Integration of Distributed Energy Resources Using Transactive Control

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For further information go to www.smargrid.gov.
The electric power system is becoming more distributed

Transactions on the rise for megawatts and negawatts - DR

Growth of renewable generation - DER

Growth of sensor communication and control technologies – Machine-to-Machine and Internet of Things

Increasing penetration of microgrids – DER 2.0
The fundamental purpose of transactive control is to coordinate new distributed smart grid assets (demand response, distributed generation & storage), largely customer-owned, to reduce grid costs.

It will accomplish this by encouraging them to offer their flexibility to:
- Reduce need for costly balancing services required to keep today’s grid stable
- Mitigate the cost impacts of renewables on grid operations
  - at the bulk system level – ramping and balancing services
  - at distribution system level – voltage fluctuations
- Reduce peak loads to maximize asset utilization and minimize need for new capacity
- Reduce wholesale energy production/purchase costs from power plants.

It does this by:
- Seamlessly coordinating the combined effect of millions of such small assets with grid operations
- Respecting customer boundaries while offering an equitable share of the benefits as incentive for their flexibility
- Providing the smooth, stable, predictable response required by grid operators.
Pacific Northwest Smart Grid Demonstration Project

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

Why:
• Develop communications and control infrastructure using incentive signals to engage responsive assets
• Quantify costs and benefits
• Contribute to standards development
• Facilitate integration of wind and other renewables

Who:
Led by Battelle and partners including BPA, 11 utilities, 2 universities, and 5 vendors
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
An incentive signal

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

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
Consider the DER node in red:

- From its neighbors it is informed about future costs and future needs
- It knows its own state and costs
- It updates its plans based on the information from neighbors
- It shares its updated plans with neighbors
- They update as needed
- The process iterates – a form of “market closing” – to convergence
- The DER node is participating in a distributed market making locally optimal decisions about its actions
Functional Elements of a Node

- **Toolkit Functions, e.g., battery storage**
- **Local Interfaces**
- **External Interfaces**
- **Asset System, e.g. Battery**
- **Utility systems**

- **Transactive Feedback Signal**
- **Transactive Incentive Signal**

- Neighboring Nodes
DER Integration example – Battery Storage

- Considered as a load – but charge and discharge cycles are included. Discharge treated as “nega-watts”
- Function provides charge and discharge rate targets based on:
  - System’s power capacity
  - State-of-charge
  - Transactive control signals (historical and predicted)
  - Preferences set by asset owner that determine responsiveness (elasticity)
- All load or supply is considered to be elastic
- Battery system inefficiencies (e.g., losses and auxiliary loads) are ignored
Battery Storage Toolkit Function –
Inputs and Outputs

Inputs:
• TIS - Transactive Incentive Signal (a time series with predicted incentives)
• SOC1[kWh] – Current state of charge (just prior to the time of the first predicted incentive signal value)
• SOCmax[kWh] – Maximum state of charge allowed for the battery
• SOCmin[kWh] – Minimum state of charge allowed for the battery
• Pc[kW] – nameplate value for battery system rate of charge
• Pd[kW] – nameplate value for battery system discharge rate
• SM[dimensionless] – a parameterized “penalty” factor applied to abrupt changes in battery’s state-of-charge

Outputs:
• ΔL (Load)[kW] – a time series with predicted change in “load” for each future prediction interval
• ACS [dimensionless] advisory control signal to the battery system
Battery Storage Toolkit Function – Basic Logic

Predict the power consumed or supplied during each future prediction time interval (i.e., elastic load prediction) and determine charge / discharge actions to achieve maximum benefit from the predicted incentive values

1. Form a state vector $\mathbf{X}$ representing SOC for the current and future time intervals
2. Calculate $\Delta \mathbf{X}$ which will be equivalent to $\Delta \mathbf{L}$
3. The system is assumed to be governed by a linear state equation representing the physics of the system: $\Delta \mathbf{x} = A \mathbf{x} + b$

   $A$ and $b$ incorporate the physical constraints such as charge and discharge rates.

4. Define an augmented cost function that applies the incentive costs and maximize this function – in other words, seek to achieve the maximum benefit from the value of the predicted future incentives. If the incentive is lower than usual one should charge, if higher than usual one should discharge

Generate the control signal to the battery system based on the results of the above calculations
Battery Storage – data examples
Conclusions

- Diversity of resources in the electric power system is increasing with new approaches needed to integrate distributed energy resources
- Transactive control is one such approach offering the advantages of:
  - Coordination with the broader power system through exchange of transactive control signals with neighboring system elements
  - Maintenance of control of by the owner of the distributed asset
  - Alignment of values for the system operator(s) and the asset owners
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