PJM Reserve Market Enhancements to Improve Market Efficiency and Reliability

Patricio Rocha Garrido
Anthony Giacomoni
Adam Keech
Melissa Maxwell
Cheryl Mae Velasco

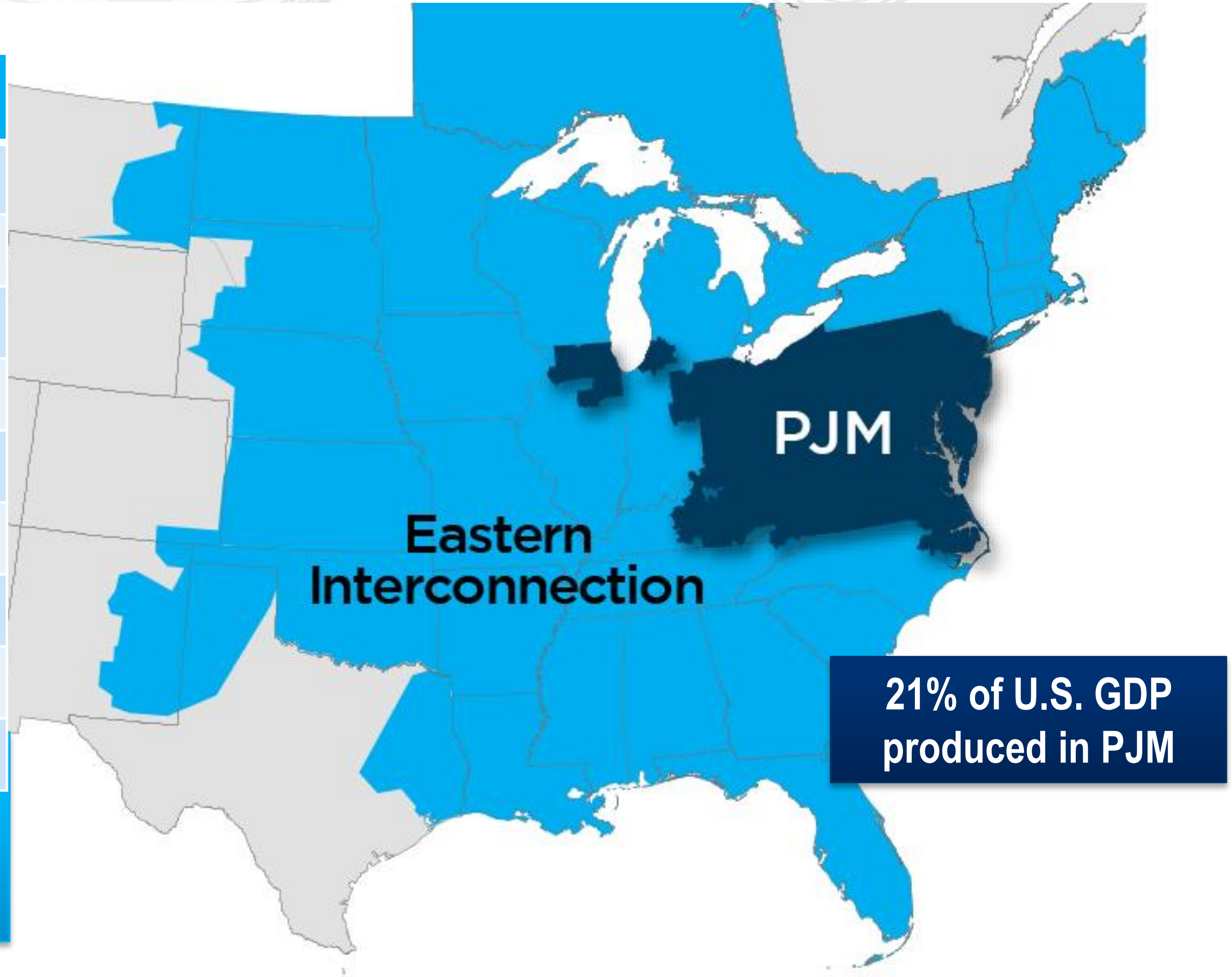
FERC Technical Conference
June 26, 2018

PJM as Part of the Eastern Interconnection

Key Statistics

Member companies	1,040+
Millions of people served	65
Peak load in megawatts	165,492
MW of generating capacity	178,563
Miles of transmission lines	84,042
2017 GWh of annual energy	773,522
Generation sources	1,379
Square miles of territory	243,417
States served	13 + DC

- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection



As of 2/2018

Outline

- Reserve Markets in PJM
- Operating Reserve Demand Curves (ORDC)
  - Reasons for Implementing
  - How to Calculate
  - Preliminary Design
- Bad Day Curves
- Formulation: Current vs. Proposed
- Examples
- Summary
- Questions

- Real-Time Reserve Market has a 10-Minute Primary Reserve Requirement and 10-Minute Synchronized Reserve Requirement
- Currently, 30-Minute Reserves are only procured in the Day-Ahead Market

Day-Ahead Scheduling Reserve
(T ≤ 30 Min)

Real-Time Contingency (Primary) Reserve
(T ≤ 10 Min)

Synchronized Reserve
(Synchronized)

Non-Synchronized Reserve
(Off-Line)

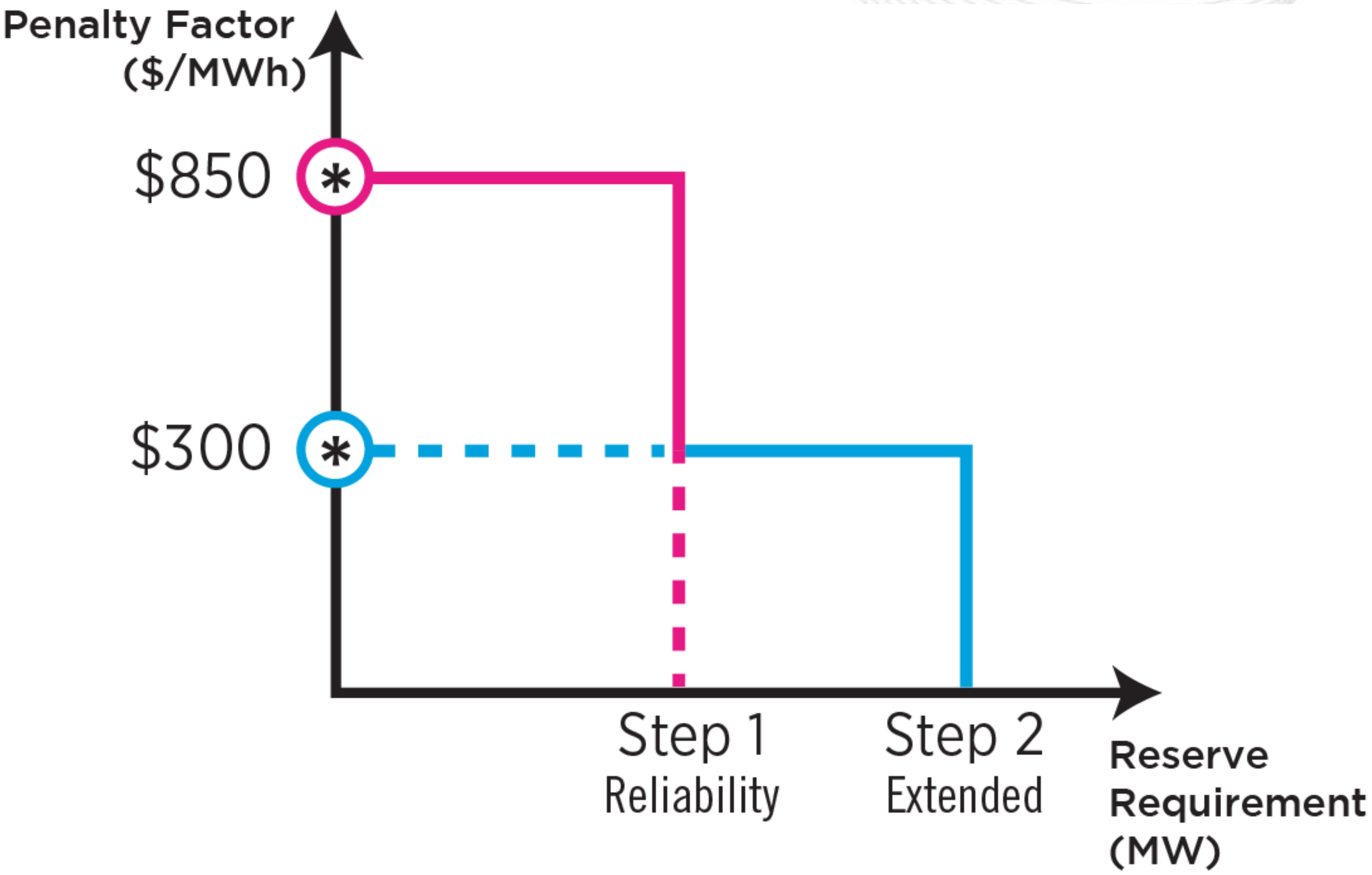
Real-Time
Secondary Reserve
(10 Min ≤ T ≤ 30 Min)

T = Time Interval Following PJM Request

Goal of Proposed Price Formation Enhancements

- Enhance scarcity pricing and implement sloped operating reserve demand curves (ORDCs) so that they better reflect the value of system reliability and provide transparent and efficient price signals to the market

Current Operating Reserve Demand Curve (ORDC)



Step 1 of Demand Curve

- Represents the Reliability Requirement, which is the output of the largest online unit
- Penalty factor for being short Step 1 is $850/MWh

Step 2 of Demand Curve

- Adds 190 MW to the Reliability Requirement
- Also includes an Optional Adder MW that can be used to capture additional reserves that are scheduled for reliability reasons
- Penalty factor for being short Step 2 is $300/MWh

Reasons for Implementing Sloped ORDCs

- Penalty Factor (for either Synchronized or Primary Reserves) falls to $0/MWh if the total MW reserves in the system are greater than the sum of Step 1 and Step 2 (even by 1 MW)
  - This indicates that additional reserves have no value. Additional reserves, however, provide reliability value in that they reduce the chance of falling below the minimum reserve requirement and the chance of a loss-of-load event.

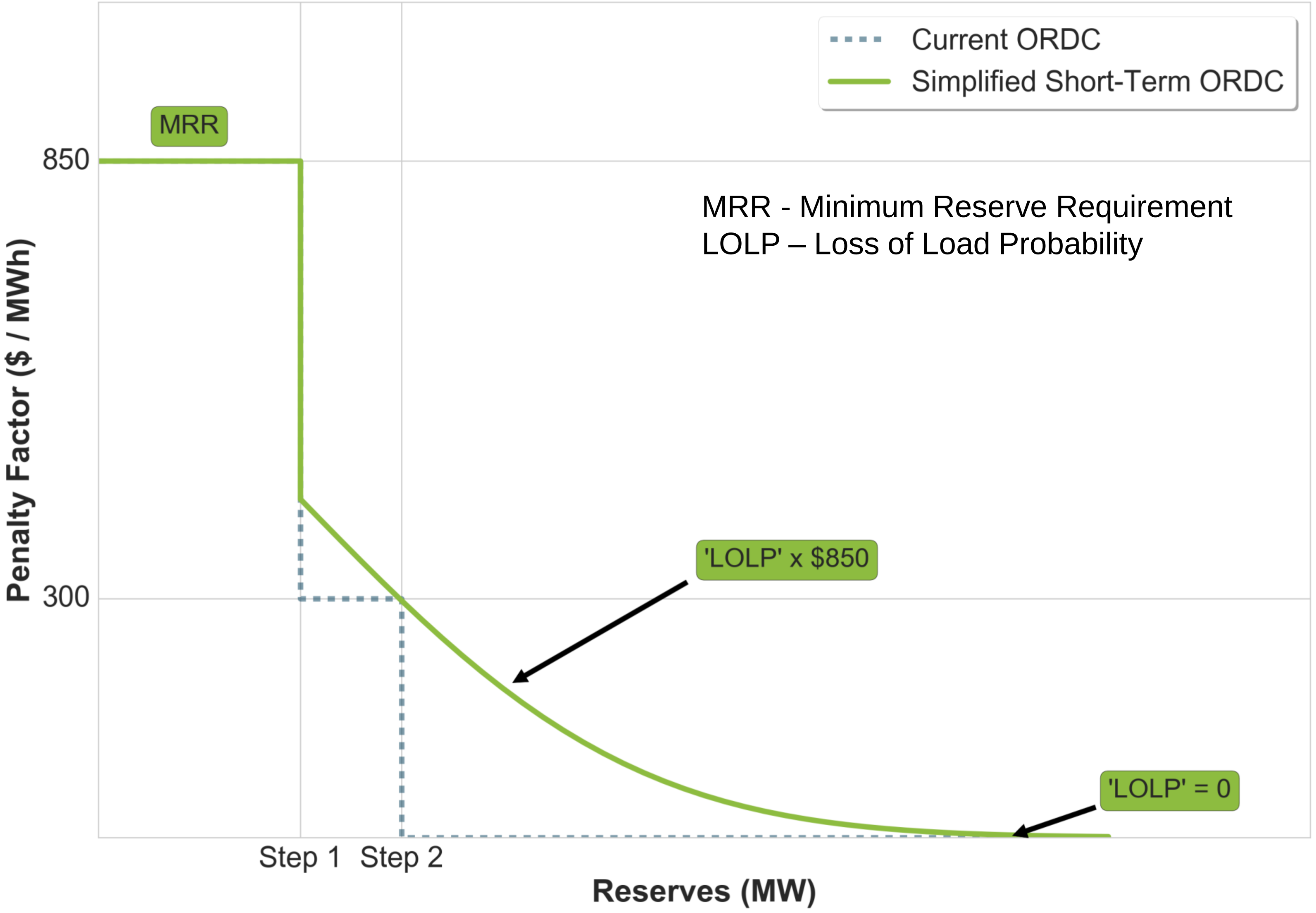
- Shifting revenues from the Capacity Market to the Energy and Ancillary Services market

- The current largest penalty factor ($850/MWh) is based on the average cost of reserves during shortage events in 2007

What is an Operating Reserve Demand Curve?

- An ORDC is, as its name indicates, a demand curve
  - Therefore, it establishes a relationship between prices and quantities.
  - It is meant to represent customers' willingness to pay for varying quantities of reserves. As per unit prices fall, customers are willing to consume more.
  - The benefit that consumers get from procuring reserves is a function of the value of avoiding involuntary load curtailments and emergency actions.

What is an Operating Reserve Demand Curve?



What is an Operating Reserve Demand Curve?

- Key concepts -
  - “Loss of Load” Definition:
    - For ORDC purposes, Loss of Load may not necessarily refer to an event in which reserves are less than 0 MW
    - Instead, it may refer to an event in which the amount of reserves is less than a Minimum Reserve Requirement (MRR). If reserves fall below this MRR, emergency actions are triggered, which may be a precursor to load curtailment.

What is an Operating Reserve Demand Curve?

- Key concepts -
  - "Loss of Load" Probability (LOLP) or Probability of Reserves Falling Below the Minimum Reserve Requirement (PBMRR):
    - For example, the MRR is 2,400 MW and the difference between available capacity and forecasted load 30-minutes before the target time is 2,700 MW.
    - In this example, the system has 300 MW of excess reserves 30-minutes ahead. However, this is just an estimate since things can change in the next 30 minutes.
    - If these uncertainties are quantified, then the PBMRR associated with 2,700 MW of reserves can be calculated.

How to Calculate a Sloped ORDC?

- The Sloped ORDC will be constructed for both Synchronized Reserves (SR) and Primary Reserves (PR)
  - Both requirements are met with resources expected to respond within the next 10 minutes from the target time

- Since reserve assignments are made 10 minutes prior to the target time, a 30 minute look-ahead uncertainty interval is reasonable to account for the total time elapsed between the reserve assignment and the reserves' response time.

How to Calculate a Sloped ORDC?

- The uncertainties to be included in the calculation should be those that impact the PBMRR for SR or PR, given the fact that 30 minutes ahead X MW of reserves are available
  - Uncertainties:
    - Load forecast
    - Wind forecast
    - Solar forecast
    - Forced outages for thermal units

- To estimate the 30-min. uncertainty distributions for load, wind, and solar, historical data is used; to estimate the 30-min. uncertainty due to forced outages, a theoretical approach is used based on individual unit performance historical data.

How to Calculate a Sloped ORDC?

- 30-minute **Load** Uncertainty

Season	TBlock	Mean (MW)	StDev (MW)
Fall	1	-16.5	259.6
Fall	2	20.1	464.6
Fall	3	-34.1	389.5
Fall	4	-12.5	303.3
Fall	5	55.6	539.8
Fall	6	-32.1	550.6
Spring	1	-73.1	268.1
Spring	2	-53.3	441
Spring	3	56.8	415.7
Spring	4	24.7	298.8
Spring	5	-71.2	440.6
Spring	6	108.2	611.9
Summer	1	-14.4	277.7
Summer	2	-34.1	427.2
Summer	3	-45.5	429.5
Summer	4	-59	395.1
Summer	5	55.2	463.9
Summer	6	47.6	541
Winter	1	-39.4	331.9
Winter	2	-21.9	513.5
Winter	3	70.1	482
Winter	4	22.5	375.8
Winter	5	9.1	615.7
Winter	6	10.6	380.8

$$Error = Actual - Forecast$$

Therefore,

Positive errors indicate under-forecasting
Negative errors indicate over-forecasting

(2015 - 2017 data)

Time-of-Day Blocks:

1 (2300-0200)
2 (0300-0600)
3 (0700-1000)
4 (1100-1400)
5 (1500-1800)
6 (1900-2200)

How to Calculate a Sloped ORDC?

- 30-minute **Wind** Uncertainty

Season	TBlock	Mean (MW)	StDev (MW)
Fall	1	-121.8	210
Fall	2	-129.6	202.1
Fall	3	-130.7	222.2
Fall	4	-82.6	216.9
Fall	5	-119.9	220.8
Fall	6	-76.1	234.4
Spring	1	-104.6	238.9
Spring	2	-126.7	234.6
Spring	3	-120.8	245.8
Spring	4	-101.3	261.8
Spring	5	-103.5	236.3
Spring	6	-123.3	266.8
Summer	1	-59.7	204.8
Summer	2	-71.3	180.2
Summer	3	-100.5	180.4
Summer	4	-57	190.8
Summer	5	-69.7	189.4
Summer	6	-77.3	216.3
Winter	1	-176.6	256.7
Winter	2	-177.5	247.7
Winter	3	-160	253
Winter	4	-150.8	250.8
Winter	5	-154.4	275.8
Winter	6	-130.9	279.9

$$Error = Actual\ - Forecast$$

Therefore,

Positive errors indicate under-forecasting
Negative errors indicate over-forecasting

(2015 - 2017 data)

Time-of-Day Blocks:

1 (2300-0200)
2 (0300-0600)
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6 (1900-2200)

How to Calculate a Sloped ORDC?

- 30-minute **Solar** Uncertainty

Season	TBlock	Mean (MW)	StDev (MW)
Fall	2	2.8	3.7
Fall	3	0.6	39
Fall	4	-29.2	46
Fall	5	-18.4	31.2
Fall	6	3.4	6.3
Spring	1	1.3	0.6
Spring	2	1.9	5.6
Spring	3	-3.8	33.5
Spring	4	-16	39.6
Spring	5	-18	36.6
Spring	6	3.2	4.8
Summer	2	-3.6	8.8
Summer	3	-3.2	30.1
Summer	4	-26	37.2
Summer	5	-32.4	33.7
Summer	6	-2.1	10.2
Winter	2	1.3	1.1
Winter	3	11.4	46.2
Winter	4	14.6	53.7
Winter	5	4.4	23.4

$$Error = Actual - Forecast$$

Therefore,

Positive errors indicate under-forecasting
Negative errors indicate over-forecasting

(2017 data)

Time-of-Day Blocks:

1 (2300-0200)
2 (0300-0600)
3 (0700-1000)
4 (1100-1400)
5 (1500-1800)
6 (1900-2200)

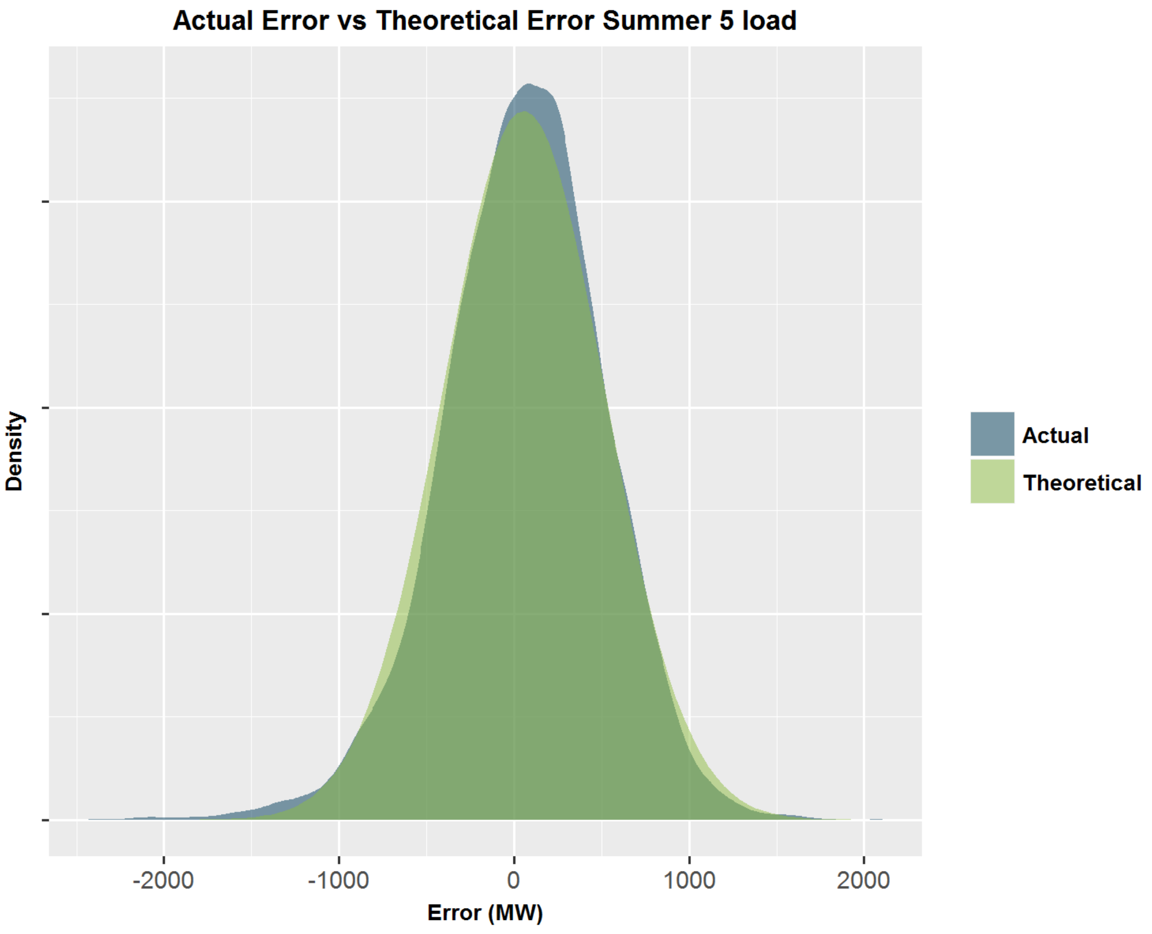
- 30-min. **Forced Outage** Uncertainty:
  - For each unit in the PJM fleet, the *mean time to failure* can be computed using Generating Availability Data System (GADS) data
    - $Mean\ Time\ to\ Failure = \dfrac{Number\ of\ Service\ Hours}{Number\ of\ Full\ Forced\ Outages}$
  - Time a unit is in service, not in a forced outage, can be modeled as a random variable with an exponential distribution
    - The mean in this exponential distribution is the *mean time to failure* of each unit

- 30-min. **Forced Outage** Uncertainty:
  - The individual probabilities can be added using convolution to derive an aggregate unavailable capacity distribution.
  - The RTO-aggregate unavailable capacity distribution calculated using units that have Capacity Interconnection Rights results in a mean unavailability rate of 0.24% and a standard deviation of 0.16%.

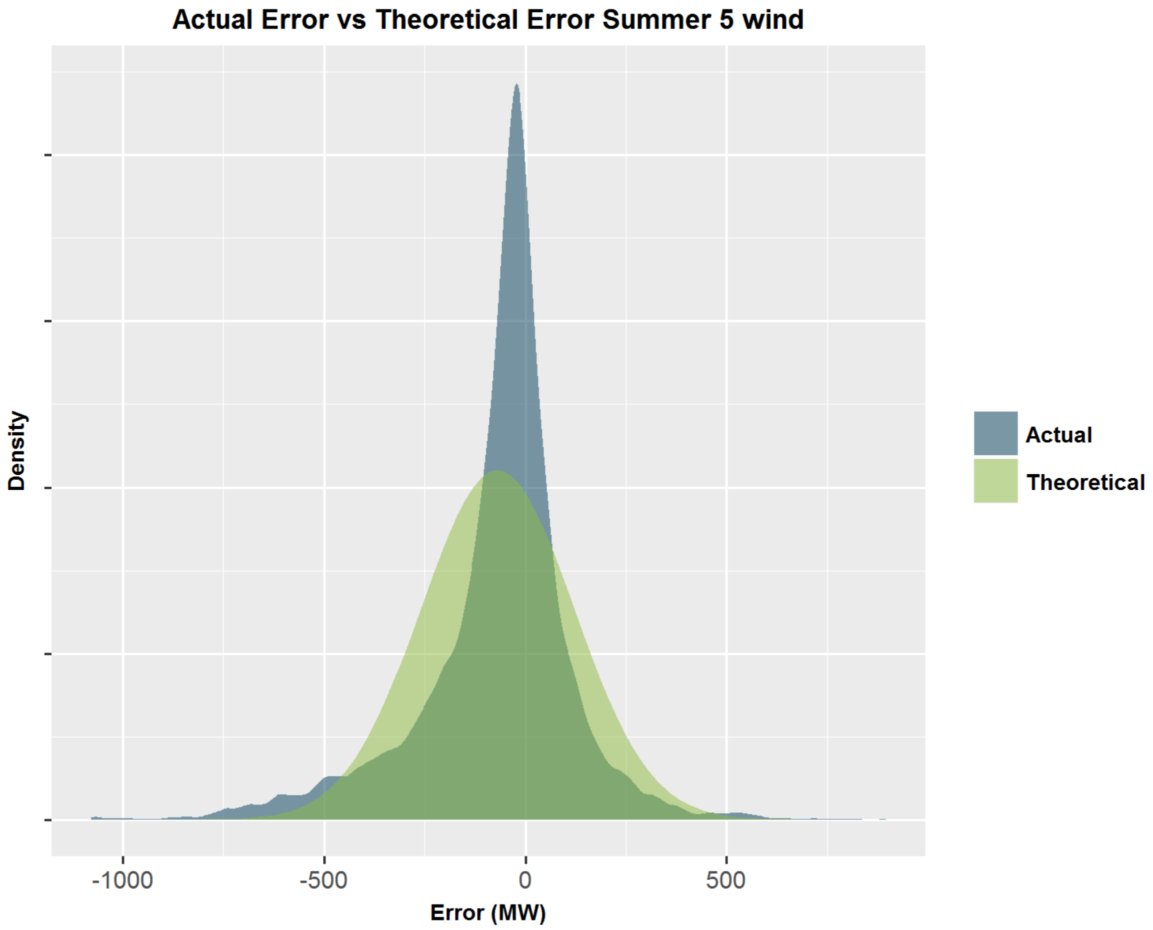
How to Calculate a Sloped ORDC?

- If the individual 30-min. uncertainties are assumed to be normally distributed, then the total 30-min. uncertainty is also normally distributed with the following parameters:
  - Mean is equal to the sum of the individual mean errors (adjusting for the sign of the error depending on the type of error, e.g., load under-forecasting and wind over-forecasting makes the total error worse)
  - Standard Deviation is equal to the square root of the total variance. The total variance is the sum of the individual variances adjusted by the potential correlation of the uncertainties (via the covariances)

Load & Wind Actual Forecast Error vs. Normal Distribution

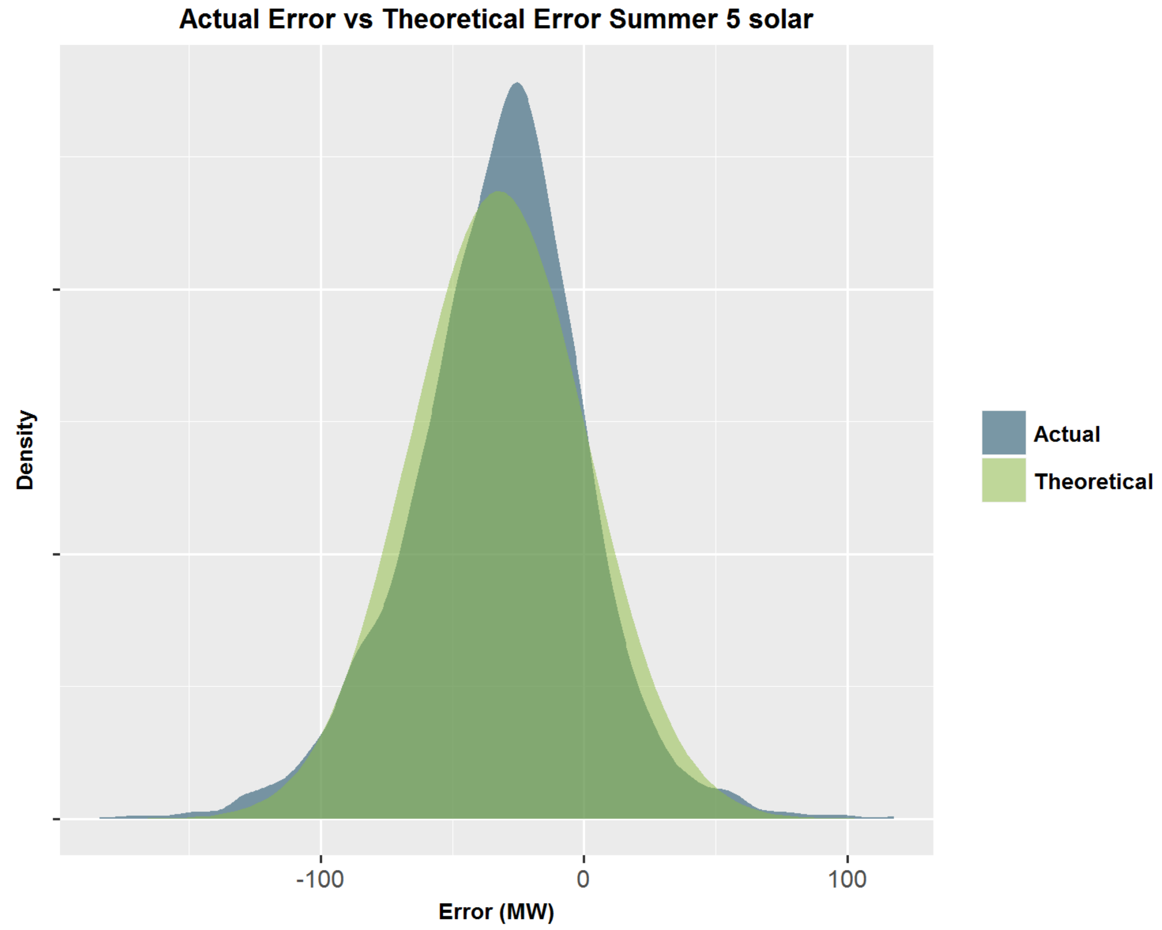


Load

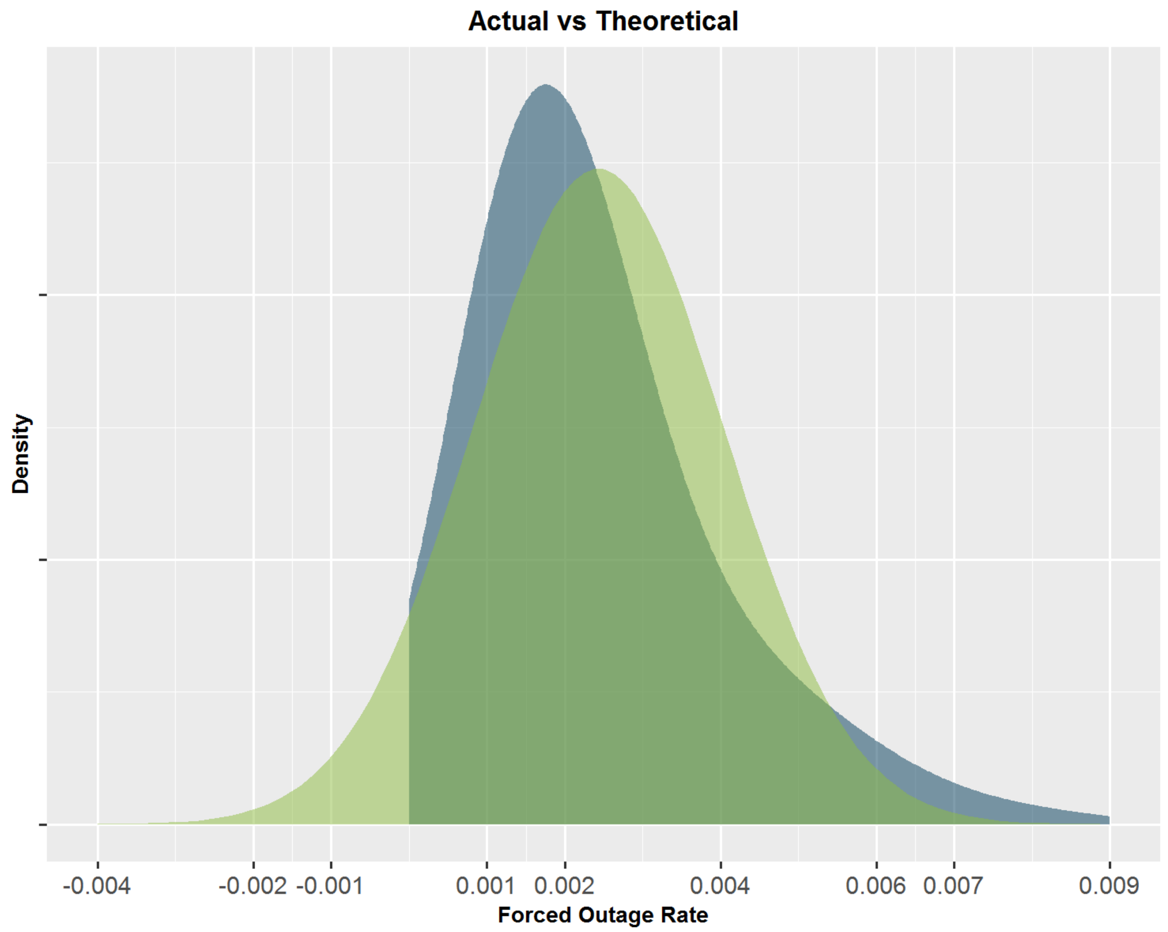


Wind

Solar & Forced Outages Actual Error vs. Normal Distribution

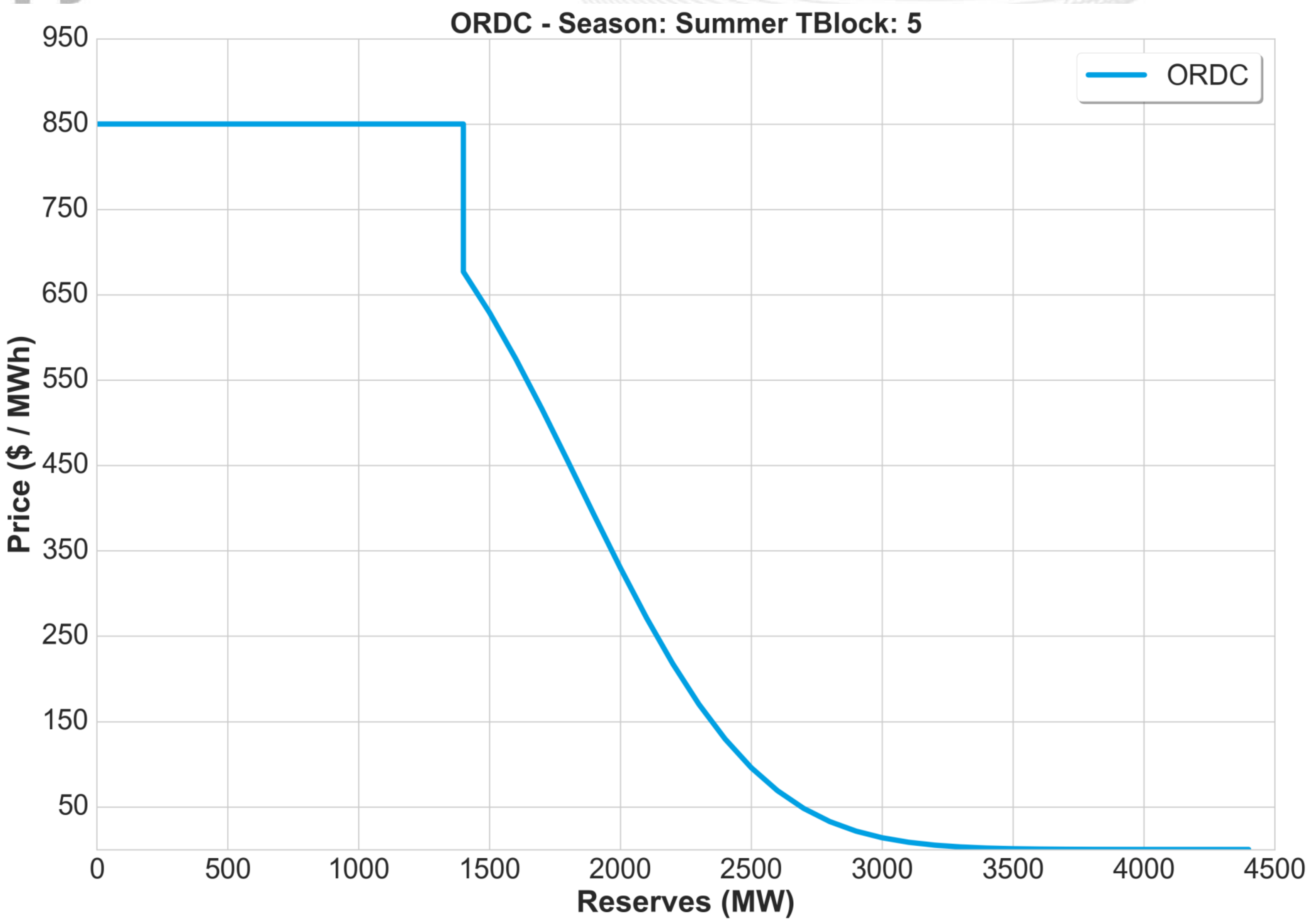


Solar



Forced Outages

Preliminary ORDC

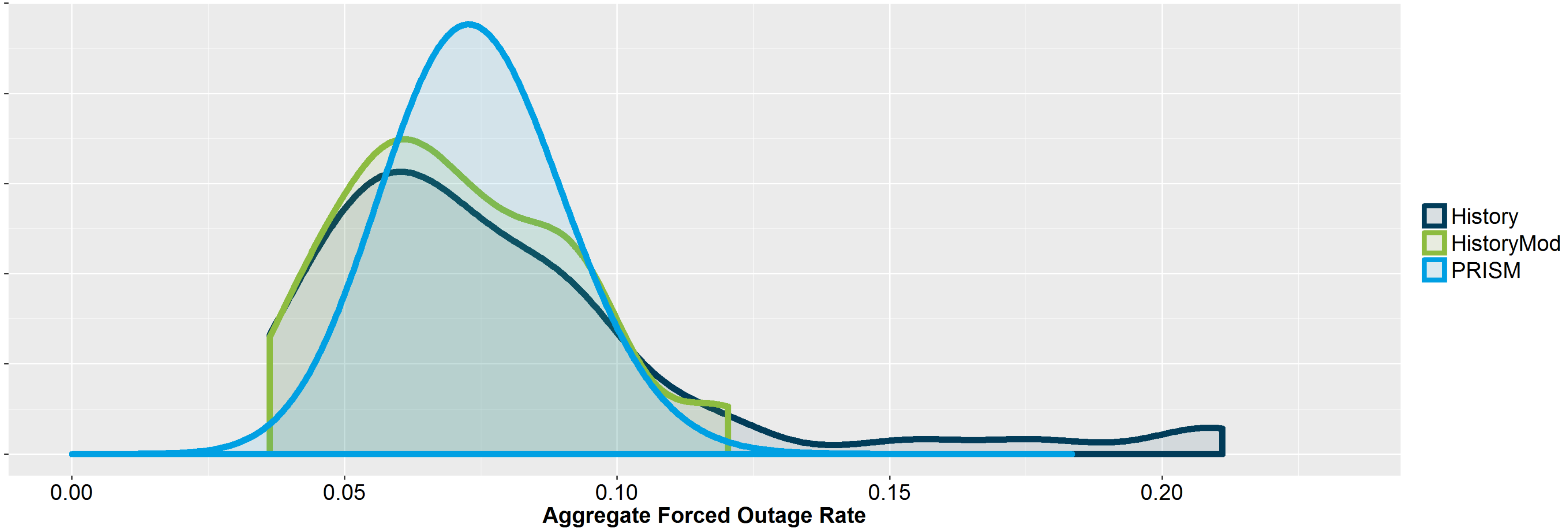


ORDC for Synchronized Reserves

Minimum Reserve Requirement = 1,400 MW

- The assumption to derive the 30-min. RTO-aggregate unavailable capacity distribution is that forced outages are independent. However, when extreme cold weather occurs, this assumption does not hold.

RTO Aggregate Forced Outages at Winter Peak – Density plot (DY 2007 – DY 2017)



- Adjustments to the 30-min. RTO-aggregate unavailable capacity distribution need to be performed in order to account for the larger volume of concurrent forced outages that may occur

- Historical aggregate force outage levels may be used to come up with such adjustments

Reserves Formulation: Current vs. Proposed

- Consider the co-optimization of energy and reserves for a single period with fixed demand for energy and:
  - A penalty curve for reserves with S steps ending at l_s each and decremental penalties F_s in each step (**Current Scenario**)
  - An ORDC curve with S steps ending at l_s each and decremental benefits B_s of using u_s reserves in each step (**Proposed Scenario**)
  - Let $F_s = B_s$ for each s in S
  - Where:
    - G is the set of generators
    - c_i is the energy offer from resource i (parameter)
    - p_i, r_i are the energy and reserve assignments to resource $i,$ respectively (decision variables)
    - x_s is the shortage in step s in the Current formulation (decision variable)
    - u_s is the reserves utilized in step s in the Proposed formulation (decision variable)

Reserves Formulation: Current vs. Proposed

Current Formulation

$$Min \sum_{i \in G} c_i p_i + \sum_{s \in S} F_s x_s$$

Subject to:

$$\sum_{i \in G} r_i + x_s \geq l_s, \qquad \forall\, s \qquad (1)$$

& other energy and reserve constraints

Proposed Formulation

$$Min \sum_{i \in G} c_i p_i - \sum_{s \in S} B_s u_s$$

Subject to:

$$u_s \leq l_s, \qquad \forall\, s \qquad (1)$$

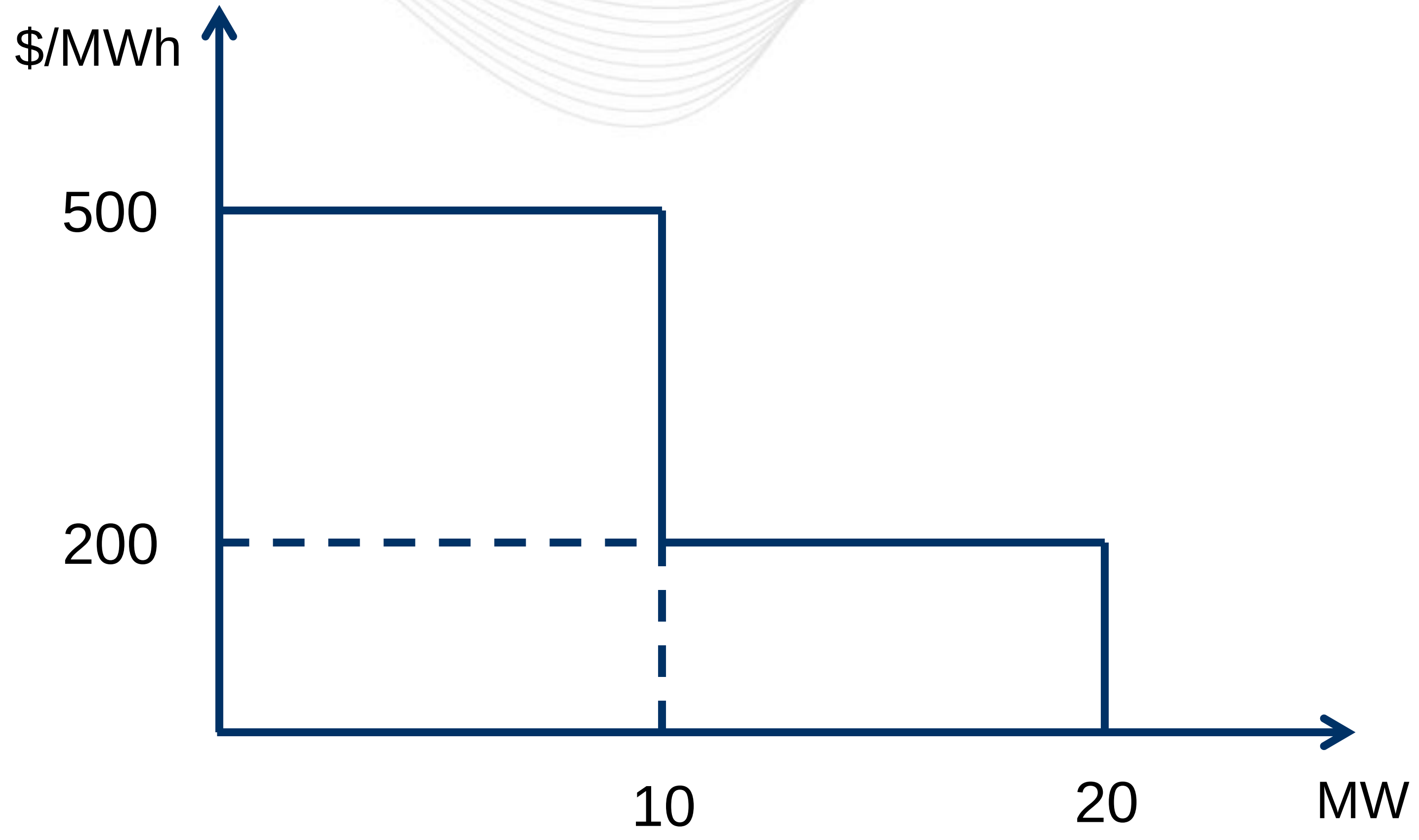
$$u_s \leq \sum_{i \in G} r_i\,, \qquad \forall s \qquad (2)$$

& other energy and reserve constraints

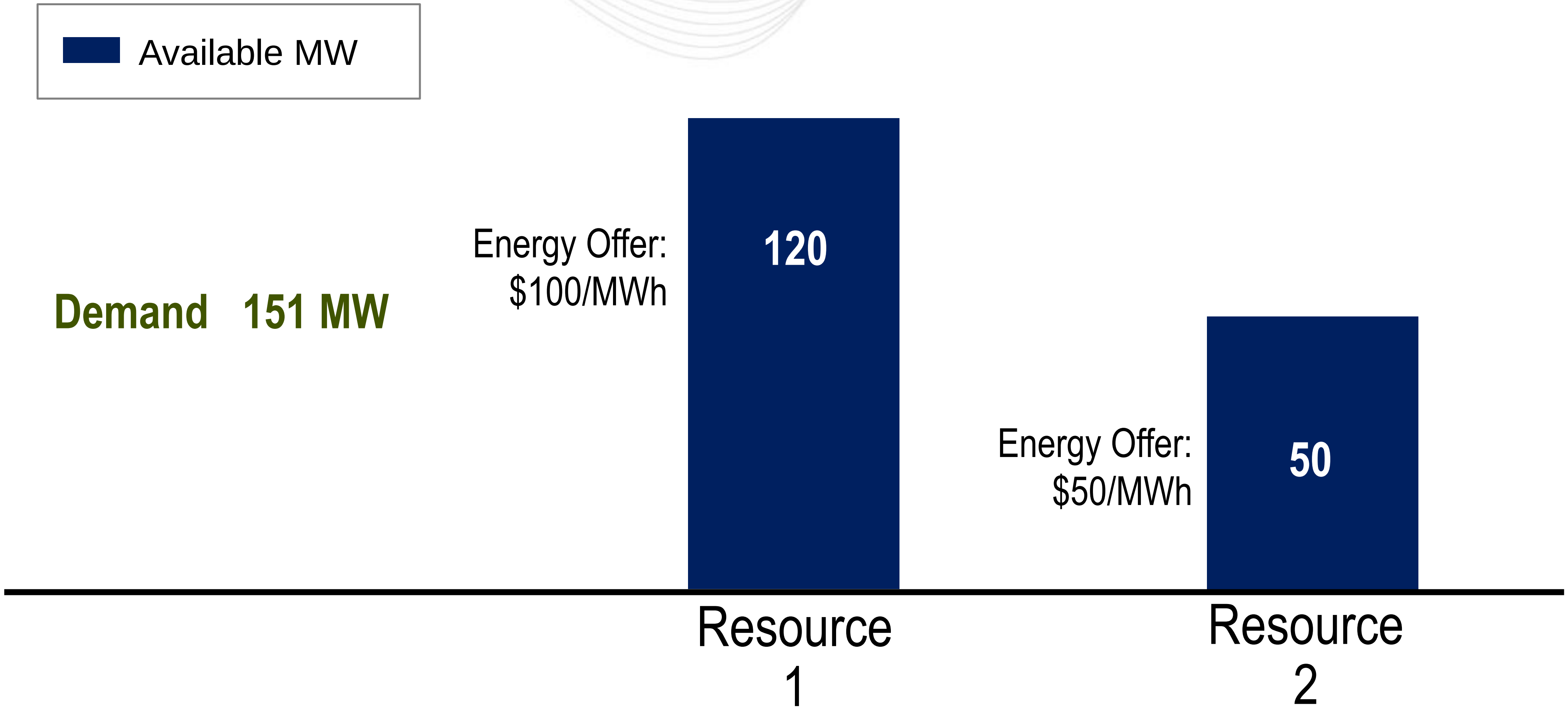
The two formulations are equivalent.

When (2) in the Proposed Formulation binds, we get $u_s = \sum_{i \in G} r_i$; using (1) in the Proposed Formulation, $\sum_{i \in G} r_i \leq l_{s\_max}$. In the Current Formulation, x_s is non-zero only when l_{s_max} - $\sum_{i \in G} r_i > 0$. In both formulations, $\sum_{i \in G} r_i$ will be as close to l_{s_max} as possible.

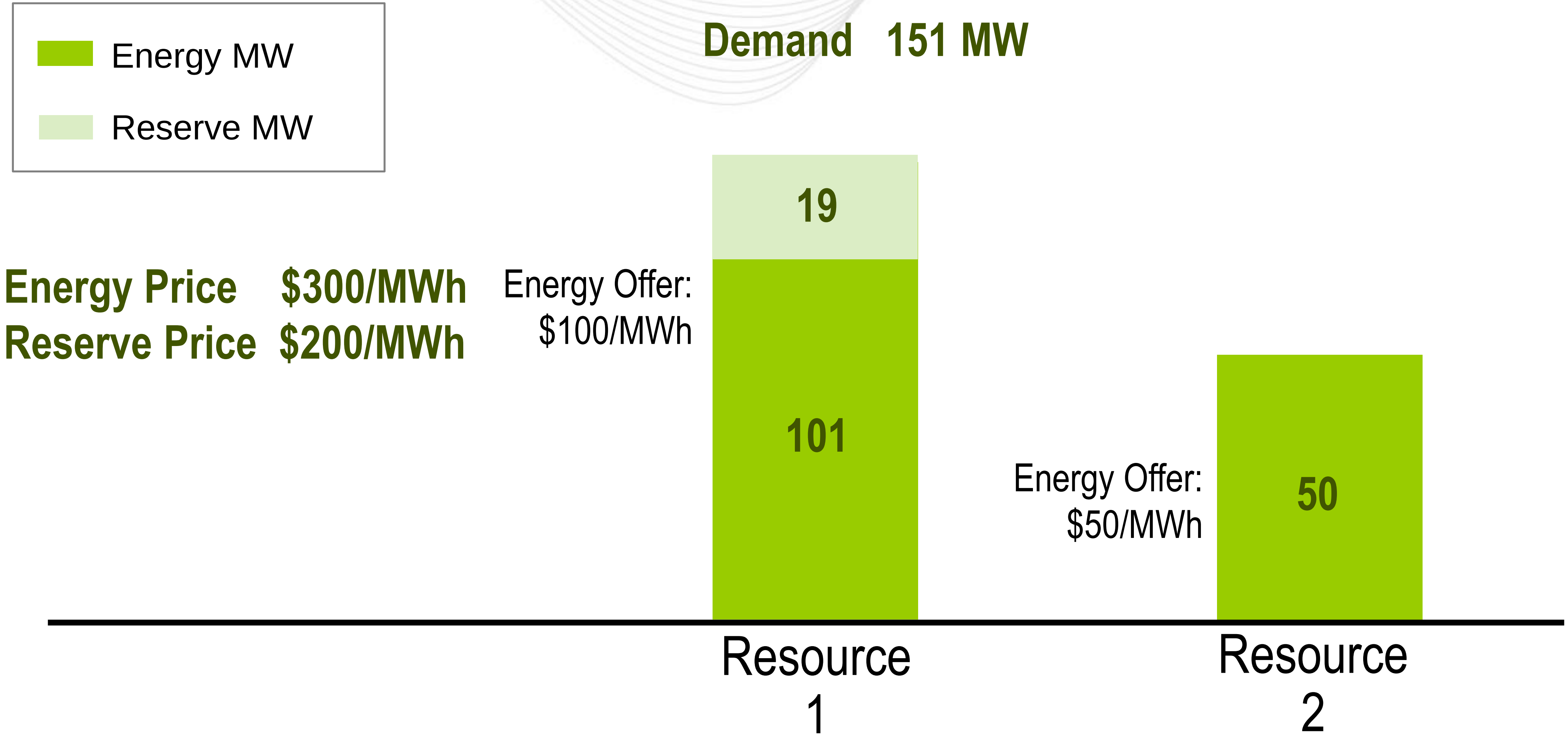
Example: ORDC



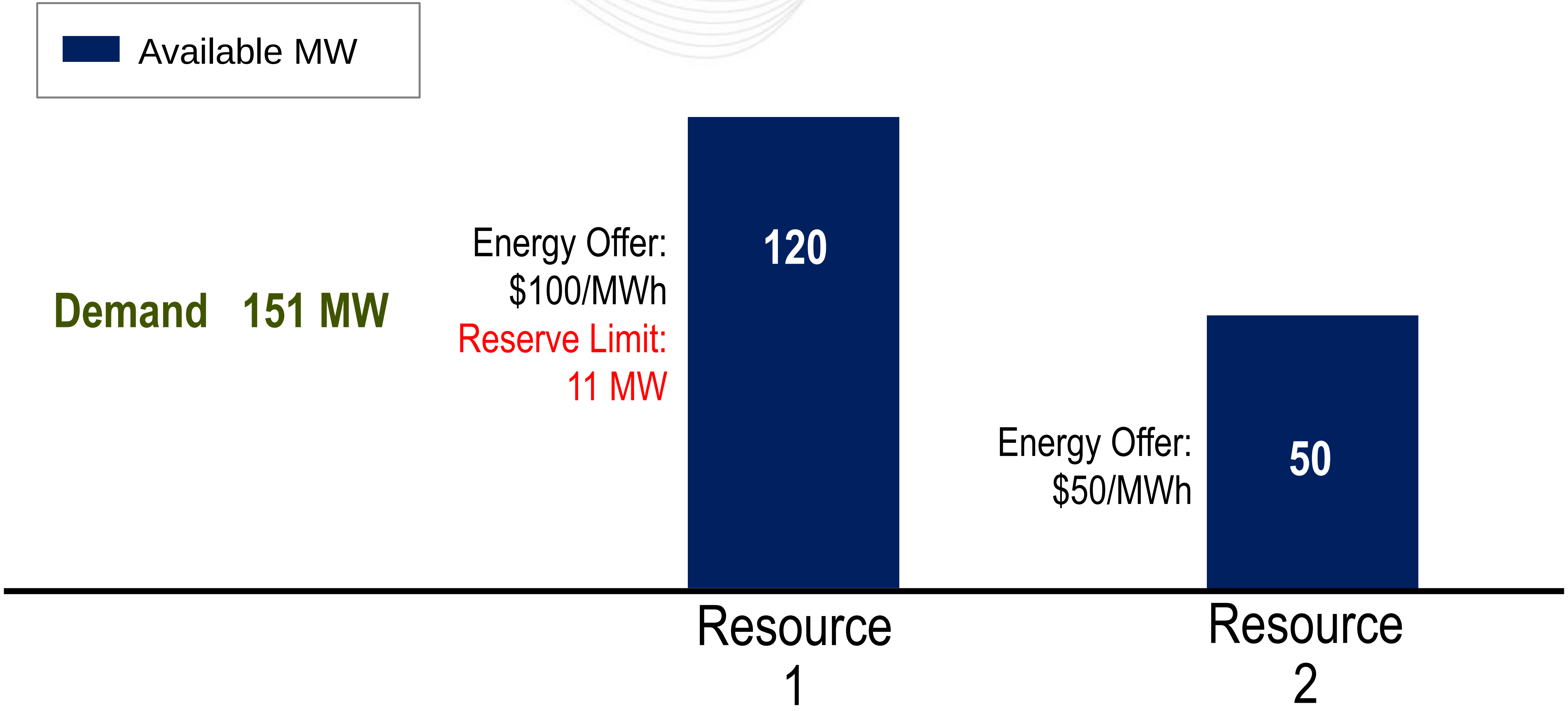
Example #1: Offers



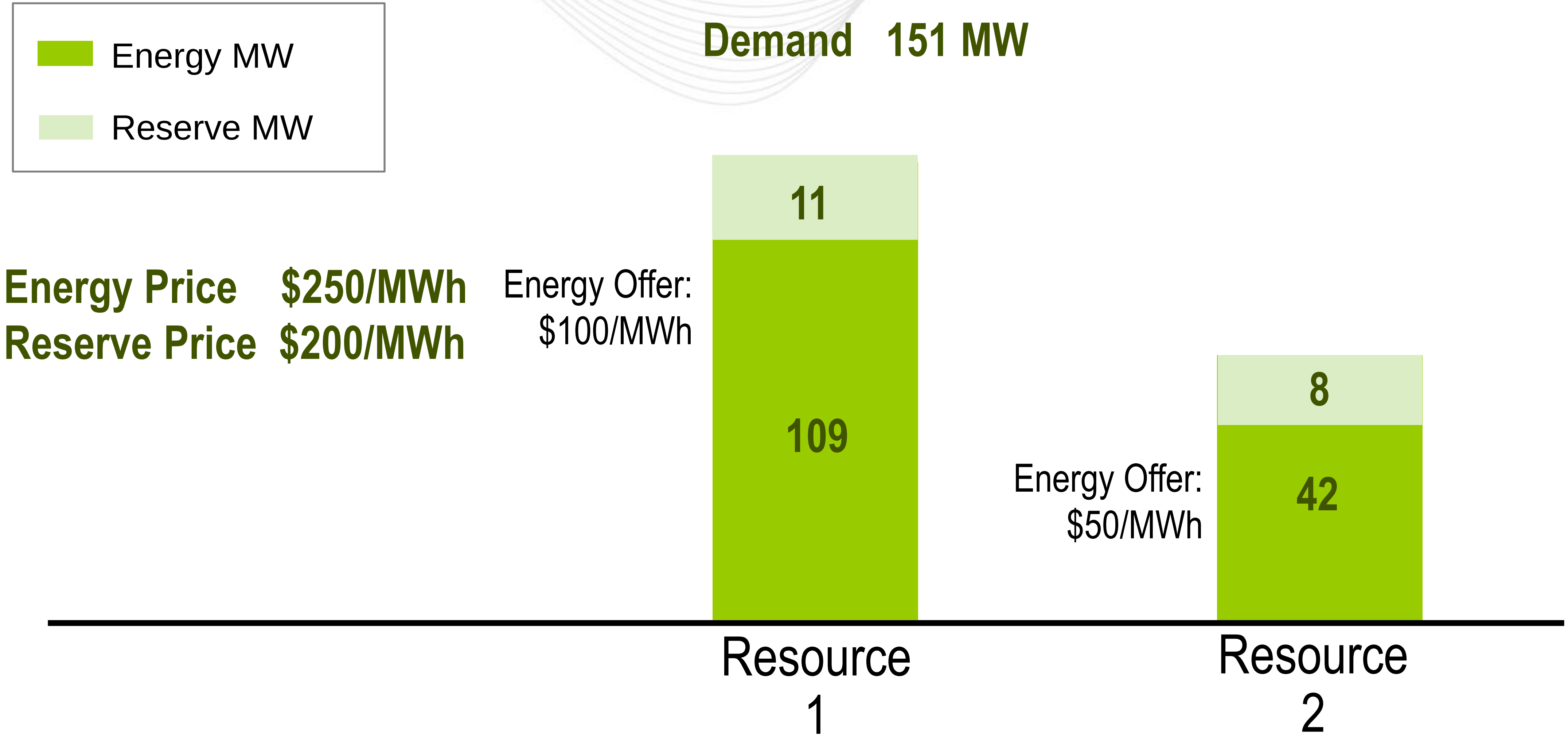
Example #1: Results



Example #2 – Ramp Constrained: Offers



Example #2: Results



Summary

- Current operating reserve demand curve (ORDC) does not value reserves beyond the minimum reserve requirement (MRR)

- Adding a sloped demand curve will better reflect the value reserves provide to system reliability and provide transparent and efficient price signals to the market

- Uncertainty in the forecasted reserves needs to be quantified in order to calculate the probability of reserves falling below the minimum reserve requirement (PBMRR)