Possibilities & Limitations of Extending the Wholesale / Bulk Power Transactive Techniques to Retail Markets & Distribution Operations

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What is Markets 3.0?

U.S. wholesale electricity markets are characterized by the following trends:

- **Need to manage new products**
  e.g., Demand Response, Variable Energy Resources, Microgrids, Self-Optimizing Customers & Energy Storage

- **Penetration of & coupling with retail resources**
  use of distributed generation and smart load resources from the industrial, commercial and residential sectors

Recent History

- FERC NOI & NOPR on VER Integration & Cost Allocation
- FERC Report on Demand Response & NOPR 745 on compensation
- FERC NOPR on Fast Regulation from Storage

**Markets 1.0**  
1995 - 2003
- Wholesale day ahead energy on hourly schedules
- Ancillary services
- Balancing and regulation
- Transmission rights

**Markets 2.0**  
2001 - 2010
- Co-optimized energy & ancillary services
- Congestion pricing
- Nodal real time dispatch
- Capacity markets for DR

**Markets 3.0**  
2011-2020
- Dynamic retail pricing
- DR for ancillary services
- Capacity markets for firming & DR
- Intra-hr scheduling of renewables
- Storage as a resource

Real-time wholesale markets meet retail resources
Integrating Distributed Energy Resources

• Early euphoria being subdued by challenge realization!
  – Visibility – no telemetry (AMI is NOT the solution!)
  – Control (Definitely NOT AMI; multiple technologies for each end use / resource
  – Grid Security - Backfeed, fault ride through, frequency response
  – Market Integration “estimated response” for settlements; estimating elasticity in market clearing

• DER Categories
  – Distributed Generation – PV, CHP, micro-wind
  – Distributed Storage
  – Dynamic Pricing – autonomous demand price elasticity
  – Dispatchable Demand Response
Integrating Demand Response: Key Research Questions

• What are the potential impacts of greater DR integration into the wholesale market?
  – What are the effects on real time markets prices & supply dispatch over time?
  – What are the conditions for preserving market convergence?

• Dispatchable Demand Response (DDR):
  – planned changes in consumption in response to direction from someone other than the customer
  – modeled as a supply resource dispatched similarly to generation

• Dynamic Pricing (DP) response:
  – customer decides whether and when to reduce consumption
  – modeled as a voluntary customer response to market prices

Categories of Distributed Energy Resources

- Distributed Energy Resources (DERs) include a variety of supply-side and demand-side resources. Those examined in this study include:
  - SOC – Self Optimizing Customers
  - DR – Demand Response (Including Autonomous Price Responsive Load (Dynamic Pricing))
  - DES – Distributed Energy Storage
  - DG – (PV – Distributed and “Behind-the-meter” PhotoVoltaics; CHP – Combined Heat and Power)
  - PEV – Plug in Electric Vehicles
Microgrid Resource Configuration

Resources Management for Microgrid

Customer Load
- Present information
- Forecast
- Variable Sources
- Present information

Real-time Power/Energy Management
- Utility level
  - Import/Export Power Control
- DER level
  - Dispatchable Sources Control
- Load level
  - Demand Response Control

Real-Time Monitoring
Real-Time Analysis
Real-Time Control

Source: Quanta
## Impacts by DER Type & Penetration

<table>
<thead>
<tr>
<th>DER Profile*</th>
<th>High DER (Max MW)</th>
<th>Mid DER (Max MW)</th>
<th>Low DER (Max MW)</th>
<th>Penetration Assumptions</th>
<th>Variability Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>7812</td>
<td>4757</td>
<td>1747</td>
<td>Scaled according to ISO scenarios for distributed PV</td>
<td>Clearness index and PV Technology. Based upon forecast errors calculated in LTPP High Load case.</td>
</tr>
<tr>
<td>CHP</td>
<td>4468</td>
<td>3092</td>
<td>1732</td>
<td>Based upon CEUS</td>
<td>Prices, temperature, conforming load</td>
</tr>
<tr>
<td>SOC</td>
<td>1277</td>
<td>806</td>
<td>337</td>
<td>Based upon CEUS</td>
<td>Prices, temperature, conforming load</td>
</tr>
<tr>
<td>PEV</td>
<td>-882</td>
<td>-662</td>
<td>-625</td>
<td>Based upon research by NREL</td>
<td>Commute time and traffic congestion</td>
</tr>
<tr>
<td>DES</td>
<td>-2808</td>
<td>-1920</td>
<td>-1033</td>
<td>Based upon CEUS</td>
<td>PV smoothing requirements and prices</td>
</tr>
<tr>
<td>DR</td>
<td>-2466</td>
<td>-1926</td>
<td>-1390</td>
<td>Based upon existing utility programs</td>
<td>Prices, load and temperature</td>
</tr>
</tbody>
</table>

High DER Penetration leads to forecast uncertainty and increased production costs.
Estimated Load Following & Regulation Requirements by Visibility Scenario

No Visibility Case

- Max Load Following Up: 5,079 MW
- Max Load Following Down: 5,683 MW
- Max Regulation Up: 1,084 MW
- Max Regulation Down: 760 MW

Visibility Case

- Max Load Following Up: 4,652 MW
- Max Load Following Down: 4,753 MW
- Max Regulation Up: 1,083 MW
- Max Regulation Down: 749 MW

Visibility provides a large reduction in the 95th percentile of Load Following requirements. Minimal Impact on Regulation.
B. Technical requirements for monitoring and control to achieve market and operational benefits

Device density and rate of change are the drivers for communications technology and costs
Communication Architectures

Various Stakeholders play in own time and density domain

Coverage / Availability Density

System Polling Time

1 min

Other/3rd-Party
Private Network

Utility DA
Private Network

5 min

Customer Internet

Public Carrier
Wireless

1 hour

Utility AMI
Private Network

Broadcast
Semi-Control Only
## Communications Architectures

<table>
<thead>
<tr>
<th>Ownership / Timeline</th>
<th>UTILITY</th>
<th>COMMON CARRIER</th>
<th>3rd Party</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>SCADA</td>
<td>Cellular GPRS</td>
<td>BAS Networks - larger commercial</td>
</tr>
<tr>
<td></td>
<td>AMI Mesh Networks</td>
<td>SMS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Broadcast Radio</td>
<td>Wi-Fi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internet POP / Ethernet/WiFi</td>
<td></td>
</tr>
<tr>
<td>Emerging</td>
<td>Distribution Automation</td>
<td>700 MHz</td>
<td>EV GPRS/ Wireless</td>
</tr>
<tr>
<td></td>
<td>AMI Mesh Networks</td>
<td>Cellular LTE</td>
<td>BAS penetration and Open ADR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wi-Fi public hot spots</td>
<td>DER maintenance via cellular / internet</td>
</tr>
<tr>
<td>2020</td>
<td>SCADA / DA on fiber / 700 MHz</td>
<td>Not Available</td>
<td>EV on next generation</td>
</tr>
<tr>
<td></td>
<td>not EOL for current AMI systems yet</td>
<td>next generation?</td>
<td>BAS ubiquitous in C&amp;I</td>
</tr>
<tr>
<td></td>
<td>migrated to other spectrum?</td>
<td>next evolution?</td>
<td>DER maintenance / ops via next generation</td>
</tr>
<tr>
<td>Pros</td>
<td>Low Latency NERC CIPS inherent for utility DER assets</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Ubiquitous and Low Cost Moderns Available</td>
<td>Ubiquitous and low costs already used for PV</td>
<td></td>
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<tr>
<td></td>
<td>Potential spectrum re-allocation to utility use.</td>
<td>Ubiquitous high performance new cellular standard</td>
<td></td>
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<tr>
<td></td>
<td>Ubiquitous and low costs already used for PV</td>
<td>low modern and nil data cost</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>ubiquitous and low modem / nil data cost</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Cons</td>
<td>Expensive / proprietary / not on LV</td>
<td>Obsolete and carriers will abandon 3-5 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Utility owned and controlled provisions for 3rd party access</td>
<td>higher modem costs and higher service impacts/costs for DER data</td>
<td></td>
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<tr>
<td></td>
<td>Ubiquitous but with spots of non-access only one way</td>
<td>not ubiquitous; security</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Utility owned and controlled provisions for 3rd party access</td>
<td>authentication and validation required possibly encryption</td>
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<td></td>
<td></td>
<td>proprietary and closed</td>
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<td></td>
<td>proprietary and closed</td>
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<tr>
<td>DER Applications</td>
<td>Utility scale PV and utility storage</td>
<td>Distributed PV Residential AC distributed storage</td>
<td></td>
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<tr>
<td></td>
<td>Rooftop PV; Residential HVAC; Distributed Storage</td>
<td>GPRS targets</td>
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<tr>
<td></td>
<td>small DR assets residential hot water and AC</td>
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<td></td>
<td>Unknown adoption in CA</td>
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<tr>
<td></td>
<td>Distributed PV Residential AC distributed storage</td>
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<tr>
<td></td>
<td>And DER near an Internet POP with WiFi access indoor esp</td>
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<tr>
<td></td>
<td></td>
<td>Any C&amp;I facility DER and most residential</td>
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<td></td>
<td></td>
<td>EV smart charging</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>commercial DER, all SOC, most CHP</td>
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<tr>
<td></td>
<td></td>
<td>distributed PV and distributed storage</td>
<td></td>
</tr>
</tbody>
</table>
C. What are the CAISO costs and expected benefits to increased DER visibility and control?

Benefits of monitoring and control are significant compared to the communication, monitoring, and forecasting infrastructure costs.
Price Elastic Load = Sequential

1. Market Measures / Forecasts Load
2. Market Clears the Supply Side Bids and Sets Prices
3. Load Reacts to Price
4. Repeat

- **Anecdote – UK in the 80’s (courtesy of Richard Tabors)**
  - *First UK Markets had industrial customers exposed to market prices*
  - *Customers would react to prices once set*
  - *Some price oscillations observed*
    - *Market did not take elasticity / behavior into account*

- **Anecdote – A 2013 Swedish study had similar findings (Sweco Energy Markets)**

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**Key to Understanding Behavior:**
- Price is a control signal
- Market clearing and the establishment of supply and demand curves are dynamic processes

**Economists are familiar with the iterative interaction between elastic supply & elastic demand:**

The “Cobweb Theorem” - Relative elasticities dictate convergence or divergence.

However, the Cobweb Theorem does not consider time dynamics.
Market Models

**Process Control Model**

*Simple market model based on control theory*
- captures generation & demand time dynamics

- Supply-demand imbalance is input to clearing function which adjusts price according to supply & demand elasticities.
- Feedback gain is inverse of sum of supply & demand elasticities. Delay equals periodicity of market clearing function.
- Critical parameters: price elasticity ratios, time delay ratios; demand elasticity error

**System Dynamics Model**

*Detailed dynamic model of a market operation using system dynamics*

- Non-linear supply curves representative of a real market and non-linear demand curves based on published demand elasticity research.
- Integrates day ahead, hour ahead, and real time energy market processes.
- Includes residential and commercial end-uses (HVAC, lighting, water heating, refrigeration).
- Does not predict price but captures market dynamics
Control Theory Modeling Results

Under some scenarios of DR integration, the markets can become unstable.

- A simple example considers how the dynamic response of generation, demand, and market operations affect market stability over ranges of relative supply and demand elasticity.
- In this case, the market misestimates demand elasticity (i.e., 100% error).
- Where generation is less elastic than demand, the system goes unstable.

There are scenarios for which the overall system will not be stable when the market misestimating demand elasticity (i.e., 100% error). Misestimating elasticity is akin to operating the market as it is operated today.
The Real World is MUCH MORE Complex

• Multiple Markets – Day Ahead, Hour Ahead, Real Time
• Multiple Supply Resources with Different Time Dynamics
• Multiple Load Side Elements
• More Complex Load Side Behaviors
• Non-linear / Time Varying Elasticities
First Key Observation

Market impacts depend on: penetration, timing of price signals, and relative duration of DP compared to the frequency of the market dispatch & price publication.

At scaled up penetration, DP response becomes unstable as shown when the duration is 60 min. Added to information latencies, this means the market is clearing for load that responded to the prior period price but is not aware of that effect.

DP responding to an hourly price signal with a 60 min duration affects RTD prices but 20 min durations do not.
Second Key Observation

DP impacts are very sensitive to DP penetration, demand elasticity, and the accuracy of estimated demand elasticity in the market clearing algorithms.

As the amount of responsive DP in the market increases, price potentially increases and can grow to be volatile.

As the amounts of viable DP in the market grow, load oscillations grow. Increased “penetration” of DP in effect increases the ratio of demand elasticity to supply elasticity and increases instability.
Thinking about ISOs, DSOs & MGOs

Wholesale Markets
- Registration
- Bidding
- Market Clearing
- Notification
- Measurement & Validation
- Settlements

Demand Side Aggregators

Wholesale Takeout Point

Suppliers

DSO

Microgrids
# The Devil is in the Details

## Rules of the Game
- Can one entity have multiple roles?
  - Direct access; DSO resource; MGO

## Bi-lateral Transactions & “Open Access Distribution” (OADIS)
- Some microgrid operators will have multiple sites on different takeout points (e.g., DOD)

## Settlements
- What constitutes a revenue meter?
  - e.g., EV and chargers have meters and comms; why duplicate?

## Validation
- The inevitable DR “what would it have been?” question

## Market Co-ordination
- Timing of bidding closure, market clearing, notification across layers
Gaps in Understanding

• Information Arbitrage
  – Interaction of DSO and ISO markets in time and opportunity to influence pricing
  – Stability of Market Behavior with layered clearing processes
    • Interaction of gate closures, processing time, notification, participant decision making

• Business Models for New Resources in Markets
Business Models – Example - Storage

• Storage as a Generator
  – Must separately bid discharging and charging and take risks of not clearing / duplicate clearing

• Storage co-optimized by market operator
  – Basis of bidding? Paid clearing price like a generator?
    – New asset class offering storage services?

• Hybrid: Storage as a (regulated) asset class and 3rd parties “own” energy in storage
And – Reliability Issues

• Today DG MUST disconnect on grid low voltage for safety reasons

• At high penetrations this can cause grid level event “magnification”
  – Routine cleared line fault becomes loss of 000’s MW of PV

• So Fault Ride through, low voltage ride through standards needed

• And – rules on “pre-emptive disconnect”
Conclusions

• If We Want to Use Price as a Control Signal
  – Better do the Control Systems Design
  – Artificial Volatility is NOT a Good Thing

• The More Complex the Market Design – the More Opportunities for “Strategic Bidding” and Unexpected Outcomes