Transactive Energy Systems and HEMS

Implementing Intelligent System Coordination

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Complex Systems

- Traffic Systems
- Ant Colonies
- Economies
- Flocks of Birds
- Ecosystems
- People
- Internet
- *Smart Grid*

Source: newmedialab.cuny.edu
**Smart Grid** is a Complex System

- The “system dynamics” are driven by complex interactions and feedback between **stakeholders and systems**.
- It is much more than just technology adoption…
Challenges

- Utility must integrate vastly different systems, programmatically
  - Residential + HEMS
  - Commercial Systems
  - Variety of hardware platforms, vendors, business models

- Must interact with existing infrastructure and constraints of operation, including distributed generation, renewables….

- 64% of utilities say the “**flexibility to adapt to new technologies is paramount for Smart Grid**”

  Source: Microsoft 2011 World Utility Survey
Future Challenges: Complexity and Computability

Complexity
- Interactions between systems can have unintended effects
- Systems interact with human behavior which changes unpredictably
- Difficult prediction, optimization

Computability
- Systems on the grid require integration with each other
- Moving from a few power plant options to millions of points of control with many states
- This is a computability problem
Improving the System
Nomenclature

- **Transactive Incentive Signal – TIS**
  - A series of “price” signals which is specific to a **NODE**
    - A Node is a location in the grid
      - A substation, or interconnect
      - A whole utility
      - Even a single home (not demonstrated or tested)
  - Corresponds to a 5 minute period in the future for energy in the first hour
  - 15 minute period for the next 5 hours
  - 1 hour period through the first day
  - 4 hour periods for the second day
  - 1 whole day for a third day

- **3 days of prices for forecasting responsive loads**
Nomenclature

- Transactive Feedback Signal – TFS
  - A series of “load” predictions based on the price signal
    - 5 minute periods in the future for energy in the first hour
    - 15 minute periods for the next 5 hours
    - 1 hour periods through the first day
    - 4 hour periods for the second day
    - 1 whole day average load for the third day
  - 3 days of load prediction with “elastic” response calculations added to the “inelastic” forecast
    - TFS = (Load – scheduled responsive systems)
TIS and TFS

- This is a new market model!!
- Normally, we exchange prices for prices in a market
  - Seller asking for 5$
  - Buyer bidding $4.50 in return
  - Continue….until an agreement is reached
- A transactive market exchanges price for *load* information
  - Seller announcement that the price is $5 per unit of volume
  - Buyer bidding a volume of goods at that price
    - I would use “this much” if that is the price…
  - In a market where the good cannot be stored (electricity), this allows for price adjustment in advance to expected to delivery constraints!
  - Can encourage / discourage demand
Transactive Control Example

Transactive Node: A location in an interconnect, a control area, a distribution micro-grid…or a HEMS!

Source: PNNL
Transactive Control Example

A low cost generation resource drives this and downstream locations' TIS lower

Source: PNNL
Transactive Control Example

More energy is consumed at affected locations. Trend is to receive more, export less energy.

Of course, the energy responses also have a feedback effect and moderate changes to the incentive signals.

Source: PNNL
Transactive Control Example

Suppose these changes threaten to overload a transmission or distribution corridor ...

Source: PNNL
Transactive Control Example

Again, the incentive signal reacts to, in this case, increase the incentive value on one side and diminish it on the other. The applied incentives again affect downstream locations.

Source: PNNL
Transactive Control Example

Responsive assets respond to the incentives and correct the congestion.

These few slide only begin to address the rich mix of incentives and responses that could simultaneously influence the grid under transactive control.

Source: PNNL
Node Structure

- **Nodes have signal processing**
  - Understanding *price information*
    - 72 hours into the future
  - Responsive *load information*
    - Predicted 72 hours into the future

- **Nodes have computational algorithms**
  - Explicitly scheduling smart-grid assets, optimally!
  - Use local and regional information
    - Weather
    - Grid conditions
    - Resource availability, dynamic resource / asset pricing
    - Program and resource constraints, regulatory and operational
Using AI for Smart Grid System Operations
Using AI in the Grid

- Marketing Operations wants to view Demand Response as a Virtual Power Plant (complex derivatives ok)
- In contrast, many program level applications use the linear least cost method
  - Next available dispatch = when price makes it available
- Complicated by costs of resources changing quickly as “opportunity” is used up, minute-to-minute
  - Penalties for over-use, missed opportunity for under-use
  - Dynamic grid conditions, changing upstream prices
- Every home is now a potential “virtual power plant” (!)

*The system is becoming more and more complex with mixed programs and variable energy resources.*
*Reliability remains the primary utility concern!*
Complex System Analysis in Smart Grids

- Scheduling horizons of resources **will be** mixed
  
  - Some resources may be used for hours, other resources for only minutes
  
  - Minimum run-times, maximum run-times, opt-out management, other time-critical concerns
  
  - After-the-fact constraints are non-trivial (cannot use a resource for a length of time after calling it)

- **Constraints on programs and resources can differ**, resulting in “products” (call and put options) that are difficult to gather and sort out (in a few minutes)
Intelligent Grid Scheduling using AI

- Concerns the integrated optimization of all available resources across the forecasting period and transactive node computation…

- Availability
- M & V
- Reliability

- Optimization
- Reliability
- Integration

- Scheduling
- Risk Mitigation
Benefits of Using AI

- An AI may be programmed to consider all constraints at once, across all time horizons, and optimize the mix for all available resources
- Electrical constraints may be included from the distribution grid layer, CA, or interconnect
  - Combines economic and electrical models
- Predictive systems may forecast loads, and heuristically calculate the most optimal mix of systems to produce the least cost
- Overcoming computability, complexity is achievable
PGE Smart Power℠ Initiative

Smart meters
- 820,000+ installed and operating

Smart Power℠
- Energy Partner Demand Response
- Distributed generation
- Renewable integration
- Utility energy storage
- Smart feeders/automatic switching
- High-reliability micro-grid
Where are we headed?

- Human history leans towards trust in systems control with less and less human intervention
  - 1950’s: manufacturing systems automation
  - 1960’s: telecommunications systems routing
  - 1970’s: neural networks (many applications)
  - 1980’s: PLCs, widespread use of the PC (many applications)
  - 1990’s: robotics, learning systems
  - 2000’s: Internet systems, complex systems simulation
- 2010’s: Smart-grid, Micro-grids, G2V - V2G, HEMS and smart appliances, grid automation, utility scale energy storage … more distributed systems… and learning machines!
Questions?

Thank you for your time

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