ORDC Supplemental Information – Part II

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Multiple Reserve Products - Product Substitution

Synch Reserves → Product Substitution → Primary Reserves

When MWs from a single product can be used to meet the requirements for multiple products

Synchronized Reserves

Requirement 1,450 MW

Available: 2,000 MW
Cleared: 1,450 MW
Remaining: 550 MW

Primary Reserves

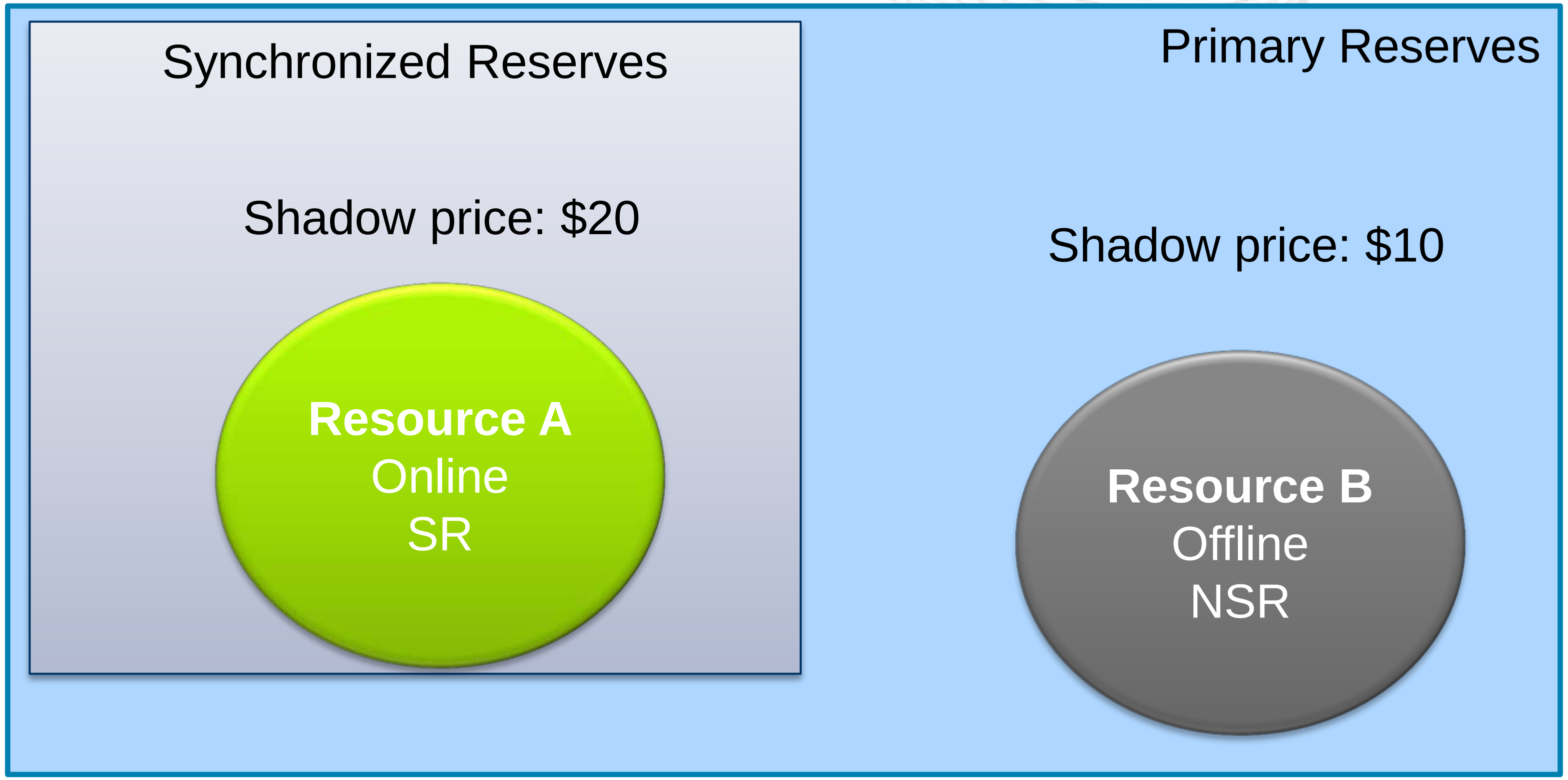
Requirement	2,175 MW
SR	-1,450 MW
	725 MW

Cleared based on most economic set

Note: Since Synchronized Reserves can be used to meet the Primary Reserve requirements, the SR clearing price must be at least as great as the NSR clearing price.

SR Price >= NSR Price

Multiple Reserve Products - Cascading Effect On Price



SRMCP = SR Shadow Price
+
PR Shadow Price

NSRMCP = PR Shadow Price

A is paid $30/MW

B is paid $10/MW

Multiple Reserve Products – Co-optimization of Energy and Reserves

- In previous presentations, we have stated that the objective function of the co-optimization of energy and reserves is

  Min (Energy Cost – Benefit of Reserves)

  – We have shown that the co-optimization reflects the trade off between energy and reserves
- If there are two reserve products, Synchronized Reserves (SR) and Primary Reserves (PR), then the objective function is

  Min (Energy Cost – Benefit of SR – Benefit of PR)

  – This objective function now reflects the trade-off between energy, SR and PR

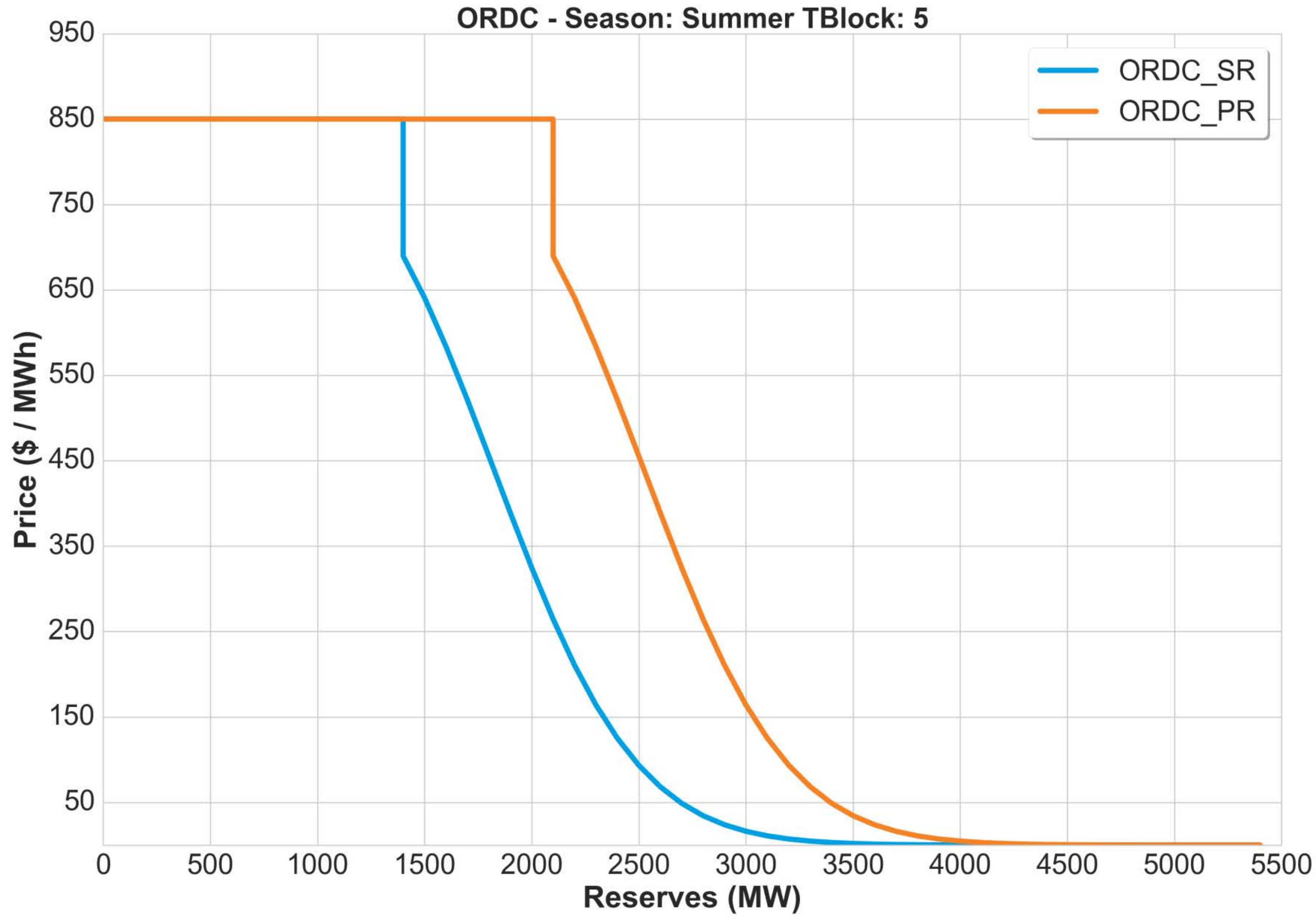
ORDC for SR and PR

- SR and PR are both expected to respond within 10 minutes of the target time
  - Therefore, the same 30 minute look-ahead uncertainty interval can be used to derive the ORDC for each of the products. The Total Forecast Error distribution is thus identical for the PBMRR calculation of SR and PR
  - However, the MRR for PR is larger than the MRR for SR.
- Therefore, for a given combination Season - Time-of-Day Block, the ORDC for PR will have the same downward-sloping shape as the ORDC for SR but the entire curve will be shifted to the right by an amount equal to the difference in MRR between PR and SR
  - This is also the case because the maximum Penalty Factors for both SR and PR are set at $850 per MWh

- For example, let's assume that the MRR for SR is 1,400 MW and the MRR for PR is 2,100
  - If we are interested in calculating the PBMRR for PR associated with a reserve level equal to 2,200 MW
  - The calculation boils down to

    PBMRR PR (2,200) = Probability Total Forecast Error is greater than 2,200 minus 2,100 (MRR For PR) = Probability (TFE > 100)
  - This is equivalent to the calculation of the PBMRR for SR associated with a reserve level equal to 1,500 MW
  - PBMRR SR (1500) = PBMRR PR (2,200)
  - Since the maximum penalty factors for SR and PR are both $850 per MWh, then the price associated with a SR reserve level equal to 1,500 MW is identical to the price associated with a PR reserve level equal to 2,200 MW

ORDC for SR and OR – Summer – Time-of-Day Block 5

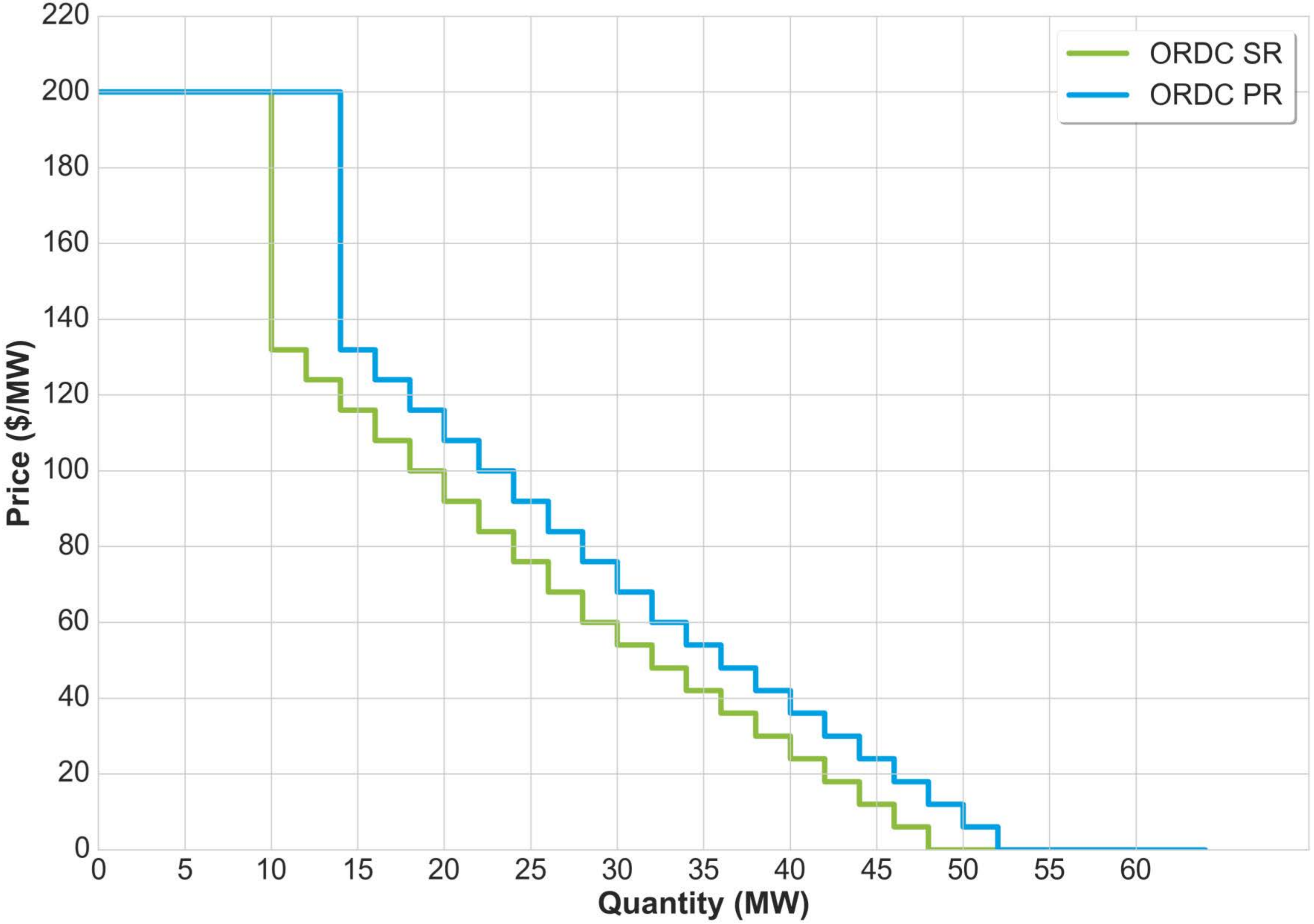


Assuming,

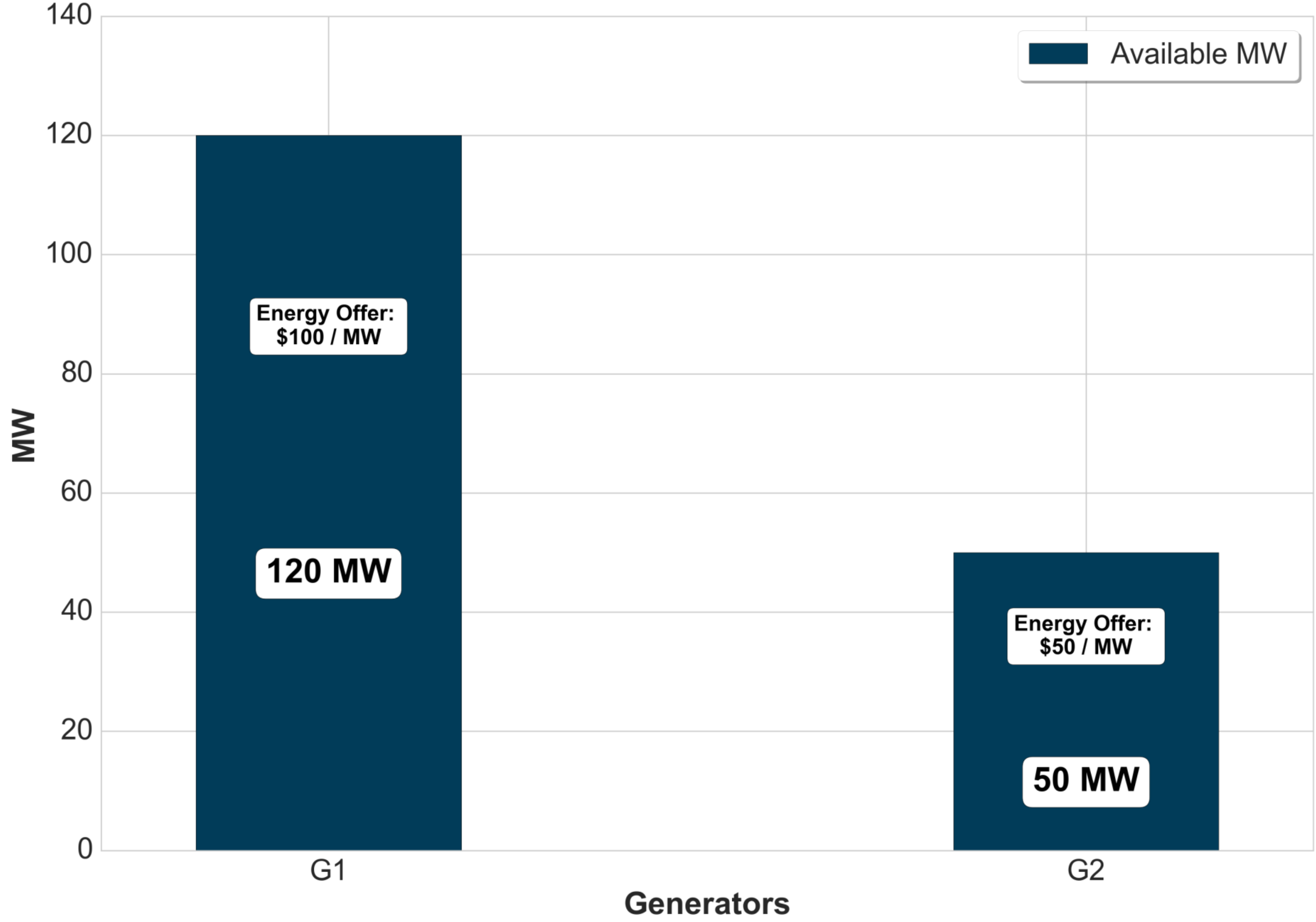
MRR SR	**1,400 MW**
MRR PR	**2,100 MW**

Energy, SR, and PR Co-Optimization Examples

SR and PR ORDCs

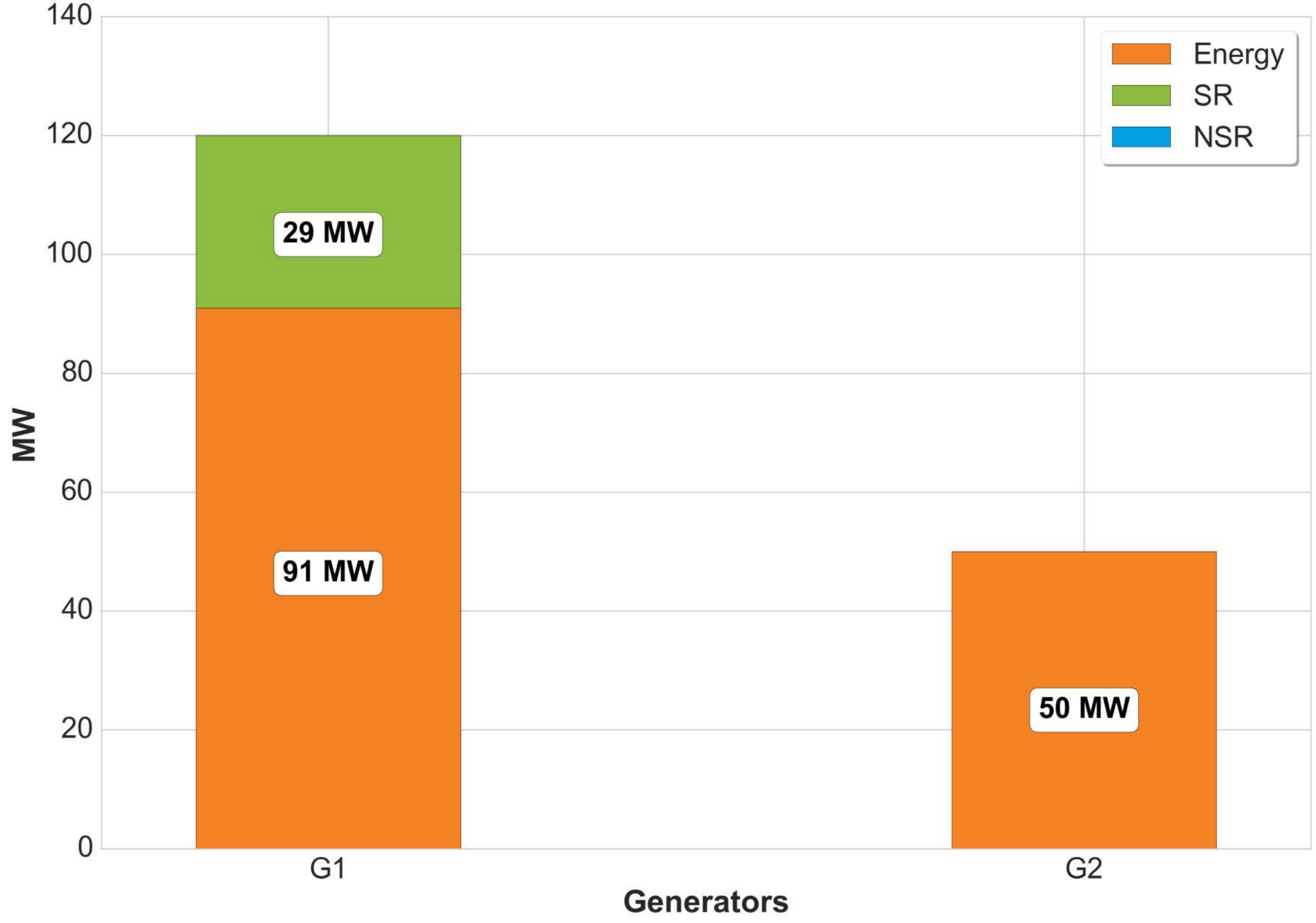


Example #1: Capacity Constrained / No NSR



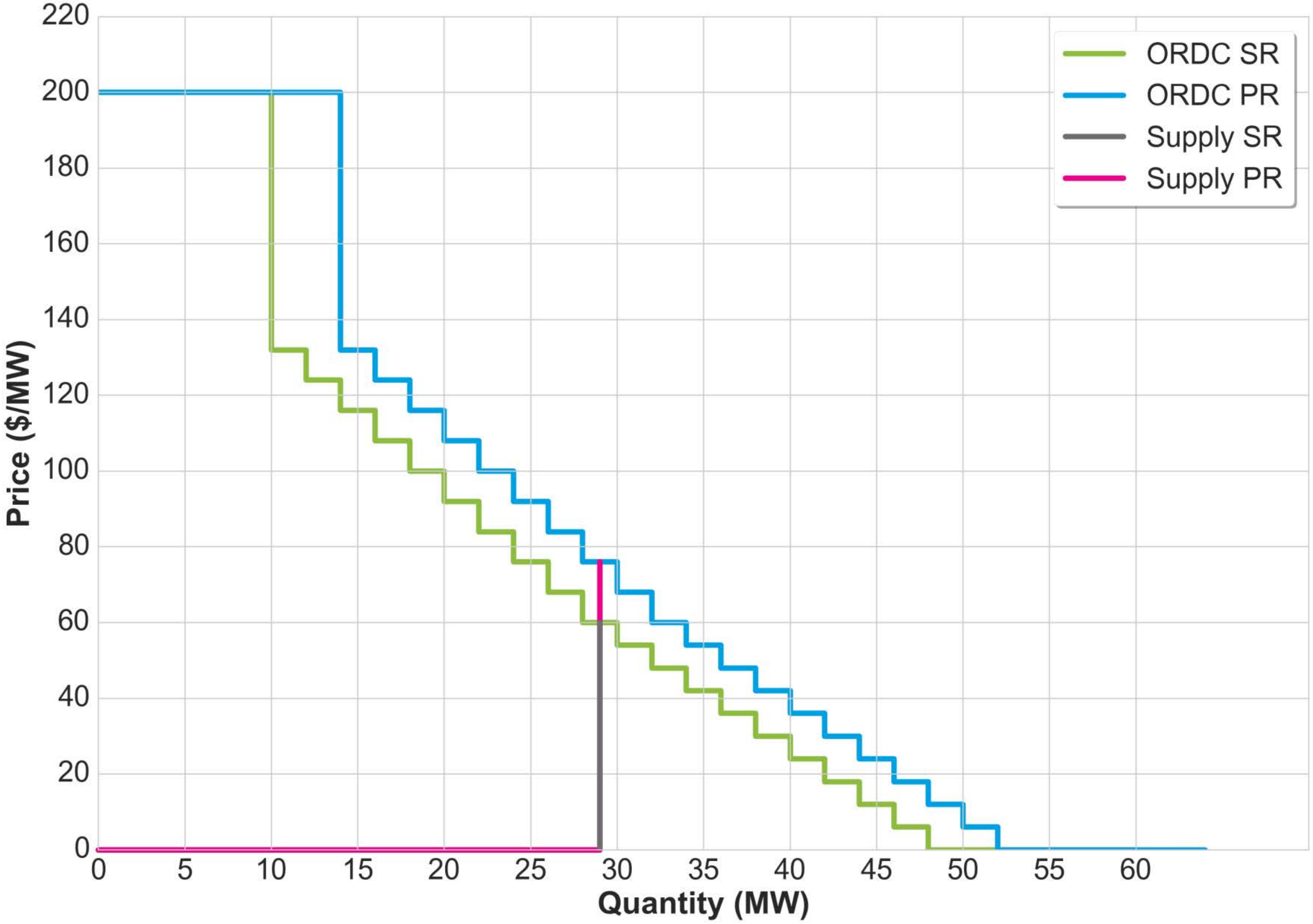
Demand **141 MW**

Example #1: Results



Energy Price	**$236/MWh**
SR Shadow Price	**$60/MWh**
PR Shadow Price	**$76/MWh**
SRMCP	**$136/MWh**
NSRMCP	**$76/MWh**

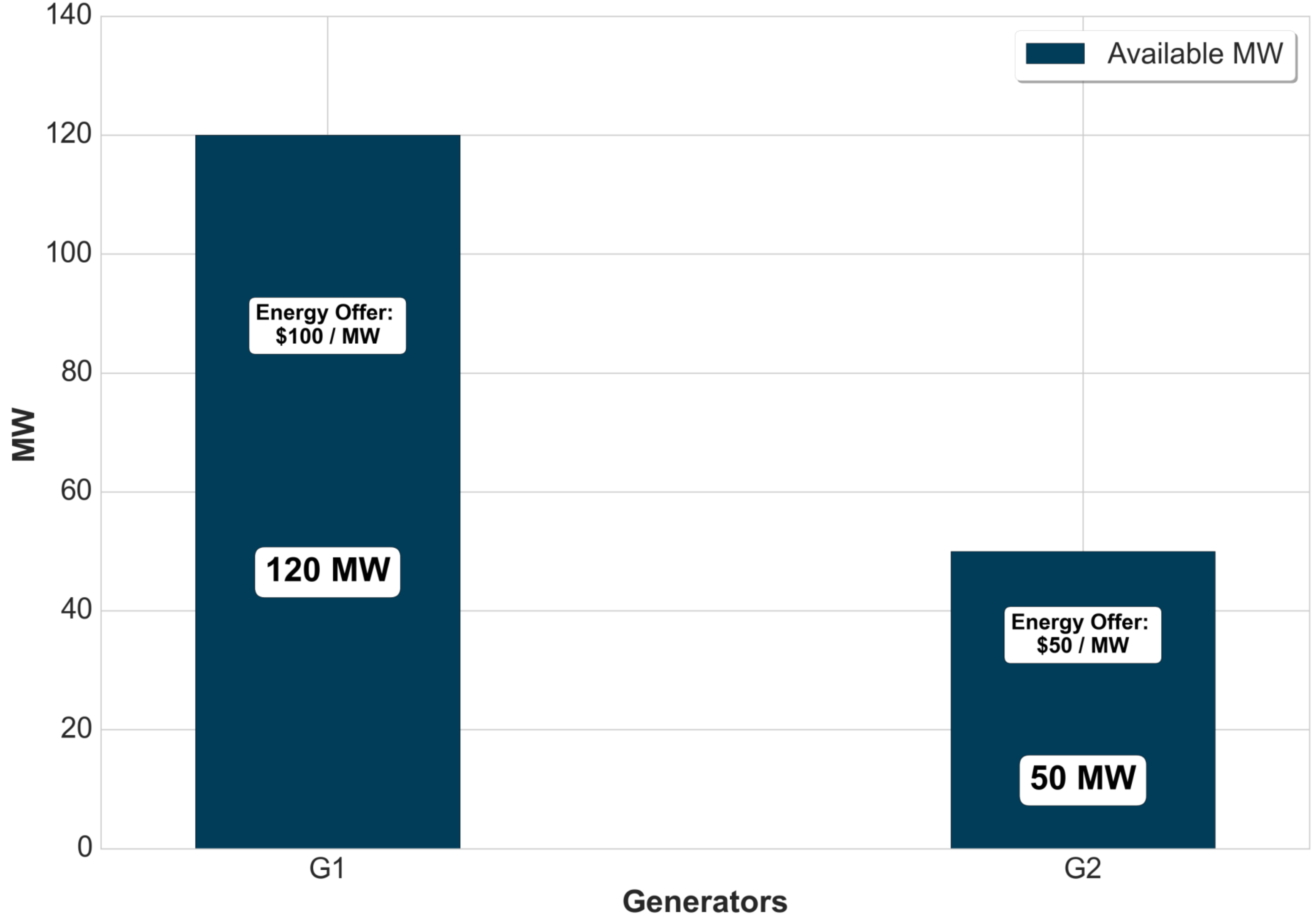
Example #1: Results - ORDC



Example #1: Notes

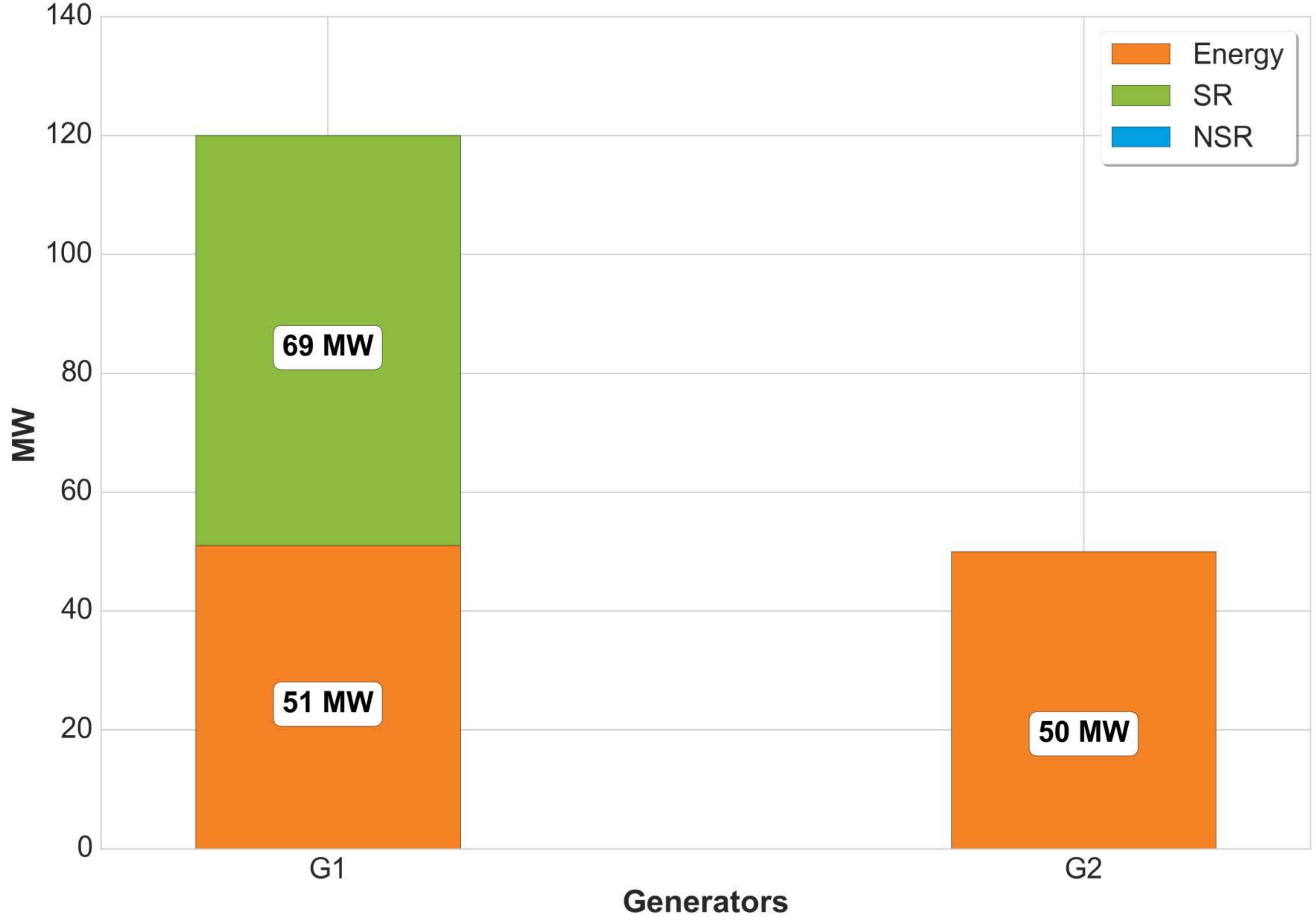
- There are 29 MW of SR in the system that can be supplied by G1. All 29 MW are cleared.
- These 29 MW contribute to meet the ORDC not only for SR but also for PR
- The G1 opportunity cost for supplying these 29 MW is $0/MWh and there is no reserve offer.
- The SR shadow price is $60/MWh while the PR shadow price is $76/MWh.
- Since the above prices are reflective of providing either SR or PR (but not both together), G1 gets paid the sum of the two shadow prices, $136/MWh
- If there were resources providing NSR, then those resources would get paid $76/MWh only (because NSR resources count towards meeting the PR ORDC only)
- The energy price is $236/MWh because the next additional MW of energy has to come from G1 (which has a $100/MWh energy cost) and it would have to come at the expense of losing a MW of SR and PR (for a total reserve benefit loss of $136/MWh)

Example #2: Surplus / No NSR



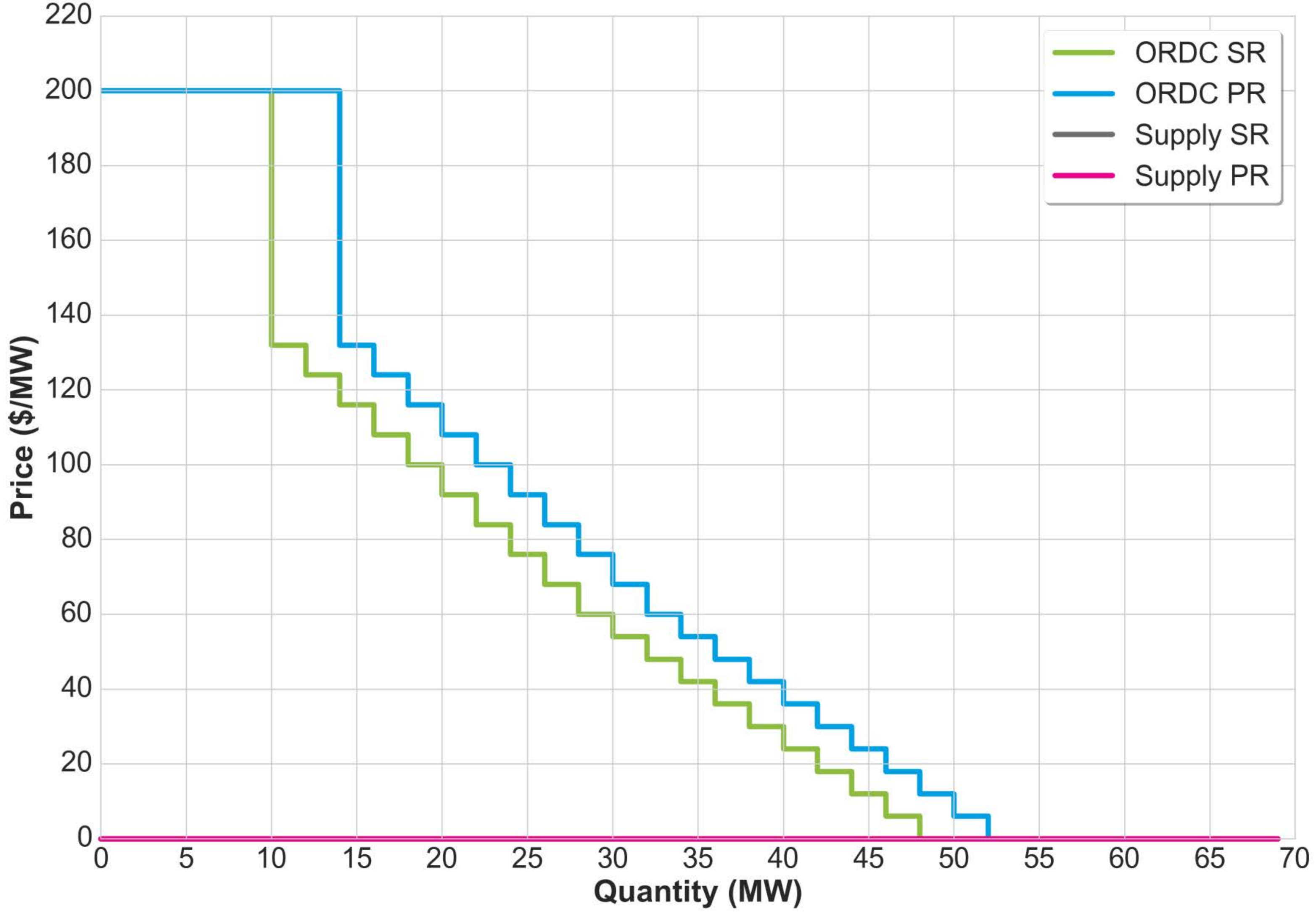
Demand **101 MW**

Example #2: Results



Energy Price	**$100/MWh**
SR Shadow Price	**$0/MWh**
PR Shadow Price	**$0/MWh**
SRMCP	**$0/MWh**
NSRMCP	**$0/MWh**

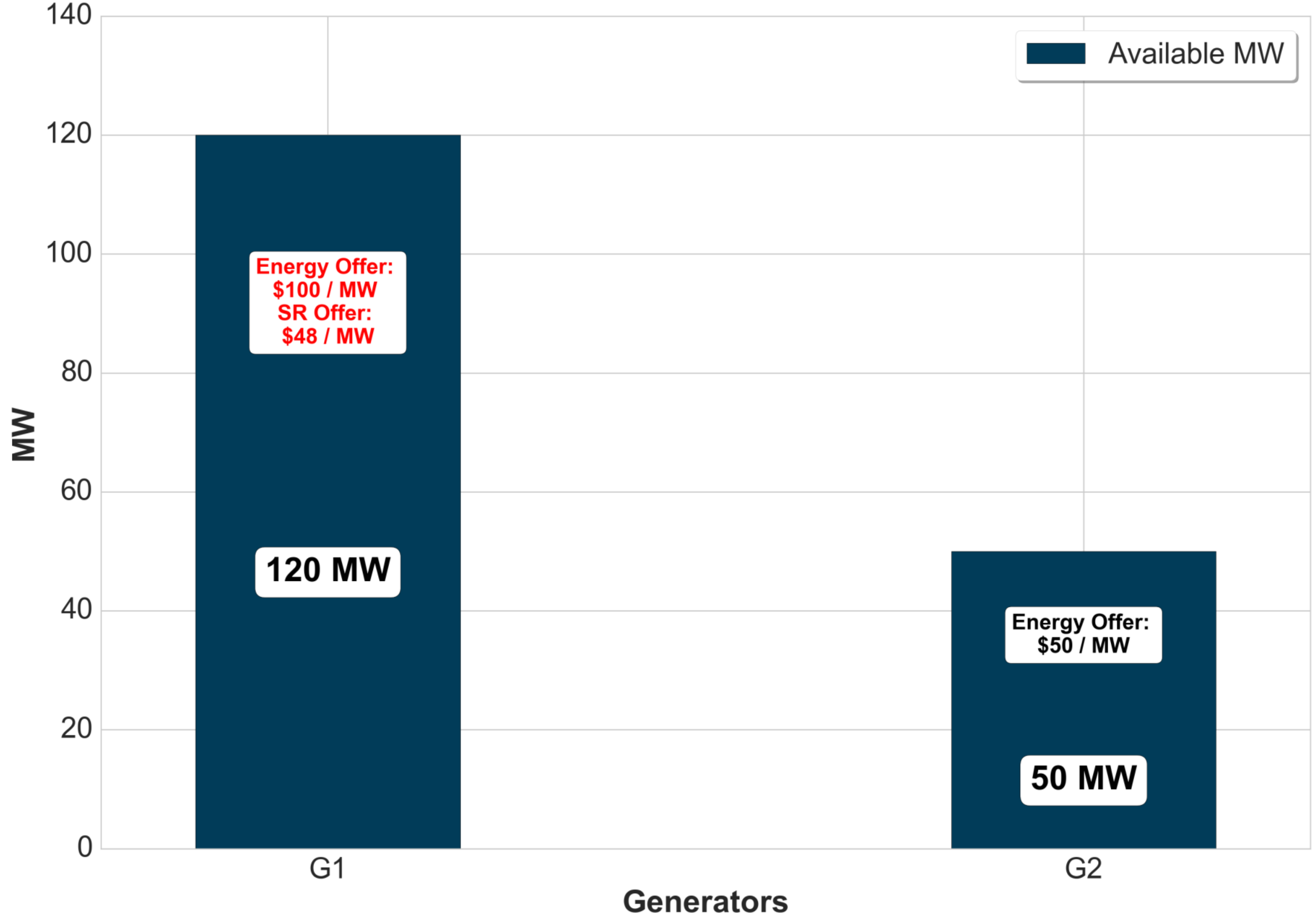
Example #2: Results - ORDC



Example #2: Notes

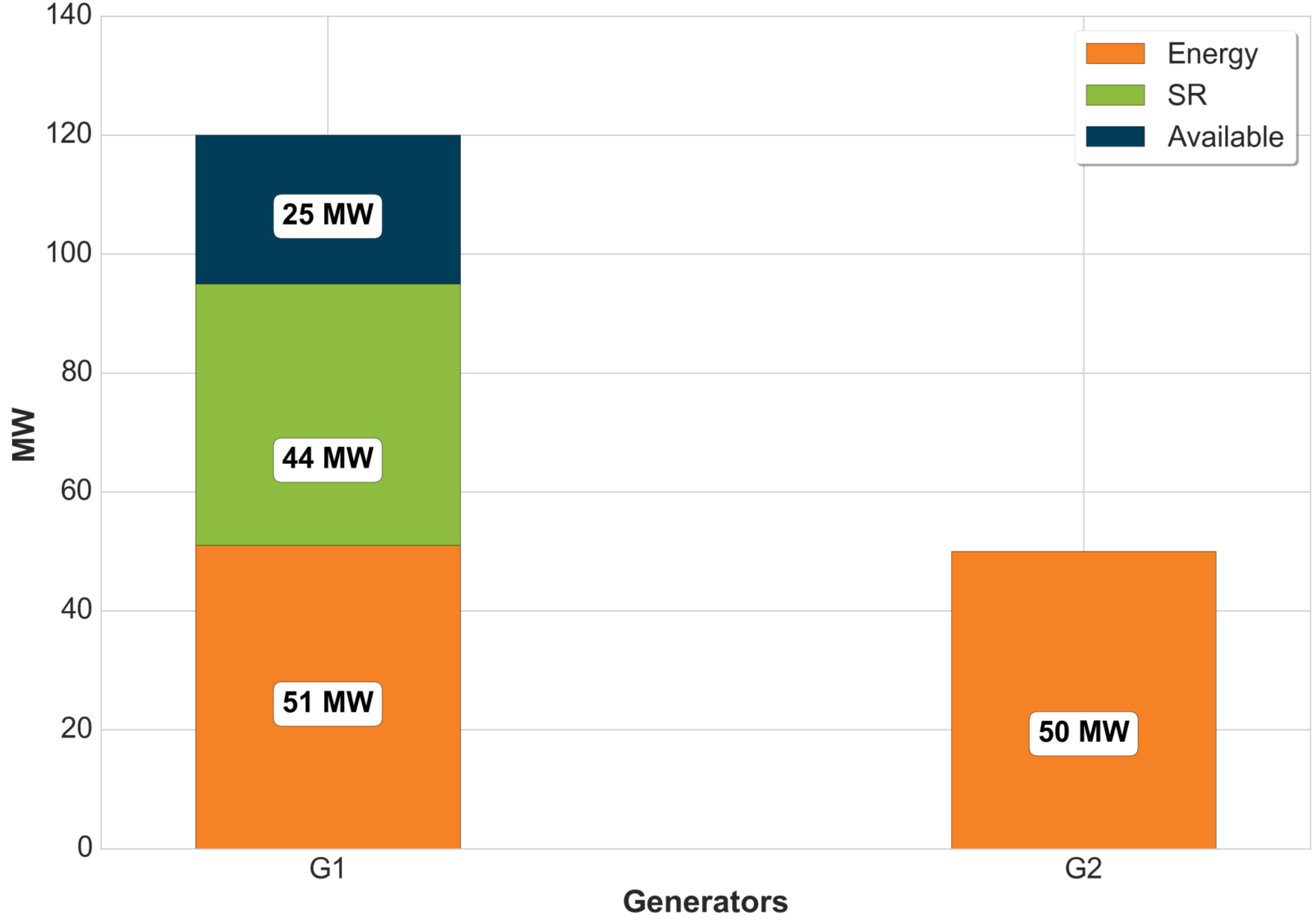
- There are 69 MW of SR in the system that can be supplied by G1 (because of the lower demand relative to Example #1). All 69 MW are cleared
- These 69 MW contribute to meet the ORDC not only for SR but also for PR
- The G1 opportunity cost for supplying these 69 MW is $0/MWh and there is no reserve offer.
- The SR shadow price is $0/MWh while the PR shadow price is also $0/MWh because both ORDCs result in a price of $0/MWh when the quantity is 69 MW
- Since the above prices are reflective of providing either SR or PR (but not both together), G1 gets paid the sum of the two shadow prices, $0/MWh
- If there were resources providing NSR, then those resources would get paid $0/MWh only (because NSR resources count towards meeting the PR ORDC only)
- The energy price is $100/MWh because the next additional MW of energy has to come from G1 (which has a $100/MWh energy cost) and it would have to come at the expense of losing a MW of SR and PR (for a total reserve benefit loss of $0/MWh)

Example #3: Surplus with Reserve Offer / No NSR



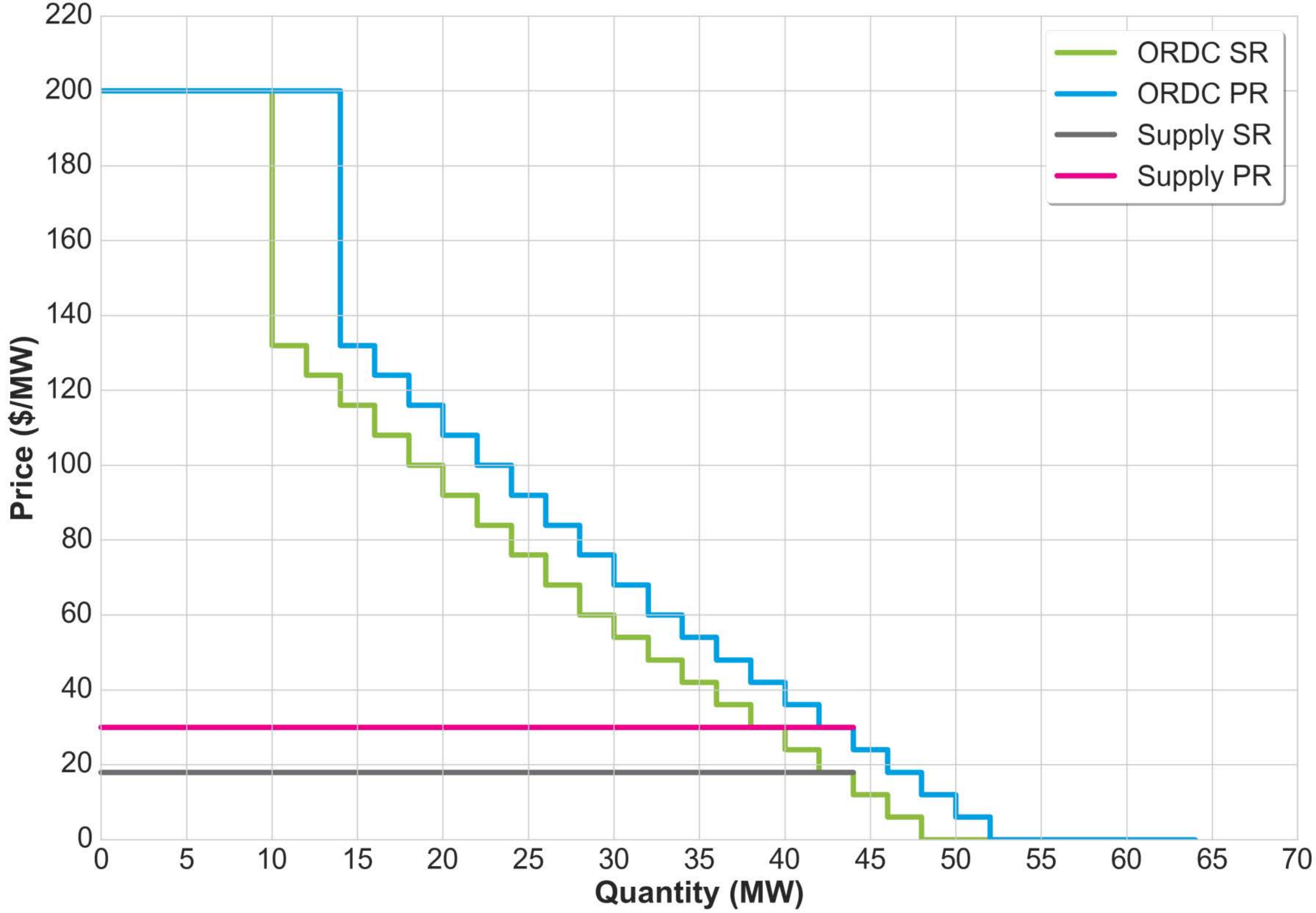
Demand **101 MW**

Example #3: Results



Energy Price	**$100/MWh**
SR Shadow Price	**$18/MWh**
PR Shadow Price	**$30/MWh**
SRMCP	**$48/MWh**
NSRMCP	**$30/MWh**

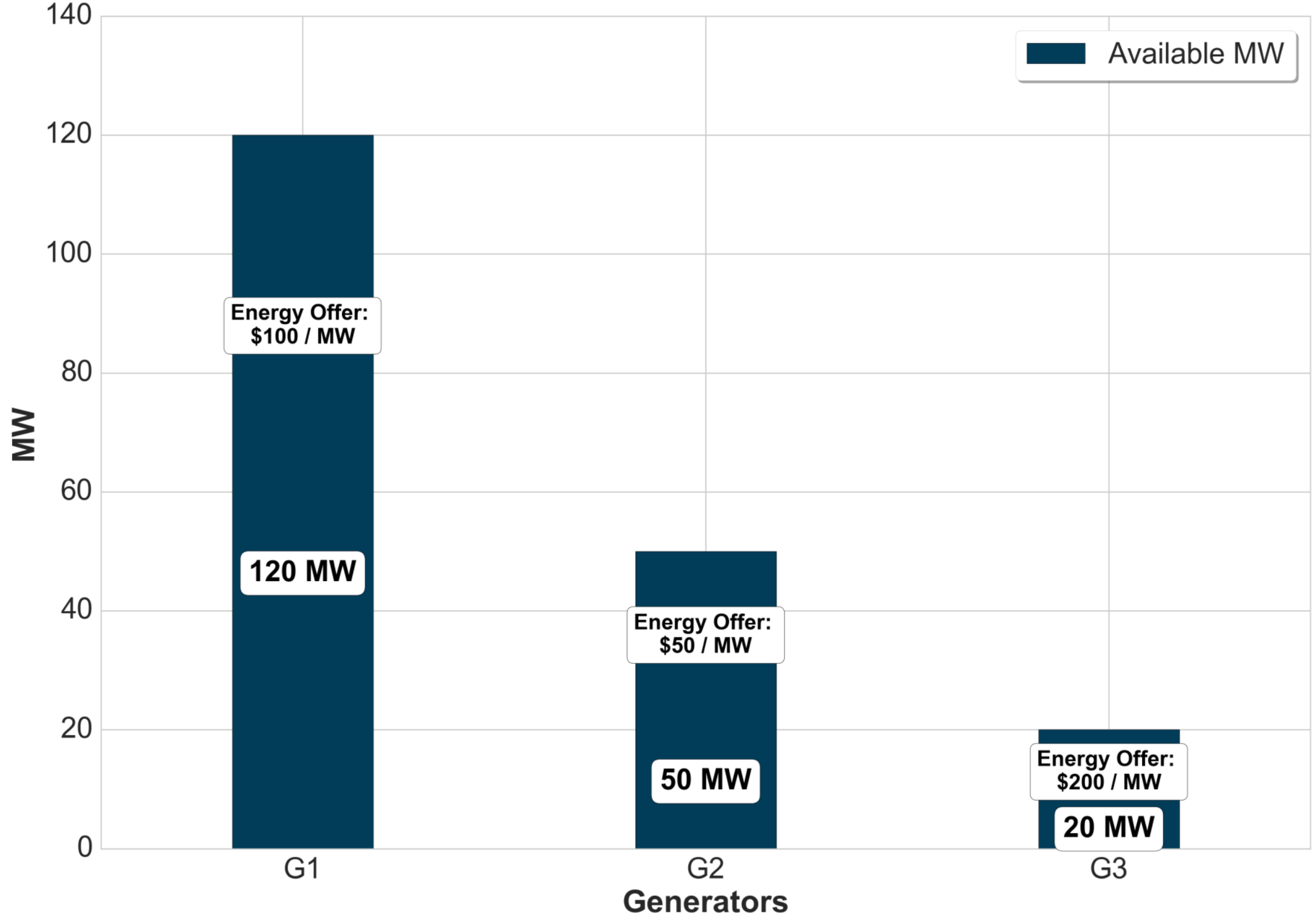
Example #3: Results - ORDC



Example #3: Notes

- There are 69 MW of SR in the system that can be supplied by G1. However, given the ORDCs for SR and PR, clearing only 44 MW is economically efficient.
- These 44 MW contribute to meet the ORDC not only for SR but also for PR
- The G1 opportunity cost for supplying these 69 MW is $0/MWh. However, G1 has a reserve offer of $48/MWh. The supply curves for SR and PR can be drawn as two horizontal lines so that the sum of the two matches G1's reserve offer.
- The SR shadow price is $18/MWh while the PR shadow price is $30/MWh because the intersection of the supply curves with the ORDCs occur at those prices
- Since the above prices are reflective of providing either SR or PR (but not both together), G1 gets paid the sum of the two shadow prices, $48/MWh
- If there were resources providing NSR, then those resources would get paid $30/MWh only (because NSR resources count towards meeting the PR ORDC only)
- The energy price is $100/MWh because the next additional MW of energy has to come from G1 (which has a $100/MWh energy cost) and it **does not** come at the expense of losing a MW of SR and PR because G1 has 25 MW of available capacity.

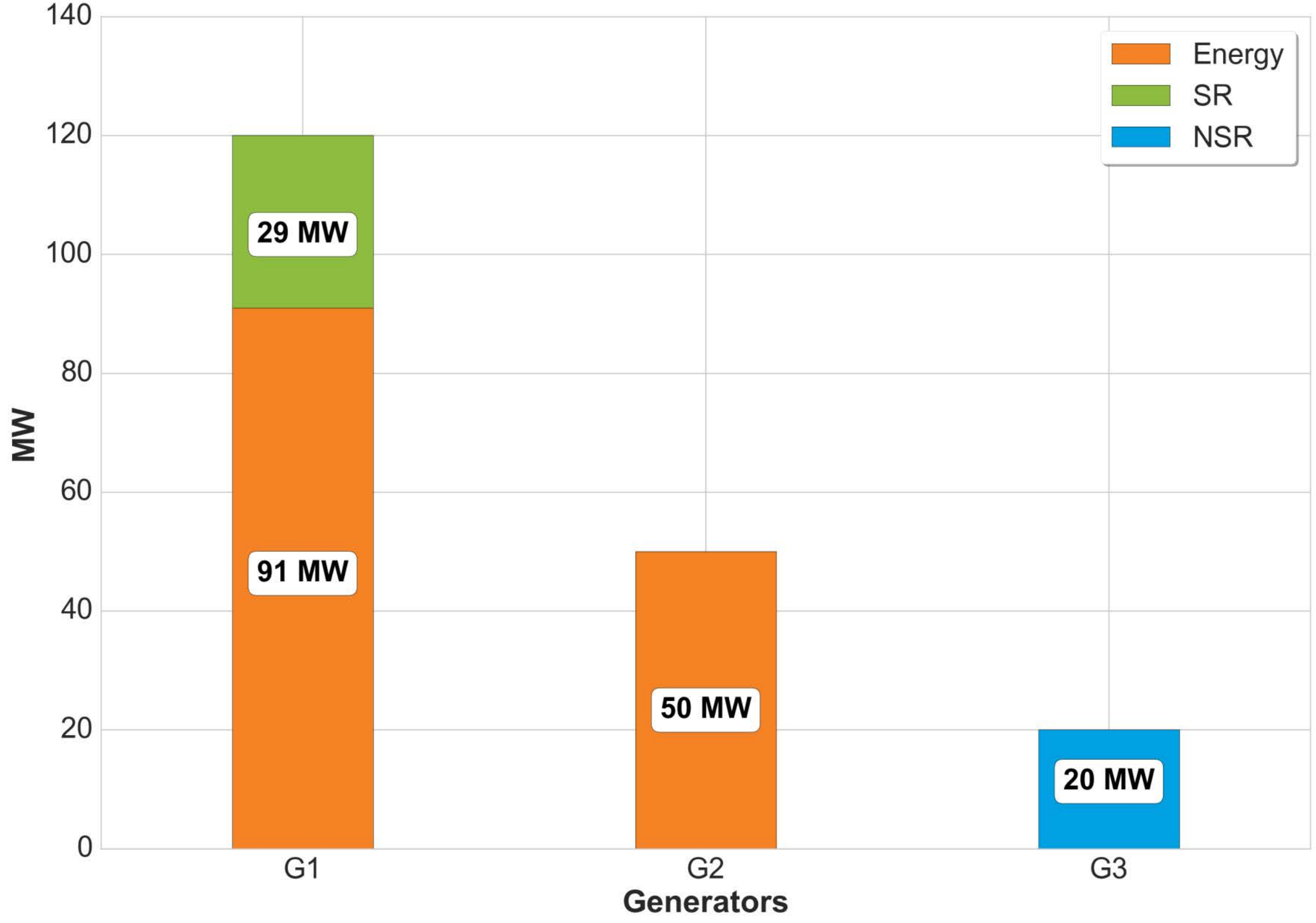
Example #4: Capacity Constrained with NSR



Demand **141 MW**

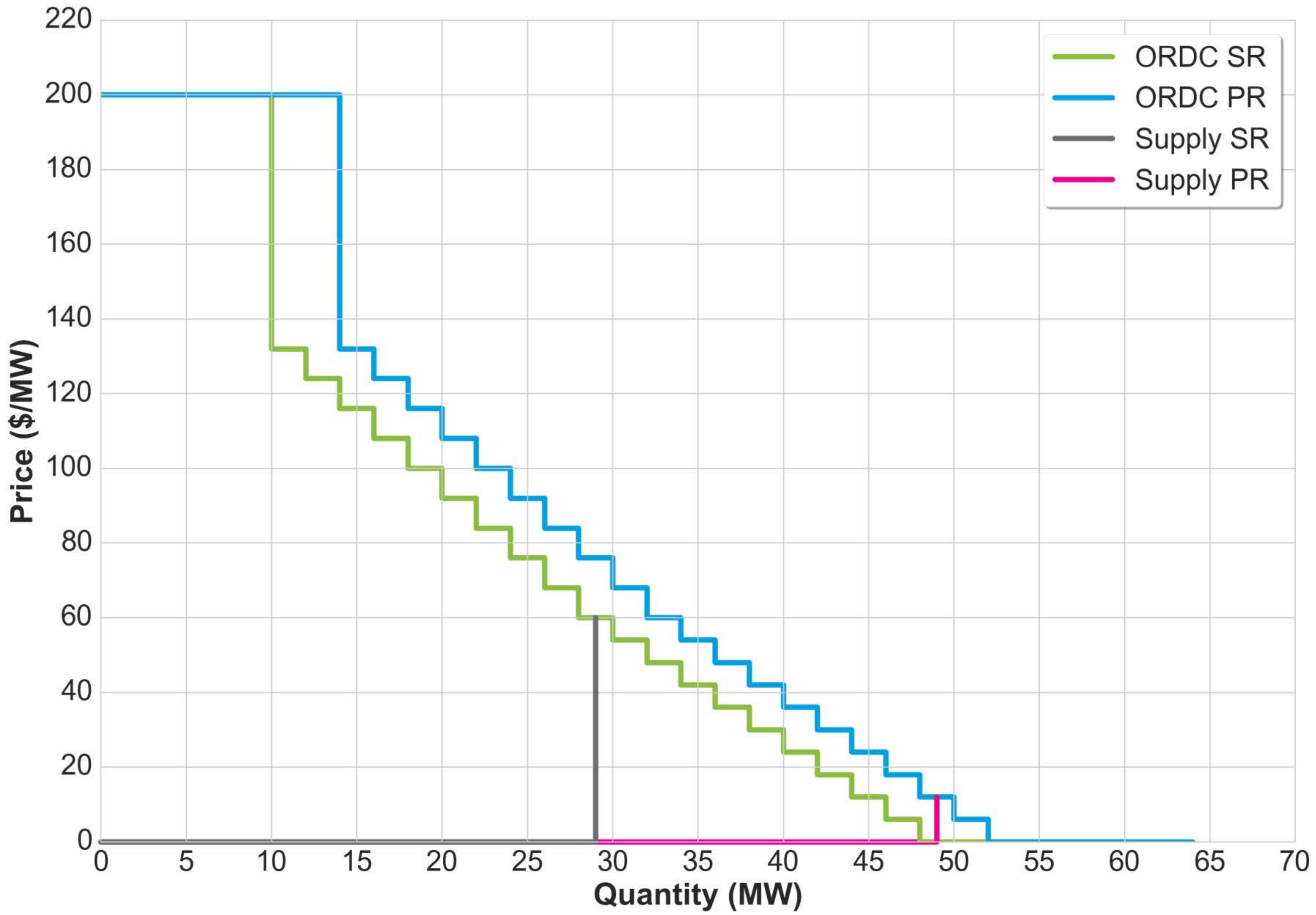
G3 is offline

Example #4: Results



Energy Price	**$172/MWh**
SR Shadow Price	**$60/MWh**
PR Shadow Price	**$12/MWh**
SRMCP	**$72/MWh**
NSRMCP	**$12/MWh**

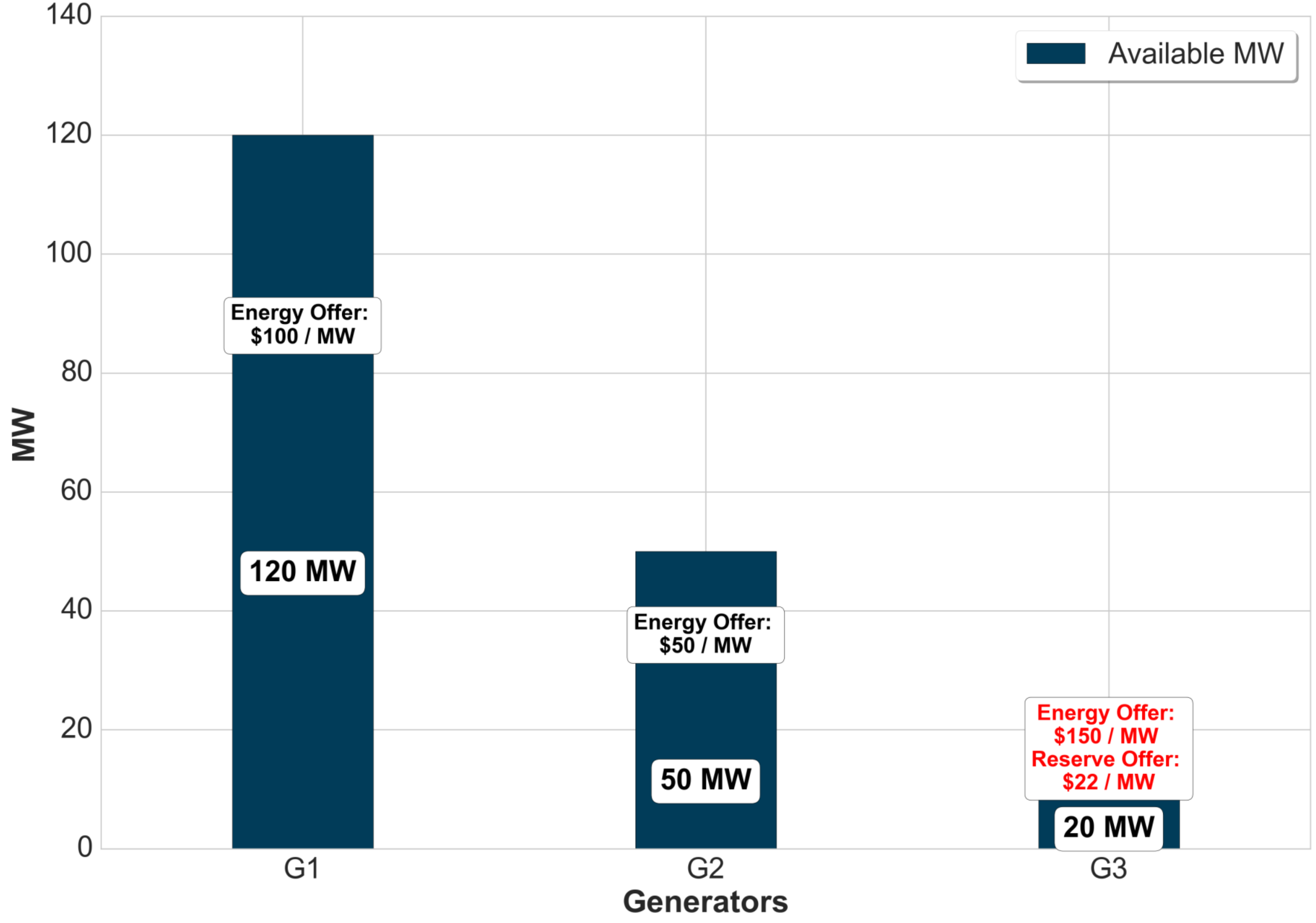
Example #4: Results - ORDC



Example #4: Notes

- G3 is an additional unit kept offline because of its high energy offer of $200/MWh. Since the energy offer is high, the opportunity cost is estimated at $0/MWh. This opportunity cost is used as G3's NSR reserve offer.
- There are 29 MW of SR in the system that can be supplied by G1 and 20 MW of NSR in the system that can be supplied by G3
- The G1 opportunity cost for supplying these 29 MW is $0/MWh and there is no reserve offer. All 29 MW are cleared as SR.
- The G3 opportunity cost for supplying 20 MW of NSR is the above estimated opportunity cost of $0/MWh. Therefore, the PR supply curve is a horizontal line at $0/MWh for a total of 49 MW (29 MW of SR + 20 MW NSR). All 49 MW are cleared (29 MW SR from G1 and 20 MW of NSR from G3)
- The SR shadow price is $60/MWh while the PR shadow price is $12/MWh because the intersection of the supply curves with the ORDCs occur at those prices
- Since the above prices are reflective of providing either SR or PR (but not both together), G1 gets paid the sum of the two shadow prices, $72/MWh
- G3 gets paid $12/MWh because NSR resources count towards meeting the PR ORDC only
- The energy price is $172/MWh because the next additional MW of energy has to come from G1 (which has a $100/MWh energy cost) and it comes at the expense of losing a MW of SR and PR (for a total reserve benefit loss of $72/MWh)

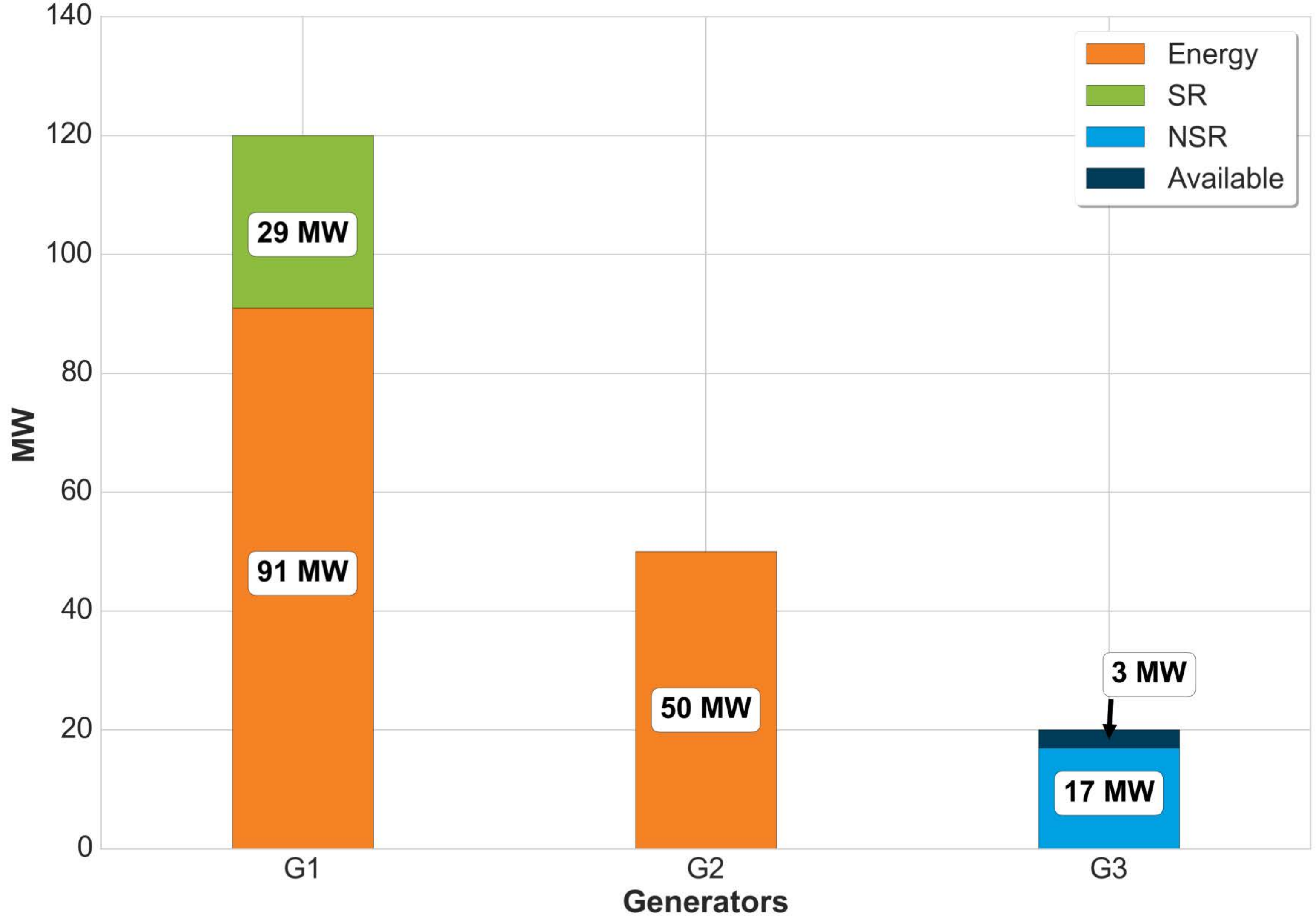
Example #5: Capacity Constrained with NSR and NSR LOC Reserve Offer



Demand 141 MW

G3 is offline

Example #5: Results

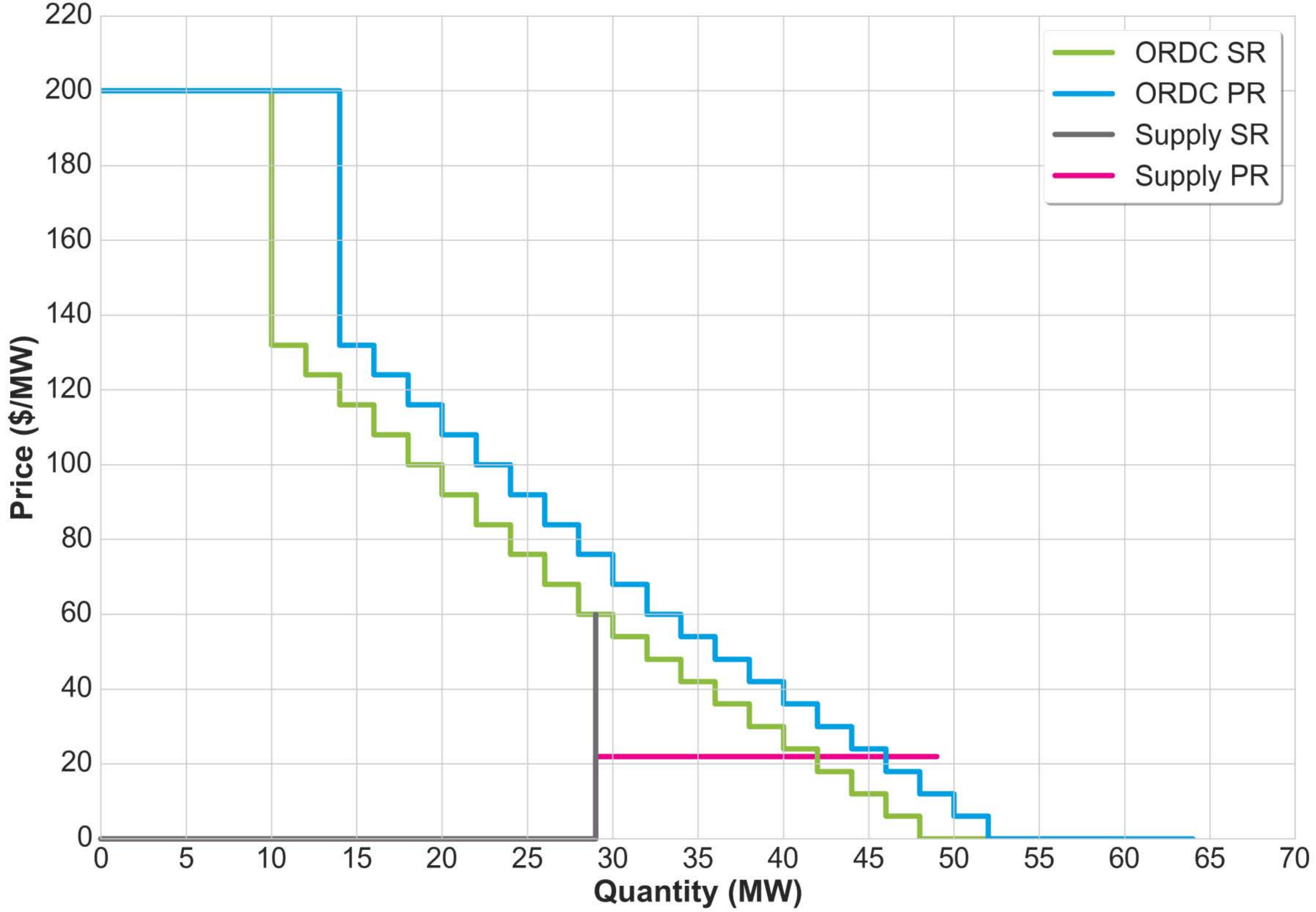


Energy Price **$182/MWh**

SR Shadow Price **$60/MWh**
PR Shadow Price **$22/MWh**

SRMCP **$82/MWh**
NSRMCP **$22/MWh**

Example #5: Results - ORDC

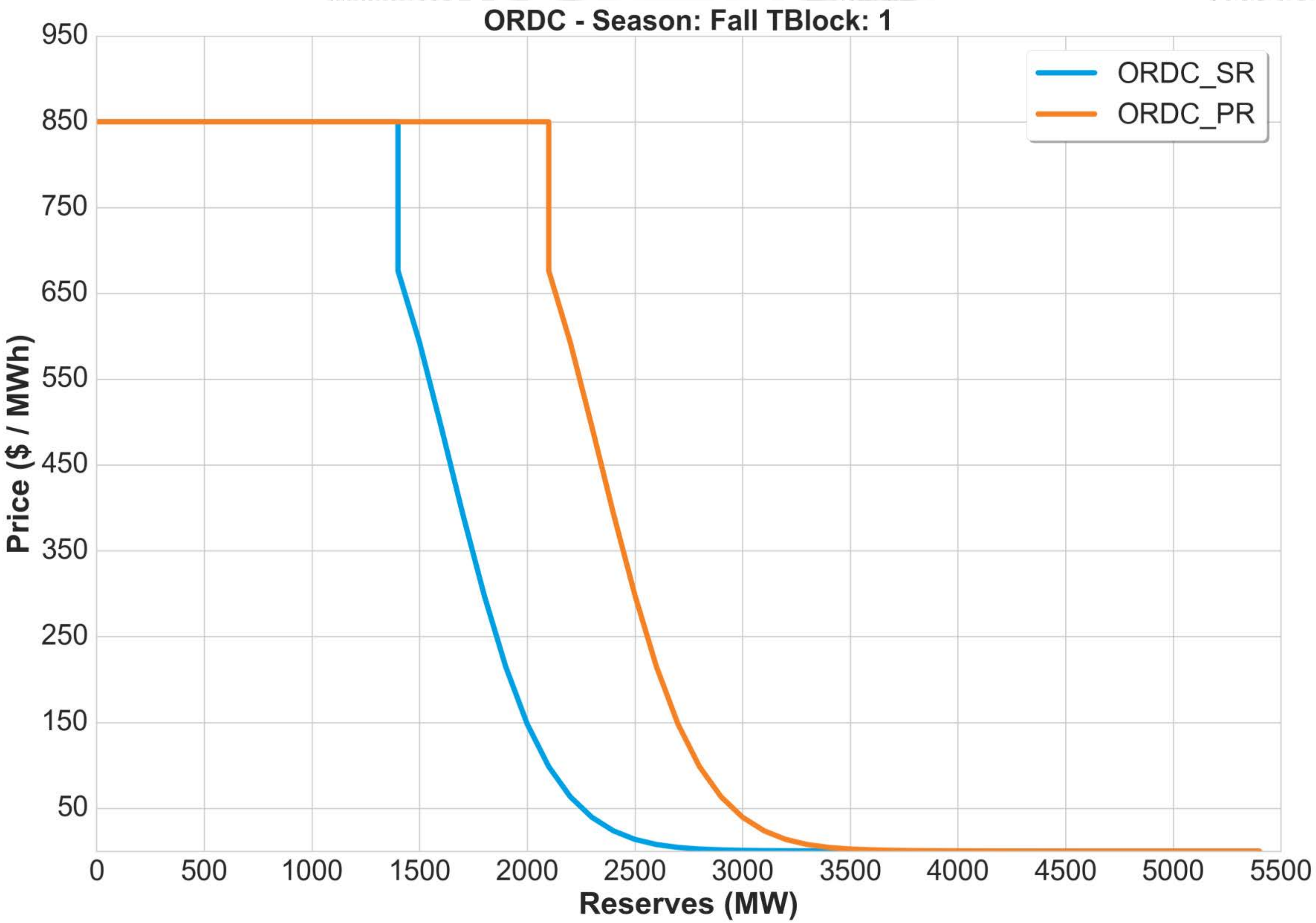


Example #5: Notes

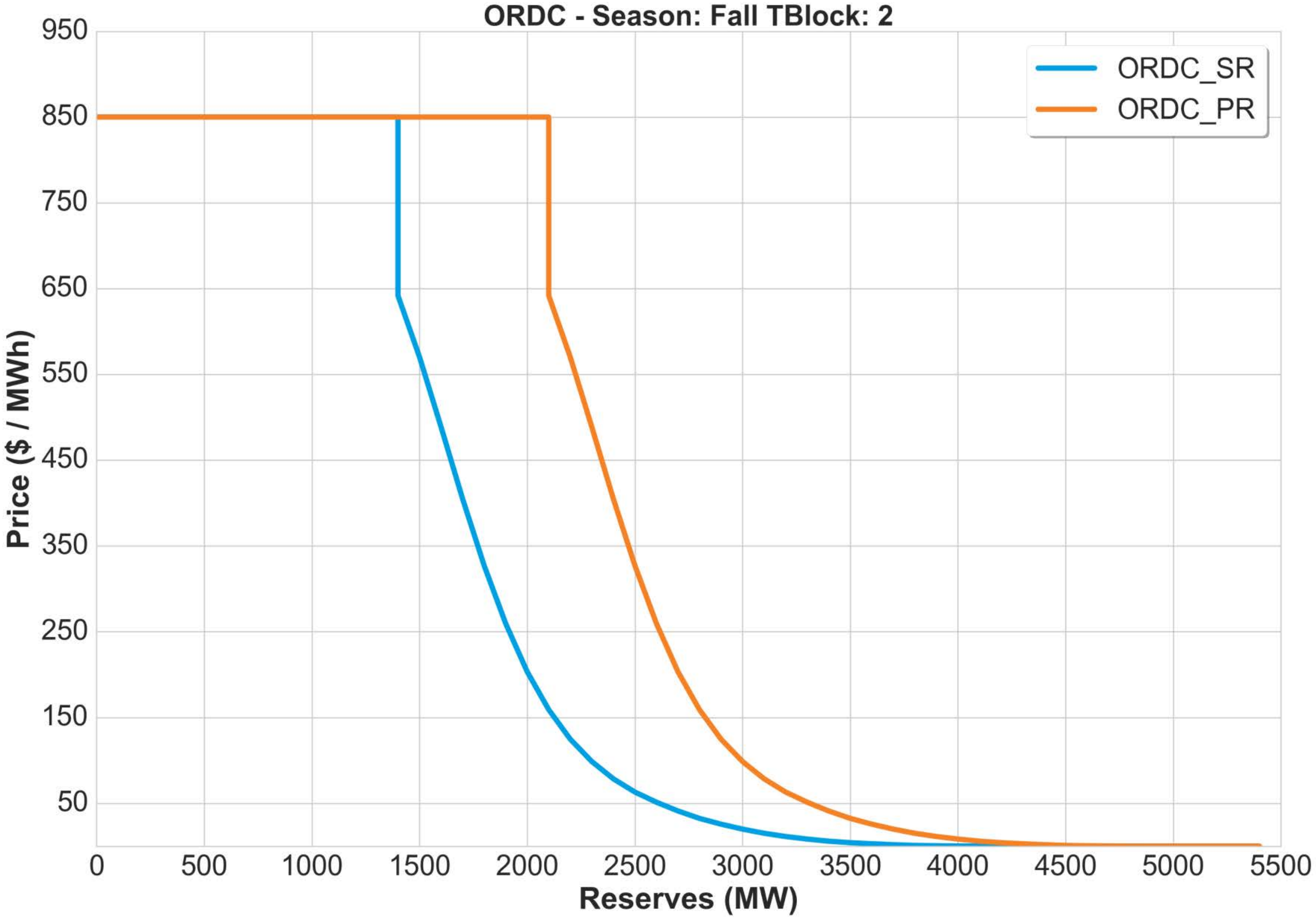
- G3 is an additional unit kept offline because of its high energy offer of $150/MWh. However, since the energy offer is not that high, a non-zero opportunity cost can be estimated ($22/MWh). This opportunity cost is used as the NSR reserve offer.
- There are 29 MW of SR in the system that can be supplied by G1 and 20 MW of NSR in the system that can be supplied by G3
- The G1 opportunity cost for supplying these 29 MW is $0/MWh and there is no reserve offer. All 29 MW are cleared.
- The G3 opportunity cost for supplying 20 MW of NSR is the above estimated opportunity cost of $22/MWh. Therefore, the PR supply curve has two steps: one of length 29 MW at $0/MWh and a second one of length 20 MW at $22/MWh. A total of 46 MW of PR are cleared (29 MW SR from G1 and 17 MW of NSR from G3). Given the ORDCs, clearing more is not economically efficient.
- The SR shadow price is $60/MWh while the PR shadow price is $22/MWh because the intersection of the supply curves with the ORDCs occurs at those prices
- Since the above prices are reflective of providing either SR or PR (but not both together), G1 gets paid the sum of the two shadow prices, $82/MWh
- G3 gets paid $22/MWh because NSR resources count towards meeting the PR ORDC only
- The energy price is $182/MWh because the next additional MW of energy has to come from G1 (which has a $100/MWh energy cost) and it comes at the expense of losing a MW of SR and PR (for a total reserve benefit loss of $82/MWh)

Appendix: SR and PR ORDCs using empirical distributions for all Season – Time-of-Day Blocks combinations (including Forced Outages Uncertainty and assuming MRR SR = 1,400 MW and MRR PR = 2,100 MW)

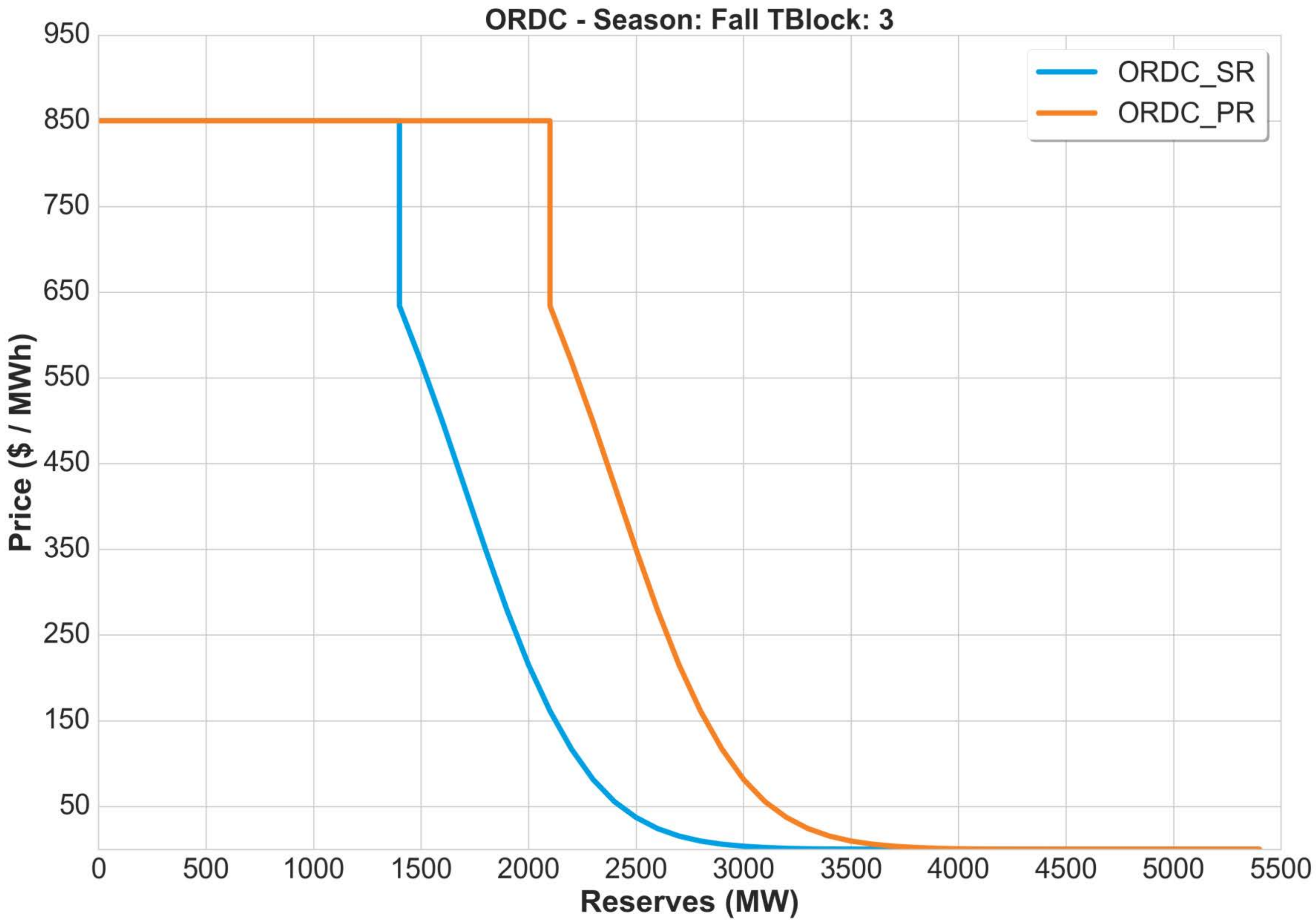
ORDC Fall TBlock 1 (2300-0200)



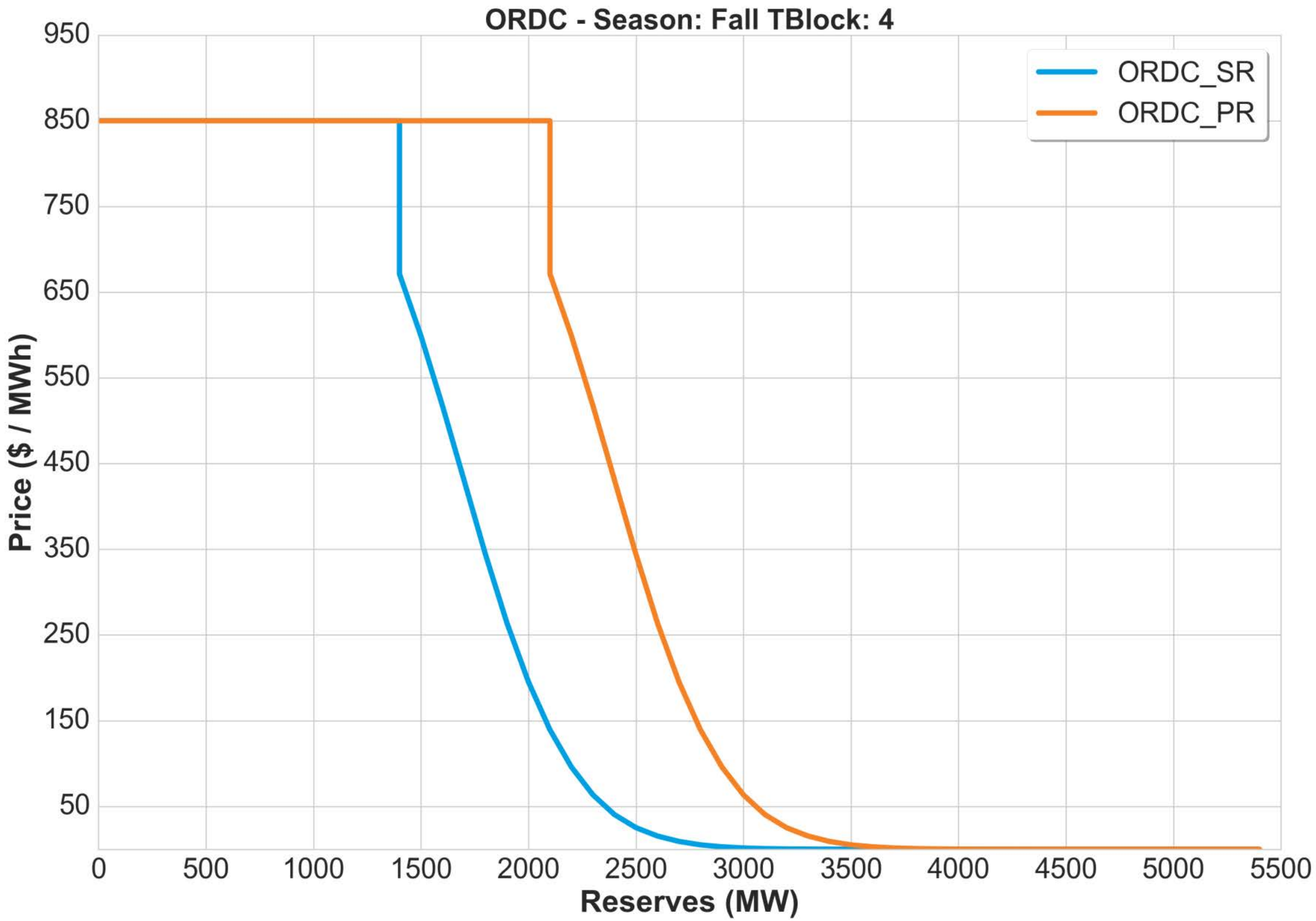
ORDC Fall TBlock 2 (0300-0600)



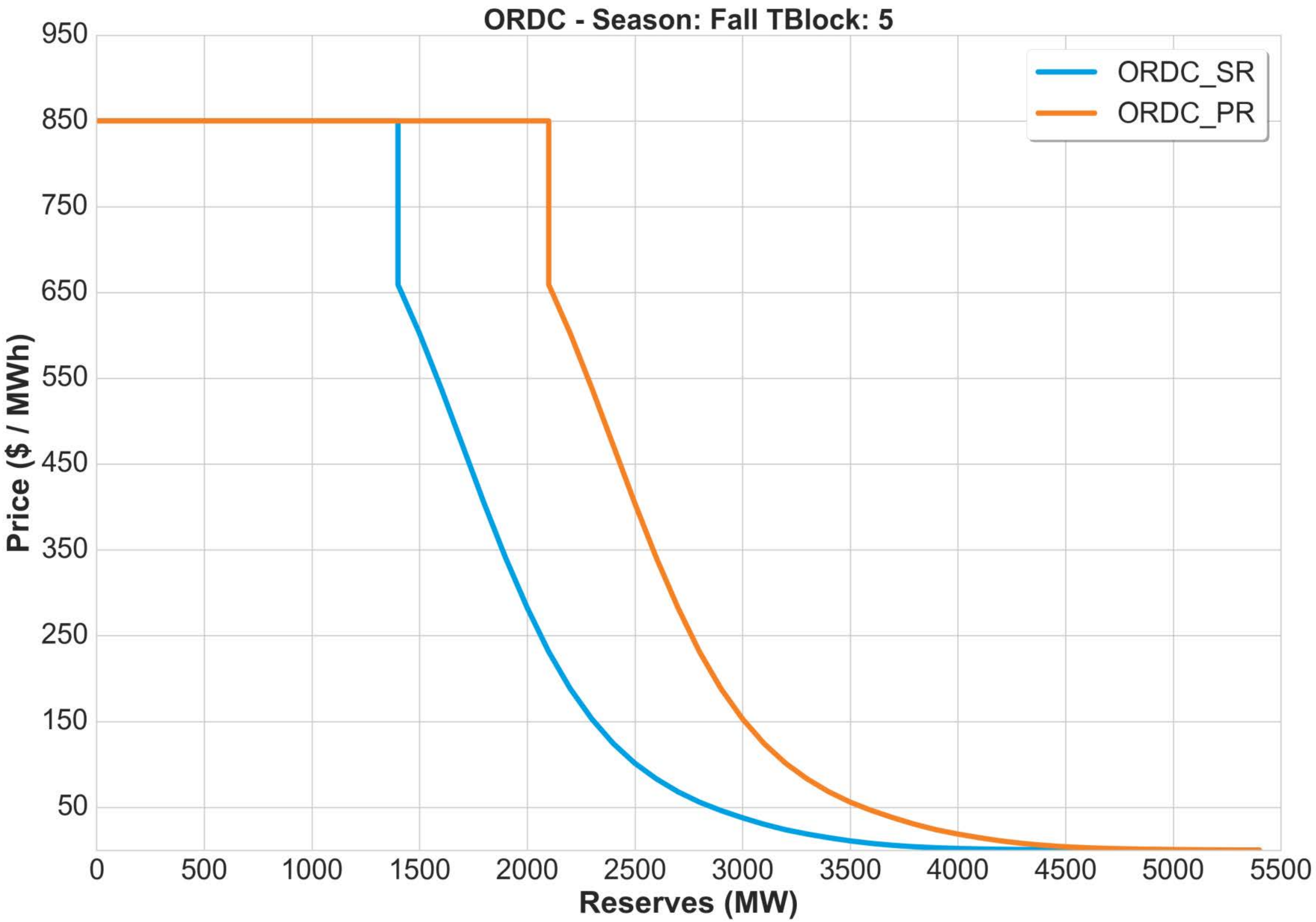
ORDC Fall TBlock 3 (0700-1000)



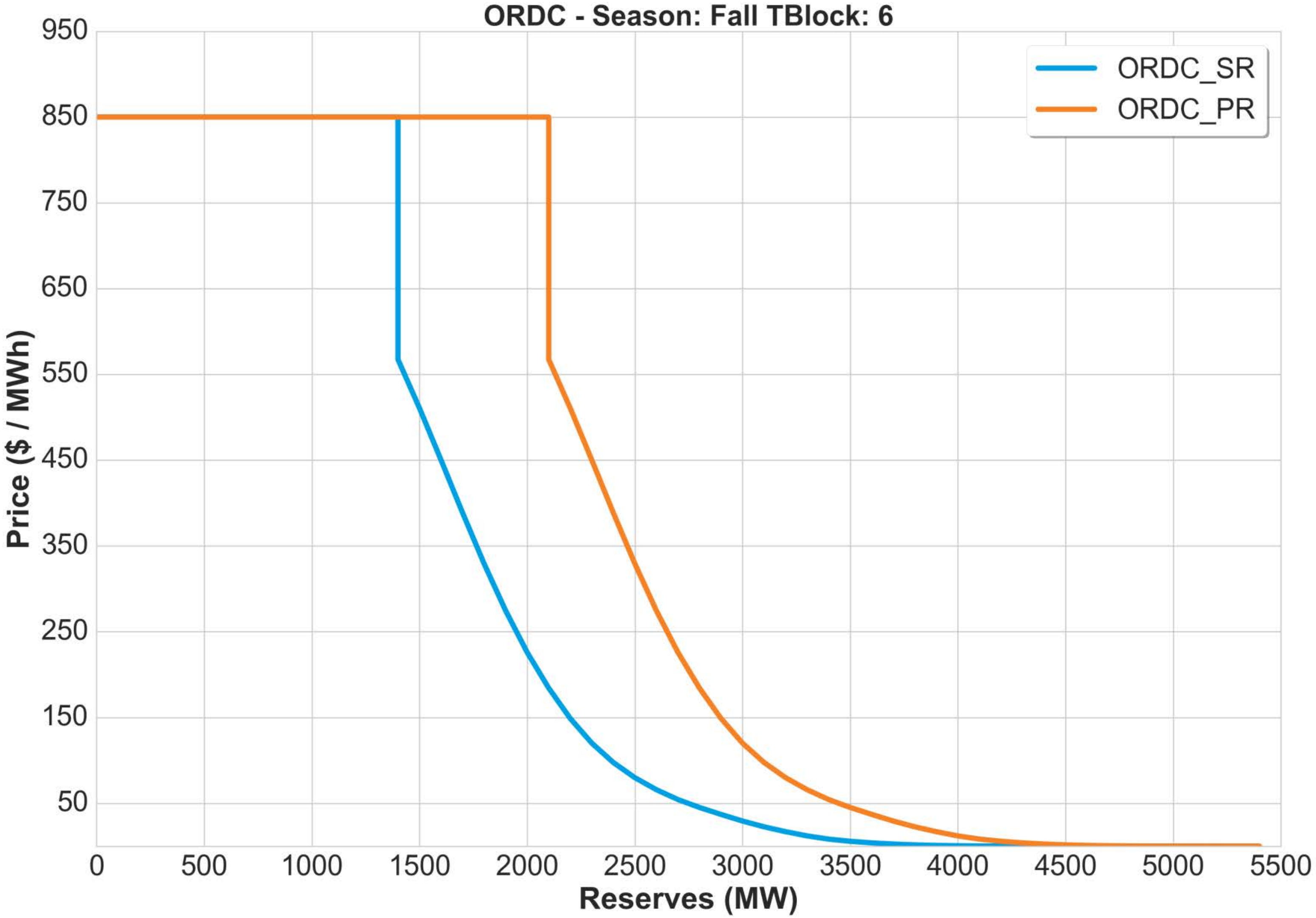
ORDC Fall TBlock 4 (1100-1400)



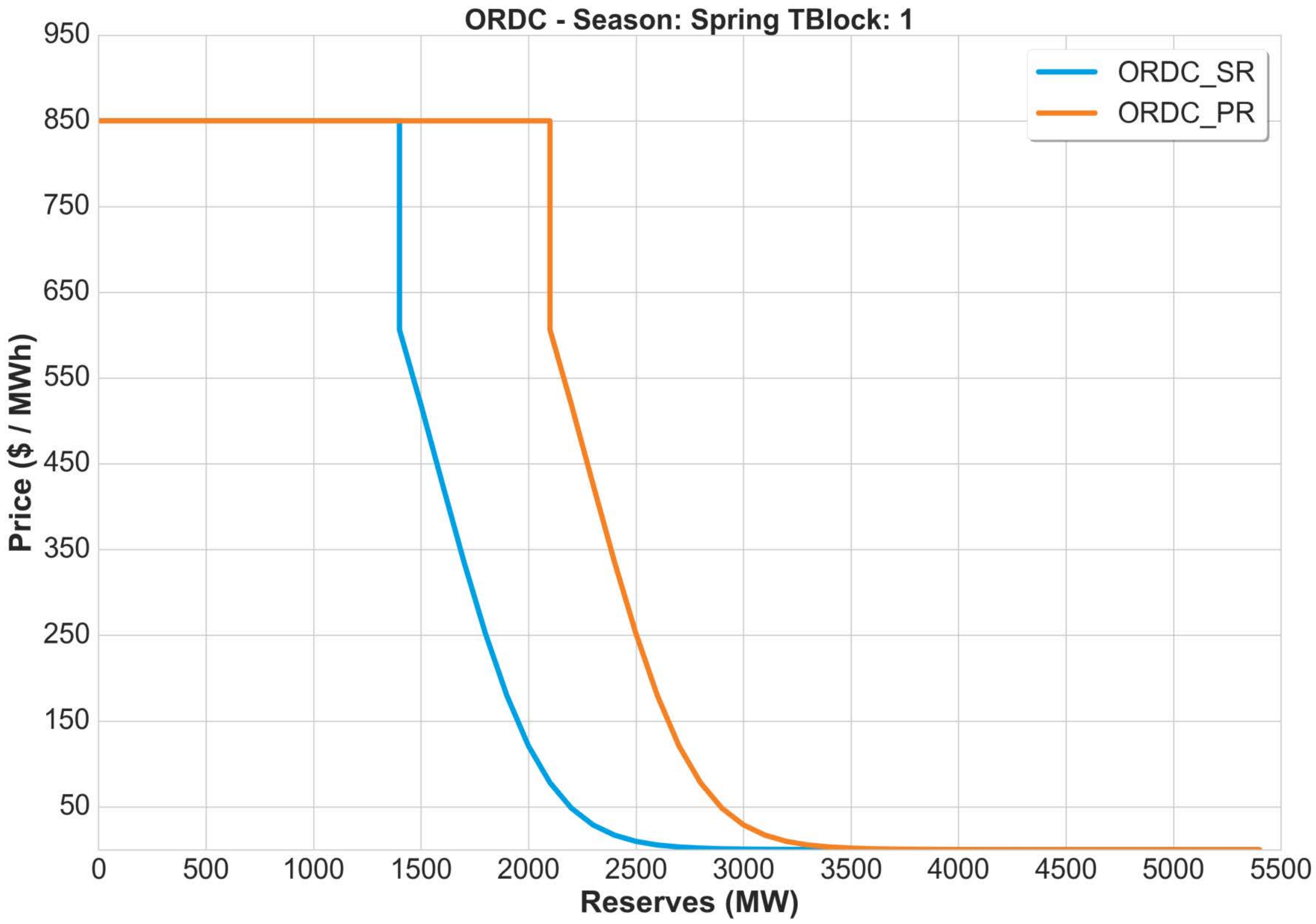
ORDC Fall TBlock 5 (1500-1800)



ORDC Fall TBlock 6 (1900-2200)



ORDC Spring TBlock 1 (2300-0200)



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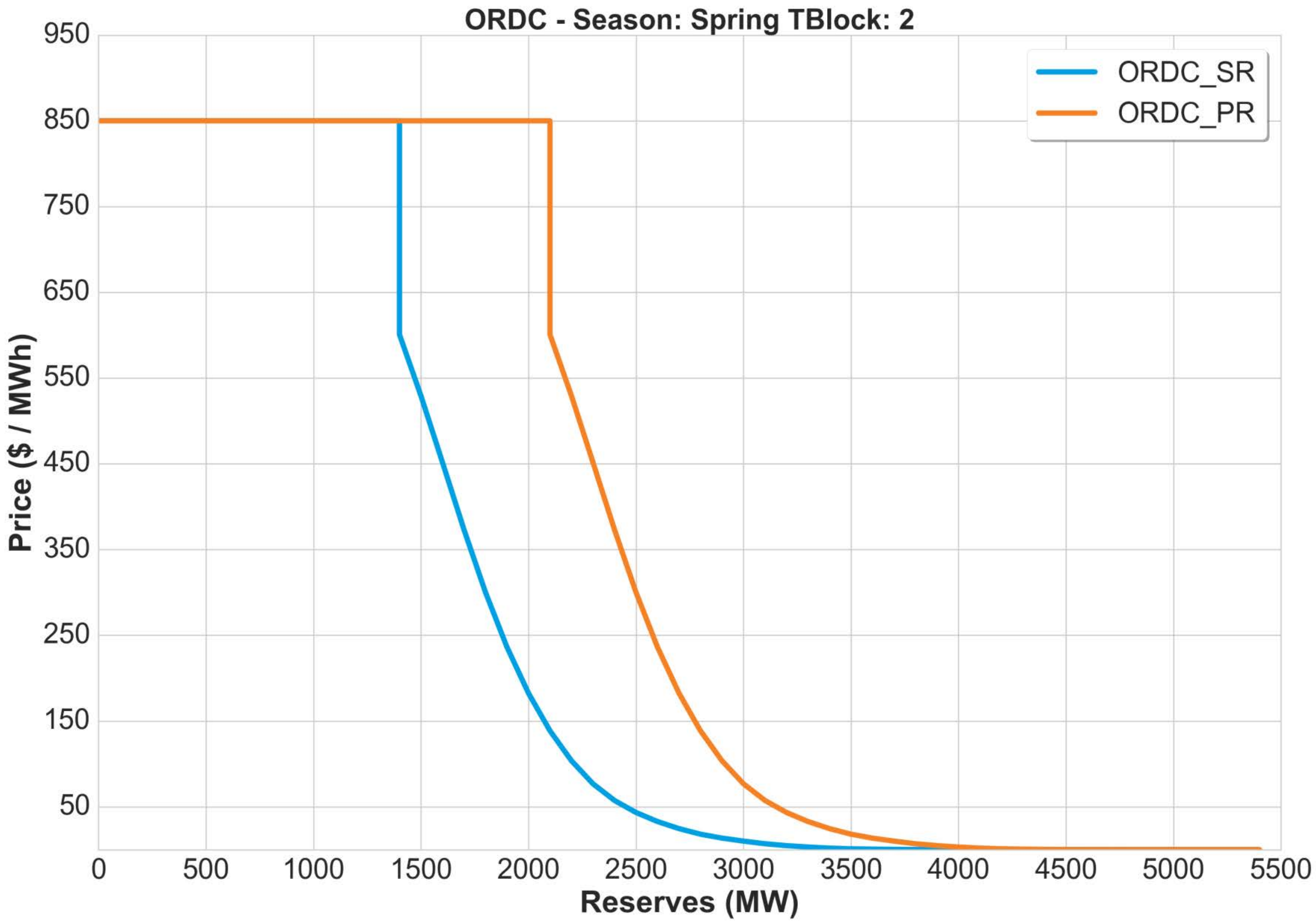

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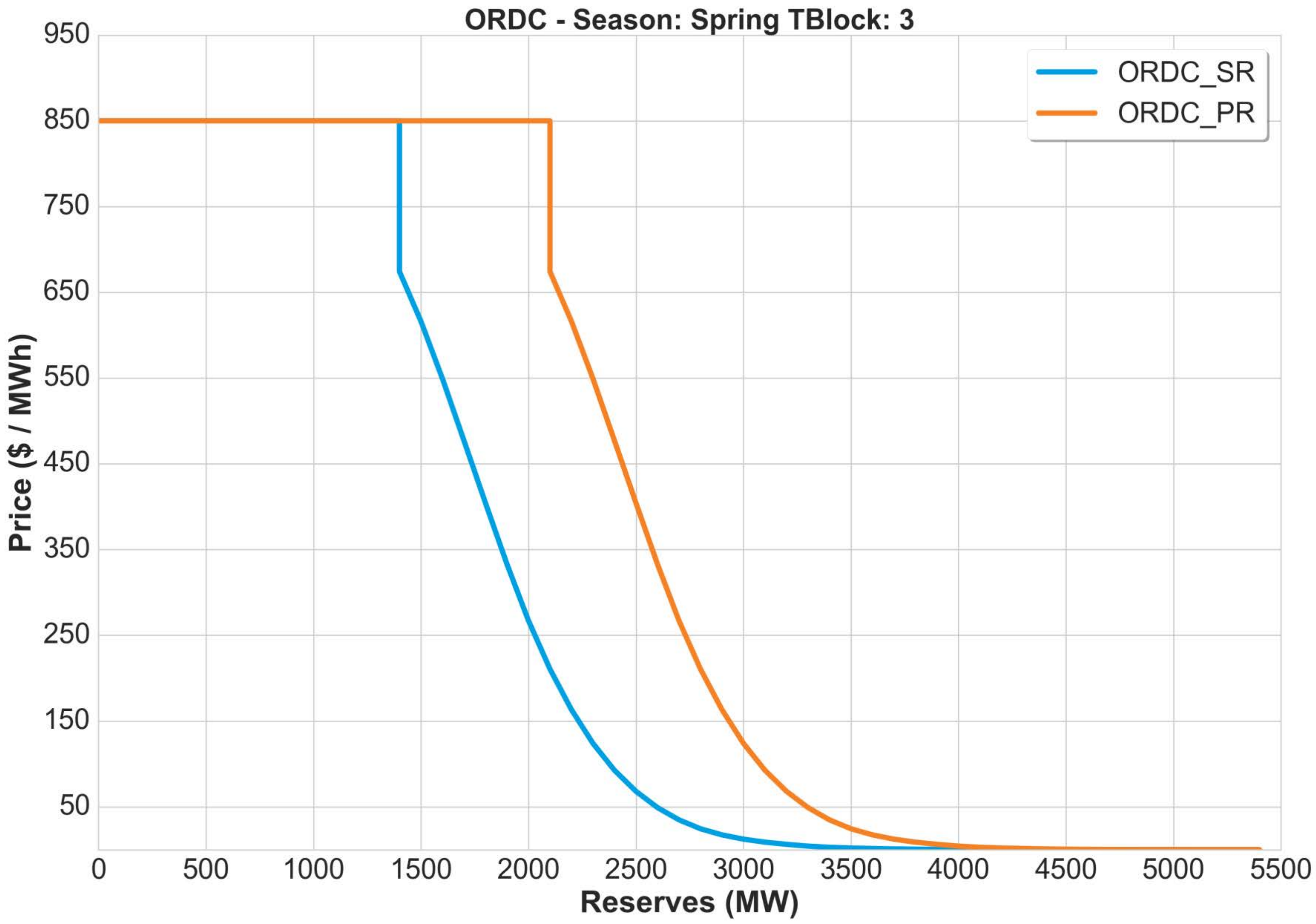
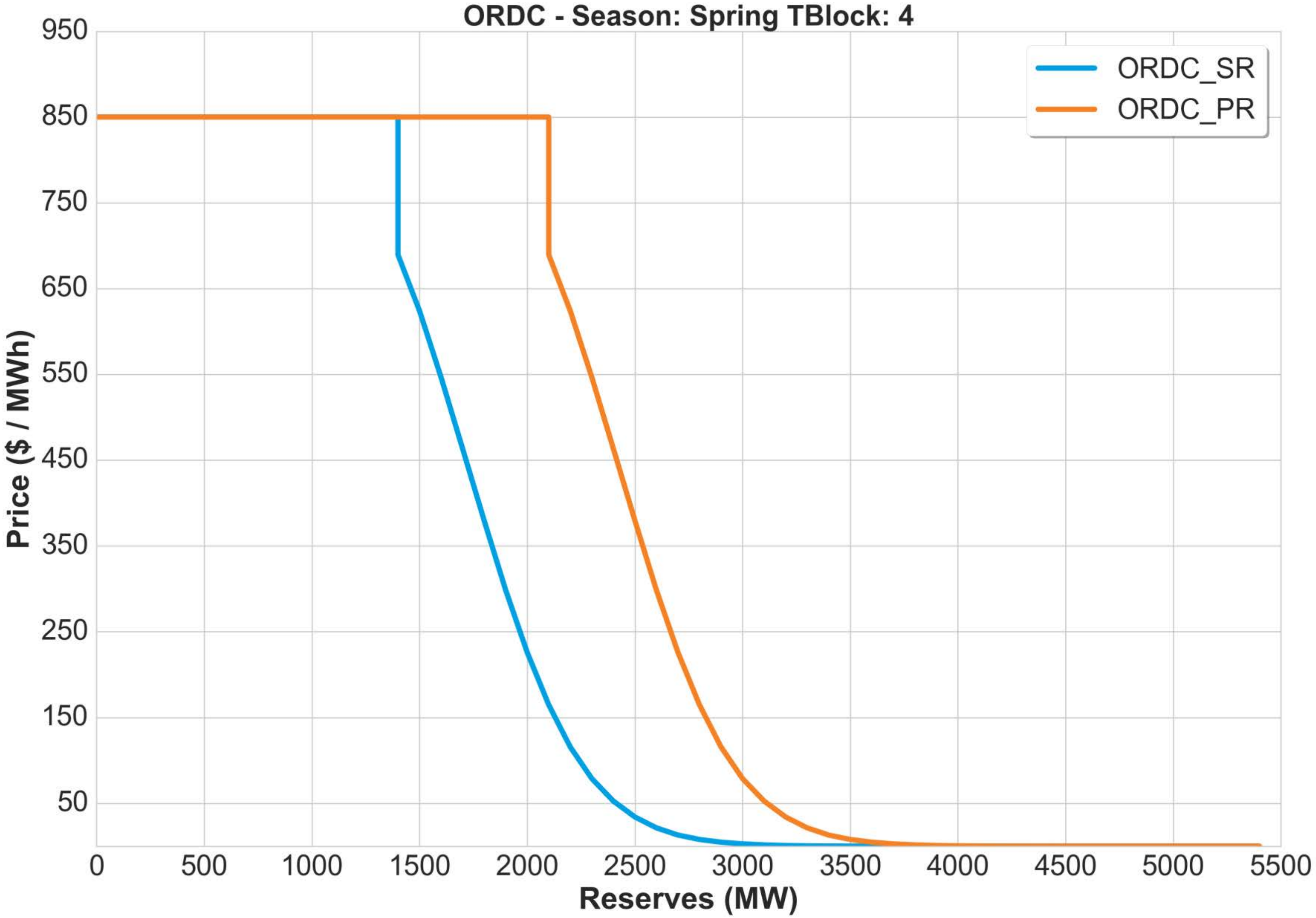
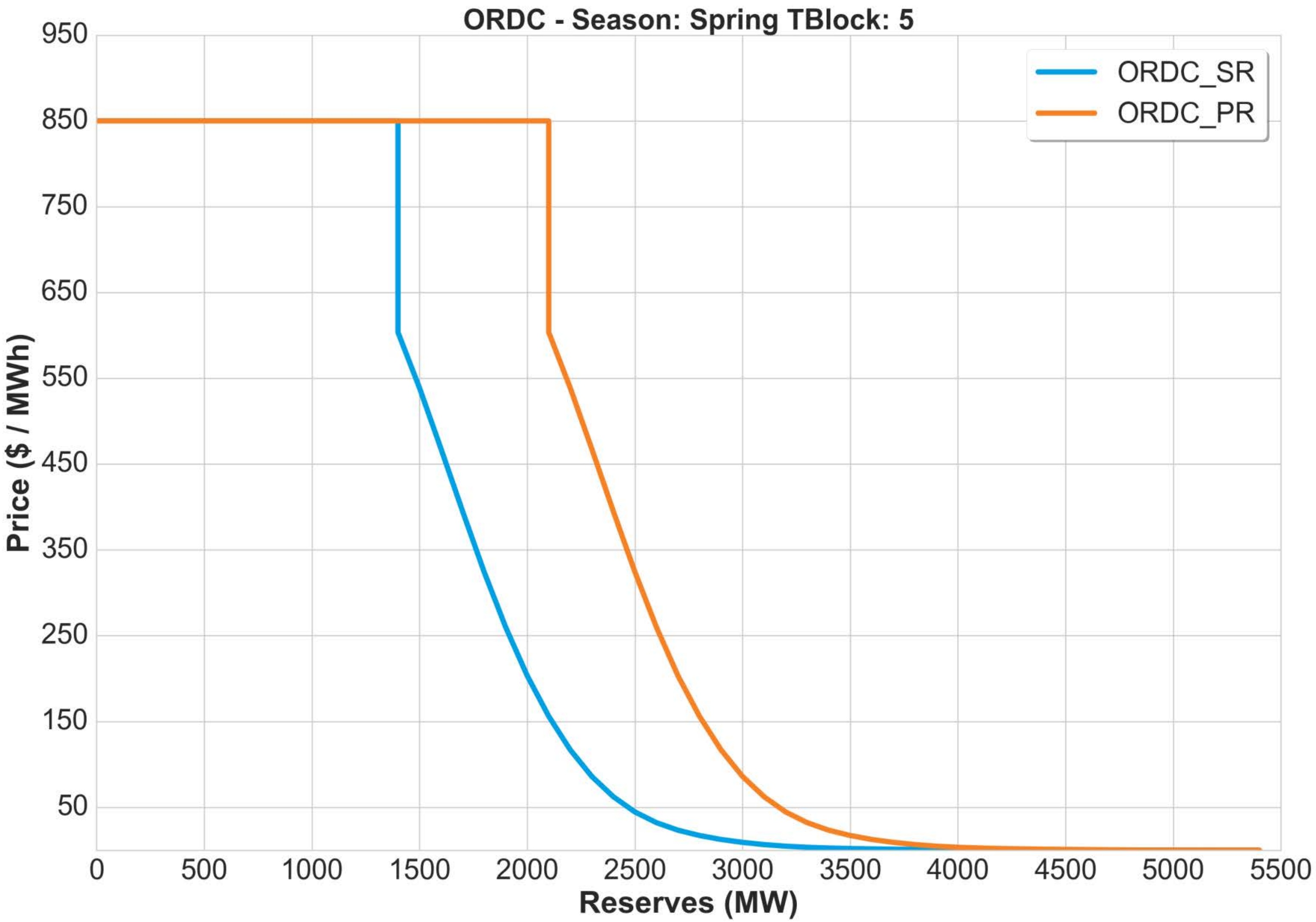


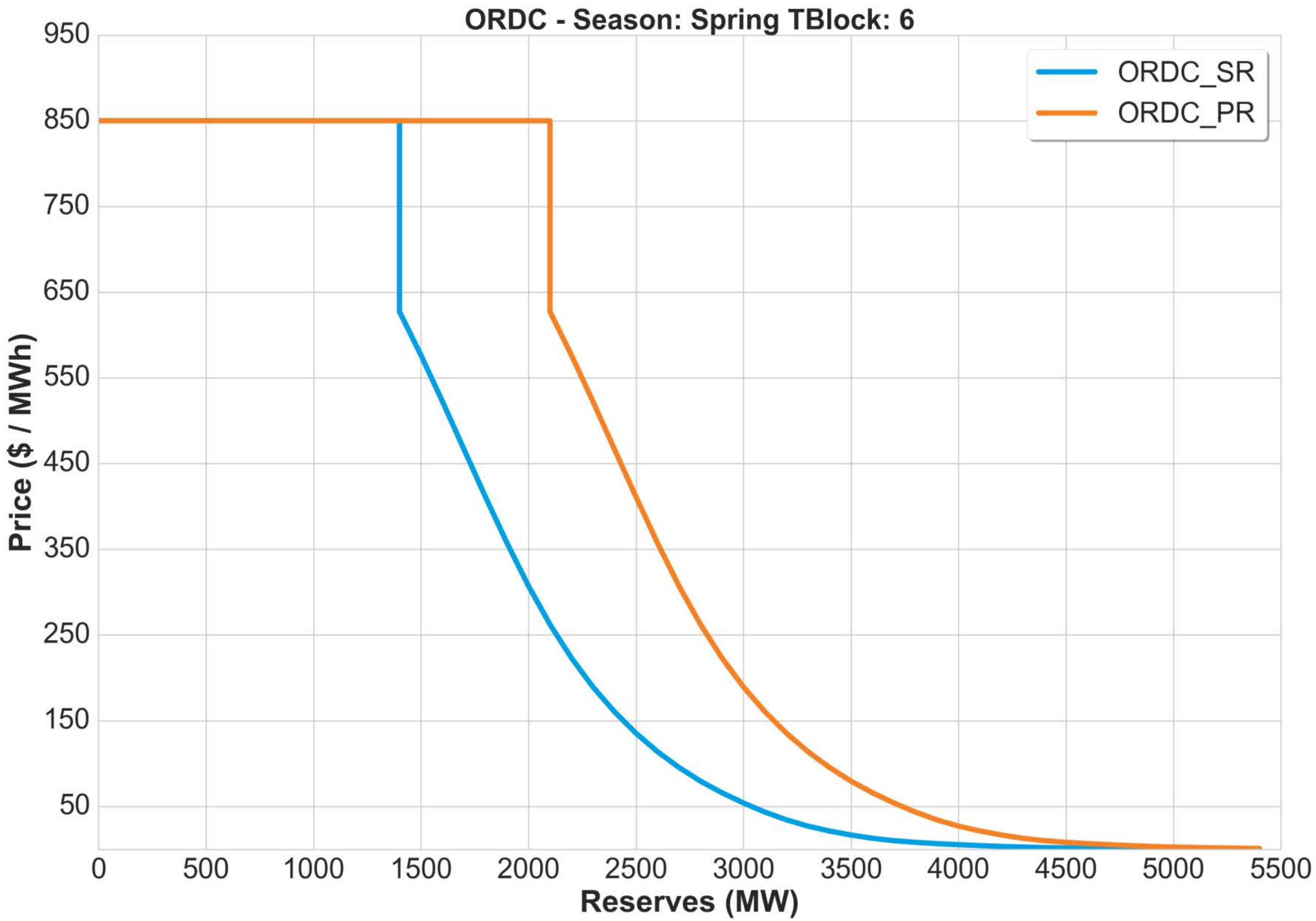
ORDC Spring TBlock 4 (1100-1400)



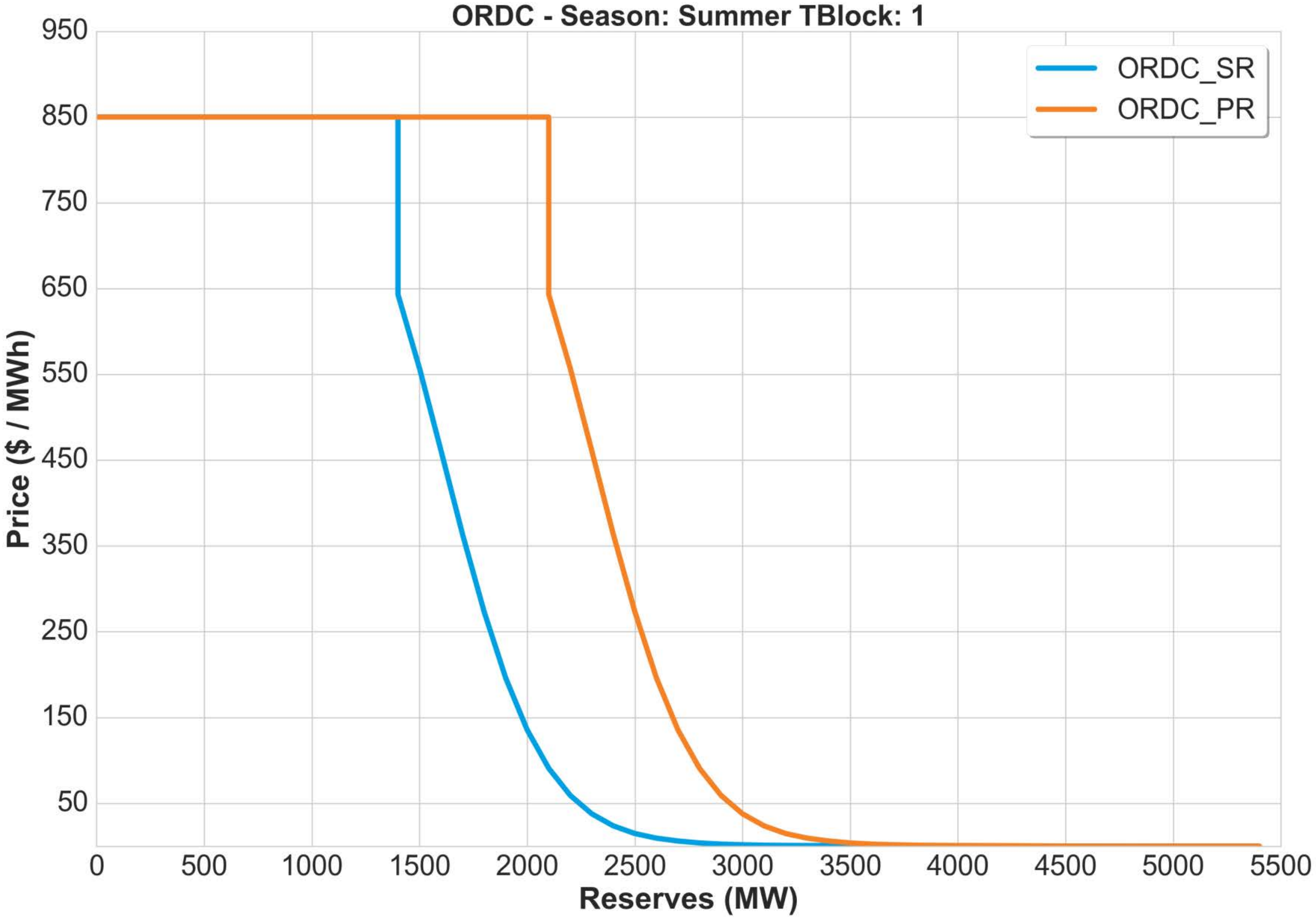
ORDC Spring TBlock 5 (1500-1800)



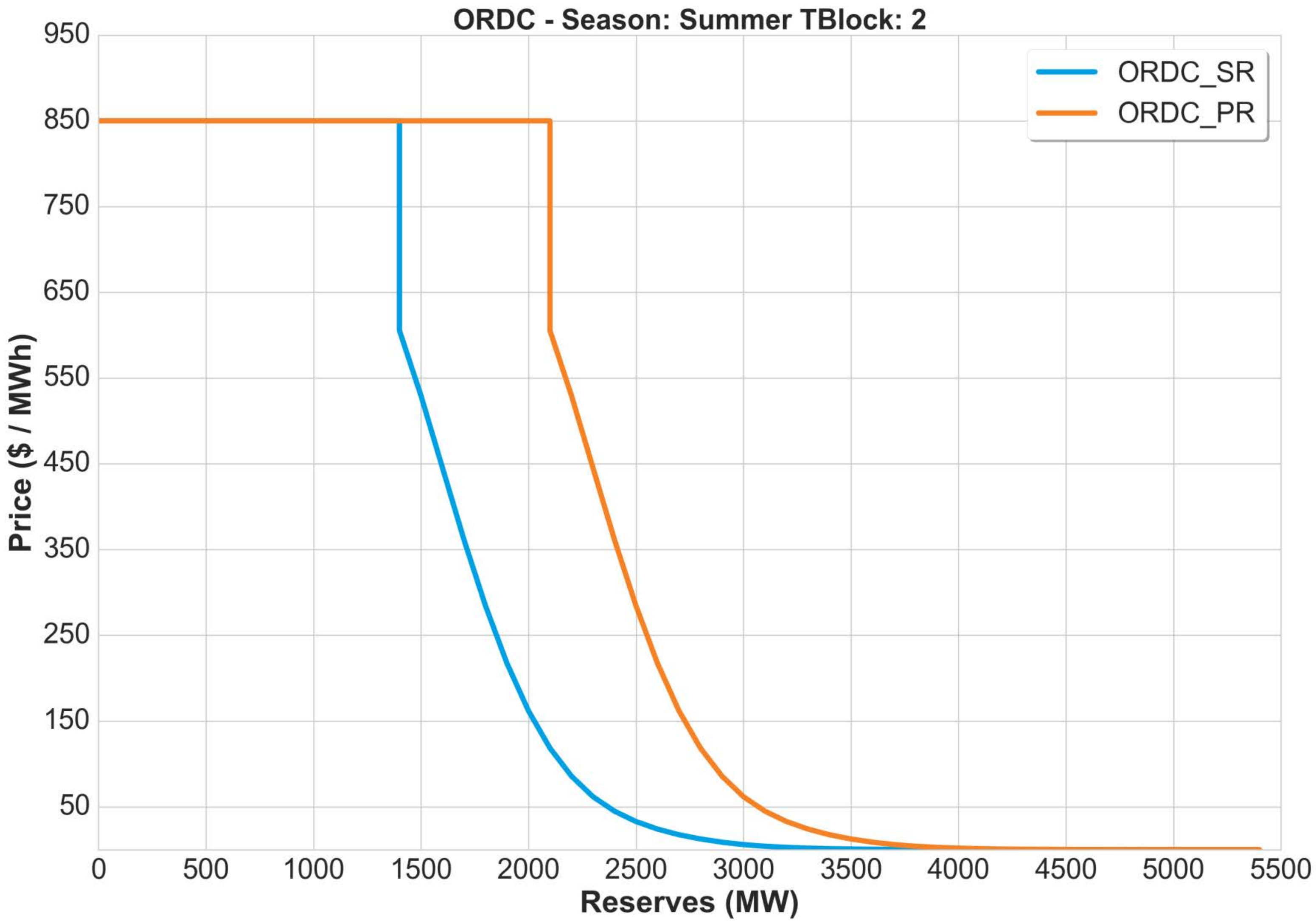
ORDC Spring TBlock 6 (1900-2200)



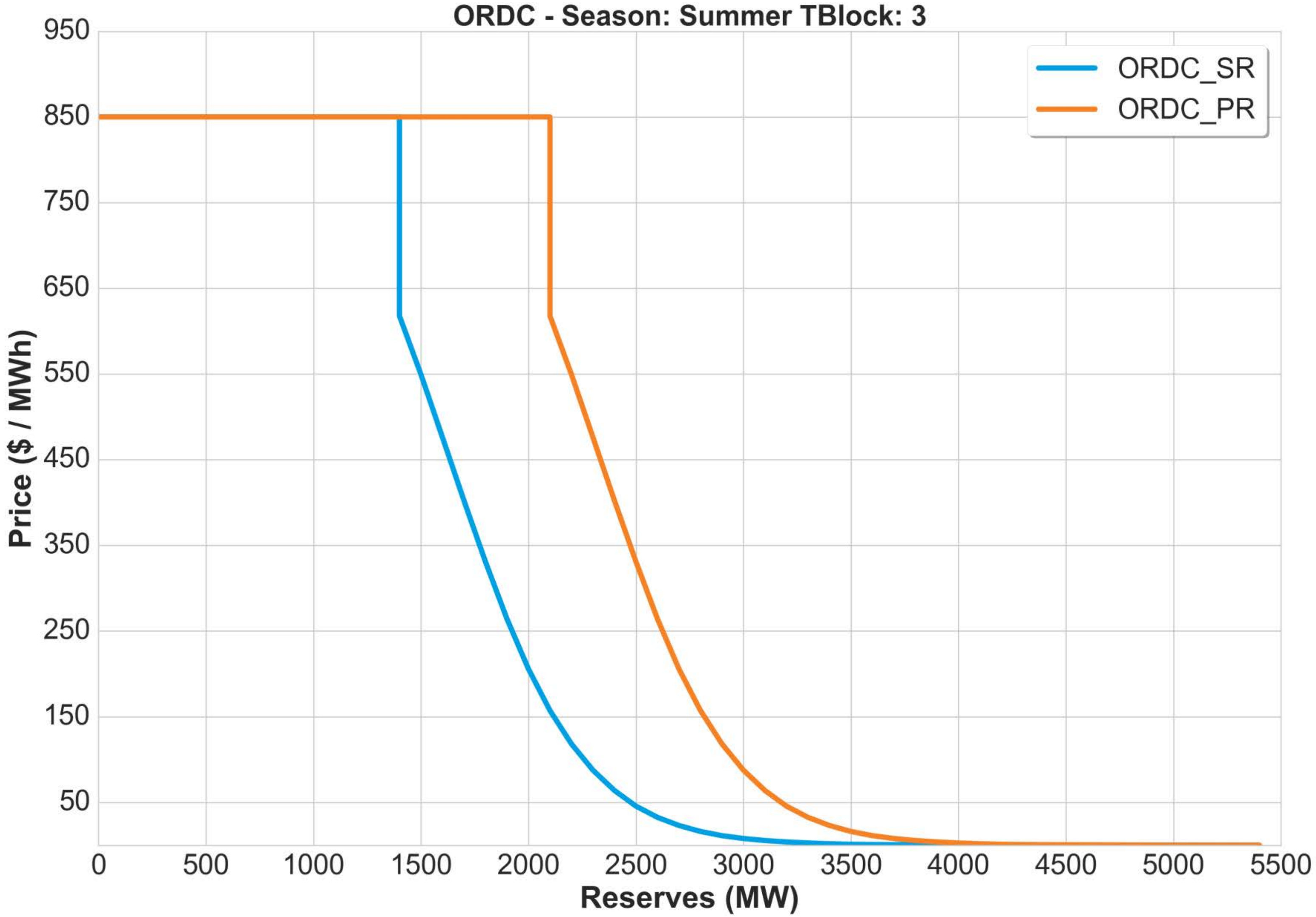
ORDC Summer TBlock 1 (2300-0200)



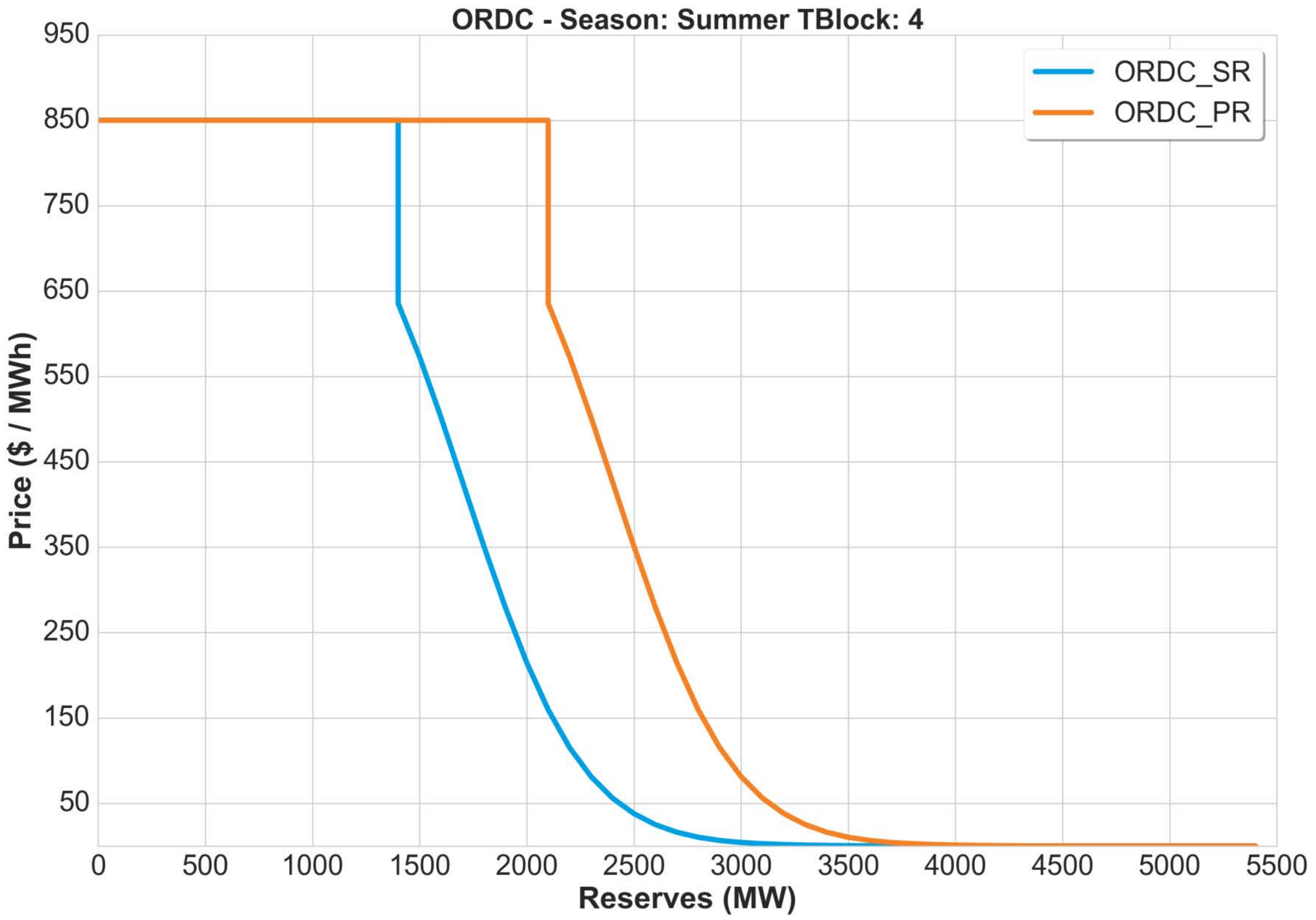
ORDC Summer TBlock 2 (0300-0600)



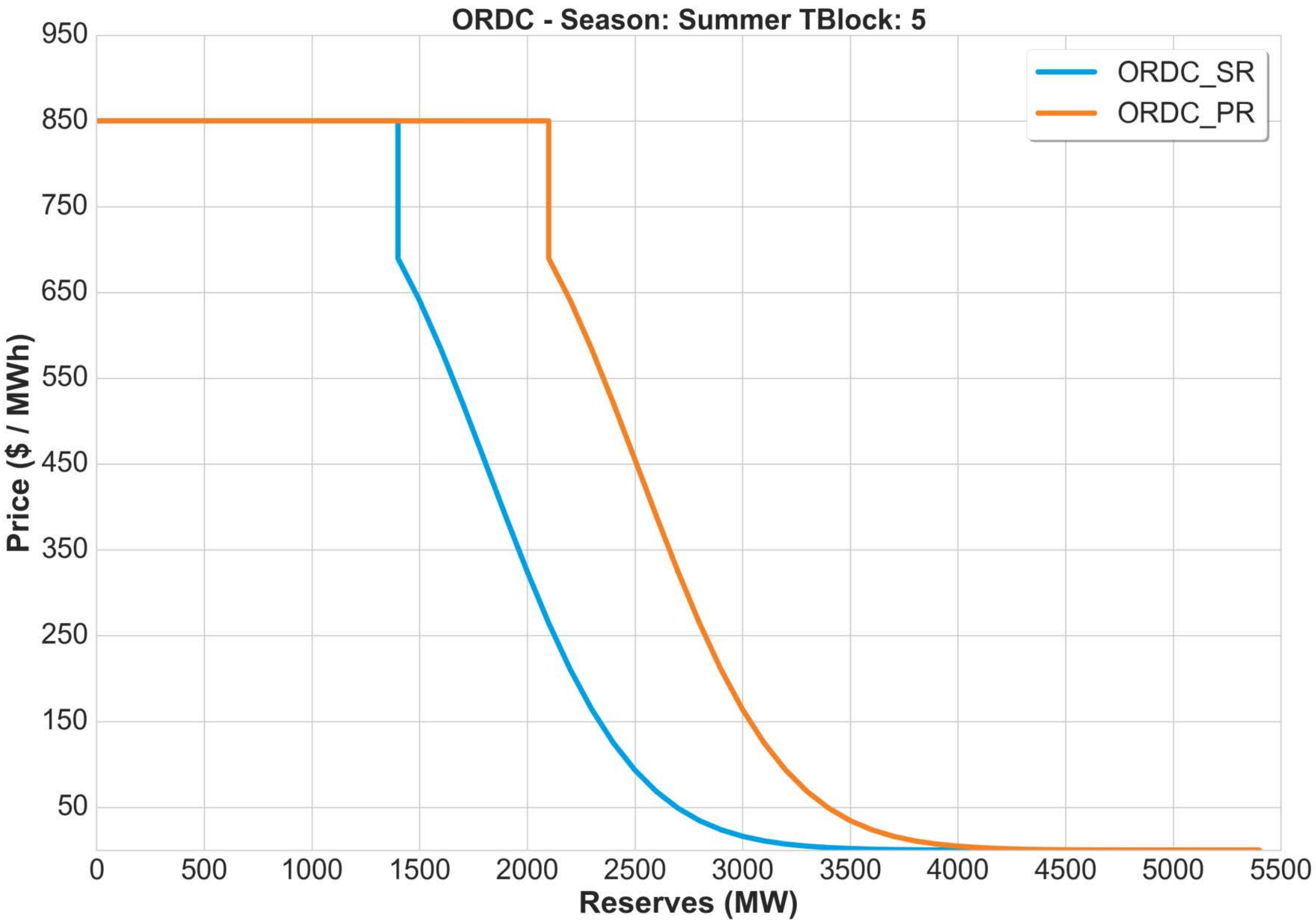
ORDC Summer TBlock 3 (0700-1000)



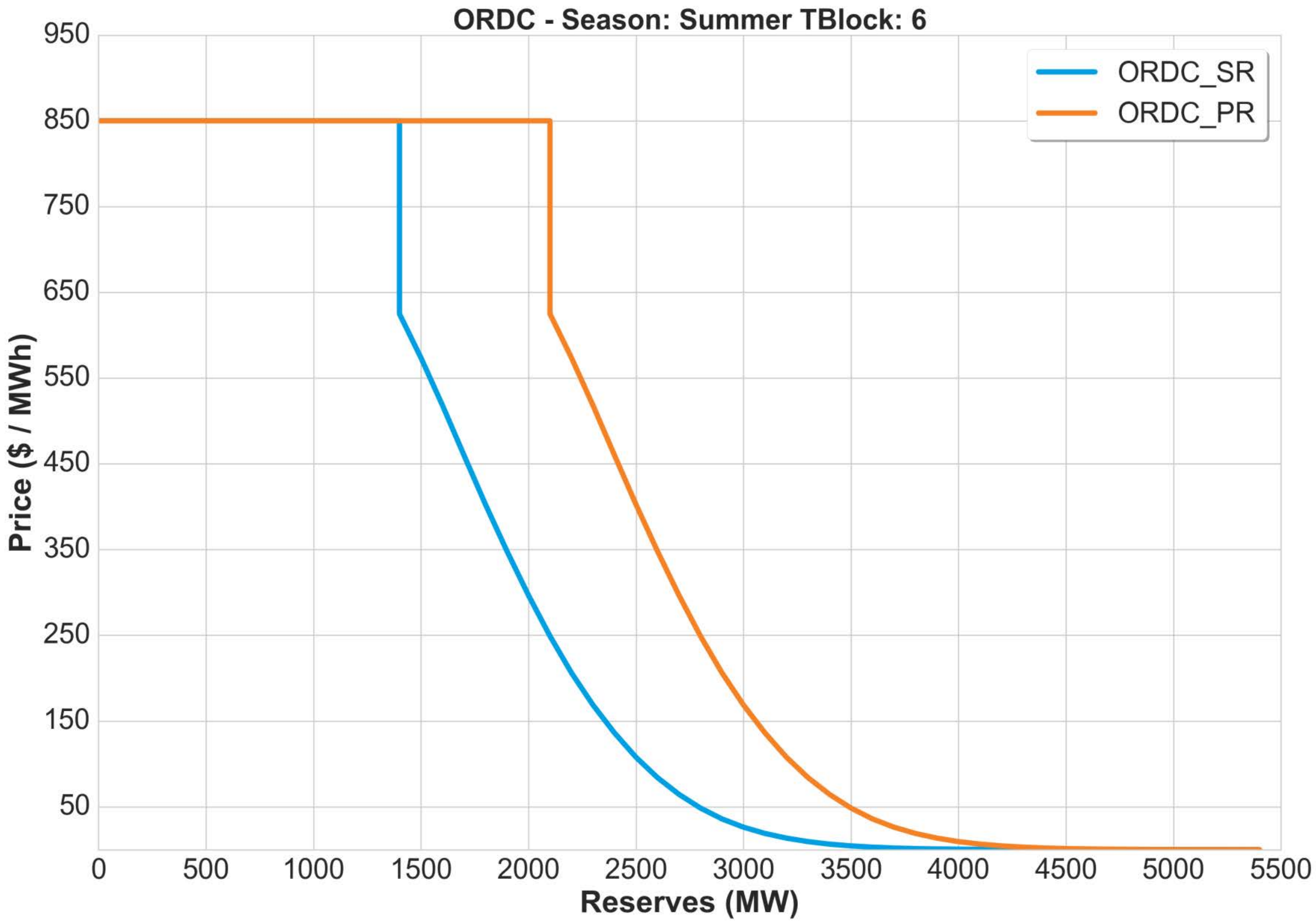
ORDC Summer TBlock 4 (1100-1400)



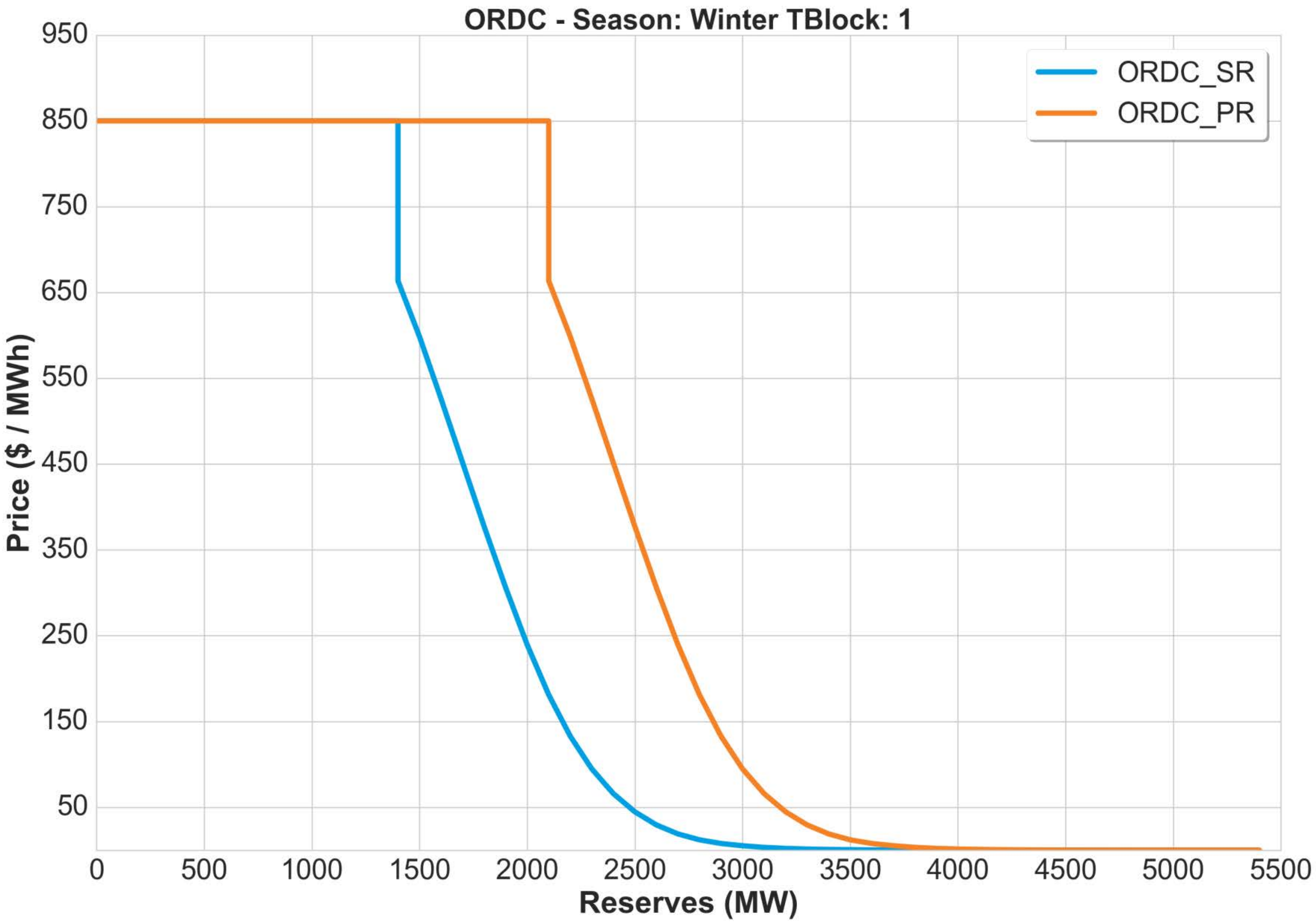
ORDC Summer TBlock 5 (1500-1800)



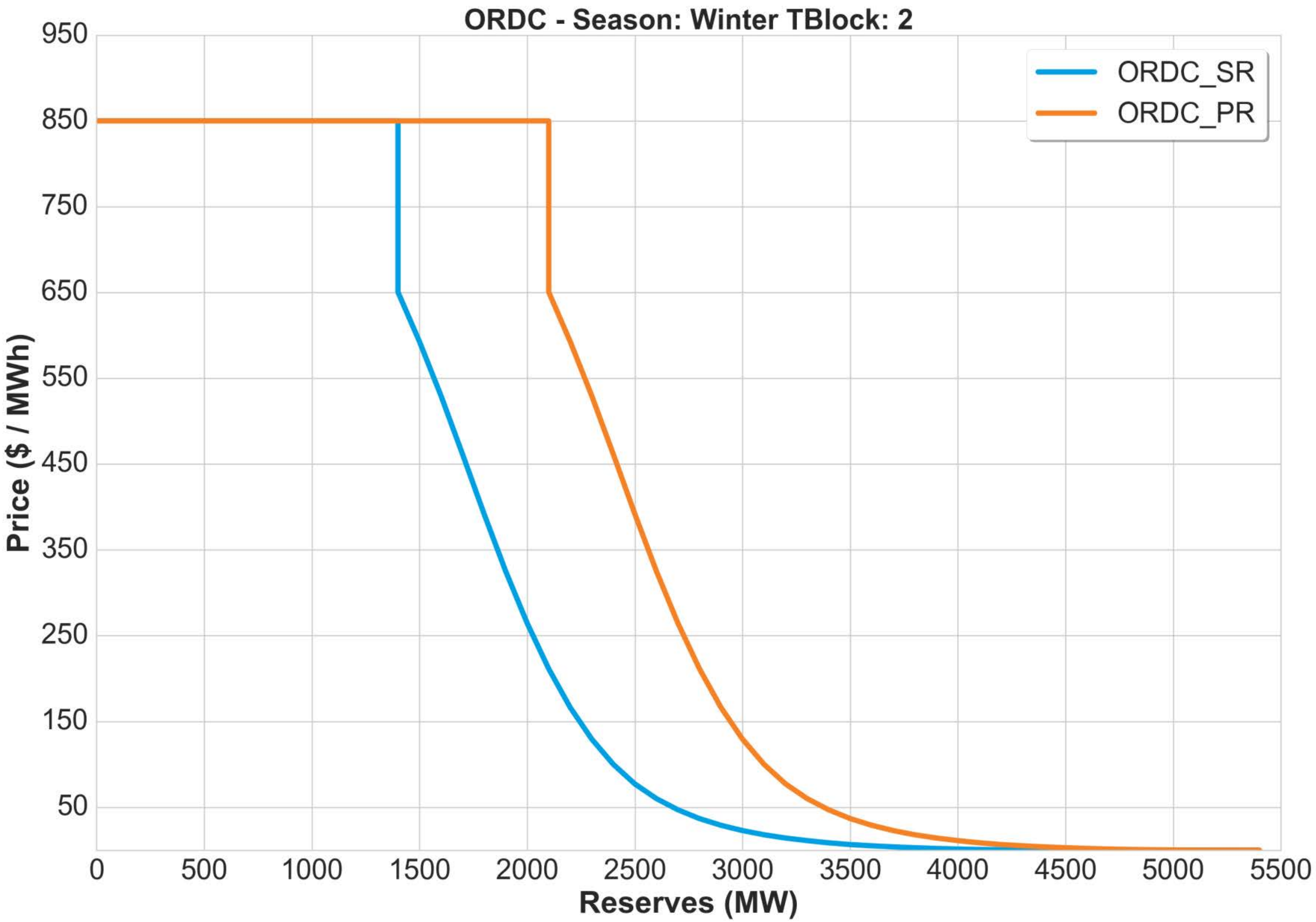
ORDC Summer TBlock 6 (1900-2200)



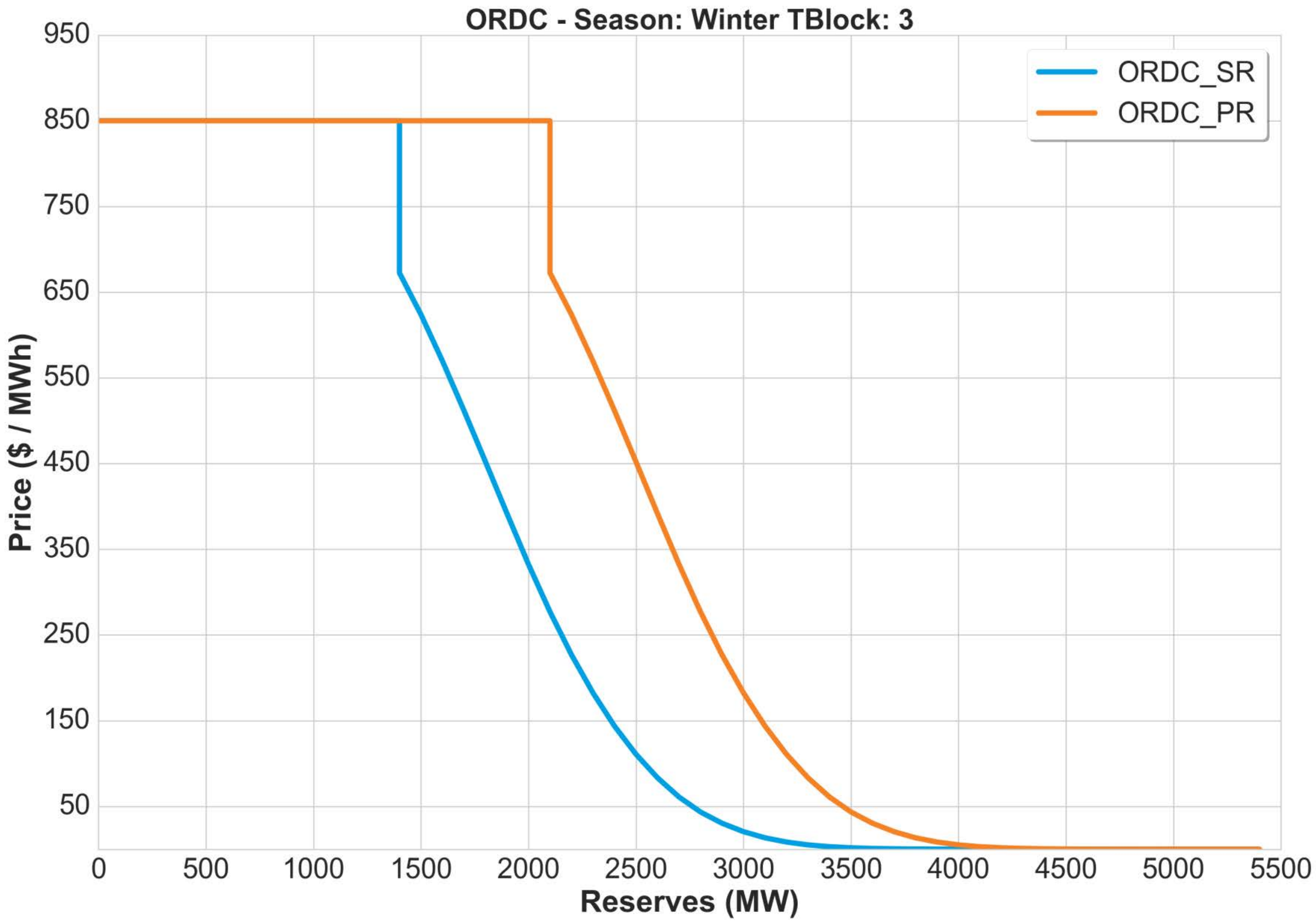
ORDC Winter TBlock 1 (2300-0200)



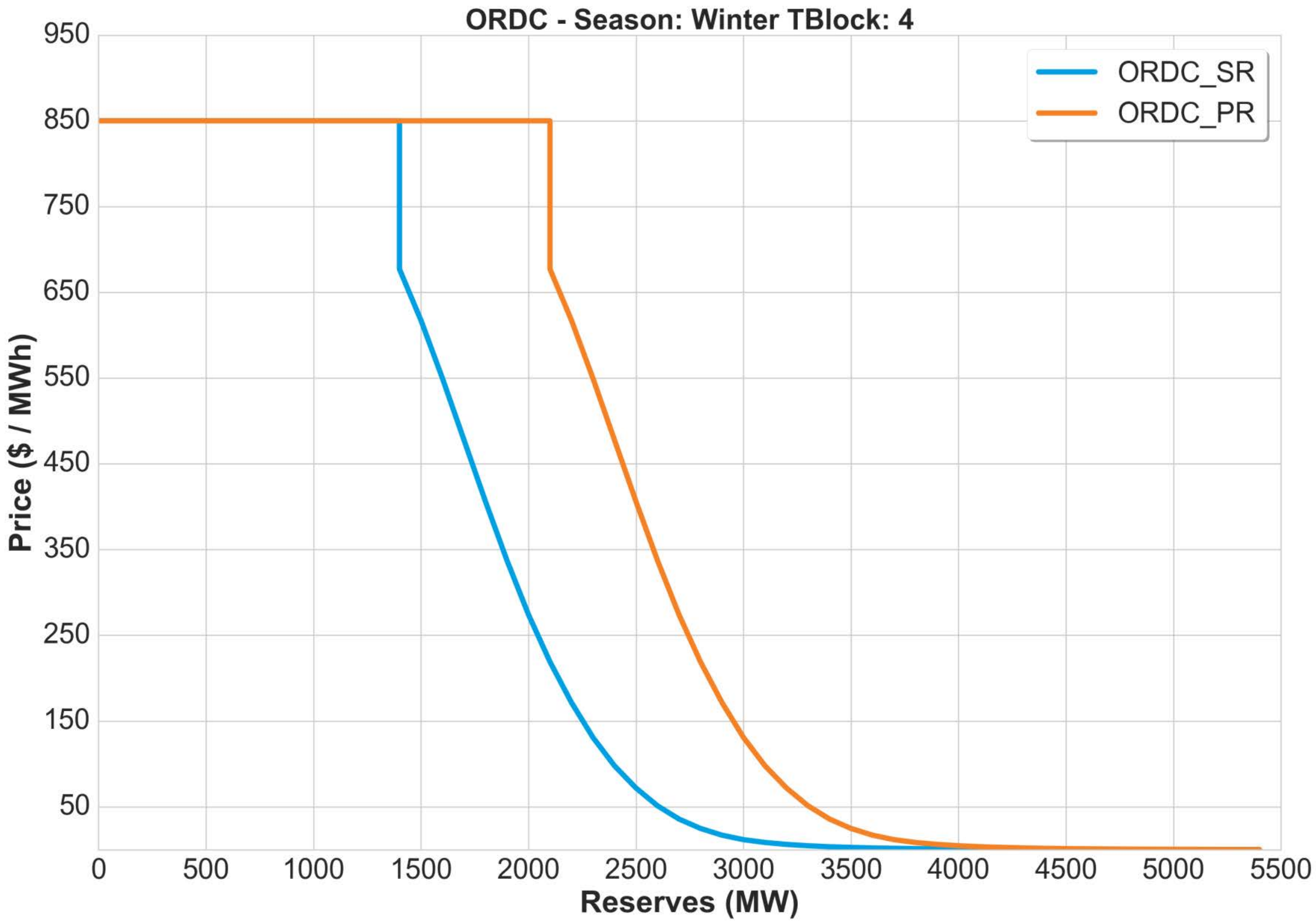
ORDC Winter TBlock 2 (0300-0600)



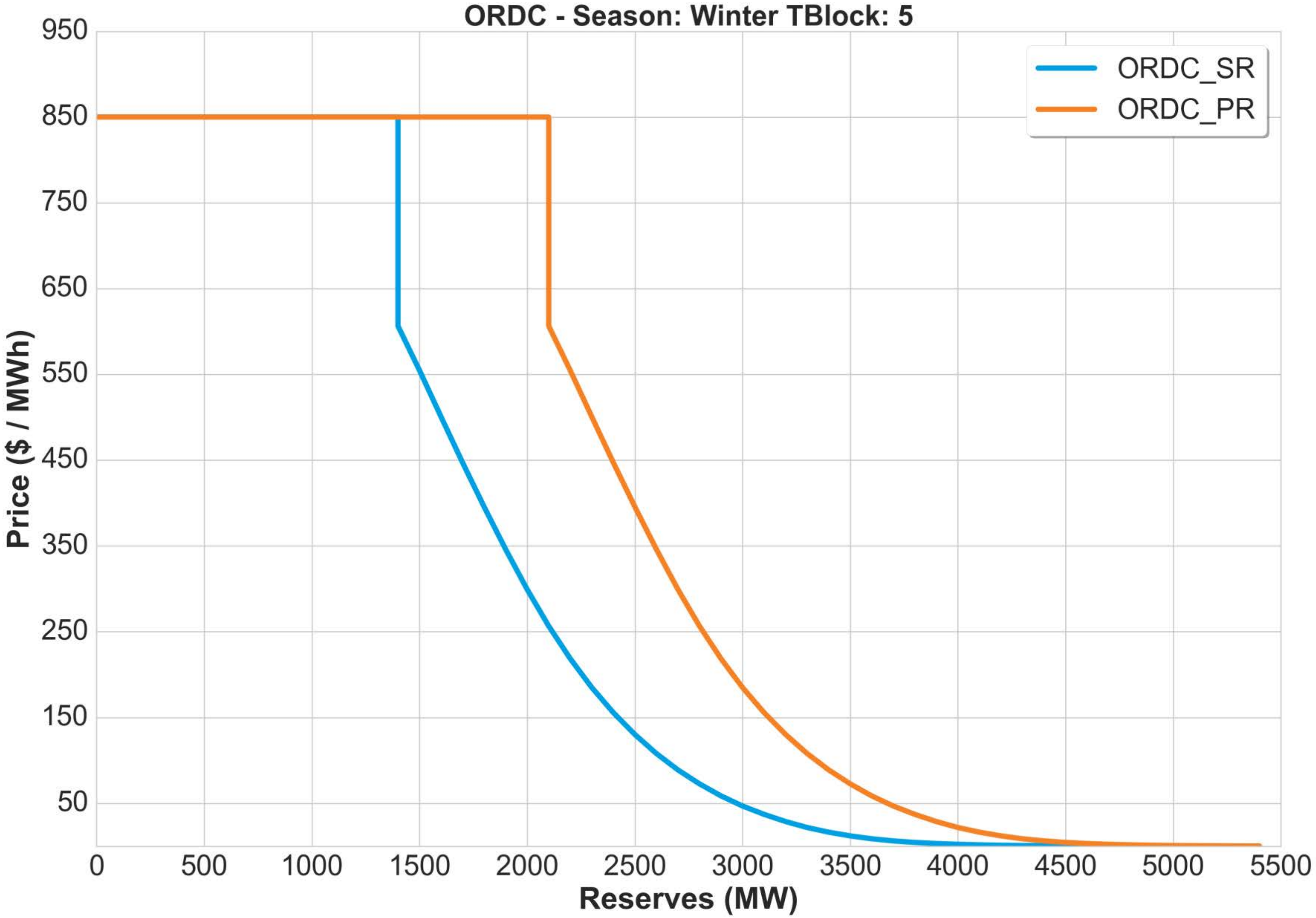
ORDC Winter TBlock 3 (0700-1000)



ORDC Winter TBlock 4 (1100-1400)



ORDC Winter TBlock 5 (1500-1800)



ORDC Winter TBlock 6 (1900-2200)