Electricity Market Design

Peter Cramton

University of Cologne and University of Maryland

www.cramton.umd.edu

1 February 2018
Goal of electricity markets: Reliable electricity at least cost

• Short-run efficiency
  – Least-cost operation of existing resources
• Long-run efficiency
  – Right quantity and mix of resources
Challenges of electricity markets

• Must balance supply and demand *at every instant*
• Physical constraints of network and resources
• Shocks in supply
  – Transmission line or generator outage
  – Intermittent resources: wind and solar
• Absence of demand response
• Climate policy
Climate policy

• Transformation to renewable

• Germany
  – Replace nuclear with renewable
  – 80% renewable (mostly wind) by 2050
  – Significant probability of multiple days with wind in-feed less than 5% of capacity
  – Must back-up wind with peaker capacity
  – Require additional 30 GW of peakers by 2030
  – How to get this built?
Market evolution

• Monopoly utility
  – Rate of return regulation

• Power pool
  – Trade among neighboring utilities

• Wholesale market
  – Unbundled generation, transmission, distribution
  – Fully integrated market with efficient trade and pricing
  – Retail competition
A successful market design

• Get the spot market right
  – Day ahead
    • Scheduling and unit commitment
  – Real time
    • Bid-based security constrained economic dispatch

• Forward trade to manage risk and support long-run investment
Day-ahead market

- Unit commitment and scheduling
  - Energy and ancillary services each hour of day
  - Prices for energy and reserves; financially binding
- Three-part offers from resources
  - Startup cost
  - Minimum-energy cost
  - Energy offer curve
- Virtual offers and bids
  - Arbitrage day-ahead and real-time markets
- Objective: maximize social welfare
  s.t. transmission and resource constraints
  - Co-optimized energy and reserves
  - Competitive equilibrium with locational marginal prices
  - LMP = marginal value of energy at each location
Day-ahead market

• Handling non-convexities, such as startup and minimum energy costs
  – If total cost of unit not covered by energy & reserve revenue, then unit gets make-whole payment for shortfall
  – Make-whole payments small in practice
  – LMPs are approximate supporting prices

• Procompetitive
  – Allows small generators to optimally schedule
  – Allows small participants to hedge real-time risk
All figures ERCOT (Texas) 2016

Convergence Between Day-Ahead and Real-Time Energy Prices

<table>
<thead>
<tr>
<th>Year</th>
<th>Day-Ahead Price</th>
<th>Real-Time Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>$46</td>
<td>$43</td>
</tr>
<tr>
<td>2012</td>
<td>$29</td>
<td>$27</td>
</tr>
<tr>
<td>2013</td>
<td>$33</td>
<td>$32</td>
</tr>
<tr>
<td>2014</td>
<td>$40</td>
<td>$38</td>
</tr>
<tr>
<td>2015</td>
<td>$26</td>
<td>$25</td>
</tr>
</tbody>
</table>

Source: Potomac Economics
Volume of Day-Ahead Market Activity by Month

- Energy Only Awards
- Three Part Awards
- Day-Ahead Purchase
- Real-Time Load
- Net System Flow

Source: Potomac Economics
Figure 28: Volume of Day-Ahead Market Activity by Hour

Source: Potomac Economics
Operating plan and adjustment period

• Generator submits operating plan for each resource
  – Online/offline, constraints
• Until 60 minutes before operating hour, plan can be adjusted
• System operator may commit additional resources for reliability, but these have a high offer floor ($1500/MWh)
Real-time market

• Security constrained economic dispatch
• Determines optimal dispatch and prices every five minutes
• Financially and physically binding
• Allows efficient settlement from forward positions
Pivotal Supplier Frequency by Load Level

Source: Potomac Economics
Figure 23: Mitigated Capacity by Load Level

Source: Potomac Economics
Incremental Output Gap by Load Level and Participant Size – Step 2

Source: Potomac Economics
Figure 6: ERCOT Price Duration Curve

<table>
<thead>
<tr>
<th>Frequency of Hours</th>
<th>&gt; $0</th>
<th>&gt; $50</th>
<th>&gt; $100</th>
<th>&gt; $200</th>
<th>&gt; $300</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>8,756</td>
<td>792</td>
<td>219</td>
<td>124</td>
<td>89</td>
</tr>
<tr>
<td>2012</td>
<td>8,780</td>
<td>287</td>
<td>93</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>2013</td>
<td>8,757</td>
<td>424</td>
<td>104</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>2014</td>
<td>8,716</td>
<td>898</td>
<td>199</td>
<td>63</td>
<td>34</td>
</tr>
<tr>
<td>2015</td>
<td>8,705</td>
<td>254</td>
<td>88</td>
<td>40</td>
<td>21</td>
</tr>
</tbody>
</table>

Source: Potomac Economics
Figure 14: Aggregated Generation Offer Stack – Annual

Source: Potomac Economics
Ancillary services

Address supply/demand uncertainty:

• Regulation: online, responds in second
  – Reg up, Reg down to maintain frequency of 60 Hz

• Responsive reserve: online, 10min response

• Non-spinning reserve: offline, 30min response

*Need for reserves depends on market; products and quantities reviewed periodically*
Ancillary Service Prices

Annual Ancillary Prices ($ per MWh)
- Responsive Reserve: 10.87
- Nonspun Reserve: 6.92
- Regulation Up: 10.59
- Regulation Down: 6.01

Source: Potomac Economics
Ancillary Service Costs per MWh of Load

Source: Potomac Economics
Scarcity pricing

• Reserves have value in avoiding load shedding
• Marginal value of reserves depends on
  – Value of Lost Load, e.g. $9000/MWh
  – Probability of Lost Load, e.g. 1 in extreme scarcity
• Load’s implicit preference for reliability given by operating reserve demand curve
Operating reserve demand curve

![Graph showing the operating reserve demand curve with VOLL at a fixed price level and availability reserves ranging from 0 to 8000 MWs.](image-url)
Forward contracts

- Forward contracts are essential to manage risk
  - California energy crisis 2000-2001
  - Forward provides hedge for load
  - Generator + fuel contract provides physical hedge for supply

- Scarcity pricing motivates forward contracts
- Forward contracting improves bidding incentives
- Congestion revenue rights are forwards in congestion rents
Capacity market

• ERCOT is “energy only”; some others have a capacity market (PJM, ISO-NE, …)
• Good capacity markets rely on scarcity pricing, just like energy only market
• Buy enough in advance
  – Conducted several years in advance, so new entry can compete before costs are sunk
  – Product is ability to deliver energy during scarcity
  – Strong performance obligation
    • Financial obligation to provide energy during scarcity
    • Provides hedge to load from scarcity prices
  – Coordinated investment to ensure adequate resources
Figure 5: Comparison of All-in Prices Across Markets

Source: Potomac Economics
Combustion Turbine Net Revenues

Source: Potomac Economics
Projected Reserve Margins

Source: ERCOT Capacity Demand Reserve Reports / 2016 from December 2015 and 2017-2021 from May 2016
# Generation Weighted Prices - 2016

<table>
<thead>
<tr>
<th>Technology</th>
<th>$ / MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Cycle (GT&gt;90MW)</td>
<td>24.6</td>
</tr>
<tr>
<td>Coal / Lignite</td>
<td>24.0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>21.5</td>
</tr>
<tr>
<td>Wind</td>
<td>16.2</td>
</tr>
<tr>
<td>Solar PV</td>
<td>32.0</td>
</tr>
<tr>
<td>Gas Steam</td>
<td>35.1 – 53.5</td>
</tr>
</tbody>
</table>

Source: Potomac Economics
Regional differences

• Most of Europe
  – Day-ahead power exchange (but not co-optimization of energy and reserves)
  – Intraday exchange trading (continuous)
  – Voluntary balancing market in real time
  – Transmission congestion not efficiently priced
  – Absence of tight integration
  – Evolved from Norway; works well in hydro-dominated system with lots of flexible resources
Regional differences

• Brazil
  – Poor, rapid growth, hydro-dominated with rare but long periods of shortage (extreme dry season)
  – Need lots of rarely used fossil resources
  – Central procurement of long-term power purchase agreements
  – Day-ahead and real-time centrally optimized as in US but cost-based bids including modeled hydro opportunity cost

• Colombia
  – Bid-based day-ahead and real-time markets
  – Firm energy market to coordinate investment
Transformation to renewable

• Wind and solar expected to dominate
  – Last year 60% of new capacity in US is wind and solar; coal hasn’t been built in years
  – Intermittent supply, zero marginal cost, no inertia
    • More uncertainty, worse price formation, faster response needed
    • Also best sites not where load is; transmission issues
  – Today’s design easily handles moderate share of wind
Solution looking forward

• But what if >80% renewable
• Core design still works well
• Battery storage and more demand response (smart homes) will complement wind, solar
  – Flexible, smooth prices

Need to encourage technology-neutral solutions!
Incoherent and unstable climate policy

- Policy built on myriad of changing subsidies and emission restrictions makes planning difficult
- Uncertainty harms investment
- Policy based on carbon price would greatly reduce uncertainty
- Carbon price is a critical input in investment and retirement decision
Conclusion

• Electricity good example of the power of market design
  – Highly efficient spot market
  – Supporting extensive forward contracting
  – Competitive retail market to foster demand response

• Good governance remains important to make sure market design continues to improve and addresses new challenges like the transition to renewables