Transactive Energy for Distributed Resource Integration

STEVE WIDEROGEN

Pacific Northwest National Laboratory
IEA Symposium on Demand Flexibility and RES Integration
Linz, Austria, 9 May 2016

PNNL-SA-117766
Our world is growing more complex faster than our control methods can handle

**Complex systems**

- Highly interconnected
- Heterogeneous device-human participation
- Extreme data
- Pervasive intelligence
- Autonomous decision-making
- Diverse and often competing objectives
Global energy goals cannot be met without changes in how we control complex systems

Energy systems offer
- Potential for substantial efficiencies in end-use systems with new controls
- More data and devices available

But
- New asset behaviors difficult to coordinate
- Existing controls antiquated to changes

Cyber-physical systems offer
- Growing “edge” computing resources
- Cloud computing scaling paradigm

But
- Existing security models challenged

Traditional centralized control approaches are a common weakness
Transactive Energy – an approach to responding to our changing world…

“A set of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.”

GridWise® Architecture Council, Transactive Energy Framework

- Use market mechanisms to perform distributed optimization
  - Reflect value in exchangeable terms (price)
  - Effectively allocate available resources and services in real-time
  - Provide incentive for investment on longer time horizon

- Use communications and automation of devices and systems as real-time agents for market interaction
  - Agents convey preferences and perform local control actions
  - Engage in one or more markets to trade for services, e.g.,
    - Real-time energy, peak-shaving
    - System reserves
Types of Smart Grid Coordination

- **Direct (Top-Down) Control**
  - Utility switches devices on/off remotely
  - No local information considered

- **Central Control/Optimization**
  - Optimization and control from a central point
  - Relevant local information must be communicated to central point

- **Price Reaction Control**
  - Prices signalled to customers and/or their automated devices
  - No communication of local information

- **Transactive Energy (TE)**
  - Automated devices engage in market interactions
  - Information exchange includes quantity (e.g., power, energy) and price

---

Slide produced with permission from Dr. Koen Kok, *The PowerMatcher Smart Coordination for the Smart Electricity Grid*, published by TNO, The Netherlands, 2013. [www.tinyurl.com/PowerMatcherBook](http://www.tinyurl.com/PowerMatcherBook)
## Smart Energy Management Matrix

<table>
<thead>
<tr>
<th>Decide local issues locally</th>
<th>Decide local issues centrally</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price Reaction</strong></td>
<td><strong>Transactive Energy</strong></td>
</tr>
<tr>
<td>↑ Full use of response potential</td>
<td>↑ Full use of response potential</td>
</tr>
<tr>
<td>↓ Uncertain system reaction</td>
<td>↑ Predictable system reaction</td>
</tr>
<tr>
<td>↓ Market inefficiency</td>
<td>↑ Efficient market</td>
</tr>
<tr>
<td>↑ Mitigates privacy issues</td>
<td>↑ Mitigates privacy issues</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Direct Control</strong></th>
<th><strong>Central Optimization</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>↓ Partial use of response potential</td>
<td>↑ Full use of response potential</td>
</tr>
<tr>
<td>↓ Uncertain system reaction</td>
<td>↑ Predictable system reaction</td>
</tr>
<tr>
<td>↓ Autonomy issues</td>
<td>↓ Privacy &amp; autonomy issues</td>
</tr>
<tr>
<td></td>
<td>↓ Scalability issues</td>
</tr>
</tbody>
</table>

**One-way communications**  
**Two-way communications**

---

*Slide produced with permission from Dr. Koen Kok, The PowerMatcher Smart Coordination for the Smart Electricity Grid, published by TNO, The Netherlands, 2013. [www.tinyurl.com/PowerMatcherBook]*
Transactive Grid Overview

1. Automated, price-responsive device controls express consumer’s flexibility (based on current needs)

2. Consumer system aggregates responses to form overall price flexibility curve

3. Service provider aggregates curves from all consumers

4. Aggregator determines price at which grid objective achieved, broadcasts to consumers

Price-Discovery Mechanism

Supply Limit

Aggregate Demand Curve (all consumers)

Load (kW)

Price ($/kWh)

Consumer Price-Flexibility Curve*

Load (kW)

Max Load

Base Load

Charge battery

Water heater

AC

Discharge battery

Price ($/kWh)

* Labels removed before sending to utility
<table>
<thead>
<tr>
<th>Highly automated, coordinated self-optimization</th>
<th>Provide non-discriminatory participation by qualified participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transacting parties are accountable for standards of performance</td>
<td>Observable and auditable at interfaces</td>
</tr>
<tr>
<td>Maintain system reliability and control while enabling optimal integration of distributed energy resources</td>
<td>Scalable, adaptable, and extensible across a number of devices, participants, and geographic extents</td>
</tr>
</tbody>
</table>

**Principles:** High-level requirements for TE systems that provide an additional point of reference for communicating with stakeholders and identifying common ground within the transactive energy community.

From GridWise Architecture Council’s Transactive Energy Framework  
[http://www.gridwiseac.org/about/transactive_energy.aspx](http://www.gridwiseac.org/about/transactive_energy.aspx)
Transactive Interaction Model

**Transactive Agent**
- Optimize local business objectives
- Register and qualify capabilities to participate in others’ programs
- Judge terms & qualifications of others
- Bid for services needed, evaluate & accept offers from supplier(s)
- Value offers for services it renders, evaluate & accept bids from buyers
- Implement control of local assets under purview according to agreement
- Deliver & receive products, rights, or service required by transaction
- Deliver & receive data, measurements & verification as required by transaction
- Execute financial settlement as required by transaction & reconcile performance differences

**Processes**
- Registration/Qualification
- Negotiation Process
- Operations Process*
- Measurement & Verification
- Settlement/Reconciliation

* E.g., operations signals or e-product exchange
Some US Transactive Energy Demonstrations

Olympic Peninsula demo, ca. 2006-07
► Established viability of transactive decision-making to coordinate multiple objectives
  ■ Peak load, distribution constraints, wholesale prices
  ■ Residential, commercial, & municipal water pumping loads, distributed generation

AEP gridSMART® demo, ca. 2010-2014
► PUC-approved real-time price tariff developed
  ■ Provides dynamic, real-time incentive to respond
  ■ Reflects real-time prices in PJM energy market
  ■ Manages AEP T&D constraints and peak load

Pacific NW Smart Grid demo, ca. 2010-2015
► Key advancements made by PNWSGD
  ■ Wind balancing
  ■ Developed look ahead signals
  ■ Standardized definition of transactive node and formalized agent testing
  ■ Showed how “old school” approaches (e.g., direct load control) can be integrated with a transactive schema
## PowerMatcher Demonstrations in Europe

<table>
<thead>
<tr>
<th>Project/Demo</th>
<th>Description</th>
<th>Results</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crisp field experiment</td>
<td>Flexibility sourced from industrial and household sites reacting to fluctuations in wind energy generation.</td>
<td>Electricity market related gain: wind imbalance reduction of 40%.</td>
<td>2005–2006</td>
</tr>
<tr>
<td>Microcogeneration field experiment</td>
<td>Flexibility from microcogeneration units at households used to perform peak-load reduction in a distribution grid.</td>
<td>Distribution grid peak-load-reduction of 30% (during summer) to 50% (during winter).</td>
<td>2006–2007</td>
</tr>
<tr>
<td>PowerMatching City</td>
<td>Demonstration of simultaneous optimization for energy trade and active distribution management. It included a value assessment of end user flexibility.</td>
<td>Based on the demo’s outcomes, the value of end user flexibility in The Netherlands may reach an estimated €3.5 billion (US$2.8 billion). The Netherlands has a population of 17 million people.</td>
<td>2009–2015</td>
</tr>
<tr>
<td>Smart-charging electrical vehicles (EVs)</td>
<td>A series of tests with smart-charging EVs coordinated using PowerMatcher, backed by large-scale simulation study (Grid4Vehicles project).</td>
<td>Active network management: distribution grid peak-load-reductions of 30–35%.</td>
<td>First EV test: about 2007; Grid4Vehicles simulation: 2010</td>
</tr>
<tr>
<td>SmartHouse/SmartGrid scalability field experiment</td>
<td>Scalability stress test of large-scale information communications technology (ICT) architecture connected to a cluster of real households.</td>
<td>Scalability beyond 1 million customers is feasible.</td>
<td>2010</td>
</tr>
<tr>
<td>EcoGrid EU demonstration</td>
<td>Large-scale demonstration of a novel real-time market involving 5-min electricity prices communicated to about 1,800 households, of which a subset ran PowerMatcher’s ICT architecture.</td>
<td>Large-scale roll-out experience for price-based and transactive smart grid technologies. Unleashed flexibility from a large number of heat pumps, making 20% of their power consumption shiftable in time.</td>
<td>2011–2015</td>
</tr>
<tr>
<td>Couperus</td>
<td>Approximately 300 apartments with heat pumps (HPs) involved in simultaneous optimization for energy trade and active distribution management.</td>
<td>Electricity market related gain: wind imbalance reduction of 80%. Active network management: proof of principle of locational-price based congestion management. Operation of HPs shiftable up to eight hours.</td>
<td>2011–2015</td>
</tr>
</tbody>
</table>

Thank you!

Steve Widergren
Pacific Northwest National Laboratory
steve.Widergren@pnnl.gov