Shortage Pricing in North American Wholesale Electricity Markets

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Table of Contents

I. Introduction

In late 2016, the AESO began its transition from a traditional "energy-only" wholesale electricity market framework into a marketplace that includes a centralized capacity market. The capacity market is expected to provide better tools for ensuring reliability as Alberta's electricity landscape evolves rapidly—to provide more efficient market signals for system investments and operations, and to support Alberta's energy policy future. This market re-design is at the very foundation of the AESO's wholesale marketplace in many respects. The transition process requires the operator and its stakeholders to re-think and refine many aspects of wholesale market design. The new capacity market and any supporting energy and ancillary services market refinements are due for implementation in 2021.

As part of the market transition, the AESO and its stakeholders are considering enhancements to the energy and ancillary services markets to provide efficient market signals for operational flexibility. This paper focuses on one aspect of these potential market design enhancements: **administrative shortage pricing**.[1] Administrative shortage pricing provides a mechanism for increasing energy and ancillary services market prices during times of supply shortage to enhance market price signals for the need and value of quick-start and fast-ramping resources. Administrative shortage pricing has been adopted by many independent system operators with centralized wholesale markets.

This briefing paper provides an overview of administrative shortage pricing designs in other markets, including some lessons learned in those markets as the market designs have been refined over time.[2]

II. Key Elements of Energy and Ancillary Services Pricing During Shortages

Efficient pricing during supply shortages involves several different market design elements that work together. Key elements include fundamentals-based price formation: as supplies shortage occurs, administrative shortage pricing can be used to simulate a demand curve for the supply,

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1 In other jurisdictions the terms "shortage" and "scarcity" are sometimes used interchangeably. Through the market redesign process the AESO and its stakeholders have refined the definition of "shortage" to include only the administrative pricing described here. The term "scarcity" is used by the AESO and its stakeholders to refer to times when the market prices are set by supplier offers (rather than set administratively).

2 This briefing paper builds upon AESO's prior review of shortage pricing principles. For example, *see* AESO, "Scarcity & Shortfall Pricing," Energy and ancillary services market changes, SAM 2.0–3.0, Session 11, November 22, 2017. Available at https://www.aeso.ca/market/capacity-market-transition/design-working-groups/energy-and-ancillary-service-market-changes/

co-optimized energy and ancillary services market that ensures resources are paid the value they can provide, and capacity market-related revenues that are contingent upon performance during shortage events. It is important to consider linkages among these design elements when designing an administrative shortage price in the energy and ancillary services markets.

Good fundamentals-based price formation reflects the marginal cost of supply and demand-side resources (including demand response offering on the supply side). Thus, the prices should reflect an increasing marginal cost of supply as the system approaches a supply shortage. Design elements that contribute to this price formation leading up to shortage times include:

- Ability for all types of resources, including demand response and new or non-conventional supply technologies, to offer into the markets;
- Ability for marginal resources to set market prices reflecting marginal costs, including when quick-start units and demand response must be deployed;
- An offer cap above the highest possible marginal cost-based offer;
- Market power mitigation to ensure that the effects of any suppliers' exercise of market power are limited (such that prices are not too high and/or high at the wrong times);

The system enters supply shortage conditions after all supplies have been deployed and the market begins depleting operating reserves to meet the system's energy demand. At that time, all supply resources are being utilized such that cost-based supply bid offer prices have been exhausted. Administrative shortage pricing helps to reflect increasing value of providing supply services as operating reserves are depleted more and more, and as the system approaches firm load shed conditions. There are three basic approaches to reflecting this value through administrative shortage pricing:

- A fixed maximum "willingness to pay" for energy and ancillary services, also known as a flat price cap;
- A price step function that increases as shortage conditions increases in severity, usually formed through "penalty factors" or price adders for depleting various types of reserves. In jurisdictions with capacity markets, the combination of this step function and capacity market performance incentives can reflect some measure of the Value of Lost Load (VOLL). VOLL is an estimate of the cost of a load shed event to customers. This value can be interpreted as a customer's willingness-to-pay for incremental energy supplies to avoid load shed.
- A "full" variable demand curve for reserves, also known as an Operating Reserve Demand Curve, or ORDC, that reflects a gradually increasing willingness-to-pay for reserves, typically ending in some measure of the Value of Lost Load.
- Hybrid of the above.

Co-optimized energy and ancillary services markets are important to the effectiveness of administrative shortage pricing. Co-optimization of energy and ancillary services market ensures that energy prices reflect the opportunity cost of providing reserves, and vice versa, and that an ancillary services price reflects the opportunity cost of providing alternative higher- or –lower-quality ancillary services products.

III. Review of Administrative Shortage Pricing in Other Jurisdictions

A number of other North American market administrators have recognized that price levels during shortage conditions are important to provide incentives to increase flexibility from resources and help ensure adequate long-term generation investment (in combination with centralized capacity markets). Figure 1 below summarizes the price caps, generators' offer caps, and administrative shortage pricing approaches (as they relate to reserve depletion) of various markets. The sections that follow describe the basic mechanics of shortage pricing in each of these jurisdictions.

Figure 1: Price Caps and Administrative Shortage Pricing in Other Markets

Market	Resource Adequacy Construct	Price Cap (in native $/MWh)	Generator Offer Cap ($/MWh)	Reserves Depletion Pricing	Relationship to VOLL
ISO-NE[6]	Forward capacity market	Highest shortage price is $2,350[13]	$1,000[12]	Additive penalty factors by type	Price cap + capacity market performance incentives = VOLL
PJM[7]	Forward capacity market	$3,700[14]	$2,000[12]	Additive penalty factors and step functions by type	Price cap + capacity market performance incentives = VOLL
NYISO[8]	Prompt capacity market	None, but highest shortage price is $2,775[12,13]	$1,000 (changing to $2,000)[12]	Additive penalty factors and step functions by type	none
CAISO[4]	Developed through regulatory process, w/ ISO procurement backstop	None, but highest shortage price is $1,000[12]	$1,000[12]	Additive penalty factors and step functions by type	none
SPP	Reserve margin requirement for utilities	$50,000[12, 15]	$1,000[16]	Additive penalty factors and step functions by type	none
MISO[5]	Voluntary capacity market	$3,500[12]	$1,000[12]	Hybrid additive penalty factors and function of VOLLxLOLP	Price cap = residential VOLL
ERCOT[3]	**Energy only**	**Highest shortage price is $9,000[12]**	**$9,000[12]**	**Step function for regulation; economic demand curves for operating reserves**	Price cap = VOLL

Sources and Notes:

[3] See Potomac (2016), Section 1-D; PUCT (2012a), Section 25.505.g; Wheeler (2012).
[4] See CAISO Q3 Report (2017), pp. 4; (2012b), Section 6; (2012c), Sections 4.3-4.
[5] See MISO (2017), pp. 1-2; (2012b), Module C 39.2.5.f, Sched. 28; (2012c), Sections 6.4-7.
[6] See ISO-NE Market Report (201609), pp. 14-15Section 8.2; (2012), Appendix E Section 3; PJM (2012c).
[7] See PJM Manual 11 (20172a), pp. 11-12Section 2.3.2; PJM (2010), p. 3.
[8] See NYISO IRC Market Design Executive Summary (20172a), Section NYISO; (2012b) Attachment F Section 21.4; Potomac Economics (2011), pp. 13-16, Appendix Sections V.F-H, VII; PJM (2012c).

[12] http://www.isorto.org/Documents/Report/20170905_2017IRCMarketsCommitteeExecutiveSummaryFinal.pdf
[13] https://www.osti.gov/pages/servlets/purl/1247648
[14] https://www.aeso.ca/assets/Uploads/3-Price-and-Offer-Cap-and-Floor-in-Other-Jurisdictions-2017-11-08.pdf
[15] FERC, "Staff Analysis of Shortage Pricing in RTO and ISO Markets," Docket No. AD14-14-000, October, 2014.
[16] Section 4.1.1 of Southwest Power Pool's Open Access Transmission Tariff, Attachment AE.

A. ISO-NE: Fixed Penalty Factors for Depletion of Each Type of Reserves

ISO-New England (ISO-NE) adds fixed administratively-determined penalty factors to energy market prices when experiencing shortages in operating reserves.[3] ISO-NE procures four types of operating reserves, ranging from the lowest-quality "replacement reserve" to the highest-quality "10-minute spinning reserve."[4] The penalty factors are designated to reflect each type of reserve shortage, and the factors can become additive depending on the location and type of shortages. ISO-NE's administrative penalty factors for each reserve type are summarized in Figure 2 below.

ISO-NE's market prices for the different operating reserve products and energy are closely related depending on the opportunity costs of supply resource providing one product versus the others. ISO-NE co-optimizes its procurement and pricing of energy and ancillary services (all of the reserve products). Resources qualified to provide higher-quality reserves are also qualified to provide lower-quality reserves. As the system approaches shortage conditions, depletion of lower-quality reserves affects market prices of higher-quality reserves and energy. Thus, the resulting market prices for the products tend to move in the same direction together. During shortages conditions, the depletion of lower-quality reserves and the application of associated penalty factors affect market prices of higher-quality reserves and energy. For example, depleting the 30-minute operating reserves and application of the associated penalty factor result in higher prices for 10-minute spinning reserves and energy.[5]

3 ISO-NE calls these "Reserve Constraint Penalty Factors," or "RCPF."

4 Additional reserves are procured for locational needs, but we do not discuss those here for simplicity.

5 FERC, "Staff Analysis of Shortage Pricing in RTO and ISO Markets," Docket No. AD14-14-000 Price Formation in Organized Wholesale Electricity Markets, October, 2014, Section V.B.

Figure 2: ISO New England Penalty Factors for Depleting Operating Reserves

Operating Reserve	Penalty Factor *($/MWh)*	Energy Price When Short *($/MWh)*
Replacement Reserve	$250	$1,250
30-Min Operating Reserve	$1,000	$2,000
10-Min Non-Spinning Reserve	$1,500	$3,500
10-Min Spinning Reserve	$50	$3,550

Sources and Notes:

Assumes the marginal offer for energy is $1,000/MWh.

Replacement Reserve penalty factor is not additive, but all others are. Note that Replacement Reserve is an additional quantity of 30-minute Operating Reserves, beyond minimum federal requirements.

Christopher Parent, TMOR RCPF & Replacement Reserve, March 11-12, 2013

ISO New England Inc. and New England Power Pool, Docket No. ER13-1736-000, Revisions to Market Rule 1 to Establish a Reserve Constraint Penalty Factor for Replacement Reserve Requirement, June 2013

ISO New England Internal Market Monitor, Review of Real-Time Replacement Reserve, May 19, 2014

ISO New England, Market Rule 1, Section III.2.7A

Throughout 2012–2016, ISO-NE implemented several changes to its shortage pricing mechanism. Below is a summary of those activities:

- Address inefficiently low administrative price adders:[6,7] ISO-NE found the prior adder for 30-minute operating reserves—$100/MWh—to be inefficiently low. At that level, the unit dispatch software did not always automatically re-dispatch resources appropriately to maintain the required reserve levels (i.e., triggered shortages too soon). In those cases, ISO-NE had to manually intervene more often than necessary to address reserve deficiencies. This had the effects of: (a) market price signal misalignment with manual dispatch instructions, and (b) market price misalignment with the cost of reserves when they were needed the most. In 2012, the price adder for 30-minute operating reserves was increased from $100/MWh to $500/MWh to address these issues. Further, in 2014 and in response to a FERC order, ISO-NE increased the administrate price adder for the 30-minute operating reserves even further, from $500/MWh to $1,000/MWh. At that time, ISO-NE also increased its price adder for the 10-minute non-spinning reserves from $850/MWh to $1,500/MWh.
- Define a new reserve product (replacement reserves):[8] In 2012–2013, the region's reliance on natural gas was increasing significantly. ISO-NE identified two issues affecting the reliability

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6 ISO-NE, "2012 Annual Markets Report," May 15, 2013, Section 1.3.2.

7 ISO-NE, "2014 Annual Markets Report," May 20, 2015, Section 1.2.1.2.

8 ISO-NE, "2012 Annual Markets Report," May 15, 2013, Section 2.1.3.3.

of electricity supply from natural gas-fired generators: (1) differences in scheduling processes in the natural gas versus electricity industries, and (2) resource adequacy in natural gas infrastructure. ISO-NE took several actions to address these problems. One action included reaching beyond minimum federal requirements for 30-minute operating reserves, and defining the additional quantity procured as a new reserve product: replacement reserves. Depletion of replacement reserves triggers shortage pricing in ISO-NE. In effect, ISO-NE increased the sensitivity of its shortage pricing trigger with the new replacement reserves product.

- Strengthen and refine capacity market performance incentives/penalties:[9] ISO-NE found that the incentives for performance by resources with capacity commitments to be ineffective, so ISO-NE implemented several changes starting in 2013. Most notably in the context of shortage pricing, ISO-NE advanced the trigger of shortage prices to shortage of the total operating reserves for at least 30 minutes, rather than a shortage in just the 10-minute reserves for at least 30 minutes. This strengthened cross-market shortage pricing signals, and it better aligned the capacity market with the energy and ancillary services markets. In 2015 ISO-NE defined even stronger performance rules for capacity resources, under its "Pay for Performance" framework.[10] Overall, ISO-NE found performance rules for capacity resources to be an important element for ensuring those resources respond appropriately during times of operating reserve and energy shortages.

B. PJM, NYISO, CAISO, and SPP: Step Function Demand Curves

At a high level, PJM's shortage pricing architecture is similar to ISO-NE's. Both RTOs utilize a step function of administrative price adders to energy prices in times of reserve shortages. The price adders define the marginal administrative cost for reserves depletion, which feeds into the energy and ancillary services co-optimization process.

In PJM, the shortage pricing mechanism is a bit more complicated than ISO-NE in that more than one "step" is defined for each reserve product. PJM co-optimizes energy with two parent reserve products: synchronized reserves (online capacity resources) and non-synchronized reserves (a.k.a. primary resources that are off-line resources that can be started within 10 minutes). Each of these reserve products has its own shortage step function, or "demand curve," that applies on its system-wide and reserve zonal areas, as demonstrated in Figure 3, for 10-minute synchronized reserves.

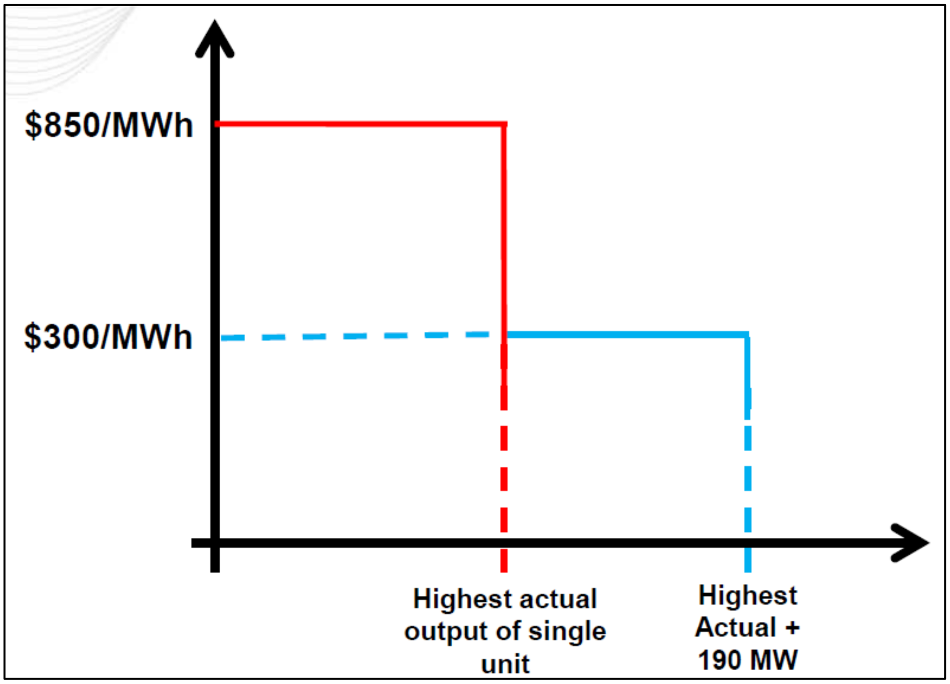
PJM's reserve requirements are calculated dynamically, based on the single largest generator contingency (represented by red vertical line in Figure 3). PJM administratively determines its penalty factors in a two-step demand curve. When reserves fall below the dynamic requirement plus 190 MW, that is, when reserves approach shortage, the penalty factor is $300/MWh. When

9 ISO-NE, "2012 Annual Markets Report," May 15, 2013, Section 3.4.3.3.

10 ISO-NE, "2016 Annual Markets Report," May 30, 2016, Section 6.1.

reserves fall below the dynamic requirement, the penalty factor is $850/MWh.[11] When there is a simultaneous shortage of primary and synchronized reserves, the real-time synchronized reserves price will be the sum of the primary reserve and synchronized reserve penalty factors.

Figure 3: PJM Shortage Pricing



Source: https://www.https://www.pjm.com/-/media/committees-groups/committees/mic/20170712/20170712-item-14-mic-shortage-pricing-update.ashx

In PJM, the penalty prices are not linked to a value of loss load, but rather to PJM's historical costs to provide these services.[12] PJM is considering revising its administrative shortage pricing curves to better align with the value of maintaining system reliability. To do so, PJM is considering enhancing its reserves demand curves with the probability of loss of load and value of lost load concepts.[13]

PJM has refined its shortage pricing rules over time, and the external market monitor has commented on PJM's shortage pricing design in detail. Below is a summary of the most relevant refinements:

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11 Section 4.2.2.1, Reserves Demand Curve and Penalty Factors, Overview of the PJM Synchronized Reserve Market, PJM M 11: Energy & Ancillary Services Market Operations, as of November 2017.

12 *A Proposal for Enhancing Energy Price Formation*, PJM Interconnection, November 15, 2017.

13 *Id.*, pp. 23-24.

- Additional reserve product (non-synchronized reserves):[14] With shortage pricing, PJM introduced a new reserve product called non-synchronized reserves.
- Refined definitions of synchronized reserves:[15] PJM can dynamically create additional zones or sub-zones for the synchronized reserve market. PJM has divided resources providing synchronized reserves into two categories: flexible and inflexible.
- Inclusion of "transient" shortage events:[16] Prior to FERC's 2014 order on shortage pricing, PJM only declared a shortage event for shortages lasting more than 30 minutes (similar to ISO-NE). The FERC order required PJM [and other RTOs] to instead declare a shortage event in any 5-minute pricing interval with a shortage. However, this presents some logistical challenges for PJM's pricing software and the timing of reserve estimates in real-time. The external market monitor had noted that, for PJM to shorten the interval that triggers a shortage event, the RTO needs to demonstrate that it can accurately measure reserves on a minute-to-minute basis. Until then, the market monitor states that the operator's discretionary decisions to declare shortage events on a 5-minute basis could distort market price signals.
- Changes in price-clearing mechanisms:[17] PJM implemented shortage pricing in 2012 and at around the same time, PJM also implemented changes to its regulation market, mostly driven by the desire to provide incentives for storage to participate in the regulation market. Before the change, the marginal cost of regulation, for example, reflected the regulation unit offer price, plus an opportunity cost of energy based on forecasted energy prices. After shortage pricing was implemented, offers to provide regulation consist of three components: a capability component that reflects the cost of reserving MW, a performance component that reflects the cost of ramping, and a PJM-calculated Lost Opportunity Cost (LOC) component that reflects any incremental lost opportunity to clearing in the energy market. To clear prices, the three-component supply offers are ranked on the performance component, which sets the Regulation Market Performance Clearing Price ("RMPCP"). The remaining components of the marginal supply offer (capability and LOC) set the residual Regulation Market Capacity Clearing Price ("RMCCP"). The final regulation market clearing price is the total marginal supply offer (by definition, the same as RMPCP plus RMCCP).

NYISO, CAISO, and SPP

NYISO's and CAISO's shortage pricing has a similar basic construct to PJM's. Both NYISO and CAISO use step-function curves that are based on type of reserve and degree of shortages. NYISO has demand curves for Regulation, 10-Minute Reserves, 30-Minute Reserves, and Spinning Reserves. The step function curves are defined for three geographic zones, including

[14] 2012 SOM Report, Volume 2, Page 280–281 (Section 9)

[15] 2012 SOM Report, Volume 2, Page 281–281 (Section 9)

[16] 2016 SOM Report, Volume 2, Page 175–177 (Section 3)

[17] 2012 SOM Report, Volume 2, Page 273 (Section 9)

the system as a whole and two sub-zones. NYISO shortage pricing is additive (a) to the energy price, (b) across reserve types, and (c) across nested zones.[18] CAISO has demand curves for Regulation-Up, Regulation-Down, Spinning Reserve, and Non-Spinning Reserve. CAISO's shortage pricing is additive across reserve types and affect prices of energy and other types of ancillary services through CAISO's co-optimization engine.[19]

SPP's current shortage pricing framework is also based on a step function. The administrative shortage pricing can be triggered in both day-ahead and real-time markets, on a system-wide and/or reserve zone basis. SPP has three main categories of operating reserves relevant to its shortage pricing: Contingency Reserves (including spinning and supplemental reserves), Regulation-Up, and Regulation-Down. SPP's shortage pricing for depletion of Contingency Reserves follows a 3-step function: as reserves are depleted to certain thresholds, an increasing "Scarcity Factor" (with values increasing from 0.25, to 0.5, to 1.0) is multiplied against the sum of the maximum energy plus contingency market offer prices (offer caps).[20] Thus, as reserves are depleted, the Scarcity Factor increases, and the shortage price increases. SPP's Regulation-Up and Regulation-Down shortage pricing reflects both causes of shortages and the severity of shortages. The Regulation demand curves include some exceptions to the application of Scarcity Factors, and Scarcity Factors are defined in six steps (instead of three for Contingency Reserves).[21]

Since this basic step-function construct has already been discussed, we do not explain NYISO, CAISO, or SPP shortage pricing in any more detail. However, in our review we have compiled a few notable observations by the operators and by their market monitors that are particularly relevant when considering the design of administrative shortage pricing:

- Shortage pricing at demand response deployment: NYISO has a special scarcity pricing rule that is triggered when the activation of demand response prevents a shortage of 30-minute reserves. Under this rule, real-time energy prices are set at a minimum of $500/MWh within the reserve zone. This rule improves price formation and reduces uplift payments when demand response is activated. This rule was a part of a package of market design changes that helped to refine deployment of demand response at locations and in quantities that would provide better value to the system.[22]

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18 FERC, "Staff Analysis of Shortage Pricing in RTO and ISO Markets," Docket No. AD14-14-000, October 2014.

19 FERC, "Staff Analysis of Shortage Pricing in RTO and ISO Markets," Docket No. AD14-14-000, October 2014.

20 https://www.ferc.gov/CalendarFiles/20171109164644-ER17-1092-000.pdf

21 https://www.ferc.gov/CalendarFiles/20171109164644-ER17-1092-000.pdf

22 NYISO's Comprehensive Scarcity Pricing, implemented in June 2016.
NYISO 2016 State of the Market Report, pp. 313–314.

- **Overscheduling operating reserves**: The market monitor has noted that NYISO tends to schedule more operating reserves than necessary within certain reserve zones, while ignore the capability and the economic value of imports from outside of the zone for maintaining the reserves.[23]
- **Reasons for selecting a (step function) demand curve approach**: CAISO has noted several reasons for its approach to shortage pricing, including, "Is one of the four approaches FERC recommended in Order 719, Is adopted by other ISOs, Clears market with the demand curve in situation of reserve shortage, Sets prices to reflect various levels of reserve shortage, and Encourage cost based bidding."[24]
- **Incentivizing fast-ramping resources**: SPP recently changed its shortage pricing from a fixed pricing step function (like ISO-NE) to the step function mechanism described above.[25] With the previous mechanism, SPP found that it was not providing the correct incentives for fast-ramping resources.[26] When a reserve shortage occurs, automatic energy and ancillary services co-optimization is infeasible. Under SPP's prior market design, they found that relaxing reserve requirements during shortages conditions helped their market-clearing software solve but resulted in depressed pricing during shortages.[27]
- **Benefits of an even more granular operating reserves demand curve**: SPP's market monitor has recommended switching to a MISO-style demand curve (discussed below).

C. MISO: Hybrid Operating Reserves Demand Curve

MISO procures three categories of ancillary services: Regulating Reserve, Spinning Reserve, and Supplemental Reserve, from highest-quality product to lowest-quality. MISO uses three demand curves in its shortage pricing framework, each corresponding with each category of reserves. Each shortage pricing curve can be triggered independently or in combination. Design of the MISO Operating Reserve Demand Curve is the focus of our discussion below.

MISO's existing administrative demand curve for operating reserves is composed of both fixed and variable prices, depending on how much of the operating reserves requirement can be met. MISO's current demand curve is shown in Figure 4 as the grey dotted line. Reading the graph from right to left, as long as reserves depletions are not below 96% of the requirement, the demand curve is fixed at a $200/MWh administrative price. When reserves are depleted to below 96% but above 10%, the demand curve is fixed at the $1,000/MWh energy offer cap plus

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23 NYISO 2016 State of the Market Report, p. 75.

24 http://www.caiso.com/Documents/BriefingonScarcityPricing.pdf

25 Attachment AE Integrated Marketplace, SPP's Open Access Transmission Tariff, Sixth Revised Volume No. 1, Effective Date December 11, 2017.

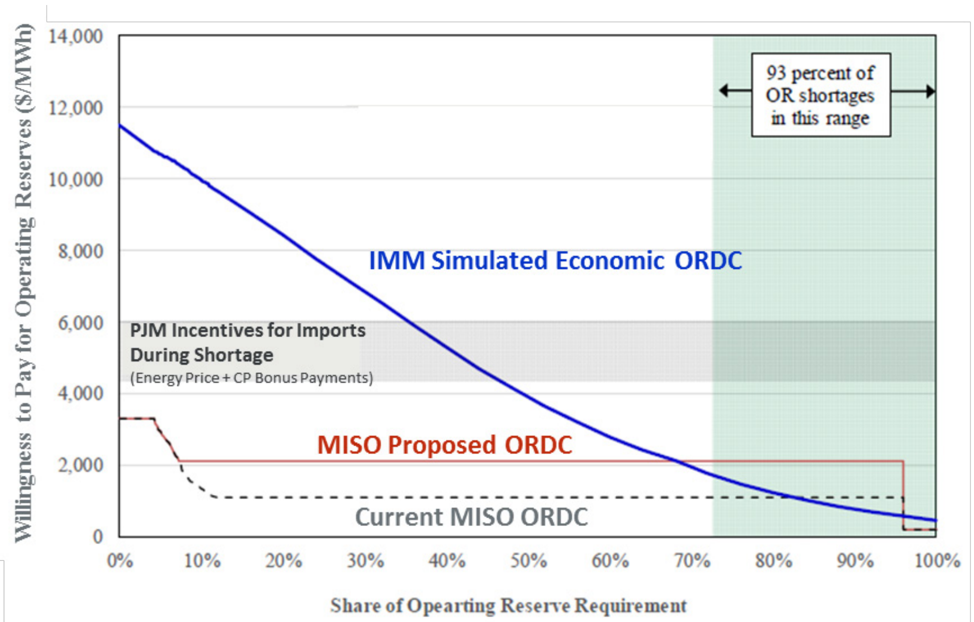
26 SPP Annual State of the Market Report 2016, p. 77

27 SPP Annual State of the Market Report 2016, p. 77

$100/MWh Contingency Reserve Offer Price Cap.[28] When reserves are depleted down to between 10% and 4%, the demand curve reflects a willingness to pay equal to the probability of lost load (POLL) times the value of lost load (VOLL). Once reserves are depleted to 4% of requirement or lower, the demand curve reflects the full residential-based VOLL of $3,500/MWh, minus the maximum market-wide regulating reserve demand curve price for that month.[29]

In response to U.S. FERC Order No. 831 on offer caps in centralized markets in late 2016, MISO proposed a new demand curve.[30] This new proposed curve is shown as the red line in Figure 4 below. The middle portion of the proposed demand curve reflects a higher energy offer cap, increasing from $1,000 to $2,000 per MWh, but it retains the same basic architecture.

Figure 4: MISO Operating Reserves Demand Curves (ORDC)



Source: Potomac Economics, 2016 State of the Market Report for the MISO Electricity Markets, June 2017.

In 2017, MISO's external independent market monitor (IMM) suggested that MISO should improve its operating reserves demand curves. The IMM stated that (a) the demand curve shape (both current and proposed) does not appropriately reflect the marginal reliability value of

28 FERC, "Staff Analysis of Shortage Pricing in RTO and ISO Markets," Docket No. AD14-14-000, October 2014.

29 FERC, "Staff Analysis of Shortage Pricing in RTO and ISO Markets," Docket No. AD14-14-000, October 2014.

30 FERC Order No. 831, Offer Caps in Markets Operated by Regional Transmission Organizations and Independent System Operators, Docket No. RM16-5-000, Issued November 17, 2016.

operating reserves, and (b) the current VOLL of $3,500/MWh is understated.[31] The blue line in Figure 4 shows the market monitor's 2017 study of a full variable operating reserves demand curve, assuming VOLL at $12,000/MWh.[32]

The IMM's simulated economic demand curve has two basic features that distinguish it from MISO's existing and proposed curves (dotted grey and red lines in Figure 6): (a) the value of reliability increases smoothly with the severity of reserves depletion, rather than relying on an administrative step function at certain reserves depletion thresholds, and (b) it reflects a materially higher VOLL. Comparing the simulated economic ORDC (blue line) with MISO's current and proposed levels (dotted grey and red lines), the external IMM believes that the current and proposed levels lead to prices that are too high at very low reserve depletion periods (as in the shaded area above 70% reserve requirement in Figure 6), and prices that are too low when the shortage is severe (that is, when reserves are below about 70% of the requirement in Figure 6).

D. ERCOT: Economic Operating Reserves Demand Curves

ERCOT's shortage pricing framework has two key characteristics for the purposes of this discussion: (1) an energy-only market, and (2) a tolerance for relatively high market prices (e.g., $9,000/MWh offer cap). ERCOT uses the Operating Reserve Demand Curves for spinning reserves and for non-spinning reserves, separately. ERCOT calculates six demand curves in each season, depending on time of day blocks.[33] Figure 5 illustrates ERCOT's demand curve for spinning reserves in summer hours 15–18.[34,35] The energy price adder is calculated based on a loss of load probability (LOLP) at each quantity of reserves remaining on the system, multiplied by the value of lost load (VOLL) minus the energy price. To calculate the shape and magnitude of the ORDC, the system operator conducted a simulation analysis to estimate the loss of load probability (LOLP) at each quantity of reserves. The LOLP is low when there is a surplus of reserve. For instance, as shown on the graph, the willingness to pay for more than 5,000 MW of reserves is very low and approaching zero. The LOLP becomes very high when reserves are in

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31 Potomac Economics, "2016 State of the Market Report for the MISO Electricity Markets," June 2017.

32 Potomac Economics, "2016 State of the Market Report for the MISO Electricity Markets," June 2017. MISO, Improved Contingency Reserve Demand Curve that reflects VOLL, June 15, 2017

33 https://www.ferc.gov/CalendarFiles/20160629114652-3%20-%20FERC2016_Scarcity%20Pricing_ERCOT_Resmi%20Surendran.pdf

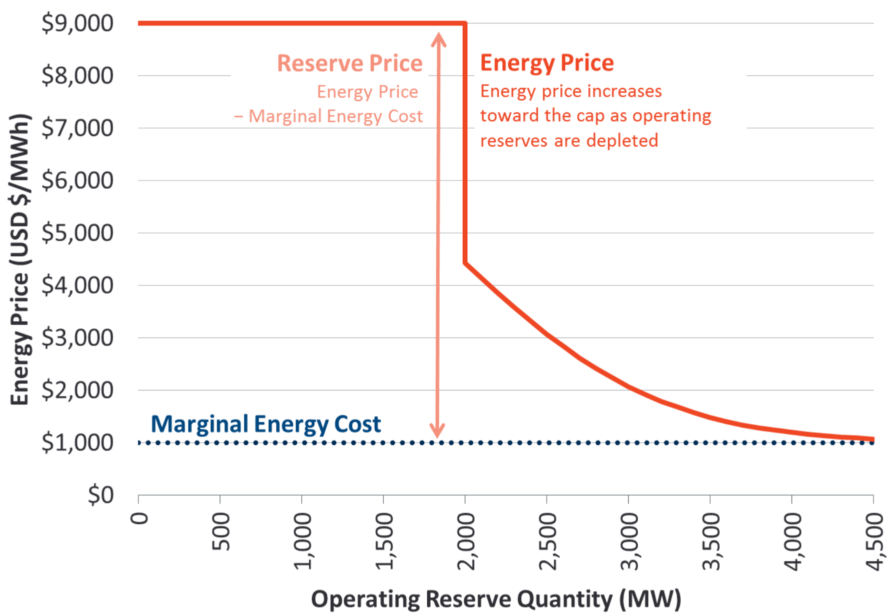
34 See ERCOT and Hogan (2013).

35 For simplicity, we show only the ORDC for spinning reserves in this figure. There is a separate ORDC representing the willingness to pay for non-spinning reserves. The maximum price for non-spinning reserves is half of that for spinning reserves.

shortage, with the ORDC causing energy prices to reach the price cap at the VOLL of $9,000/MWh.[36,37]

The ERCOT Operating Reserve Demand Curves were implemented in 2014.

Figure 5: ERCOT Operating Reserve Demand Curve



Sources and Notes:

Represents the curve in Summer Hours 15–18, assumes marginal energy cost of $1,000/MWh. See ERCOT and Hogan (2013).

E. Summary of Lessons Learned in Other Jurisdictions

While the specific implementation of reserve shortage pricing varies considerably across jurisdictions, there are many common themes in implementation and experiences.

36 FERC, "Staff Analysis of Shortage Pricing in RTO and ISO Markets," Docket No. AD14-14-000, October 2014.

37 The ORDC is implemented as additive to the marginal energy offer, but the price cap for energy is $9,000/MWh. Because the marginal energy offer can be at any height, the vertical scale of the ORDC varies with system conditions as VOLL minus the marginal energy offer. As a result, the maximum energy price is always $9,000/MWh, but the maximum price for spinning reserves can be close to the VOLL (if the marginal energy offer is very low) or fairly small (if the marginal energy offer is very high).

Basic architecture: mostly step functions, adjusted upwards over time

In the jurisdictions we reviewed, shortage pricing architecture ranged from fixed penalty factors, to more complex step functions, to full variable economic demand curves. The vast majority of jurisdictions, however, have implemented some type of step function that is unique in some ways to each jurisdiction. Many of the demand curves have been adjusted upwards over time, either concurrently with offer or price cap increases (e.g., MISO), concurrently with other market design changes (e.g., NYISO), based on experience (e.g., ISO-NE), and/or with more analytical grounding to an economic variable demand curve (e.g., ERCOT).

Recognized benefits of shortage pricing

While we are not aware of a quantitative comparison of prices or revenues for suppliers with versus without shortage pricing, we have found that the trends in shortage pricing design over the past several years indicate tangible and material benefits in the operating timeframe. Efforts to improve market price signals to better reflect the cost of resources providing the right types of products at the right times appear to reduce uplift payments (e.g., SPP's experience with fast-start resources). The designs and the resulting market prices overall seem to better reflect the severity of shortages, both in terms of how much reserves are depleted and what types of reserves are depleted.

In areas with organized capacity markets, shortage pricing design must be fully integrated with capacity market design

In the capacity market jurisdictions ISO-NE and PJM, capacity market and shortage pricing design are linked by how reserve margins affect the quantity and severity of shortage events, and by interactions between shortage pricing and any capacity performance incentives.

Co-optimization of energy and ancillary services ensures that pricing among products reflect opportunity costs and value of higher-quality versus lower-quality reserve products

We find that the markets reviewed typically co-optimize their energy and ancillary services markets (except for ERCOT). When supply shortages occur in a market, the administrative shortage pricing typically provide the signals for resources to provide the highest-quality products they can, while minimizing system costs. The reserve prices would reflect the opportunity cost of not produce energy and the shortage prices in the energy market would reflect the fact that reserves are being depleted and thus the system is under stress. Among the different reserves products, prices are typically higher for higher-quality reserves and lower for lower-quality reserves. For example, when both spinning reserves and non-spinning reserves are short, a resource that can provide either product should see a higher price and incentive to provide spinning reserves. A co-optimized system would sort through the resources (and their bids) such that the resource with the greatest ability to provide energy or the highest quality reserves at the lowest cost would be asked to provide those products.

Mixed efforts to achieve theoretical VOLL in market signals to generators

We observe that every jurisdiction has its own approach to reflect some measure of VOLL in its administrative shortage pricing. In MISO and ERCOT, VOLL is included explicitly in shortage pricing calculations, although with different estimates of VOLL. ERCOT has set its VOLL at $9,000/MWh, while MISO has set its VOLL at $3,500/MWh.[38] Further, MISO's independent market monitor has recommended a full ERCOT-style variable economic demand curve based on a VOLL of $12,000/MWh.[39] In jurisdictions with a centralized capacity market, ISO-NE and PJM are implementing capacity performance incentives that could signal up to $6,000/MWh to generators during shortage.[40] Other jurisdictions do not incorporate VOLL into market pricing. On one hand, tying shortage pricing to VOLL provides a more rigorous analytical basis for determining the efficient shape of shortage pricing demand curves. On the other hand, sanctioning very high market prices—even if only in rare events—is daunting to market administrators, stakeholders, and policymakers.

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38 Surendran, R, W. Hogan, H. Hui, and C. Yu. 2016. Scarcity Pricing in ERCOT. FERC Technical Conference. June 27-29.

39 Potomac Economics, 2016 State of the Market Report for the MISO Electricity Markets, June 2017.

40 See http://www.nyiso.com/public/webdocs/markets_operations/committees/bic_icapwg/meeting_materials/2017-11-06/Performance%20Assurance%20Comments%20by%20MMU__10132017.pdf