Opportunity Costs for Energy Storage Resources

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Agenda

- Reference Level Overview
- Opportunity Cost Overview for Energy Storage Resources (ESRs)
- LBMPs and Scheduling
- Derivation of an Opportunity Cost
- Example of an Opportunity Cost Calculation
- Opportunity Costs in Reference Levels
- Next Steps

Reference Level Overview

Reference Levels for ESRs

- **The NYISO will be required to calculate a Reference Level for ESRs**
  - A Reference Level is a "proxy" intended to reflect the offers that a Market Participant would submit for a generator if it was in a competitive market and could not exercise Market Power
  - Opportunity cost is expected to be the largest component of an ESR's Reference Level for Incremental Energy
  - The NYISO has developed a standardized methodology for calculating the opportunity cost of these resources based on expected LBMPs that it plans to use as a baseline
  - Market Participants will be allowed to submit opportunity costs that were calculated using other methods, provided they are fully documented and accepted by the NYISO

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Opportunity Cost Adjustments

- **NYISO will add a means for all Generators to reflect changes to their opportunity costs while injecting or withdrawing**
  - This will work similar to a thermal unit utilizing the Fuel Cost Adjustment functionality
  - Instead of submitting updated fuel costs, Generators will submit updated opportunity costs
  - Like a fuel cost update, allowed updated opportunity cost updates will revise the affected Generator's Reference Levels
  - There will be a penalty if inaccurate opportunity costs are submitted that result in the unit failing the conduct and impact tests

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OCAs and FCAs

- Costs that are submitted or bid as fuel costs, shall not also be submitted or bid as opportunity costs
- Costs shall not be submitted or bid in two parts, as both a fuel cost and an opportunity costs, in order to evade applicable thresholds
- Fossil generators shall not submit or bid fuel costs, including balancing costs, as opportunity costs

Opportunity Cost Overview for Energy Storage Resources

Assumptions

- The following assumptions are made when calculating the opportunity cost for an ESR
  - At the beginning of the day, the energy storage level for an ESR will be its minimum level
  - An ESR will be able to completely charge or discharge within a single hour
- Day-Ahead Market calculations are described on the following slides

Assumptions

- **The calculations and algorithms do not currently account for more complex scenarios**
  - ESRs that take longer than a single hour to charge or discharge The calculations and algorithms do not currently account for additional risks that are found in the Real-Time Market
  - In real-time the software won't be optimizing over a 24 hour period
  - Changes in revenue from buying out of a Day-Ahead schedule

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Opportunity Cost Calculation

- **The main steps to calculate the opportunity cost for an ESR are**
  - Determine an expected LBMP path for the day
  - Use the expected LBMP path for the day to determine the ESRs' optimal schedule
  - Assume an incremental change in the optimal schedule for a single hour
  - The impact on the daily revenue is used to determine the opportunity cost for that hour

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LBMPs and Scheduling

Expected LBMP Path

- **Determine an expected LBMP path**
  - Pull daily Day-Ahead Market LBMPs for the last 90 days
    - 90 days is the historical period used for the development of Reference Levels for other generating units
  - Calculate the average LBMP for each hour of the day using the historical sample
    - The average LBMPs will be adjusted to account for changes in fuel costs
  - This will be the expected LBMP path used for the calculation of opportunity costs in the Day-Ahead Market
  - For calculating Opportunity Costs in the Real-Time Market for a given market day, use the Day-Ahead Market LBMPs for that market day as the expected LBMP path

Optimal Schedule Algorithm

- Identify all peaks and troughs
- Assume starting storage level is zero
- Assume zero scheduled MWs in hours not associated with either a peak or trough
- Look at the difference between peaks and trough to see if that is profitable, accounting for round trip efficiency

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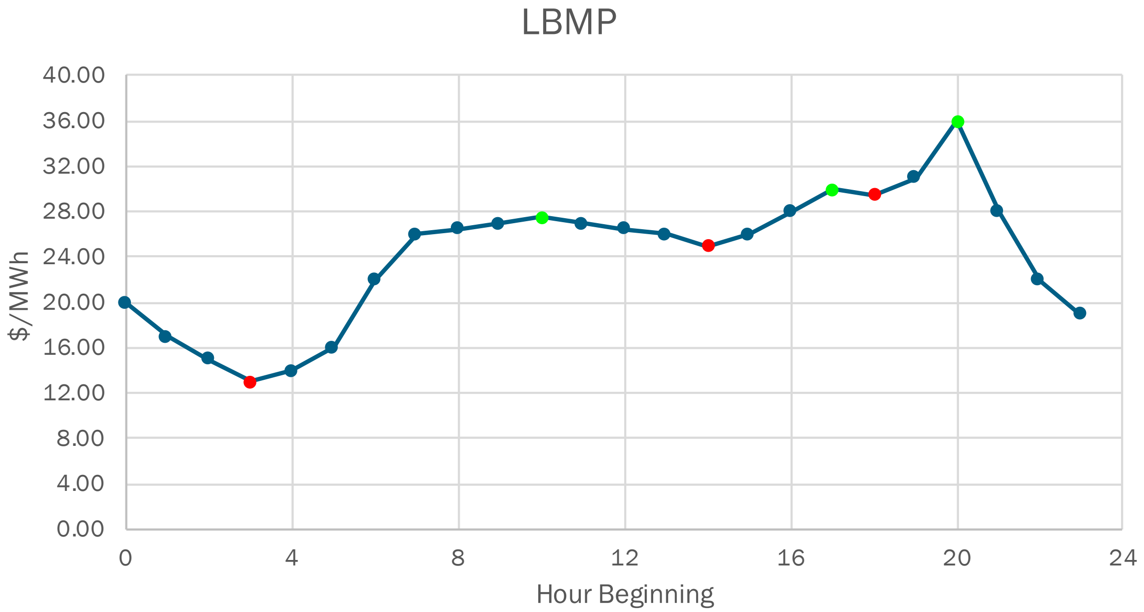
Optimal Schedule Algorithm



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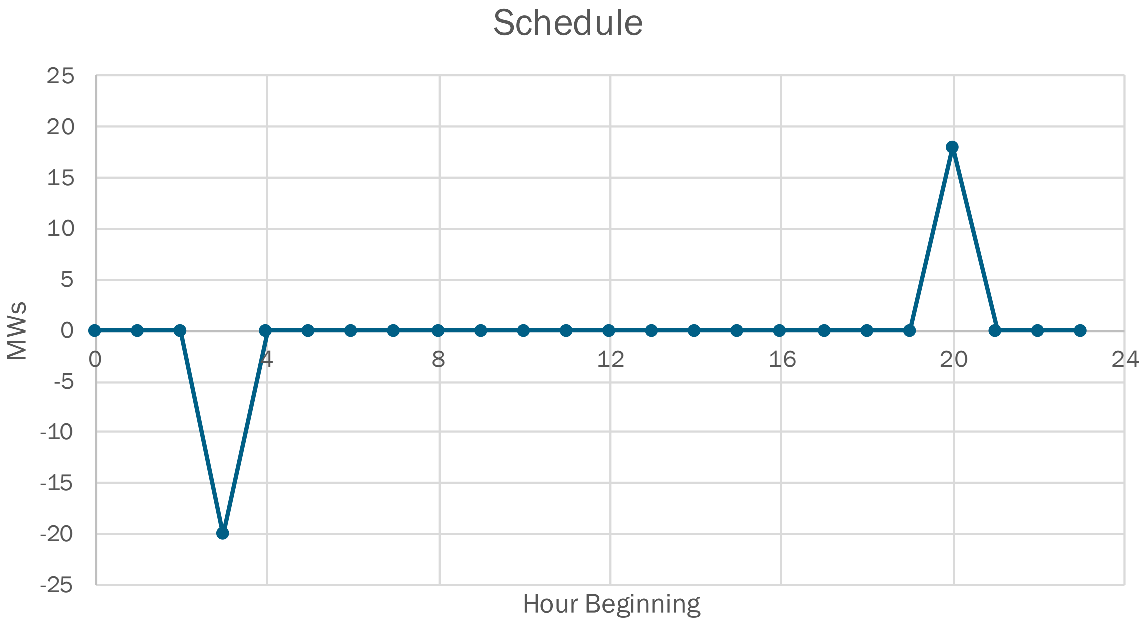
Optimal Schedule Results



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Derivation of an Opportunity Cost

Revenue From the Optimal Schedule

- The revenue the ESR receives for operating at its optimal schedule can be defined as follows:
  - $Rev = P_1 * MWp - T_1 * MWt + P_2 * MWp - T_2 * MWt + ...$
    - $MWp = MWt * E$
  - $Rev = (P_1 * E - T_1 + P_2 * E - T_2 + ...) * MWt$
  - Where:
    - P is the LBMP for an hour in which the unit is scheduled to inject
    - MWp is the amount of MWhs the unit is scheduled for during a max injection
    - T is the LBMP for an hour in which the unit is scheduled to withdraw
    - MWt is the amount of MWhs the unit is scheduled for during a max withdrawal
    - E is the round trip efficiency

Revenue From A Sub-Optimal Schedule

- The revenue the ESR receives due to a change to its optimal schedule by injecting an incremental MWh in hour H rather than at the peak LBMP P can be stated as follows:
  - $Rev' = P_1 * MWp - T_1 * MWt + LBMP_H * \Delta MW - P_1 * \Delta MW$
    - $MWp = MWt * E$
  - $Rev' = (P_1 * E - T_1) * MWt + (LBMP_H - P_1) * \Delta MW$
  - Where:
    - $LBMP_H$ is the LBMP in hour H
    - ΔMW is the incremental MWhs injected in hour H

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Calculating Opportunity Cost

- If we set Rev equal to Rev', we can replace $LBMP_H$ with a variable (OC) and solving for that variable will give the LBMP that would need to be received in hour H for the sub-optimal schedule to be as profitable as the optimal schedule:
  - $Rev = Rev'$
  - $(P_1 * E - T_1) * MWt = (P_1 * E - T_1) * MWt + (OC - P_1) * \Delta MW$
  - $\cancel{(P_1 * E - T_1) * MWt} = \cancel{(P_1 * E - T_1) * MWt} + (OC - P_1) * \Delta MW$
  - $0 = (OC - P_1) * \Delta MW$
  - $OC = P_1$

Example of an Opportunity Cost Calculation

Opportunity Cost Calculation

Hour	LBMP	Optimal Schedule	Opportunity Cost - Withdrawal	Opportunity Cost - Injection
0	20.00	0		
1	17.00	0		
2	15.00	0		
3	13.00	-20	14.00	17.78
4	14.00	0		
5	16.00	0		

- **For hours with a scheduled withdrawal:**
  - OC to withdrawal =
    - $\min(\min(LBMP_{hour0 \rightarrow trough - 1}), \min(LBMP_{trough + 1 \rightarrow peak - 1}), LBMP_{peak} * E)$
    - $\min(\min(\text{LBMP in hours } 00 - 02 \text{ and hours } 04 - 19), \text{LBMP in hour } 20 * E)$
    - $\min(15,14,36 * .9) = 14.00$
  - OC to inject =
    - $(-LBMP_{trough} + \min LBMP_{trough + 1 \rightarrow peak - 1} + \min LBMP_{hour0 \rightarrow trough - 1})/E$
    - $(-\text{LBMP in hour3} + \min(\text{LBMP in hours } 04 - 19) + \min(\text{LBMP in hours } 00 - 02))/E$
    - $(-13 + 14 + 15)/.9 = 17.78$

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Opportunity Cost Calculation

Hour	LBMP	Optimal Schedule	Opportunity Cost - Withdrawal	Opportunity Cost - Injection
18	29.50	0		
19	31.00	0		
20	36.00	18	20.70	31.00
21	28.00	0		
22	22.00	0		
23	19.00	0		

- **For hours with a scheduled injection:**
  - OC to withdrawal =
    - $(-\mathrm{LBMP}_{\mathrm{peak}} + \mathrm{maxLBMP}_{\mathrm{peak}\,+\,1\,\rightarrow\,\mathrm{hour23}} + \mathrm{maxLBMP}_{\mathrm{trough}\,+\,1\,\rightarrow\,\mathrm{peak}\,-\,1})$
    - $\left(-\mathrm{LBMP\ in\ hour20} + \max(\mathrm{LBMP\ in\ hours\ 21-23}) + \max(\mathrm{LBMP\ in\ hours\ 03-19})\right) * \mathrm{E}$
    - $(-36 + 28 + 31) * .9 = 16.10$
  - OC to inject =
    - $\max\left(\max(\mathrm{LBMP}_{\mathrm{trough}\,+\,1\,\rightarrow\,\mathrm{hour23}}), \frac{\mathrm{LBMP}_{\mathrm{trough}}}{\mathrm{E}}\right)$
    - $\max\left(\max(\mathrm{LBMP\ in\ hours\ 04-23}), \frac{\mathrm{LBMP\ in\ hour\ 3}}{\mathrm{E}}\right)$
    - $\max(31, \frac{13}{.9}) = 31.00$

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Opportunity Cost Calculation

Hour	LBMP	Optimal Schedule	Opportunity Cost - Withdrawal	Opportunity Cost - Injection
0	20.00	0	15.30	15.31
1	17.00	0	13.50	22.22
2	15.00	0	13.00	18.89
3	13.00	-20	14.00	17.78
4	14.00	0		
5	16.00	0		

- **For hours before the first scheduled withdrawal:**
  - OC to withdrawal =
    - $\max(\max(LBMP_{hour+1 \rightarrow trough-1}) * E, LBMP_{trough})$
    - Example for hour 00
    - $\max(\max(\text{LBMP in hours } 01-02) * E, LBMP_{trough})$
    - $\max(17 * .9, 13) = 15.30$
  - OC to inject =
    - $\min(LBMP_{hour0 \rightarrow hour-1})/E$
    - Example for hour 02
    - $\min(\text{LBMP in hours } 00-01)/E$
    - $\frac{17}{.9} = 18.89$
    - In hour 00, the opportunity cost is the max of the expected trough LBMP divided by the round trip efficiency or the opportunity cost to withdraw in hour 00 plus $0.01

Opportunity Cost Calculation

Hour	LBMP	Optimal Schedule	Opportunity Cost - Withdrawal	Opportunity Cost - Injection
18	29.50	0		
19	31.00	0		
20	36.00	18	20.70	31.00
21	28.00	0	19.80	36.00
22	22.00	0	17.10	31.11
23	19.00	0	0.00	24.44

- **For hours after the last scheduled injection:**
  - OC to withdrawal =
    - $\max(\mathrm{LBMP}_{\mathrm{hour}\,+\,1\,\rightarrow\,\mathrm{hour23}}) * \mathrm{E}$
    - Example for hour 21
    - $\max(\mathrm{LBMP\ in\ hours\ 22-23}) * \mathrm{E}$
    - $(22 * .9) = 15.40$
    - In hour 23, the opportunity cost is zero
  - OC to inject =
    - $\min(\min(\mathrm{LBMP}_{\mathrm{peak}\,+\,1\,\rightarrow\,\mathrm{hour}\,-\,1})/\mathrm{E}\,,\mathrm{LBMP}_{\mathrm{peak}})$
    - Example for hour 23
    - $\min(\min(\mathrm{LBMP\ in\ hours\ 21-22})/\mathrm{E}\,,\mathrm{LBMP\ in\ hour\ 20})$
    - $\min(22/.9\,,36) = 24.44$

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Opportunity Cost Calculation

Hour	LBMP	Optimal Schedule	Opportunity Cost - Withdrawal	Opportunity Cost - Injection
3	13.00	-20	14.00	17.78
4	14.00	0	13.00	17.78
5	16.00	0	13.00	24.44
6	22.00	0	14.40	27.78
7	26.00	0	19.80	27.78
8	26.50	0	23.40	27.78
9	27.00	0	23.85	27.78
10	27.50	0	24.30	27.78
11	27.00	0	24.75	27.78
12	26.50	0	24.75	27.78
13	26.00	0	24.75	27.78
14	25.00	0	24.75	28.89
15	26.00	0	24.75	31.11
16	28.00	0	24.75	32.78
17	30.00	0	25.20	32.78
18	29.50	0	27.00	34.44
19	31.00	0	27.00	36.00
20	36.00	18	20.70	31.00

- **For hours between a scheduled withdrawal and a scheduled injection**
  - OC to withdrawal =
    - $\max(\max(LBMP_{trough+1 \rightarrow hour-1}) * E, LBMP_{trough})$
    - Example for hour 11
    - $\max(\max(\text{LBMP in hours } 04-10) * E, \text{LBMP in hour } 03)$
    - $\max(27.50 * .9, 13) = 24.75$
  - OC to inject =
    - $\min(\min(LBMP_{hour+1 \rightarrow peak-1})/E, LBMP_{peak})$
    - Example for hour 11
    - $\min(\min(\text{LBMP in hours } 12-19)/E, \text{LBMP in hour } 20)$
    - $\min(25/.9, 36) = 27.78$

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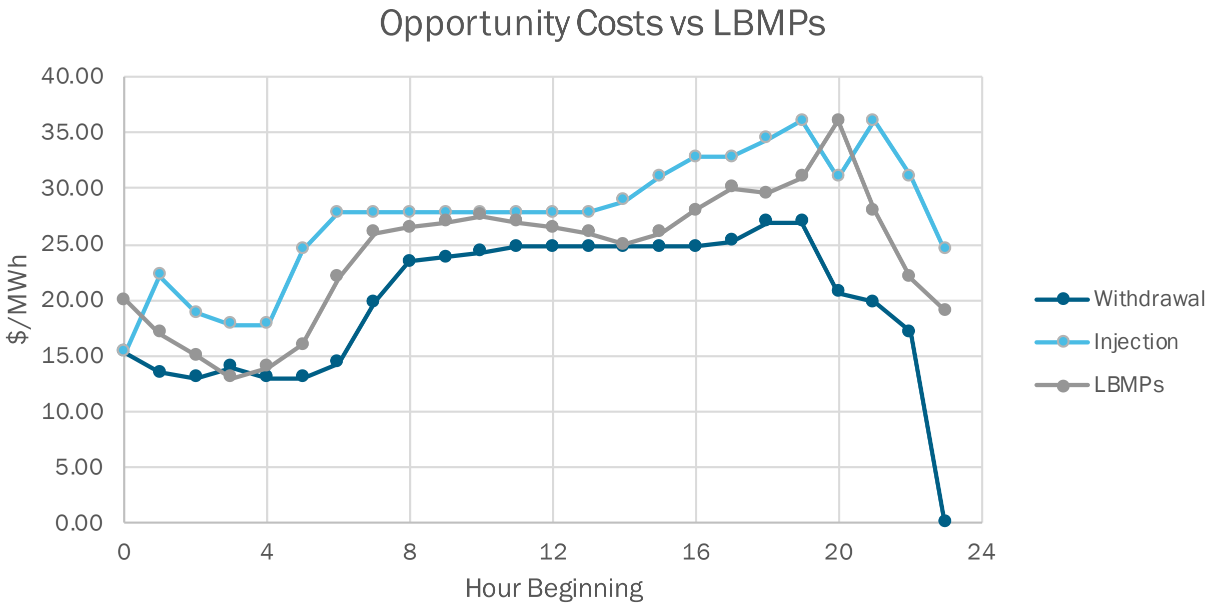
Opportunity Cost Calculation



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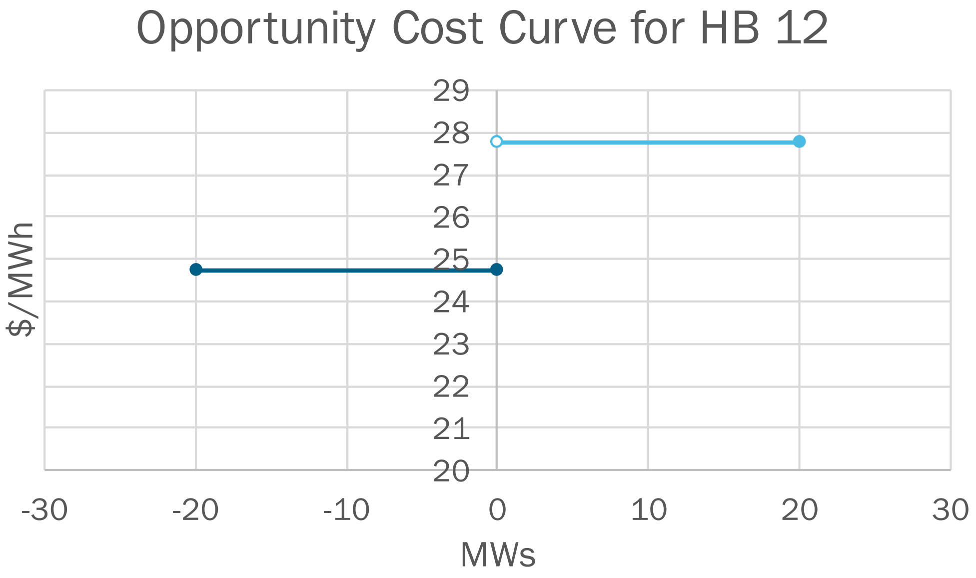
Opportunity Cost Calculation



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Opportunity Costs in Reference Levels

Opportunity Costs in Reference Levels

- Reference Levels for ESRs will consist of opportunity costs plus any additional adders that the Market Participants can substantiate
  - Additional adders could include, but are not limited too, variable operating and maintenance adders or risk adders
- Reference Level = Opportunity Cost + VOM + Risk Adder

Next Steps

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Next Steps

- Refine formulas to account for additional complexities
- Review Feedback

Questions?

We are here to help. Let us know if we can add anything.

Appendix 1

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LBMP Tables

Hour	LBMP	
0	20.00	
1	17.00	
2	15.00	
3	13.00	Trough
4	14.00	
5	16.00	
6	22.00	
7	26.00	
8	26.50	
9	27.00	
10	27.50	Peak
11	27.00	
12	26.50	
13	26.00	
14	25.00	Trough
15	26.00	
16	28.00	
17	30.00	Peak
18	29.50	Trough
19	31.00	
20	36.00	Peak
21	28.00	
22	22.00	
23	19.00	

Hour	LBMP	Optimal Schedule
0	20.00	0
1	17.00	0
2	15.00	0
3	13.00	-20
4	14.00	0
5	16.00	0
6	22.00	0
7	26.00	0
8	26.50	0
9	27.00	0
10	27.50	0
11	27.00	0
12	26.50	0
13	26.00	0
14	25.00	0
15	26.00	0
16	28.00	0
17	30.00	0
18	29.50	0
19	31.00	0
20	36.00	18
21	28.00	0
22	22.00	0
23	19.00	0

Hour	LBMP	Optimal Schedule	Opportunity Cost - Withdrawal	Opportunity Cost - Injection
0	20.00	0	15.30	15.31
1	17.00	0	13.50	22.22
2	15.00	0	13.00	18.89
3	13.00	-20	14.00	17.78
4	14.00	0	13.00	17.78
5	16.00	0	13.00	24.44
6	22.00	0	14.40	27.78
7	26.00	0	19.80	27.78
8	26.50	0	23.40	27.78
9	27.00	0	23.85	27.78
10	27.50	0	24.30	27.78
11	27.00	0	24.75	27.78
12	26.50	0	24.75	27.78
13	26.00	0	24.75	27.78
14	25.00	0	24.75	28.89
15	26.00	0	24.75	31.11
16	28.00	0	24.75	32.78
17	30.00	0	25.20	32.78
18	29.50	0	27.00	34.44
19	31.00	0	27.00	36.00
20	36.00	18	20.70	31.00
21	28.00	0	19.80	36.00
22	22.00	0	17.10	31.11
23	19.00	0	0.00	24.44

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- Operating open, fair and competitive wholesale electricity markets
- Planning the power system for the future
- Providing factual information to policy makers, stakeholders and investors in the power system

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