ELECTRICITY MARKET DESIGN AND THE GREEN AGENDA

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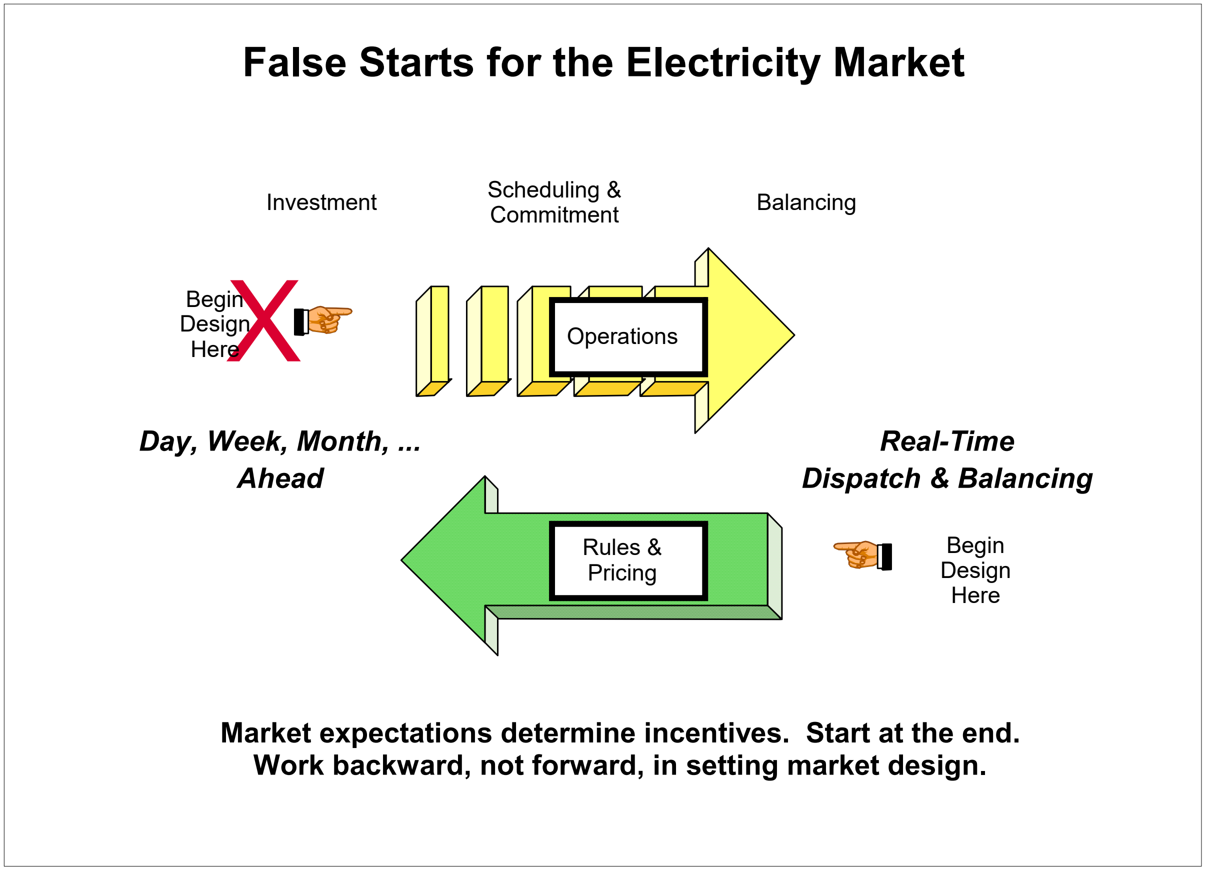
A core challenge for all electricity systems is between monopoly provision and market operations. Electricity market design depends on critical choices. There is no escape from the fundamentals.

Integrated Monopoly	Competitive Markets
• Mandated	• Voluntary
• Closed Access	• Open Access
• Discrimination	• Non-discrimination
• Central Planning	• Independent Investment
• Few Choices	• Many Choices
• Spending Other People's Money	• Spending Your Own Money
• Average Cost Pricing	• Marginal Cost Pricing

A Key Market Design Objective

Supporting the Solution: Given the prices and settlement payments, individual optimal behavior is consistent with the aggregate optimal solution.

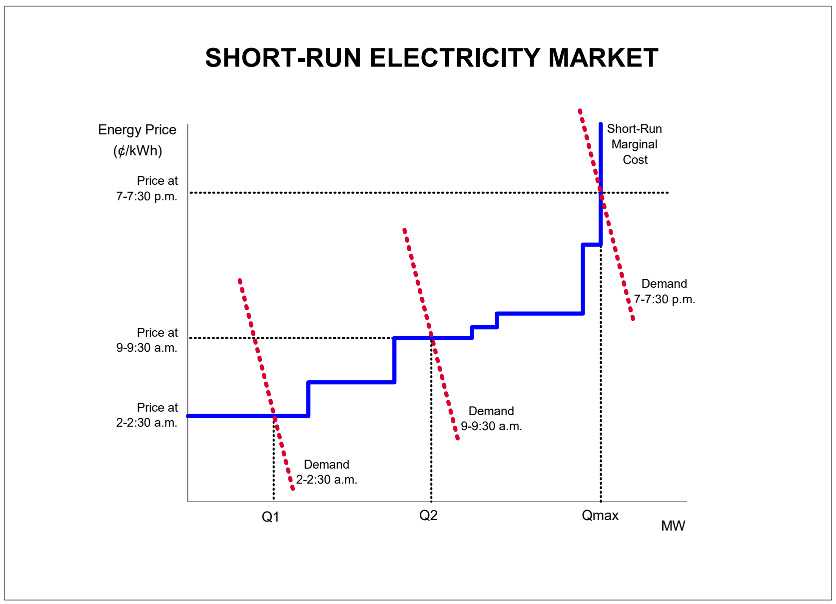
The solution to open access and non-discrimination inherently involves market design. Good design begins with the real-time market and works backward. A common failure mode starts with the forward market, without specifying the rules and prices that would apply in real time.

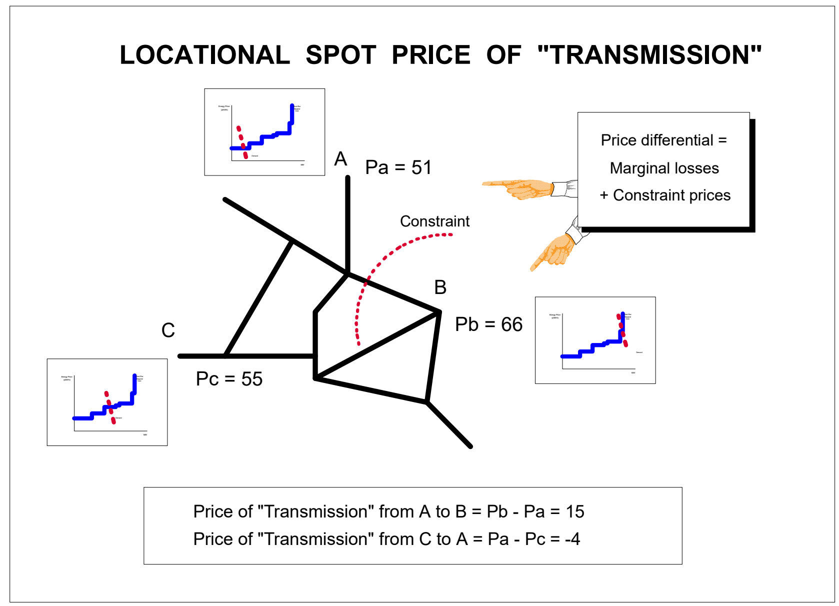


All energy delivery takes place in the real-time market. Market participants will anticipate and make forward decisions based on expectations about real-time prices.

- **Real-Time Prices:** In a market where participants have discretion, the most important prices are those in real-time. "Despite the fact that quantities traded in the balancing markets are generally small, the prevailing balancing prices, or real-time prices, may have a strong impact on prices in the wholesale electricity markets. … No generator would want to sell on the wholesale market at a price lower than the expected real-time price, and no consumer would want to buy on the wholesale market at a price higher than the expected real-time price. As a consequence, any distortions in the real-time prices may filter through to the wholesale electricity prices." (Cervigni & Perekhodtsev, 2013)
- **Day-Ahead Prices:** Commitment decisions made day-ahead will be affected by the design of day-ahead pricing rules, but the energy component of day-ahead prices will be dominated by expectations about real-time prices.
- **Forward Prices:** Forward prices will look ahead to the real-time and day-ahead markets. Although forward prices are developed in advance, the last prices in real-time will drive the system.
- **Getting the Prices Right:** The last should be first. The most important focus should be on the models for real-time prices. Only after everything that can be done has been done, would it make sense to focus on out-of-market payments and forward market rules.

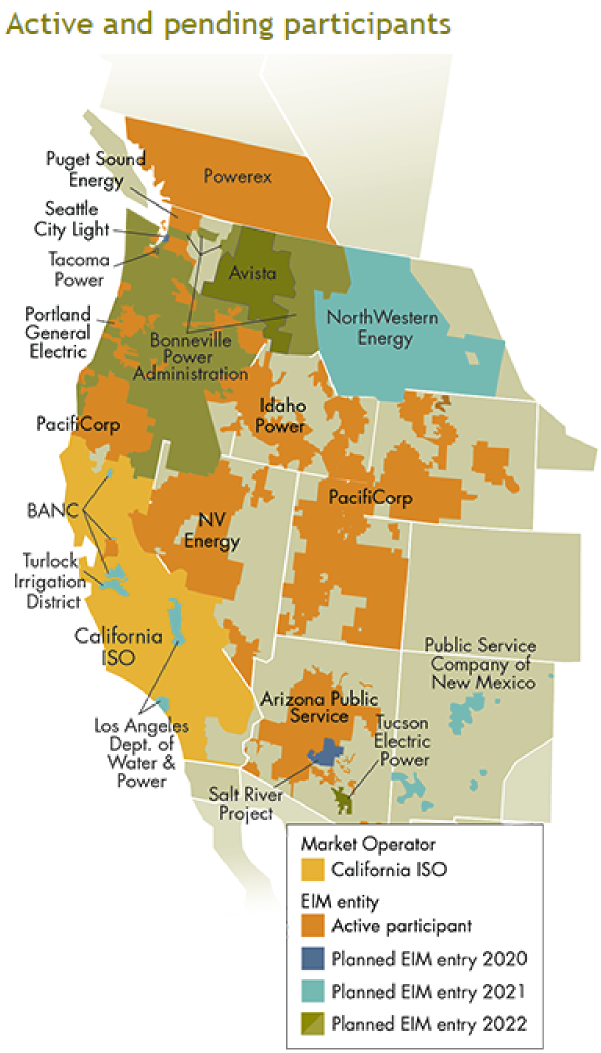
An efficient short-run electricity market determines a market clearing price based on conditions of supply and demand balanced in an economic dispatch. Everyone pays or is paid the same price. The same principles apply in an electric network. (Schweppe, Caramanis, Tabors, & Bohn, 1988)

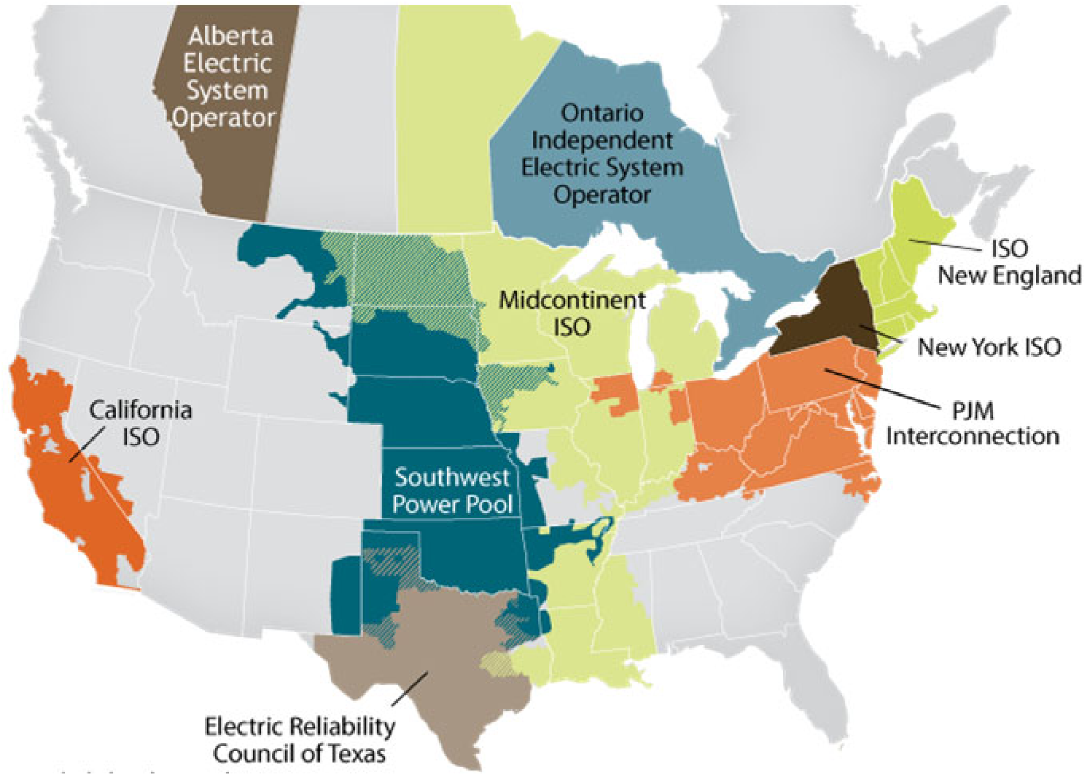




The basic model covers the existing Regional Transmission Organizations in the United States and is expanding through the Western Energy Imbalance Market. (www.westerneim.com)

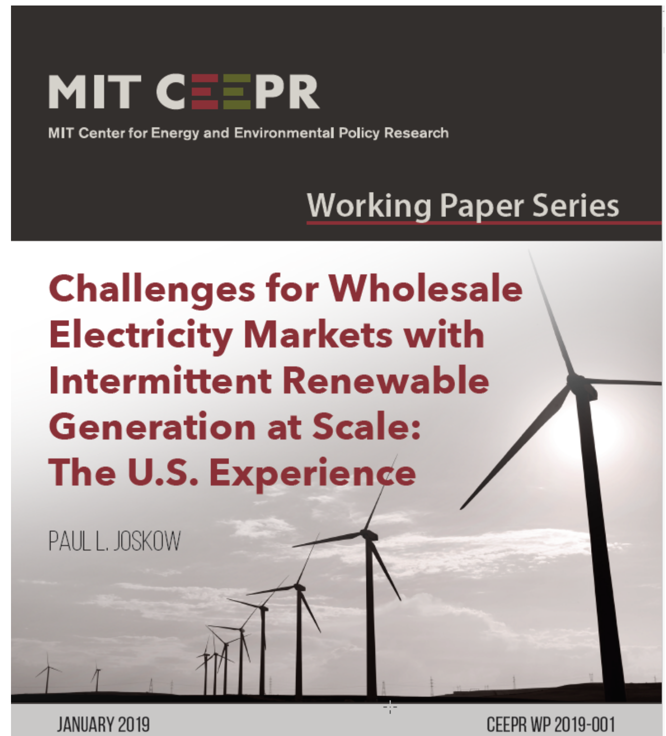
(IRC Council and CAISO maps)



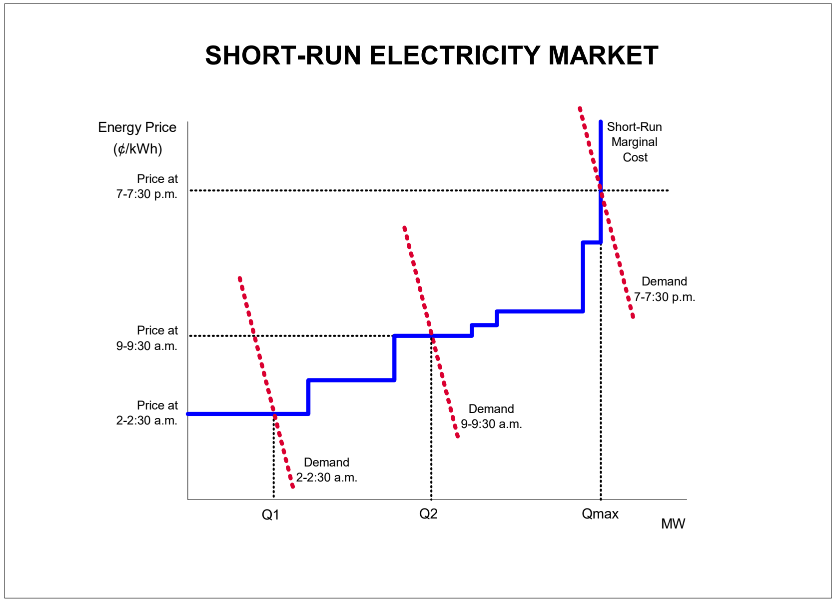


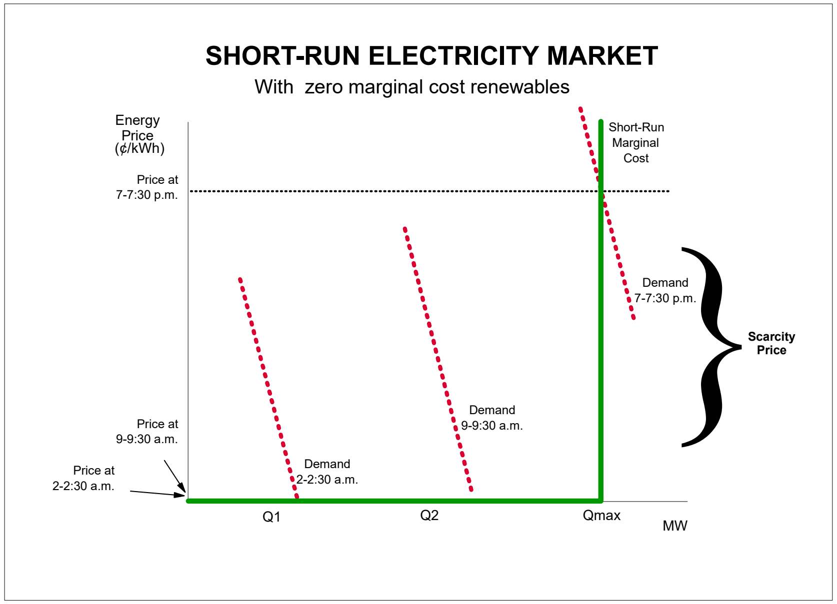
The expansion of intermittent sources and the rise in special subsidies is seen as a threat to efficient electricity market design.

“The supply of intermittent wind and solar generation with zero marginal operating cost is increasingly rapidly in the U.S. These changes are creating challenges for wholesale markets in two dimensions. Short term energy and ancillary services markets, built upon mid-20th century models of optimal pricing and investment, which now work reasonably well, must accommodate the supply variability and energy market price impacts associated with intermittent generation at scale. These developments raise more profound questions about whether the current market designs can be adapted to provide good long-term price signals to support investment in an efficient portfolio of generating capacity and storage consistent with public policy goals. … Reforms in capacity markets and ***scarcity pricing mechanisms*** are needed if policymakers seek to adapt the traditional wholesale market designs to accommodate intermittent generation at scale. However, if the rapid growth of integrated resource planning, subsidies for some technologies but not others, mandated long term contracts, and other expansions of state regulation continues, more fundamental changes are likely to be required in the institutions that determine generator and storage entry and exit decisions.” (Joskow, 2019) (emphasis added)



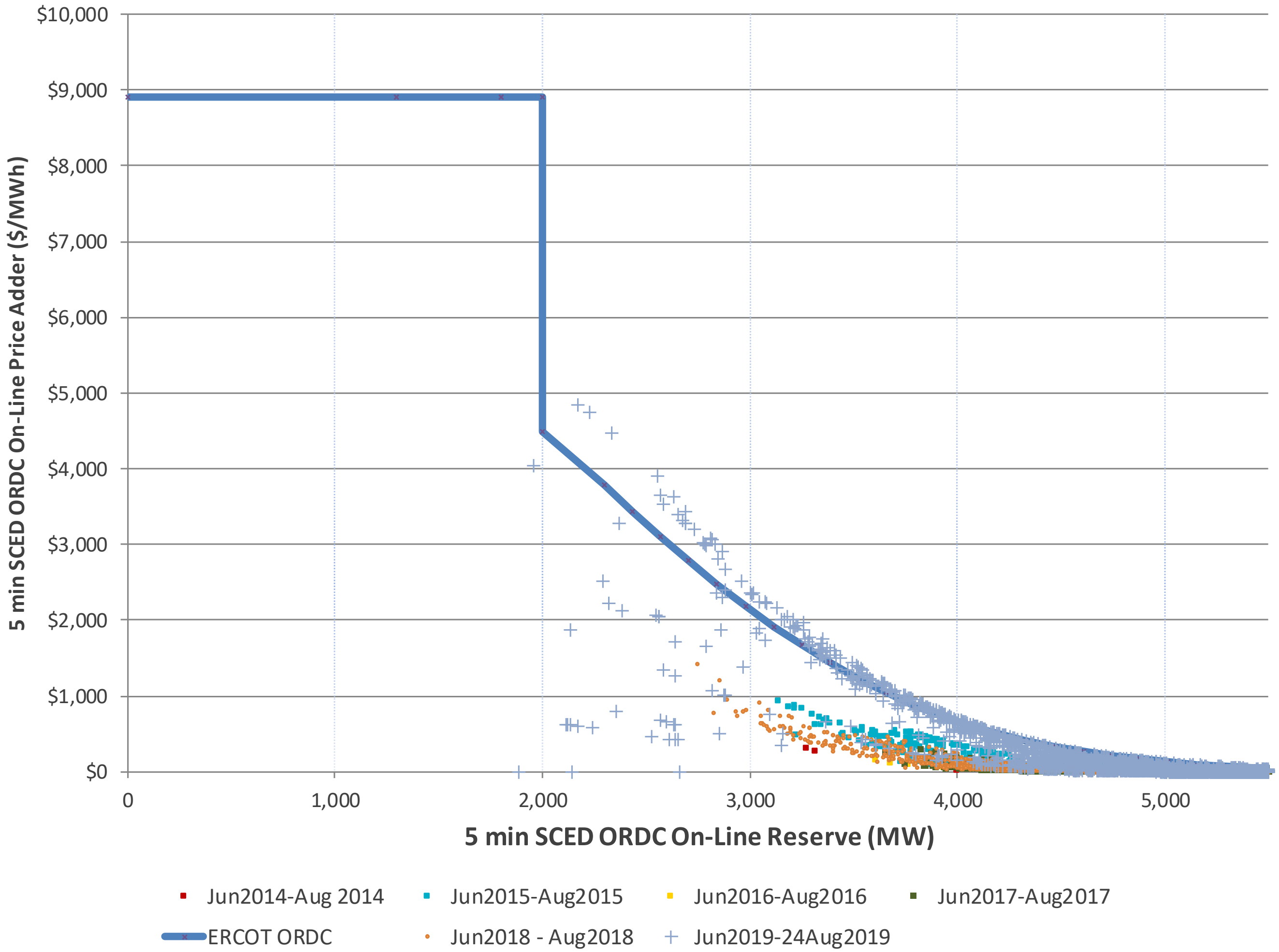
An efficient short-run electricity market determines a market clearing price based on conditions of supply and demand balanced in an economic dispatch. Everyone pays or is paid the same price. The thought experiment of a no-carbon/zero-variable-cost, green energy supply reveals that the basic efficiency principles still apply. The same principles apply in an electric network. (Schweppe et al., 1988) **Storage will be important, but does not change the basic design analysis.** (Korpås & Botterud, 2020)





A key feature would be to increase the importance of scarcity pricing. ERCOT adopted an Operating Reserve Demand Curve in 2014. (Hogan, 2013) **PJM has proposed a series of reforms for energy price formation, motivated in part by the impact of increased penetration of intermittent renewable resources.** (PJM Interconnection, 2017) (PJM Interconnection, 2019) (Federal Energy Regulatory Commission, 2020b)

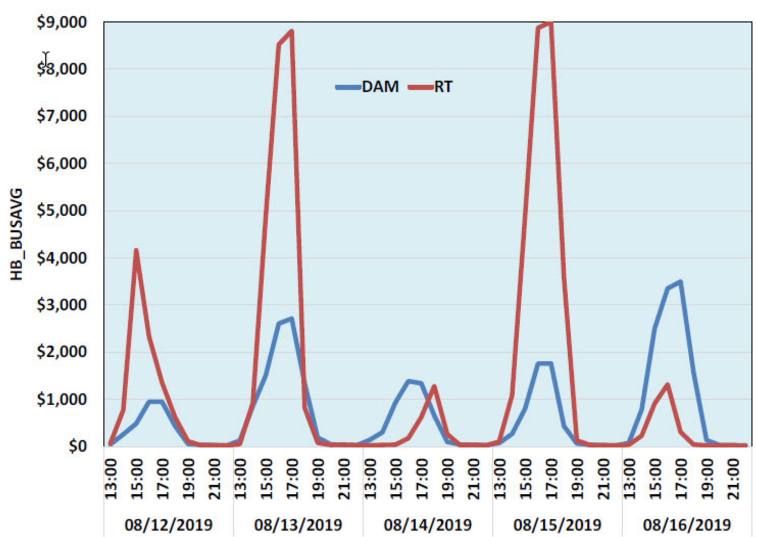
ERCOT launched implementation of the ORDC in in 2014. The summer peak is the most important period. The first five years of results show recent scarcity of reserves and higher reserve prices.



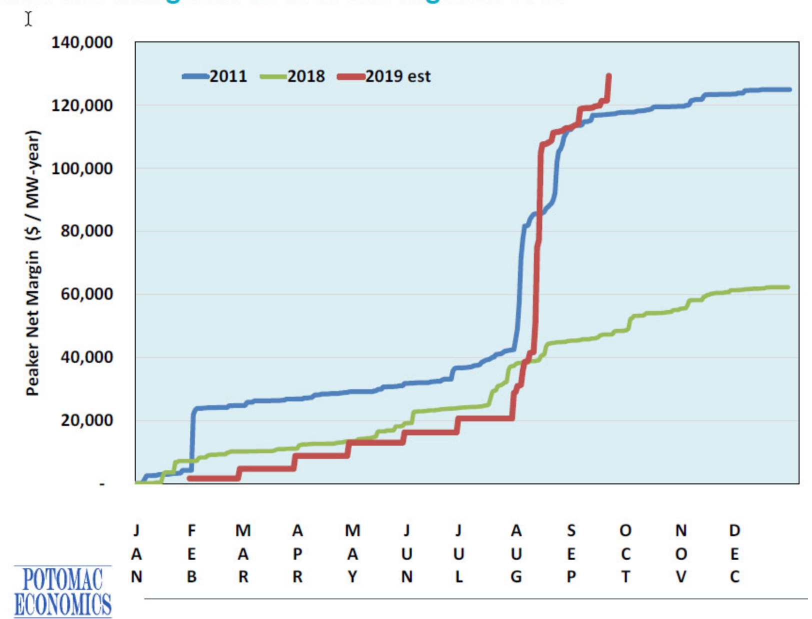
Source: Resmi Surendran, ERCOT, EUCI Presentation, Updated 8/31/2019. The ORDC is illustrative. See also (Hogan & Pope, 2017)

After introduction of the ORDC scarcity prices and the contribution to Peaker Net Margin were low for several years, but this changed in 2019.[1] The PNM target level is $80,000-$95,000/MW-Yr.
(Potomac Economics, 2019, p. 112)

Day Ahead vs Real-Time Prices



Peaker net margin in 2019 is the highest ever



1 Beth Garza, "Independent Market Monitor Report," Potomac Economics, ERCOT Board of Directors Meeting Presentation, October 8, 2019.

An ERCOT review of the Summer of 2019 underscored that scarcity pricing was consistent with performance of the system.[2]

Key Observations for Summer 2019

- Early summer was mild, and August was very hot (September was also above normal).
- There were many days with tight conditions, and an Energy Emergency Alert (EEA) Level 1 was declared twice.
  - Emergency Response Service (ERS) deployments prevented the need for EEA2.
- Peak demand day saw higher Intermittent Renewable Resource (IRR) production.
  - As a result, it was not one of the highest-priced days, and there was no EEA.
- Tightest conditions frequently occurred earlier than time of peak demand.
- Resource performance continues to outpace historical patterns.
- Overall, the market outcomes supported reliability needs.
- Even with significant pricing events, there were no mass transitions.

Notably, high prices occurred at the right time, and were not socialized through capacity market charges spread over all load.

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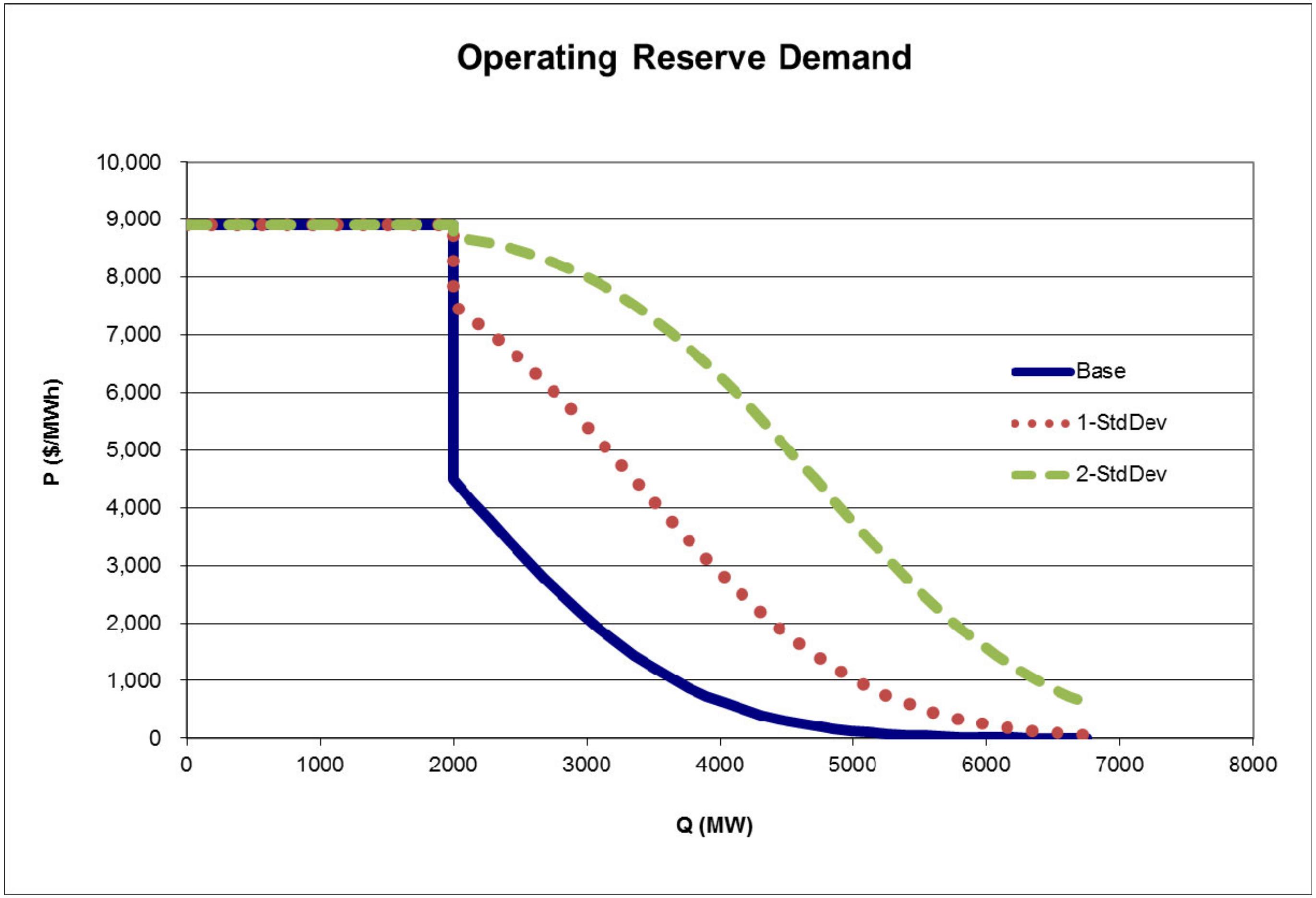
[2] Dan Woodfin and Carrie Bivens, “Summer 2019 Operational Review”, ERCOT Board of Directors Meeting Presentation, October 8, 2019.

A conservative assumption addressed at reliability would be to increase the estimate of the loss of load probability. A shift of one standard deviation would have a material impact on the estimated scarcity prices. The choice would depend on the margin of safety beyond the economic base. Texas applied this approach in 2019 and 2020 by implementing 0.25 standard deviations shifts.



The extension of market design to distribution systems seems straightforward in principle. (Caramanis, Bohn, & Schweppe, 1982) **But in practice the challenges will be different.**

- **High Voltage Grids (Wholesale Markets)**
  - Small Losses
  - Simpler Voltage Control Challenges
  - Market Design Assumes Sufficient Reactive Power
  - Network Interactions with Thousands of Locations
  - Workable Approximations
    - DC Load Model, at least for local adjustments
    - Nomograms and Interface Constraints
    - Centralized Coordination
    - Long-history with Optimization Models
    - "Dispatch-Based Pricing" Models Accommodate Operator Interventions
- **Low Voltage Grids (Distribution Markets)**
  - Larger Average and Marginal Losses
  - Voltage Control a Central Problem
  - Largely Radial Systems with Millions of Devices
  - Moving from Passive Revelation to Active Participation
  - Less Operating Experience with Optimization Models

The Federal Energy Regulatory Commission set out a framework for DER. (Federal Energy Regulatory Commission, 2020c) **Some of the market design challenges (an incomplete list):**

- **Product Definition**
    - Demand Response vs. Demand Participation
    - Stacked Values
        - Price Equilibrium and Energy Value
        - Additive or Alternatives
        - Carbon Pricing (Federal Energy Regulatory Commission, 2020a)
- **Coordination**
    - Centralized
    - Decentralized
    - Role of Aggregators
    - Hybrid Models (Gross Pool versus Net Pool Debate)
    - Operator Interventions

- **Efficiency (Optimization) and Pricing**
    - Dispatch Signals and Settlement Prices
    - Non-Convexities
        - Commitment Decisions
        - Switching Decisions
        - AC Models
    - Uplift (Side Payments and ELMP) (Gribik, Hogan, & Pope, 2007) (Chao, 2019)

The Federal Energy Regulatory Commission set out a framework for DER. (Federal Energy Regulatory Commission, 2020c) **Some of the market design challenges (an incomplete list), continued:**

- **Intertemporal Optimization and Efficiency**
    - Rolling Update of Dispatch with Look Ahead
    - With Convex Conditions and No Uncertainty: Dispatch Signals = Settlement Prices
    - Non-convexities from Commitment Decisions
        - Dispatch Signals Differ from Settlement Prices (ELMP)
        - Sunk Costs Matter
    - Convexity but with Uncertainty and Intertemporal Updates (Hua, Schiro, Zheng, Baldick, & Litvinov, 2019) (Hogan, 2020)
        - Ramping Constraints
        - Dispatch Signals Differ from Settlement Prices
        - Sunk Costs Matter

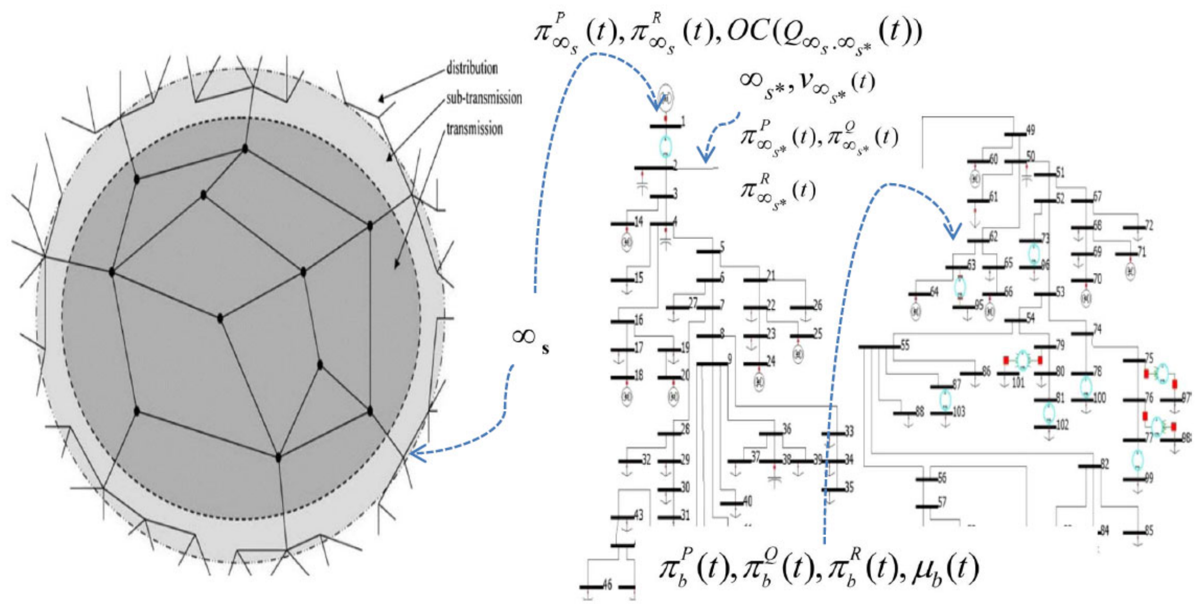
Then New York initiative on "Reforming the Energy Vision" stimulated wide discussion of reforms for pricing in the distribution system.

> "REV calls for facilitation of a market for DER products and services. This paper describes how New York State could create a new power market for DER products at the distribution level. DER would sell three core electric products in that market: ***real energy, reactive power, and reserves***. Real energy and other products that derive from it have the greatest economic value because customers consume those products directly. Distribution Utilities require reactive power to maintain voltage within an acceptable band that prevents damage to voltage sensitive equipment such as drive motors, compressors and many electronic devices. Reserves represent a commitment to deliver energy in the future. These core products can be bundled or unbundled, sold day ahead or in real time, or aggregated individually in time and space. In addition, they may be valued and / or sold forward as a basis for the calculation of the avoided cost of future capital investments.
>
> The design of this new market would draw upon the extensive experience with electric market design at the wholesale level. A key lesson from that experience is the importance of getting the prices right. Prices in this new market should reflect the value of core electric products from DER as a function of the time at which DER produces those products and the location at which DER produces them. This approach, referred to in this paper as more granular pricing, would identify where, when and how DER could provide significant value through reduction in system operating cost or where their ability to respond reduces the need for additional capital investment. This value is incremental to the environmental or other policy benefits of DER." (Tabors, Parker, Centolella, & Caramanis, 2016) (emphasis added)

Extension of the "transactive" market to the distribution system moves from thousands of locations on the (a) high voltage grid to millions of locations and devices that must coordinate on (b) the lower voltage distribution system.

Transmission **Distribution**

The prices expand from treating real power and reserves to include the important reactive power effects. In principle, the numbers of prices, quantities and constraints expand by several orders of magnitude.



(a) (b)

A computational challenge for tomorrow: "This paper presents a distributed, massively parallel architecture that enables tractable transmission and distribution locational marginal price (T&DLMP) discovery along with optimal scheduling of centralized generation, decentralized conventional and flexible loads, and distributed energy resources (DERs). …[an] architecture intended to realize Fred Schweppe's 1978 visionary "power systems 2000 …". (Caramanis, Ntakou, Hogan, Chakrabortty, & Schoene, 2016) See also (Kraning, Chu, Lavaei, & Boyd, 2013)

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