Intertemporal ORDC

EPFSTF

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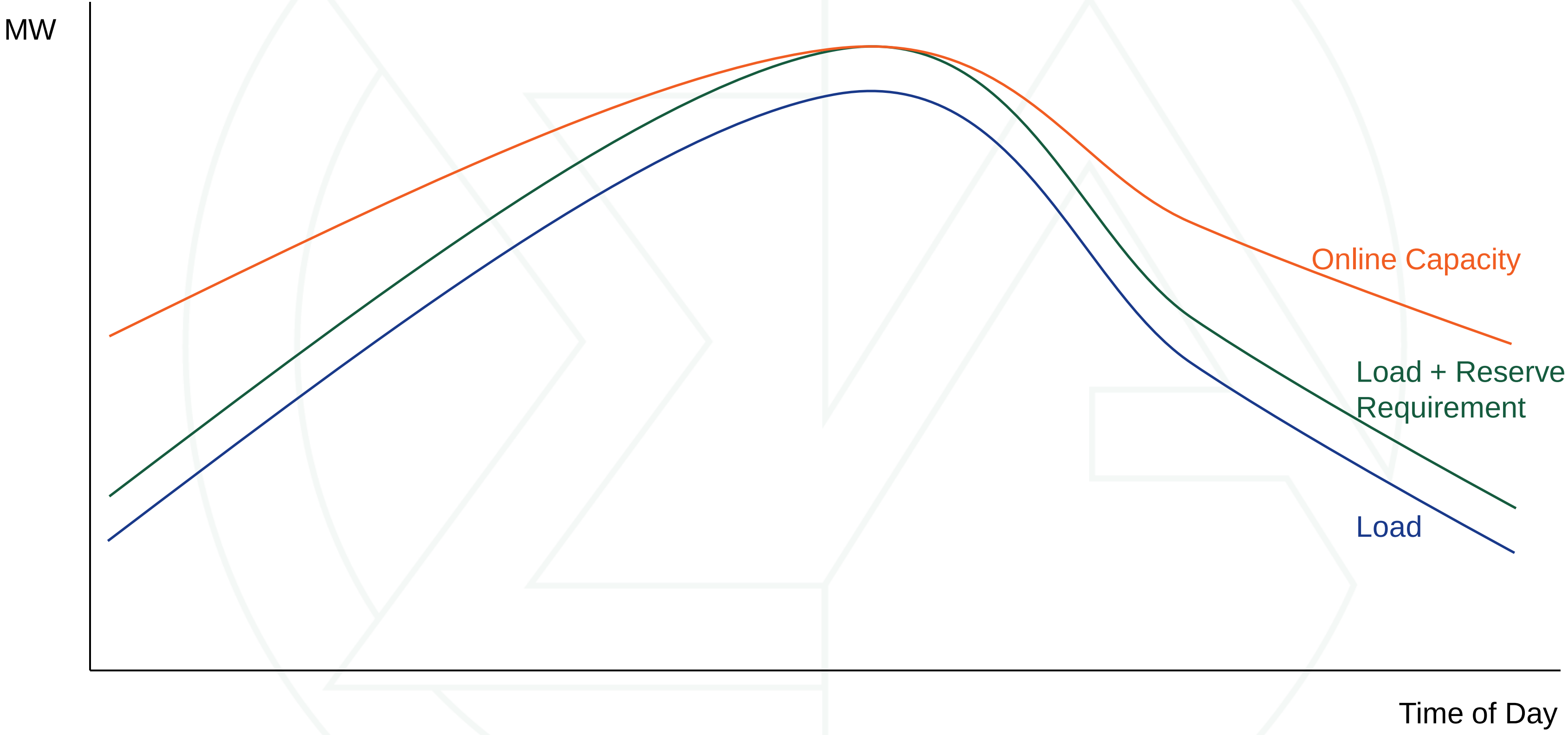
Price Formation and Scarcity Pricing

- Underlying issue EPFSTF set out to address is the appropriateness of falling prices when load rises
- Real-time unit commitments to meet increasing load or declining reserves can lower price when more capacity is brought online
- Capture some of the intertemporal dynamics of the market in the reserve demand curves (ORDCs)
- Support prices at times when additional reserves provide a more economic commitment though not necessary to meet the concurrent reserve requirement

Daily Reserve Pattern

- **Reserve levels vary over the course of an operating day.**
  - **Ample reserves when load is low**
  - **Closer to reserve requirement when load peaks**
- **When load is low, reserves exceed requirement because the most economic commitment to meet load includes long minimum run time (baseload) units.**
- **The market commits the additional reserves for energy needs, not to meet concurrent reserve requirement.**

Daily Reserve Pattern



Monitoring Analytics

Fluctuations in Supply and Demand

- Suppose the total amount of reserves falls due to fluctuations in supply and demand.
- Possible outcomes:
  1. No impact because plenty of reserves
  2. Reserves fall below requirement
  3. No concurrent shortage, but market is tighter and more reserves are expected to be needed for the next peak
- Current ORDC addresses 1 and 2.
- Outcome 3. creates a demand for reserves that may lead to a real time unit commitment.

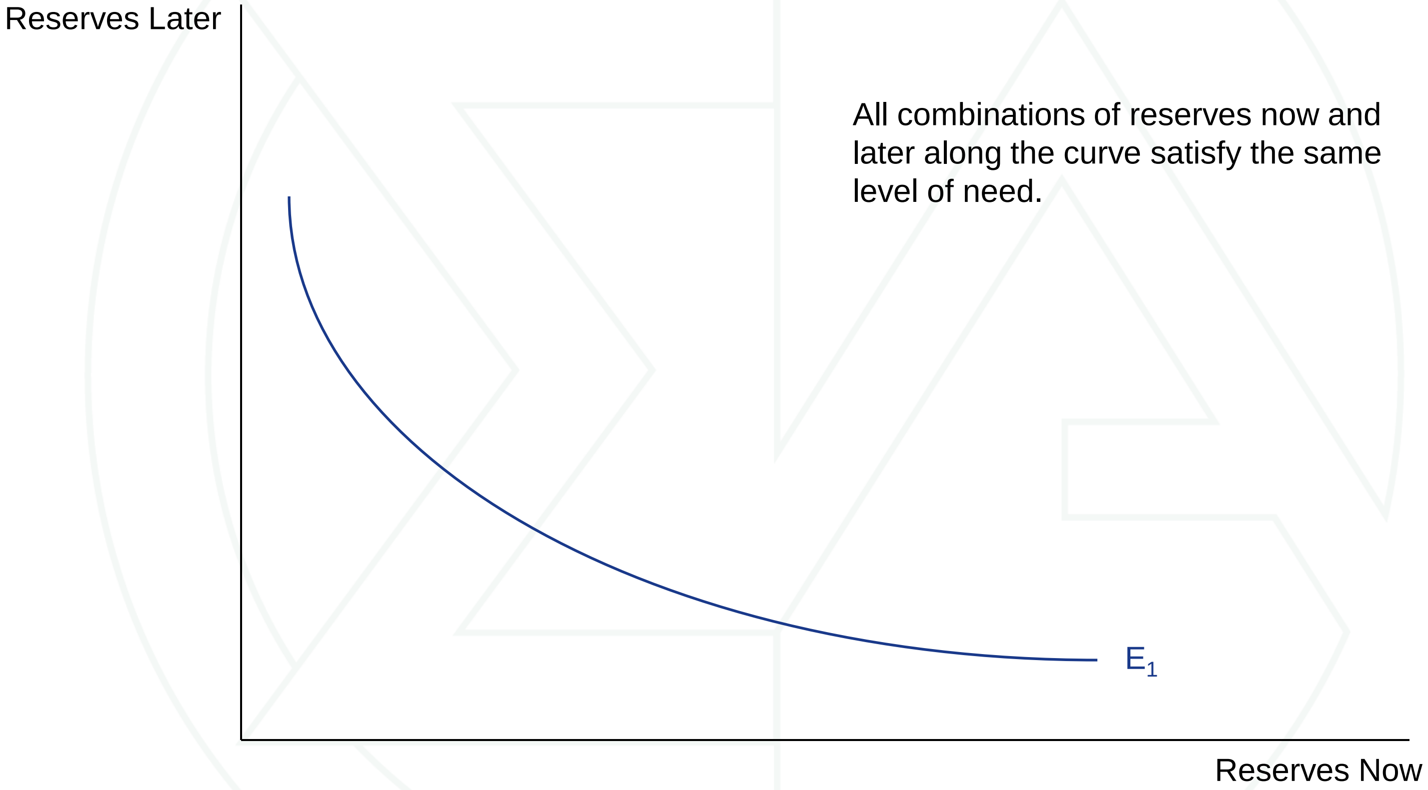
Demand for Additional Reserves

- Operator anticipates persistent reduction in reserves
- Need to bring more capacity online to maintain energy and reserves through the next peak period
- Can purchase more reserves now or later
- Microeconomic approach to deriving demand equates marginal benefit to marginal cost
  - The relative effectiveness of reserves brought online now or closer to the peak period
  - The relative cost of reserves brought online now or closer to the peak period
- Demand is the expected cost savings of purchasing more now to avoid a higher cost later.

Effectiveness of Reserves Now and Later

- Reserves purchased hours ahead of time may no longer be online later.
- Reserves purchased close to when needed are more likely to be available when needed.
- Reserve effectiveness is the probability that a MW of reserves now will meet the peak reserve requirement.

Effectiveness of Reserves Now and Later

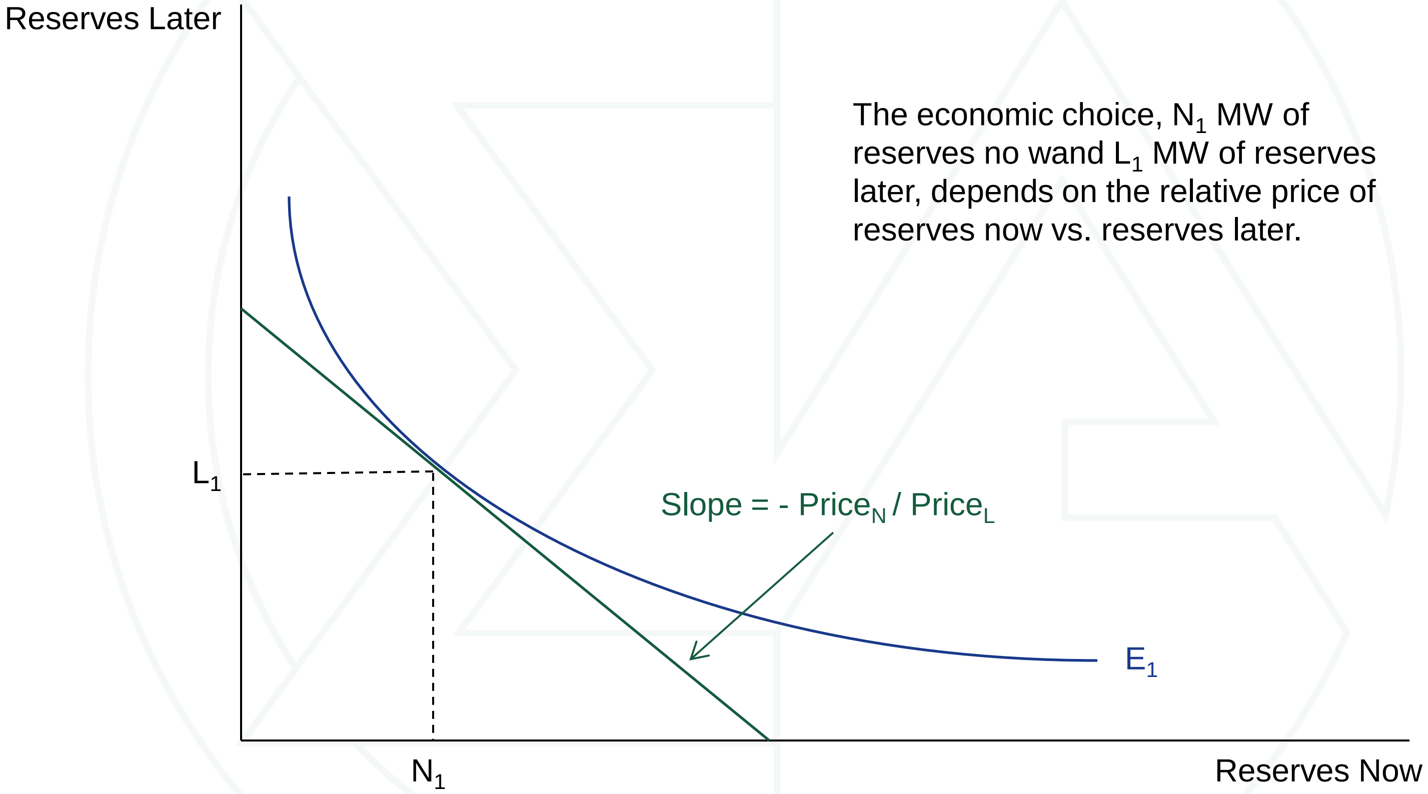


All combinations of reserves now and later along the curve satisfy the same level of need.

Cost of Reserves Now and Later

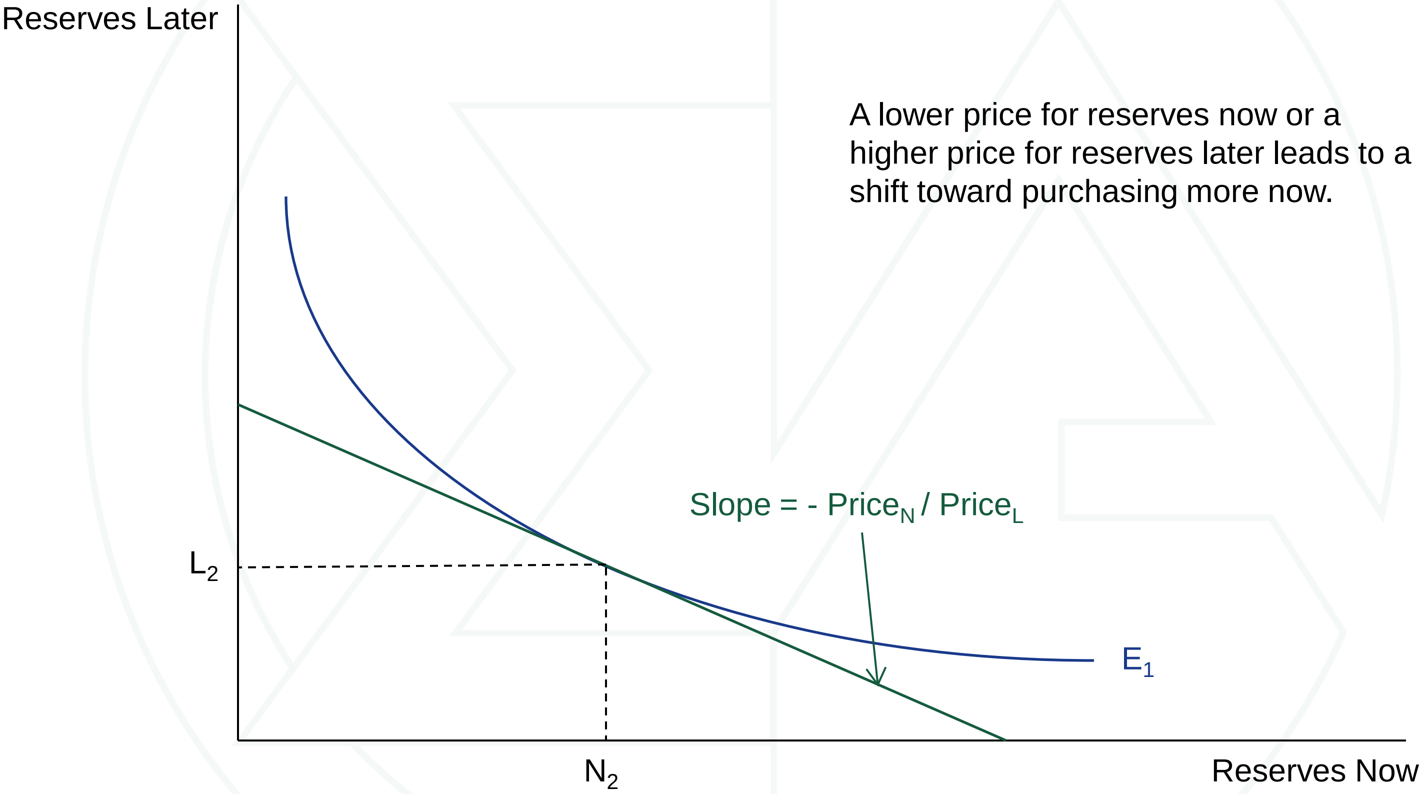
- The need for more reserves occurs later, during the peak period, when prices are higher.
- Prices are currently lower.
- As the relative price of reserves now versus later falls, purchase more now.

Choice of Reserves Now and Later



The economic choice, N_1 MW of reserves no wand L_1 MW of reserves later, depends on the relative price of reserves now vs. reserves later.

Choice of Reserves Now versus Later



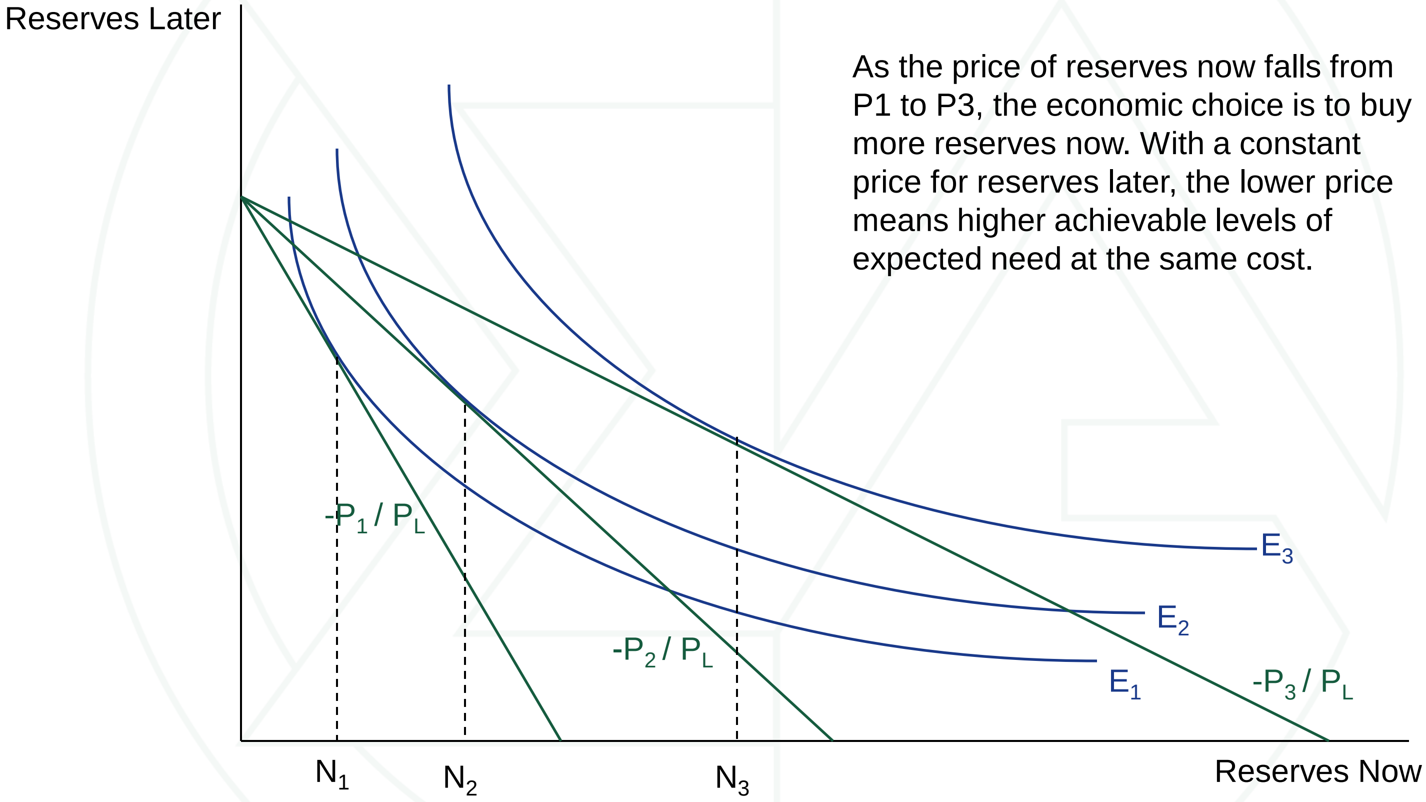
A lower price for reserves now or a higher price for reserves later leads to a shift toward purchasing more now.

Deriving Demand for Reserves Now and Later

- **The relationship between the increasing economic purchase of reserves now and the falling price of reserves now is the demand curve for additional reserves now.**
- **The demand curve equates the relative effectiveness per dollar of reserves now to the relative effectiveness per dollar of reserves later.**

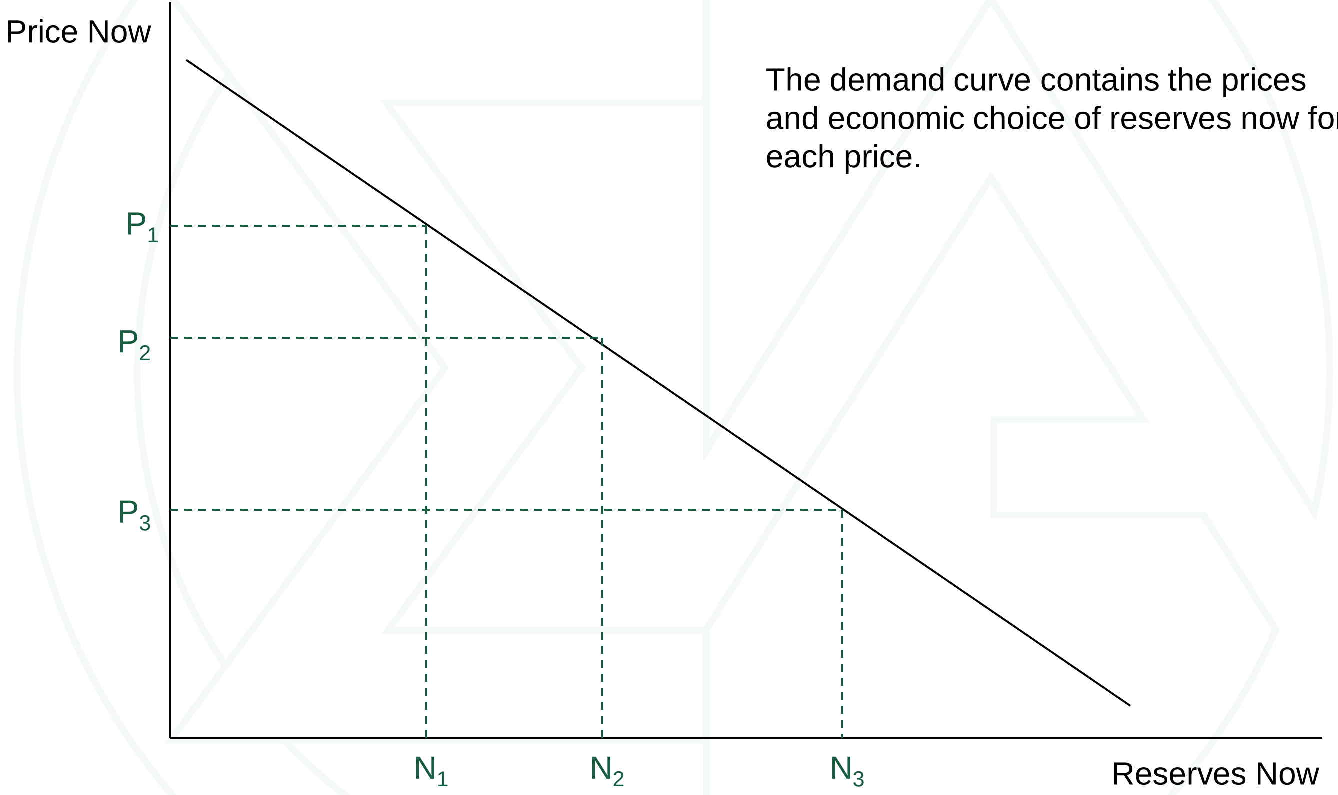
$$\frac{Effectiveness\ Now}{Price\ Now} = \frac{Effectiveness\ Later}{Price\ Later}$$

Deriving Demand for Reserves Now and Later



As the price of reserves now falls from P1 to P3, the economic choice is to buy more reserves now. With a constant price for reserves later, the lower price means higher achievable levels of expected need at the same cost.

Deriving Demand for Reserves Now and Later

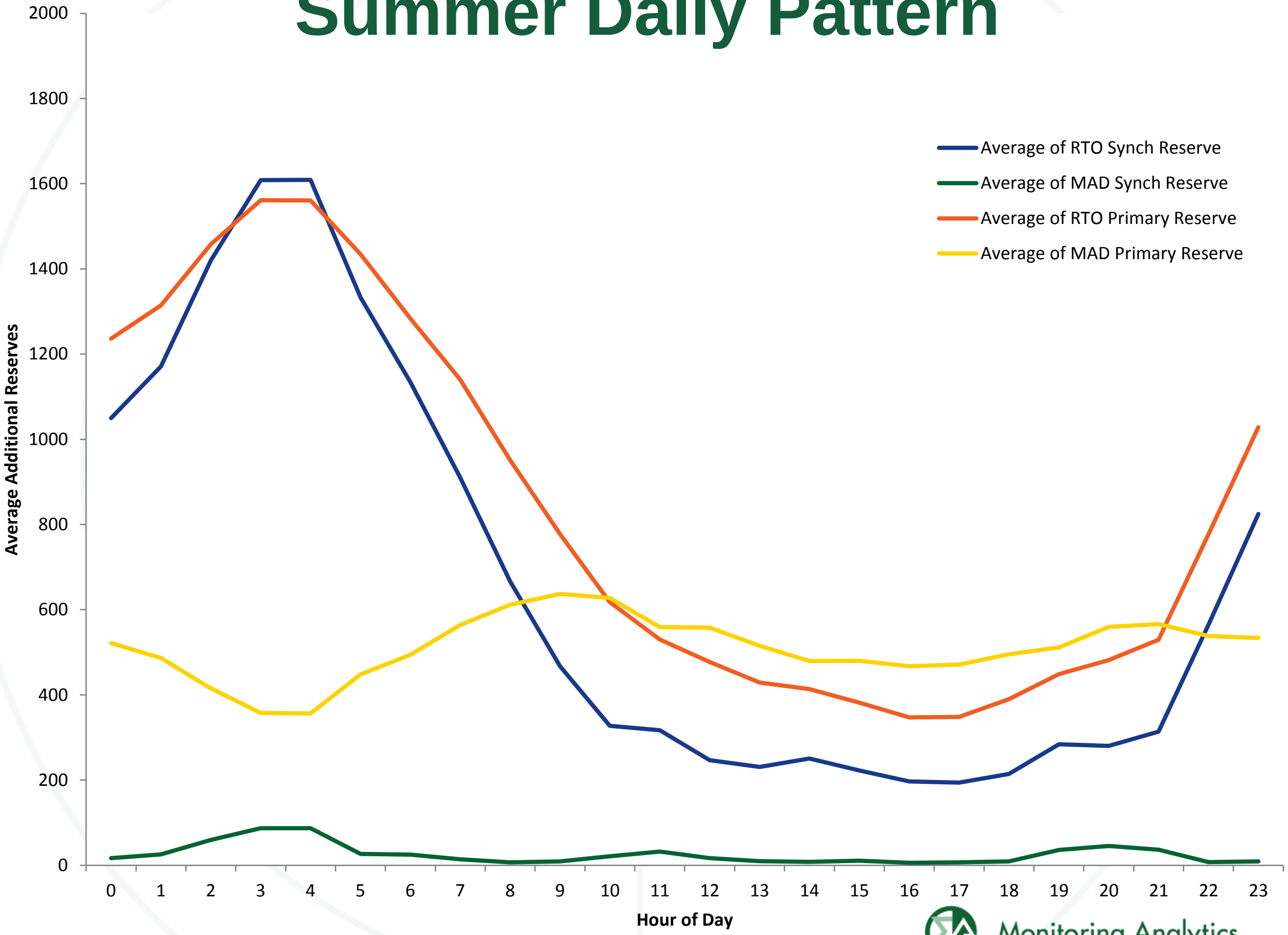


The demand curve contains the prices and economic choice of reserves now for each price.

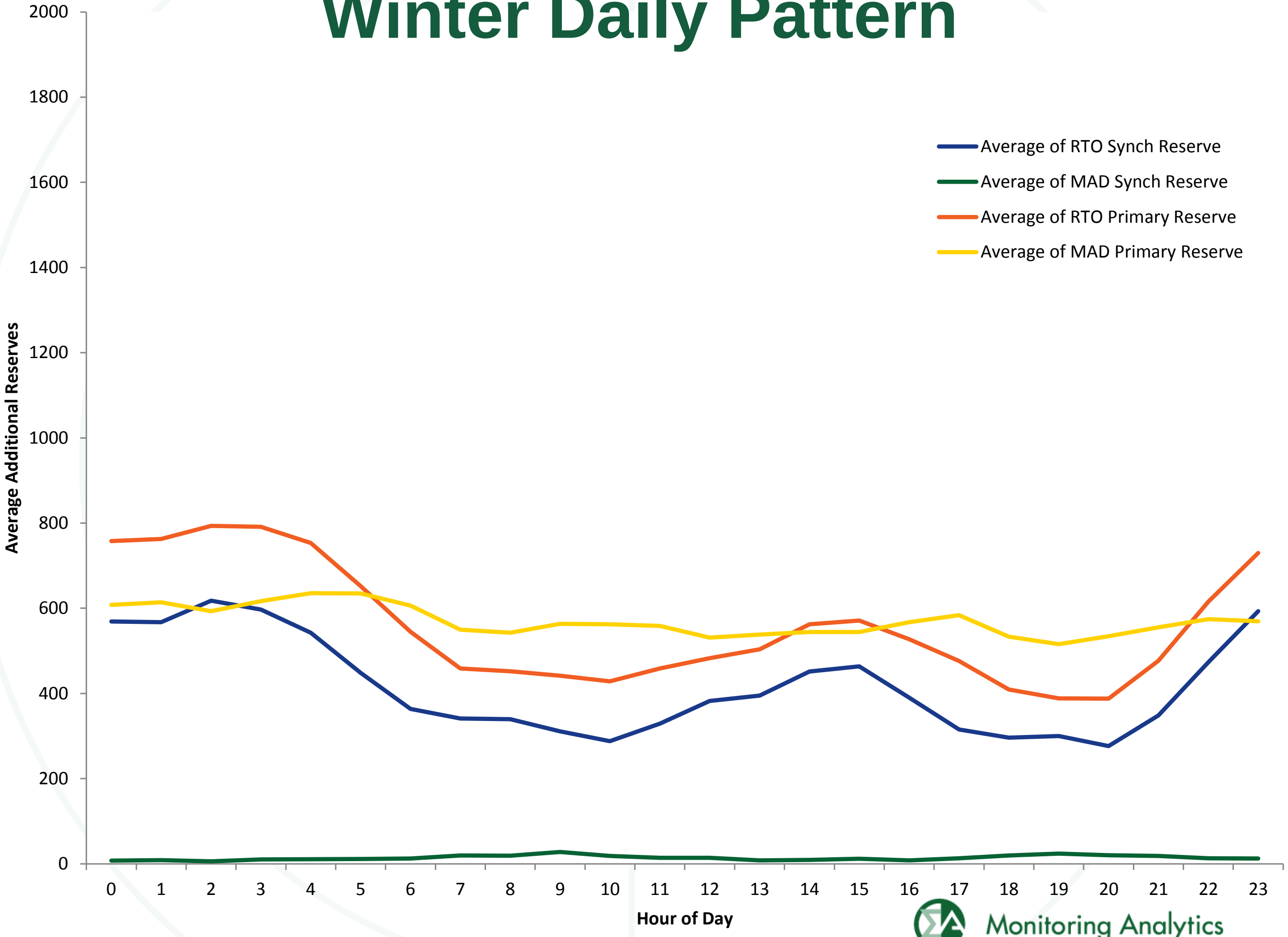
Historical PJM Reserves

- IMM analyzed historic five minute reserves for 2015, 2016, and 2017.
- Average hourly reserves varied from small shortages to more than 1,600 MW above the requirement.
- Daily reserve patterns vary by season.

Summer Daily Pattern



Winter Daily Pattern



Tight Days

- Tight day definition: primary reserves within 150 MW of the reserve requirement for 36 five minute intervals during the peak hours of the day
- Based on feedback, revised definition of tight days
  - Peak period includes an additional, earlier morning hour
  - Load change exceeds 2,500 MW for more than 12 intervals during the peak hours
- Tight days include:
  - Annual peak load days in 2015, 2016, and 2017
  - Winter peak load days in 2015 and 2017
  - Highest balancing uplift days 2016 and 2017

Days with Tight Peak Periods by Season and Load Level 2015, 2016, and 2017

Season	Load Level	Tight Days	Percent of Days	Revised Tight Days	Percent of Days
Fall	Over 125 GW	11	68.8%	7	43.8%
Winter	Over 125 GW	6	30.0%	7	35.0%
Summer	100 to 125 GW	64	45.7%	46	32.9%
Summer	Over 125 GW	56	50.9%	36	32.7%
Spring	100 to 125 GW	17	30.9%	12	21.8%
Winter	100 to 125 GW	78	45.3%	33	19.2%
Fall	100 to 125 GW	22	37.3%	9	15.3%
Spring	85 to 100 GW	35	21.6%	6	3.7%
Fall	85 to 100 GW	57	35.8%	3	1.9%
Winter	85 to 100 GW	33	43.4%	1	1.3%
Fall	0 to 85 GW	15	38.5%	-	0.0%
Spring	0 to 85 GW	19	32.8%	-	0.0%
Summer	85 to 100 GW	6	23.1%	-	0.0%
Spring	Over 125 GW	-	0.0%	-	0.0%
Winter	0 to 85 GW	-	0.0%	-	0.0%

Calculating the Benefit of Additional Reserves

- Some probability of a tight day regardless of the level of reserves.
- As reserves shrink, the probability of a tight day increases.
- The purchase of more reserves can decrease the probability of a tight day.
- Relative effectiveness of a reserve purchase now instead of later is
  - Probability of a tight day given the reserve level now
  - Minus the overall probability of a tight day

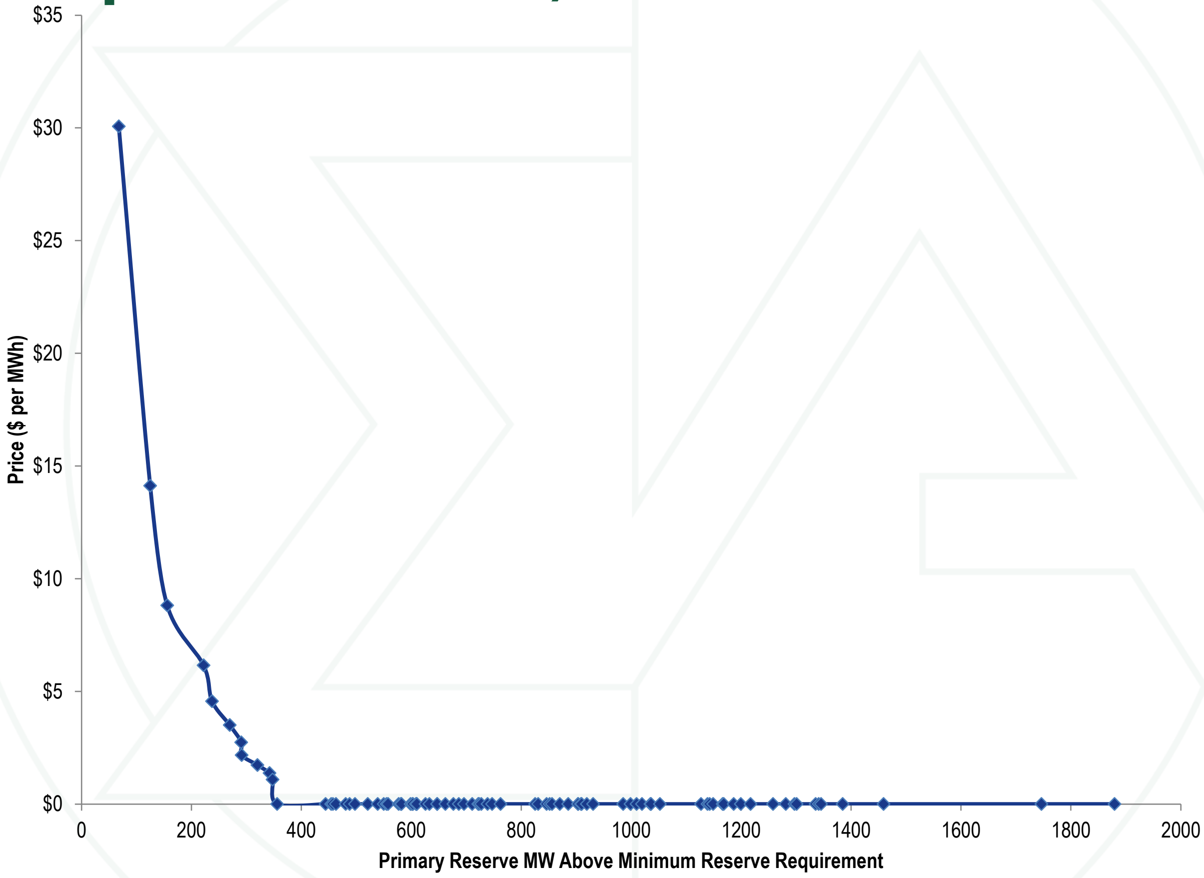
The Cost of Additional Reserves

- **The price of additional reserves during the peak period is no greater than the peak period LMP, which is the next best option for available capacity.**
- **Multiplying the price by the relative effectiveness of reserves now vs. later provides the willingness to pay for more reserves now.**

Example for Winter, 4AM Load 85 to 100 GW

Additional Reserve MW	Percent of Tight Days Given Reserve Level at 4:00 AM	Difference in Percent Tight Days Given Reserve Level and Overall	Peak Hour Average LMP	Willingness to Pay for Additional Reserves
67.8	100.0%	94.3%	$31.88	$30.07
124.9	50.0%	44.3%	$31.88	$14.13
155.9	33.3%	27.7%	$31.88	$8.81
222.0	25.0%	19.3%	$31.88	$6.16
237.4	20.0%	14.3%	$31.88	$4.56
269.7	16.7%	11.0%	$31.88	$3.50
290.6	14.3%	8.6%	$31.88	$2.74
291.2	12.5%	6.8%	$31.88	$2.17
320.2	11.1%	5.4%	$31.88	$1.73
342.1	10.0%	4.3%	$31.88	$1.38
347.8	9.1%	3.4%	$31.88	$1.09
1,879.5	5.7%	0.0%	$31.88	$0.00

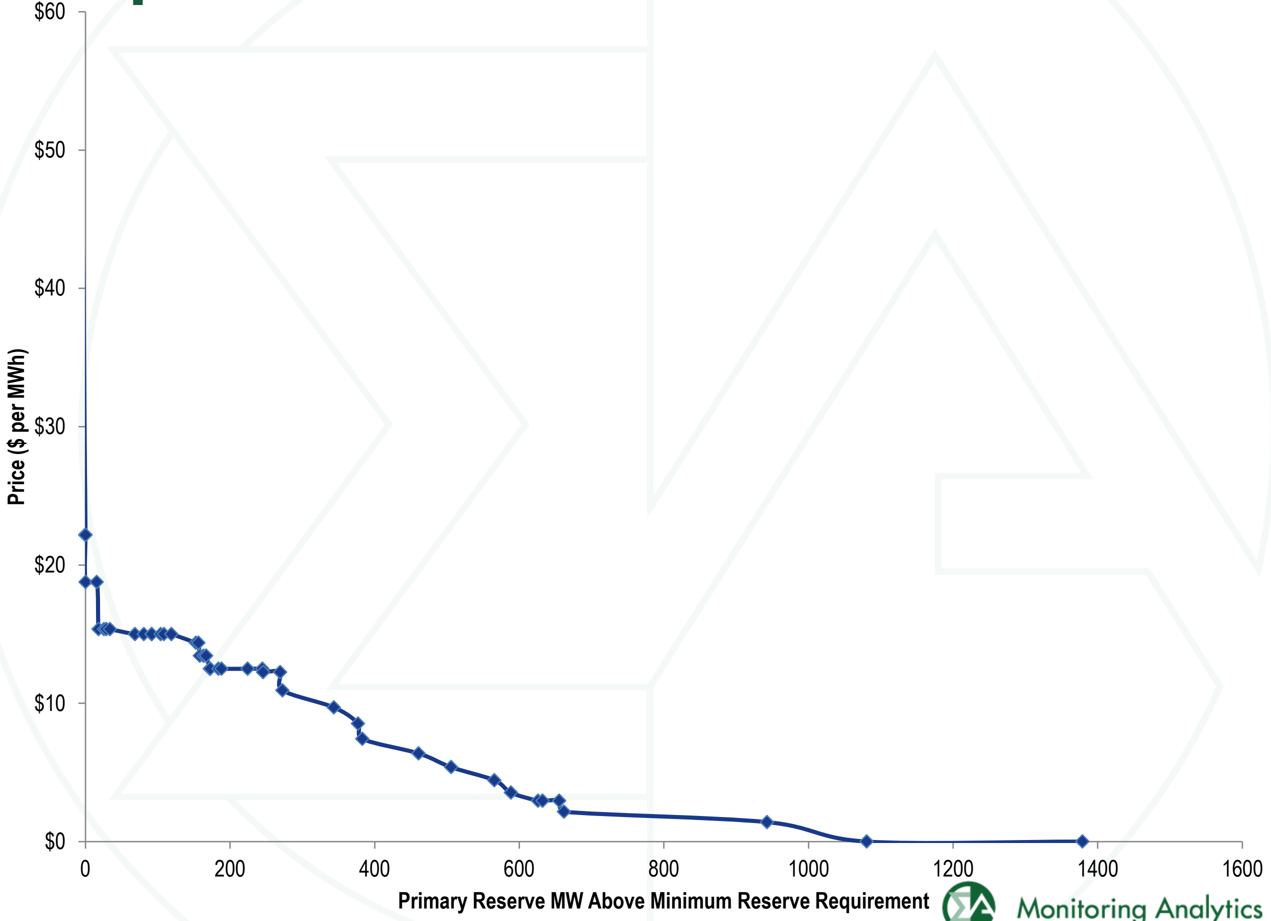
Example for Winter, 4AM Load 85 to 100 GW



Example for Winter, 4PM Load Over 110 GW

Additional Reserve MW	Percent of Tight Days Given Reserve Level at 6:00 PM	Difference in Percent Tight Days Given Reserve Level and Overall	Peak Hour Average LMP	Willingness to Pay for Additional Reserves
(23.1)	100.0%	60.4%	$81.88	$49.47
-	66.7%	27.1%	$81.88	$22.18
15.5	62.5%	22.9%	$81.88	$18.76
172.0	53.8%	14.3%	$81.88	$11.68
272.3	52.9%	13.4%	$81.88	$10.94
505.8	46.2%	6.6%	$81.88	$5.38
625.9	42.9%	3.3%	$81.88	$2.68
942.6	41.3%	1.7%	$81.88	$1.41
1,379.0	39.6%	0.0%	$81.88	$0.00

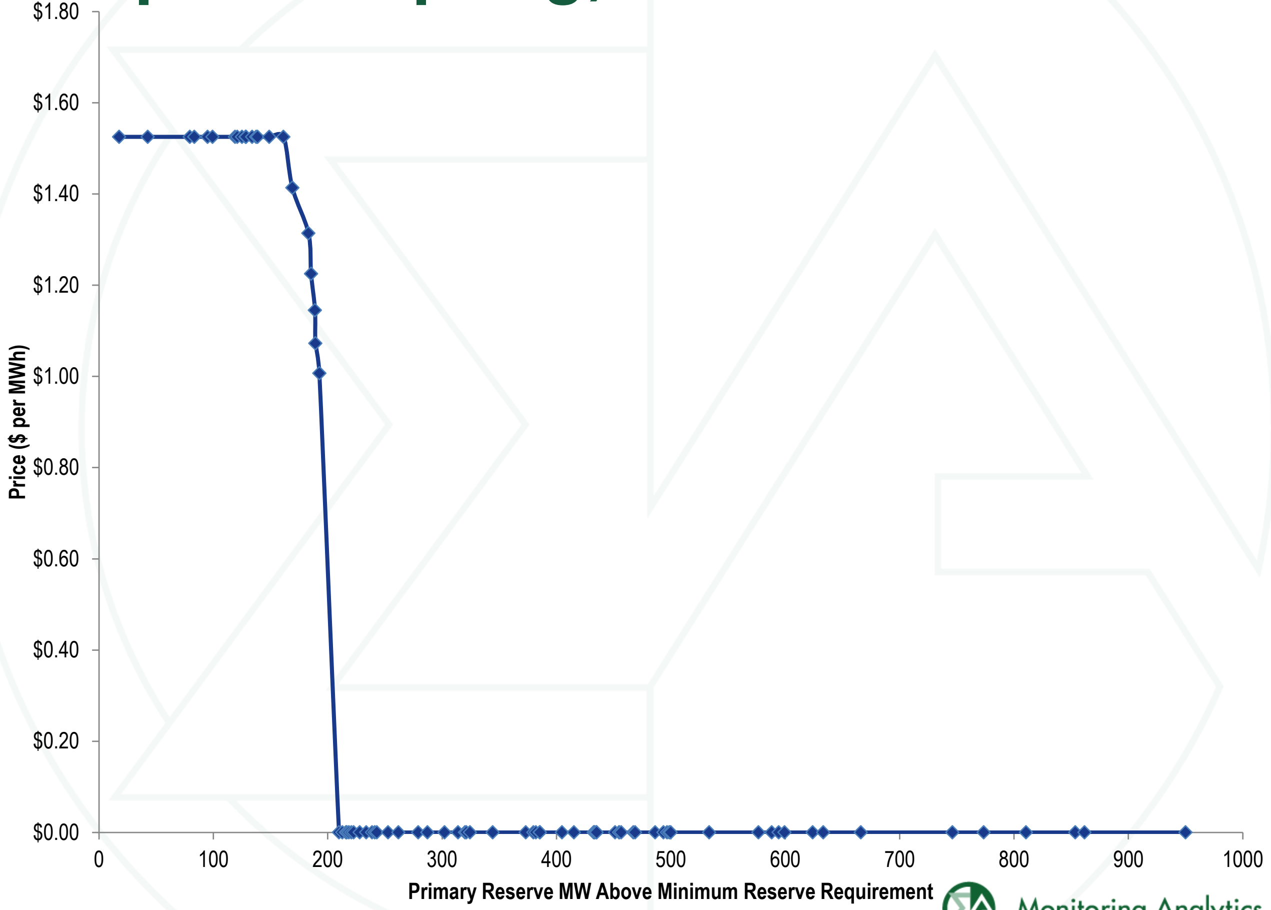
Example for Winter 4PM Load Over 110 GW



Example for Spring, 4PM Load 85 to 90 GW

Additional Reserve MW	Percent of Tight Days Given Reserve Level at 6:00 PM	Difference in Percent Tight Days Given Reserve Level and Overall	Peak Hour Average LMP	Willingness to Pay for Additional Reserves
161.3	6.3%	5.0%	$30.41	$1.53
161.3	6.3%	5.0%	$30.41	$1.53
169.1	5.9%	4.6%	$30.41	$1.41
183.1	5.6%	4.3%	$30.41	$1.31
185.4	5.3%	4.0%	$30.41	$1.22
188.9	5.0%	3.8%	$30.41	$1.15
189.2	4.8%	3.5%	$30.41	$1.07
192.6	4.5%	3.3%	$30.41	$1.01
950.0	1.2%	0.0%	$30.41	$0.00

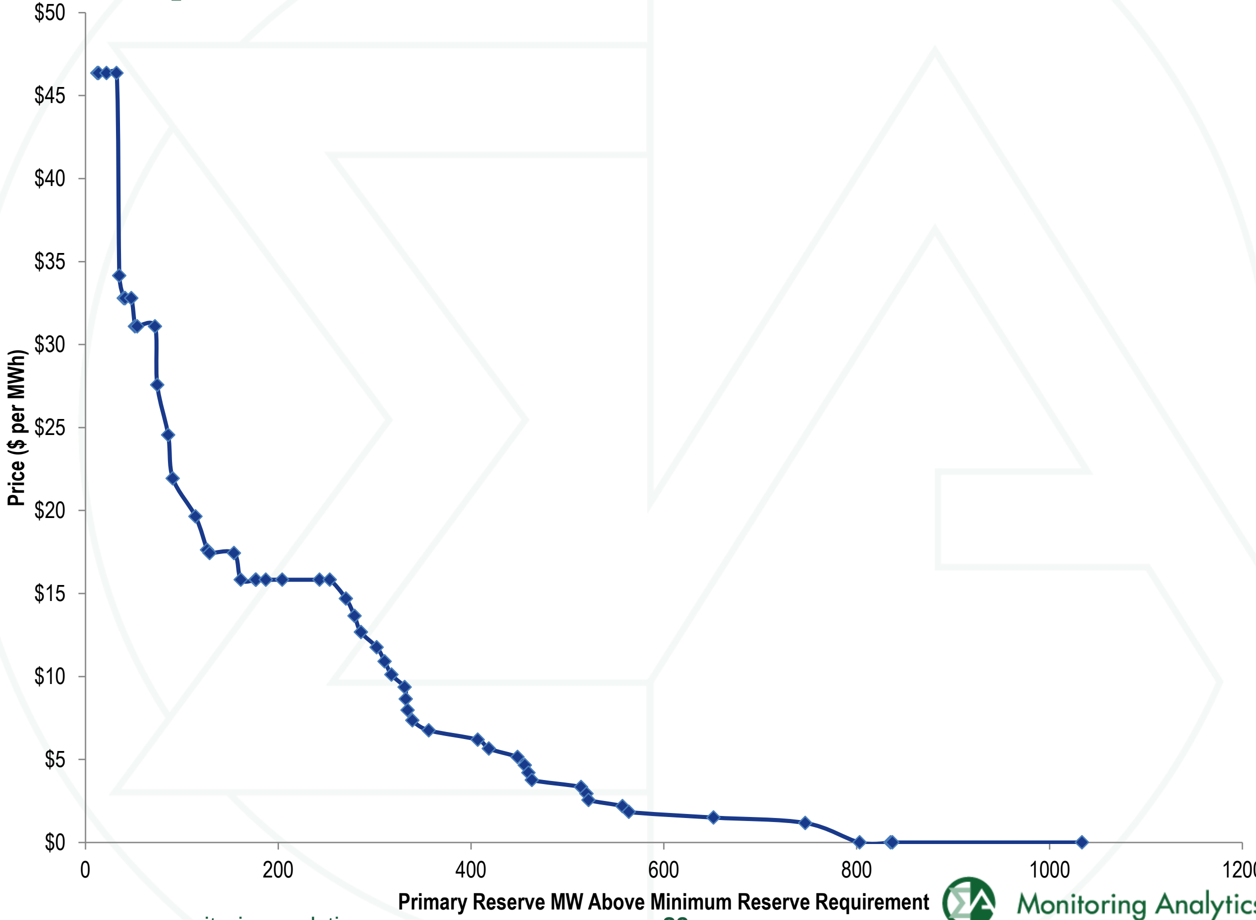
Example for Spring, 4PM Load 85 to 90 GW



Example for Fall, 2PM Load Over 105 GW

Additional Reserve MW	Percent of Tight Days Given Reserve Level at 6:00 PM	Difference in Percent Tight Days Given Reserve Level and Overall	Peak Hour Average LMP	Willingness to Pay for Additional Reserves
12.4	100.0%	75.9%	$61.06	$46.36
35.2	80.0%	55.9%	$61.06	$34.15
51.3	70.0%	45.9%	$61.06	$28.04
85.8	64.3%	40.2%	$61.06	$24.55
126.2	52.9%	28.9%	$61.06	$17.63
176.6	47.6%	23.5%	$61.06	$14.38
279.1	46.4%	22.4%	$61.06	$13.65
339.2	36.1%	12.0%	$61.06	$7.35
459.7	31.0%	6.9%	$61.06	$4.20
557.0	27.7%	3.6%	$61.06	$2.19
651.5	26.5%	2.5%	$61.06	$1.50
746.6	26.0%	1.9%	$61.06	$1.18
1,033.8	24.1%	0.0%	$61.06	$0.00

Example for Fall, 2PM Load Over 105 GW



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