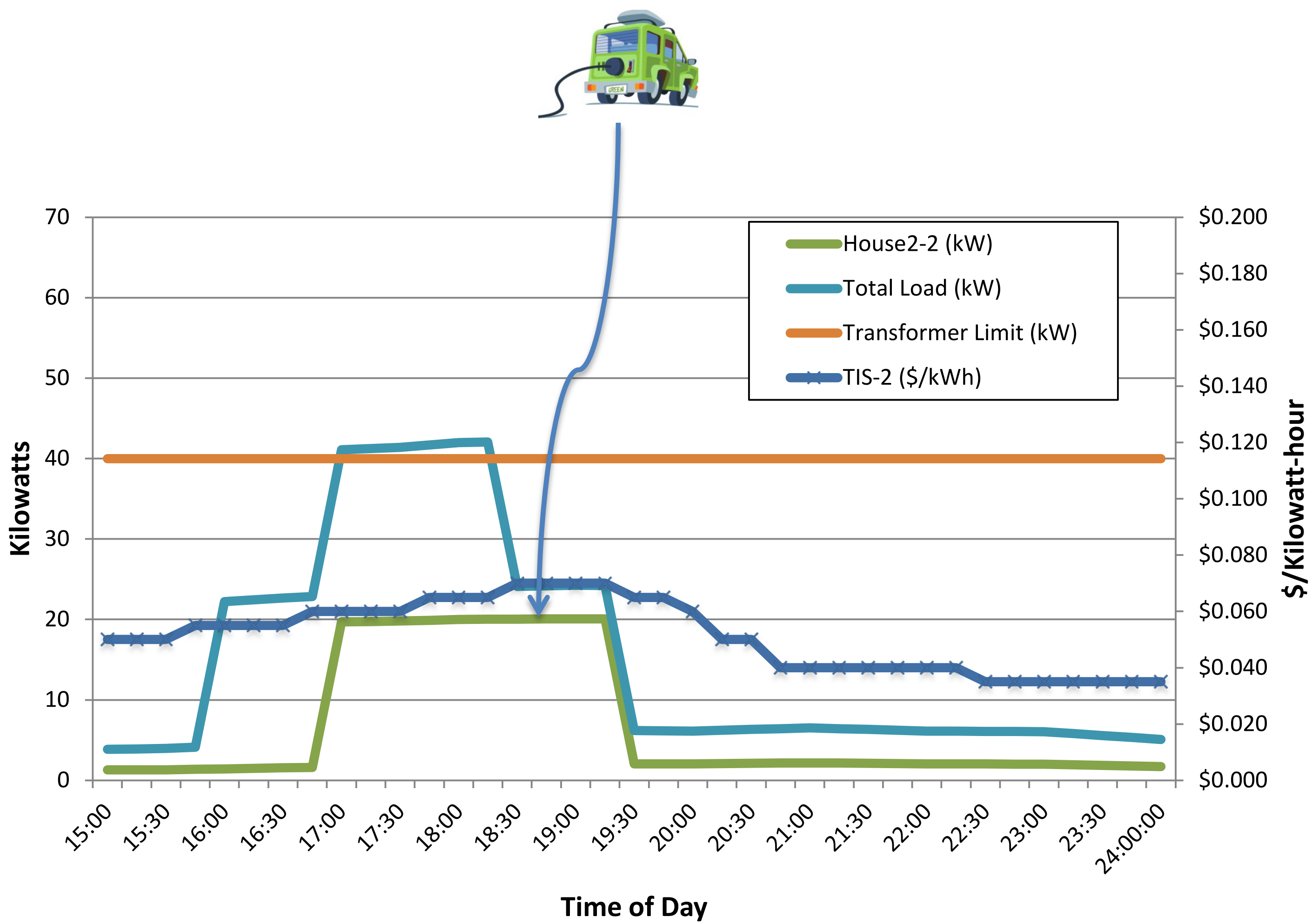




House 1 plan revealed



House 2 plan revealed



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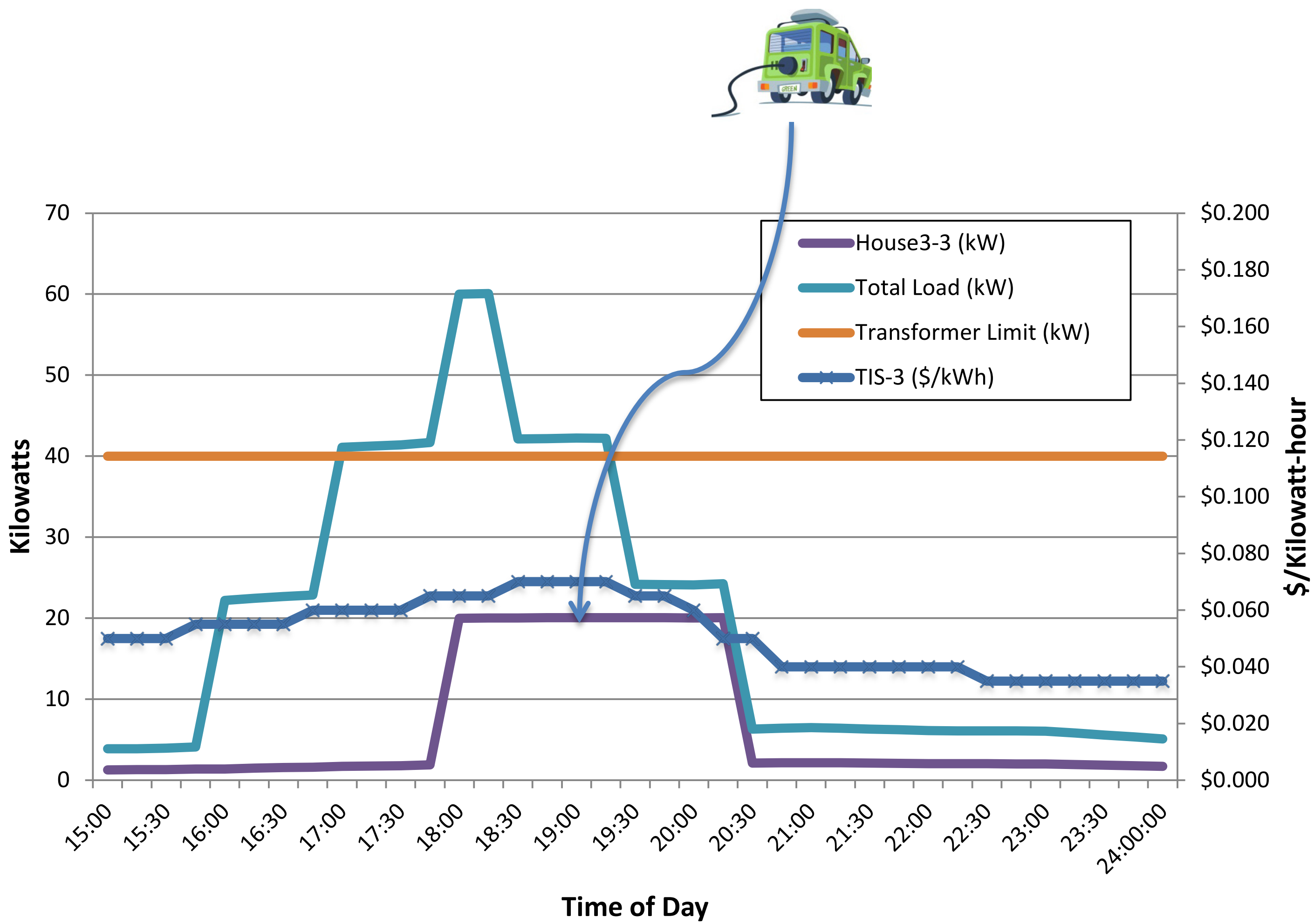
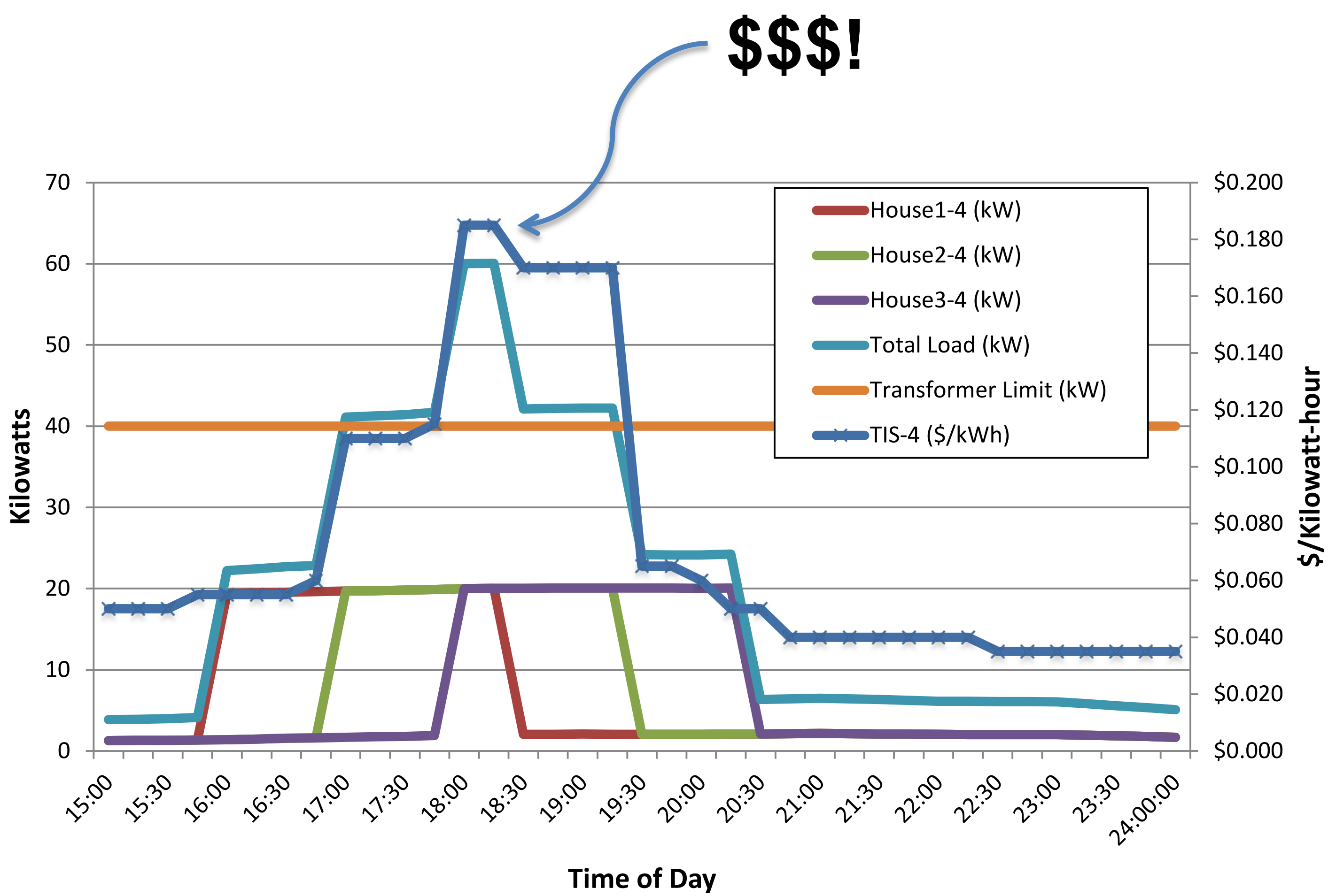
House 3 plan revealed



TIS changed in response to charging plans



House 1 responds to TIS change

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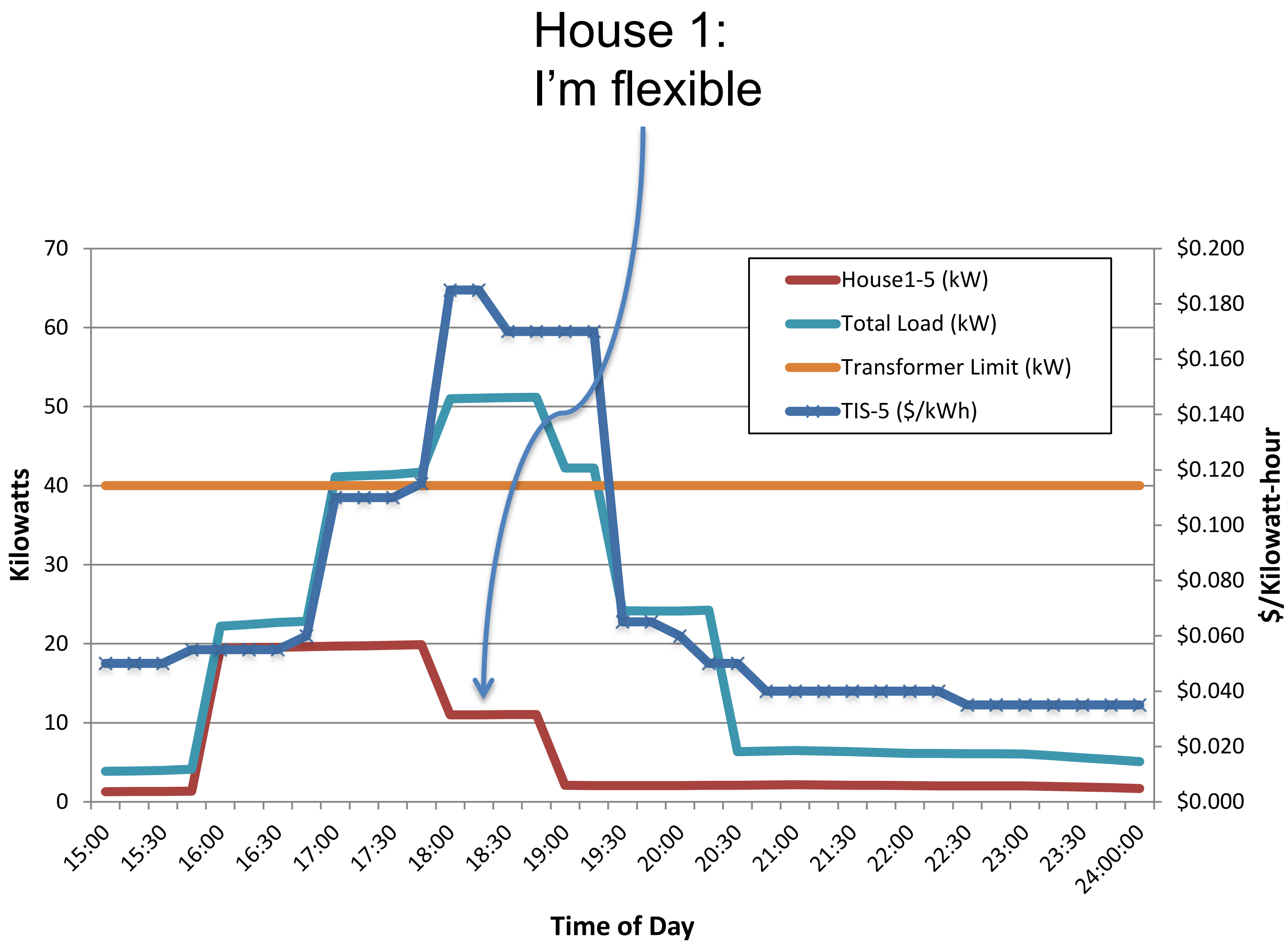

House 3 responds to TIS change - shift

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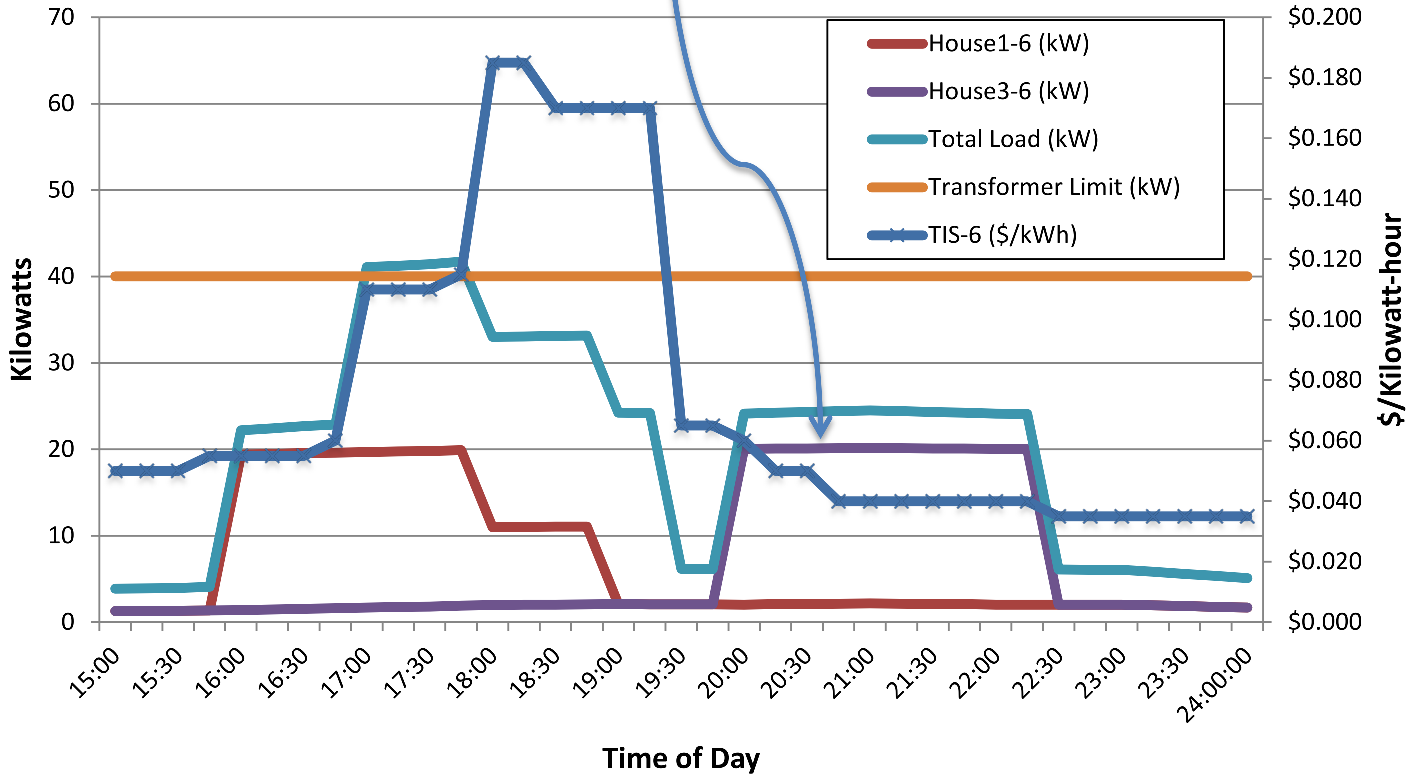
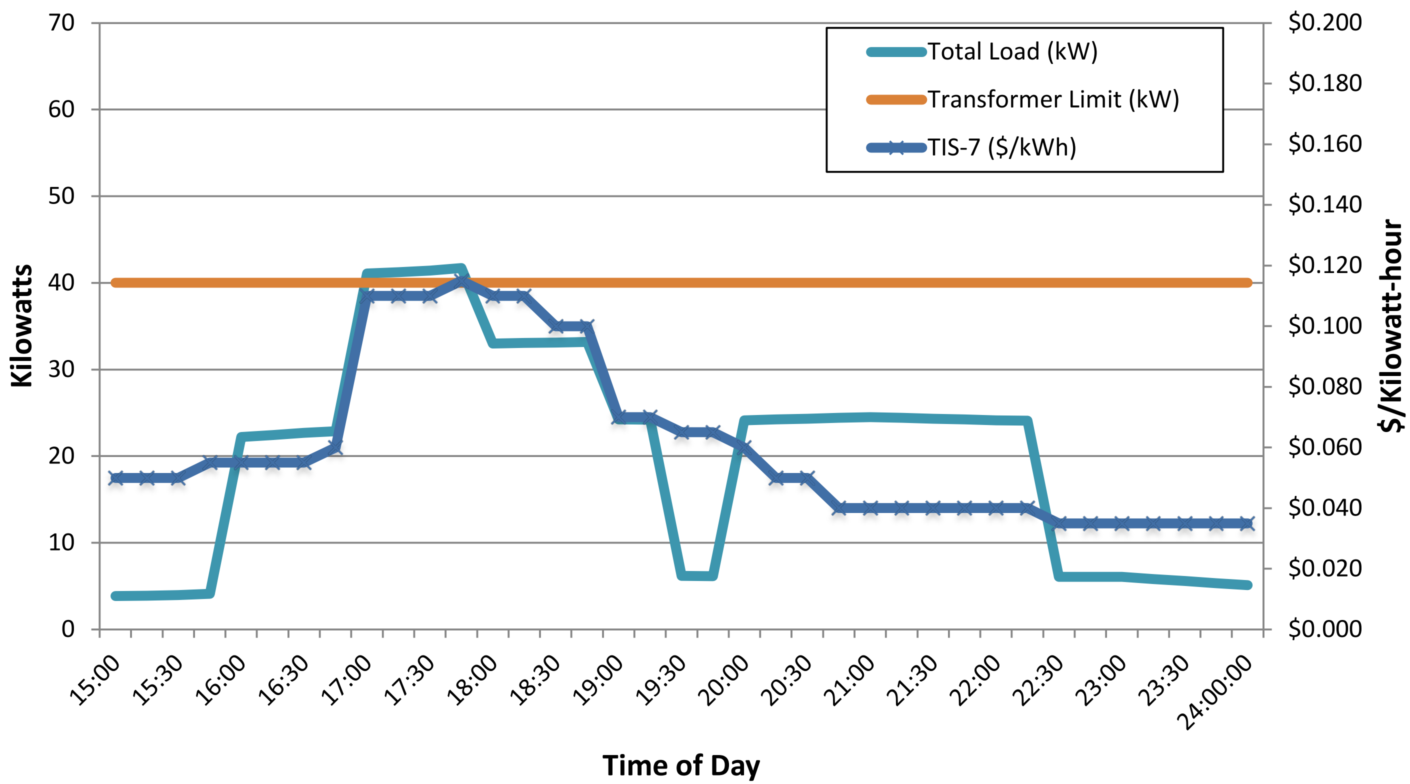
House 3:
I'm a bargain hunter



TIS responds to new plans – agreement

House 2:
I want it now!
I didn't make any change.
I will pay the higher price.

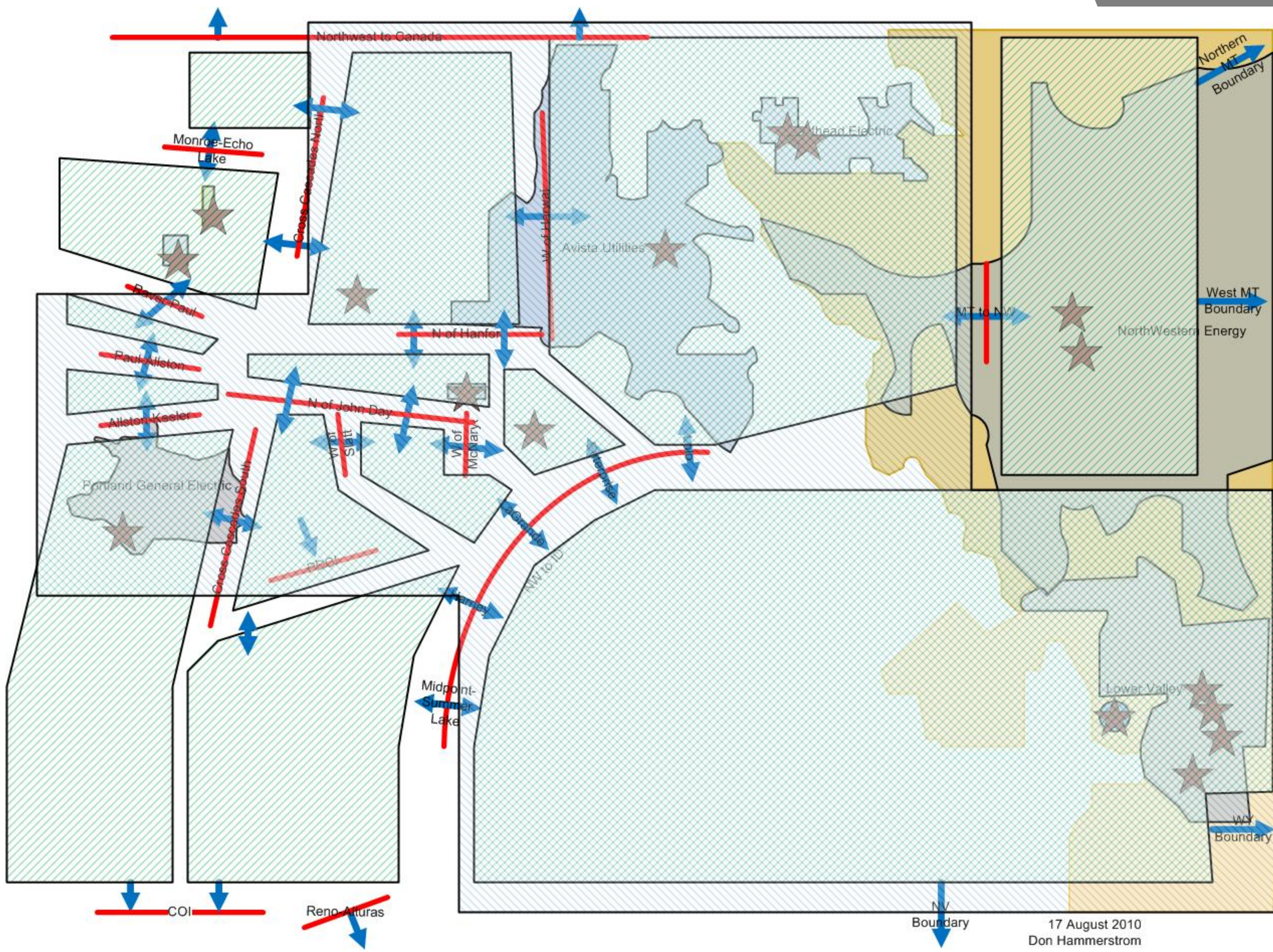


Implementation of Transactive Control in the Pacific Northwest Smart Grid Demonstration Project

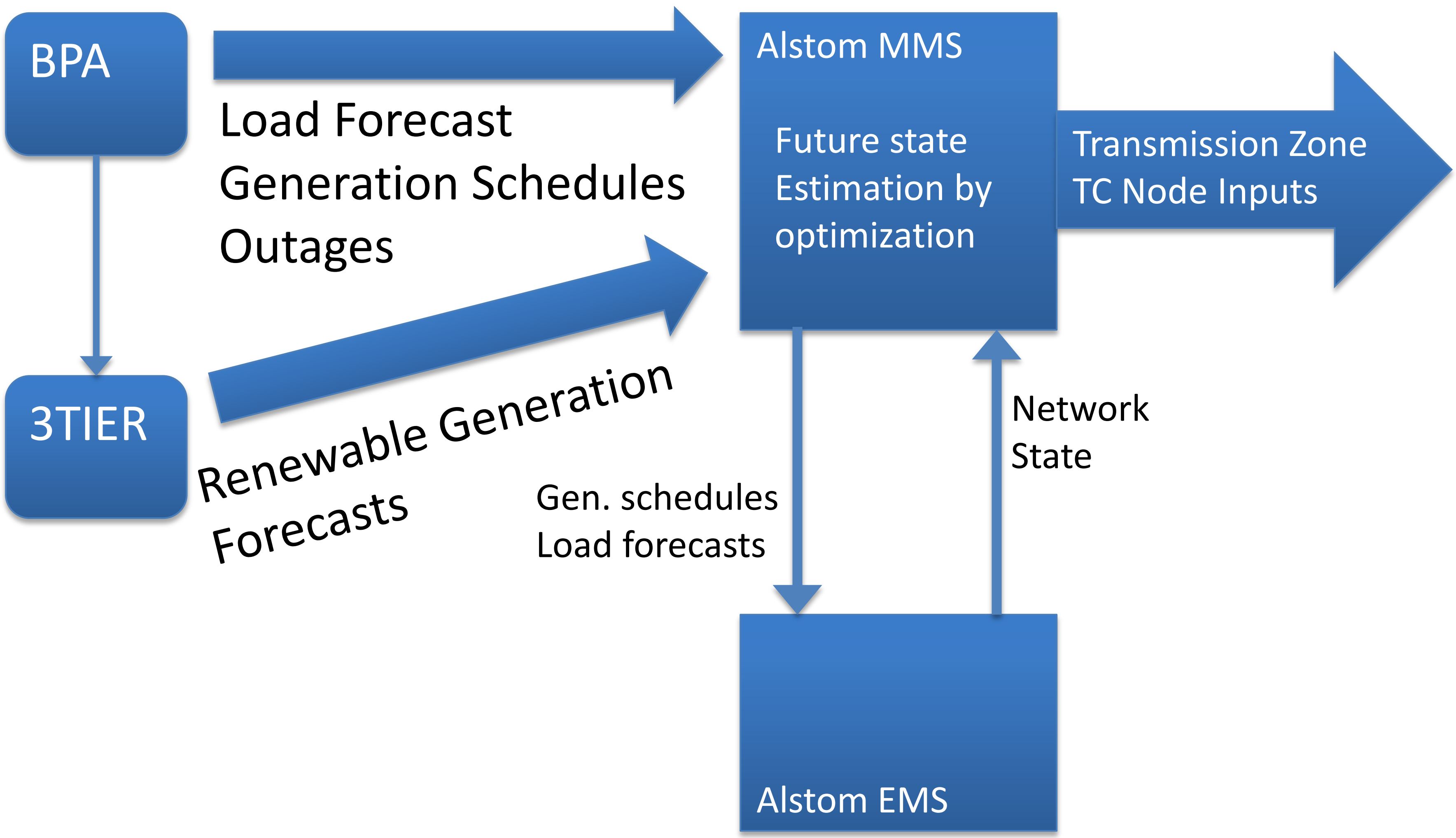
NW Region "Influence Map"--Topology

Cut Plane

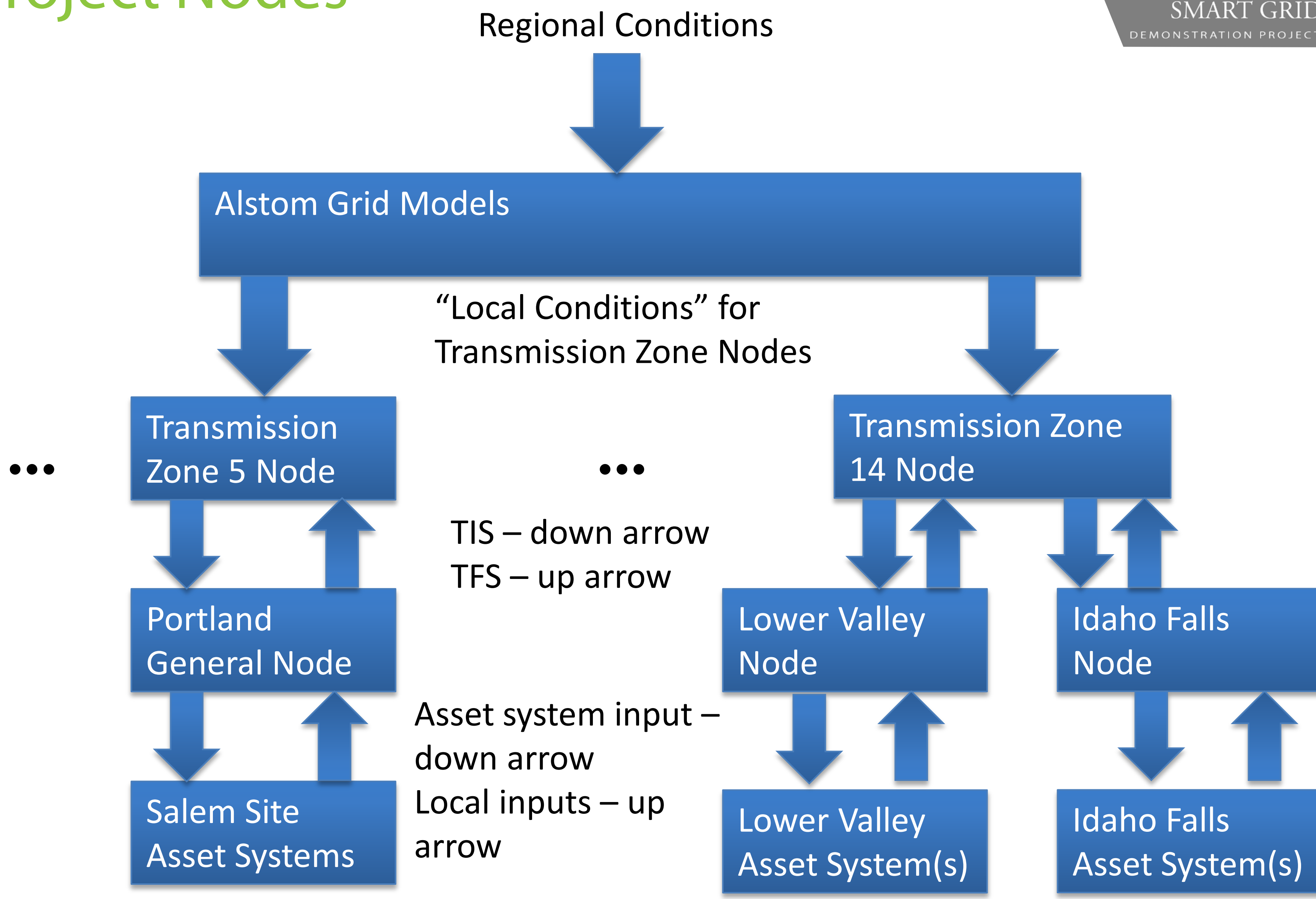
Flowgate



Regional Modeling



Project Nodes



Formalizing Transactive Control

- A formal model of transactive control has been designed with the following features:
  - Scalable
  - Algorithmic
  - Support for interoperability
- A standardized approach is being promoted through design and implementation of a toolkit
  - Well defined interfaces for utility asset systems
  - Simple, common, algorithms for updating transactive signals and determining "control" signals to responsive asset systems

Progress Towards Project Objectives

Project Objectives

Lay the foundation for a regional Smart Grid

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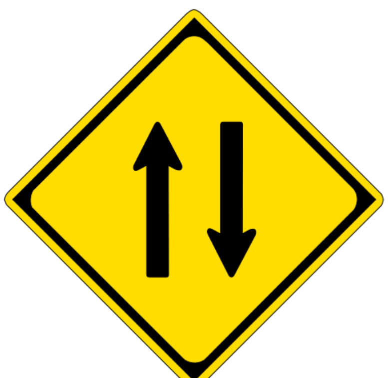
Measure and validate costs and benefits

Develop Standards for interoperable Smart Grid



Develop and validate two-way communication

Integrate renewable Energy

Subproject Test Case Summary

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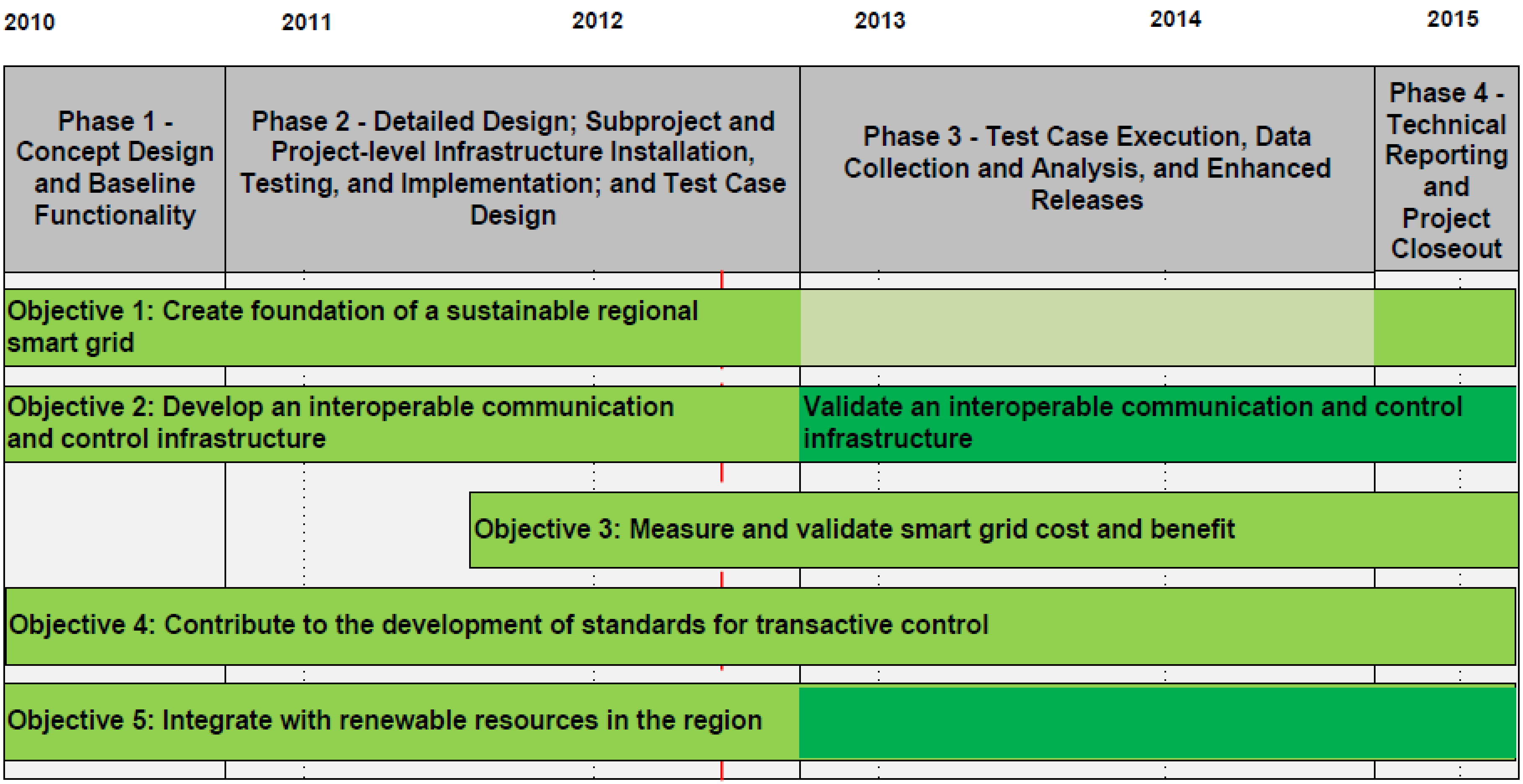
	Transactive Control	Reliability	Conservation /Efficiency	Social	Totals
Avista Utilities	4	3	5	3	15
Benton PUD	1	1	1	0	3
City of Ellensburg	1	0	8	0	9
Flathead Electric	6	2	0	0	8
Idaho Falls Power	8	2	3	3	16
Lower Valley Energy	3	2	6	1	12
Milton-Freewater	3	0	0	0	3
NorthWestern Energy	4	1	3	1	9
Peninsula Light	2	1	1	0	4
Portland General Electric	4	1	1	2	8
UW/Seattle City Light	5	0	3	0	8
Totals	41	13	31	10	95

Progress Towards Project Objectives



Summary – Project Benefits

- Opportunity to leverage smart grid assets installed by regional utilities using an innovative incentive structure
- Extend and validate the concepts demonstrated in Oly-Pen project
  - Flexible approach to integrating BPA's and Utilities' operational objectives and responsive resources
  - Standardized, interoperable approach to facilitate broad application
- Prove and refine the transactive approach
  - Gather regional cost-benefit information
  - Understand scale-up challenges and opportunities
- Continue the region's legacy of national leadership in power system innovation

2015 and beyond

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- At the end of the demo project:
  - ~ 100 Megawatts of distributed responsive assets engaged
  - Transactive control validated as a means of balancing intermittent renewable resources
  - Base of smart grid equipment installed at 11 utilities
- Beyond the demo project
  - Scale up to engage additional responsive assets
  - Transition from R&D to operations
  - Operationalize for balancing authorities (regional value)
  - Further deployment with energy service providers to enhance value to their operations (local value)

Acknowledgement & Disclaimer

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- "Annual Report"
- Quarterly newsletters
- Participant summaries
- Background on technology