Comparing performance of explicitly and implicitly scheduled operating reserve

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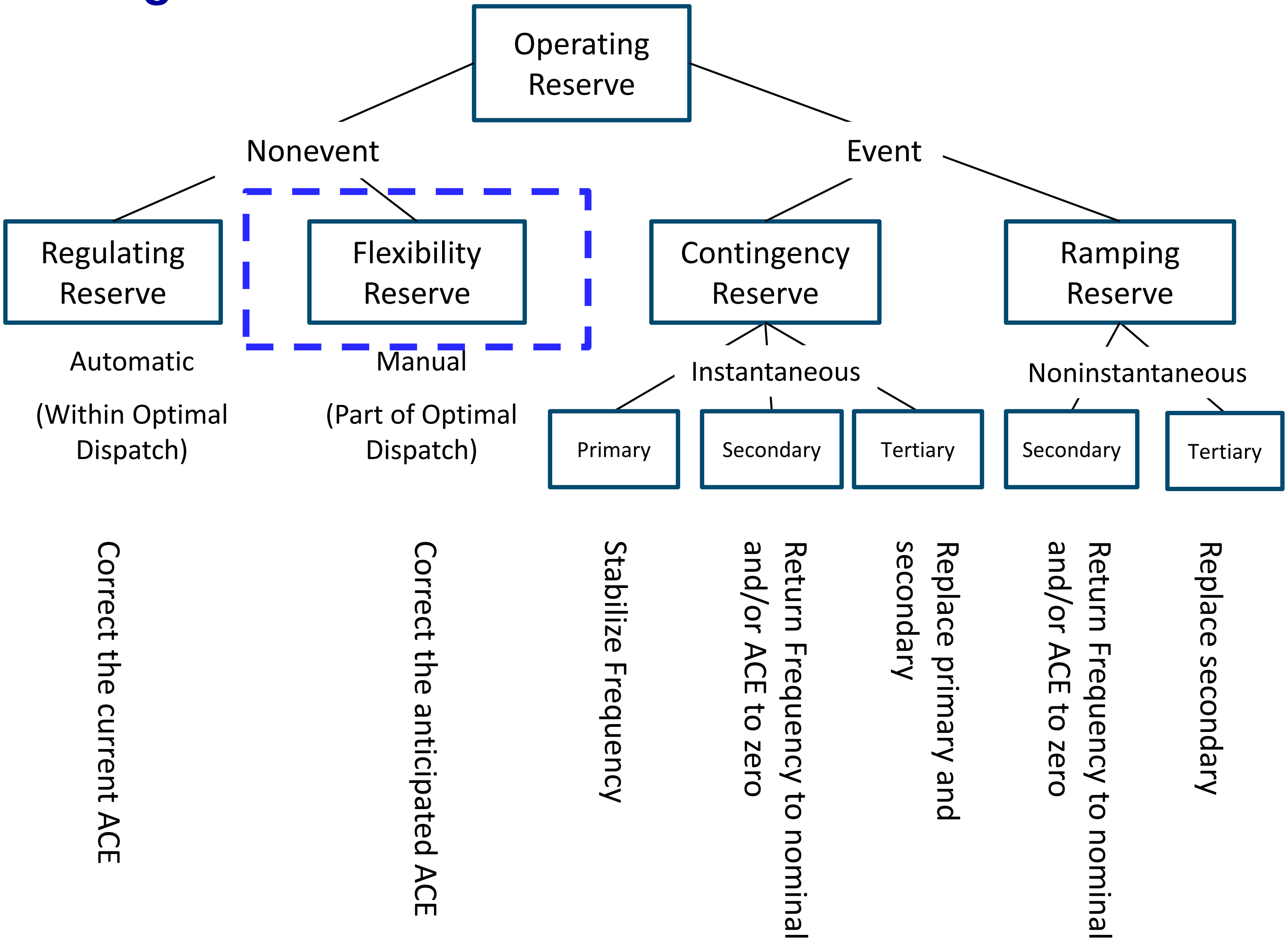
Definitions (for this presentation)

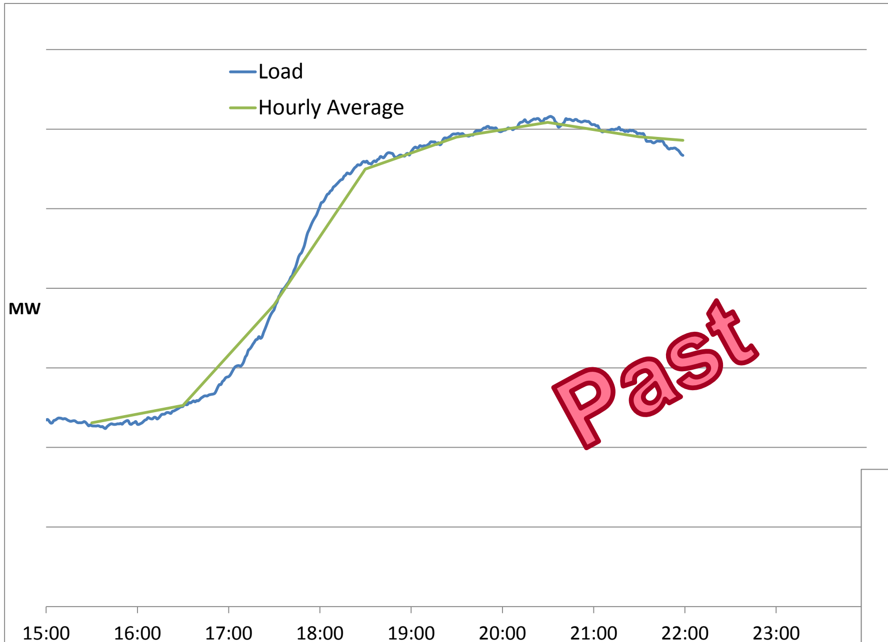
- Operating Reserve: Active Power Capacity that is held above or below expected average energy levels to respond to changing system conditions
- Dynamic Reserve Requirements: Reserve requirements that may change based on actual and/or anticipated system conditions
- Stochastic Programming/unit commitment: Scheduling application that enables schedules to meet multiple potential system conditions at least expected costs
- Probabilistic forecasts: Scenario-forecasts with associated probabilities
- Look-ahead modeling: Scheduling applications that optimize over multiple periods in the future
- Variability: Changes in system conditions across time (may be expected)
- Uncertainty: Changes in system conditions across decision horizons (not expected)
- Explicit reserve: Met through reserve requirement constraint
- Implicit reserve: Met through a scheduling procedure which inherently schedules reserve
- Multi-cycle Modeling: Suite of scheduling tools with cycling decision points with decisions that mimic actual steady-state operations

Operating Reserve



Ela, Kirby, Milligan, Operating Reserves and Variable Generation, NREL/TP-5500-51978, Aug. 2011

Motivation



Past: Load cyclic and did not change directions often over longer-term timescales

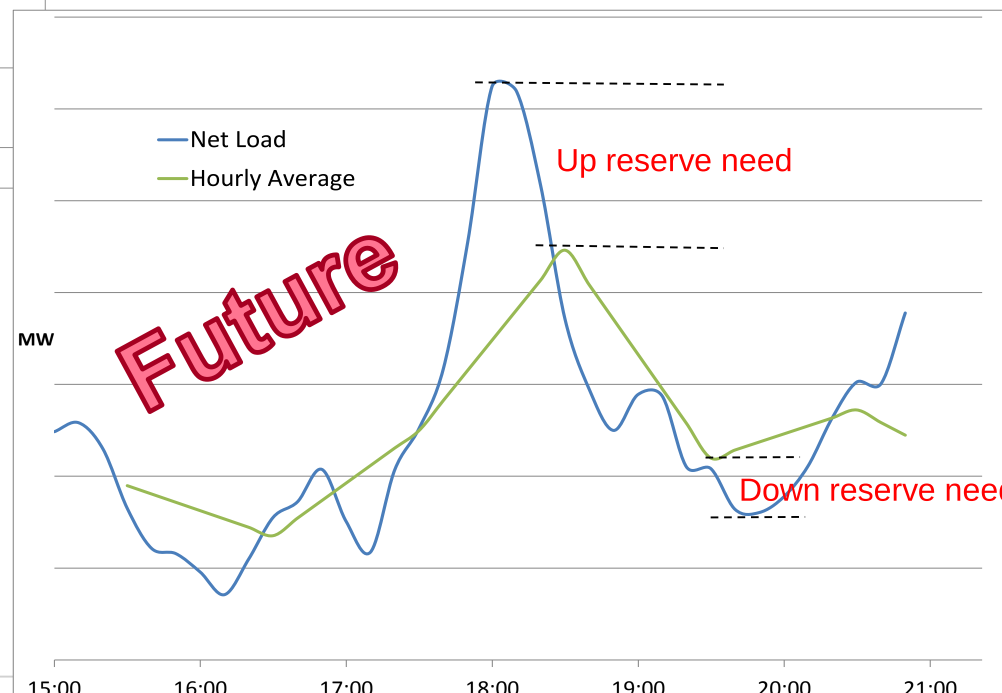
Future: Net load has different trends each day, and each hour

Past: Reserve for reliability

Future: Operating reserve provides efficiency benefits along with reliability benefits

Past: Probability of a conventional generating unit being forced out is generally the same at any point in time

Future: Availability of VG can be predicted and its availability changes over time and accuracy of prediction increases at horizons closer to real-time



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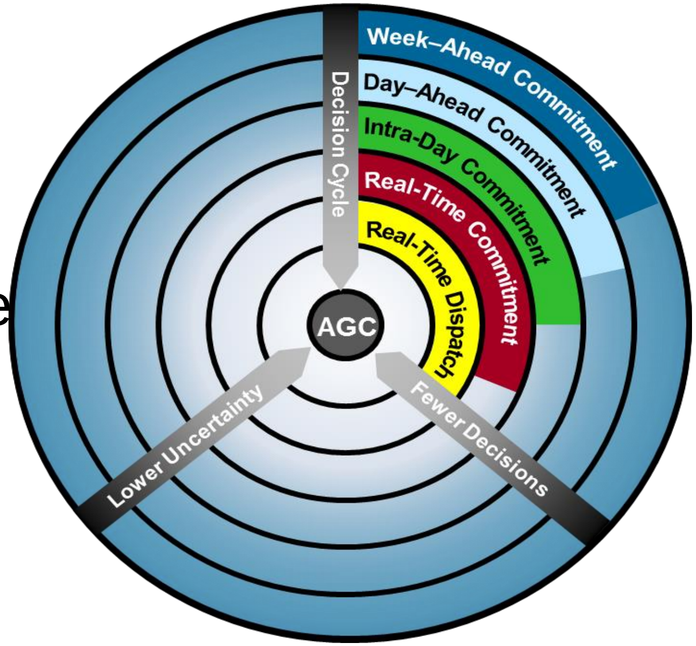
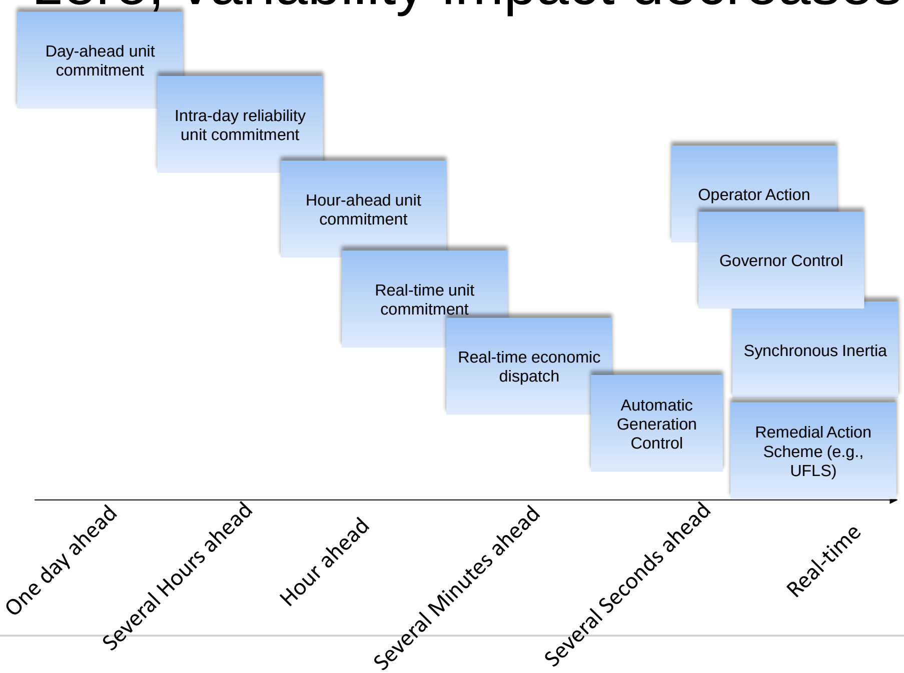
Multiple cycles

- Historical simulation tools did not capture the multi-cycle multi-decision, multi-timescale approach of current steady-state electricity operations
- As horizon approaches real-time, uncertainty impact decreases
- As timescale resolution approaches zero, variability impact decreases

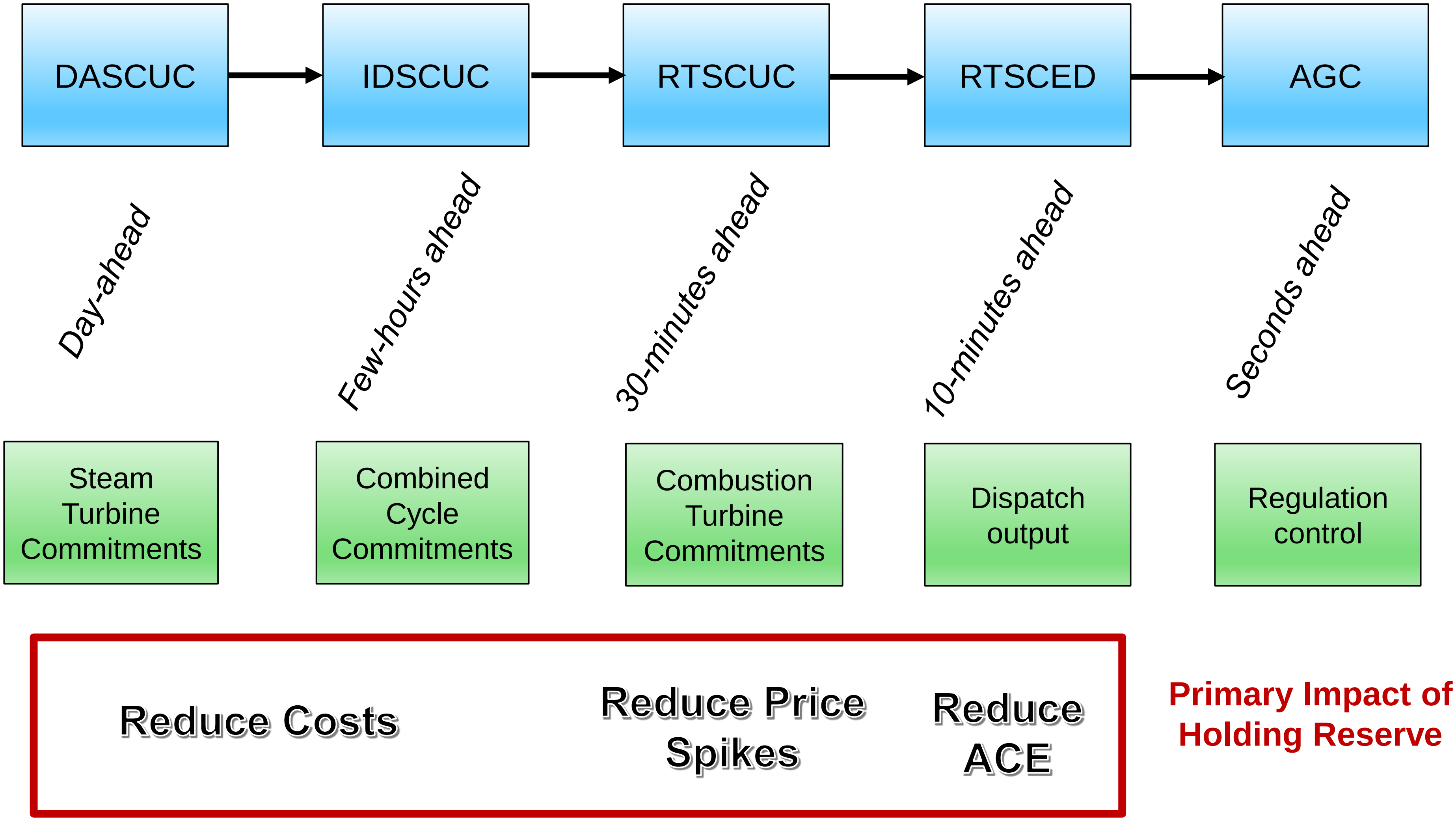


Adapted from MISO slides



- As horizon approaches real-time, fewer decisions are available to the operator
- Simulation tools that model multiple cycles can more realistically represent the impacts of variability and uncertainty and the mitigation strategies for those impacts

Impact of Holding Reserve



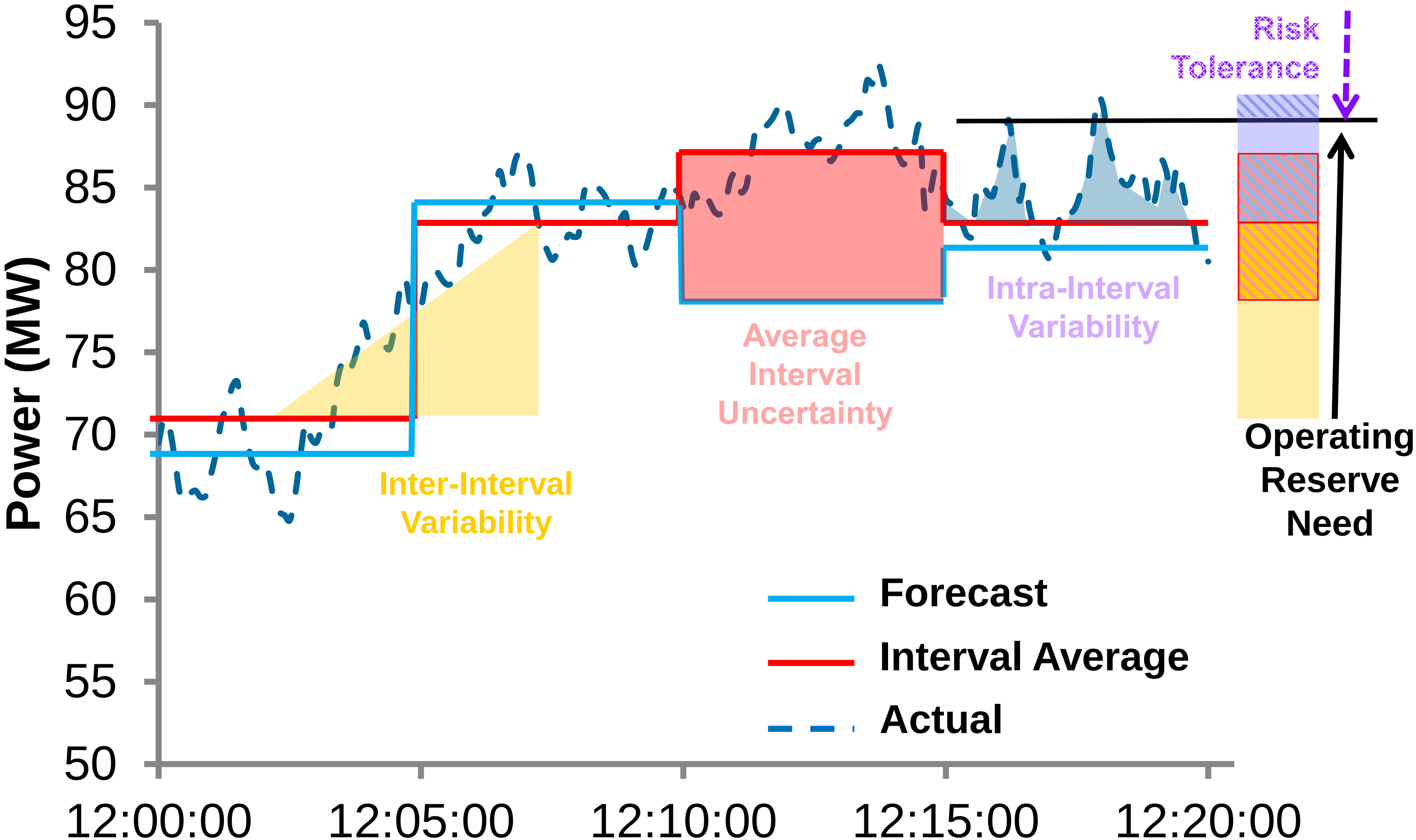
Operating Reserve Need

1. Hold capacity now to meet the **variability** that occurs **within** the **current** scheduled time interval.

2. Hold capacity now to prepare for **anticipated variability** that occurs **after** the current time interval.

3. Hold capacity now to prepare for **uncertain outcomes** that occur in **current or future** scheduled time intervals.

Three Central Reserve Needs



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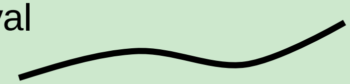
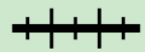
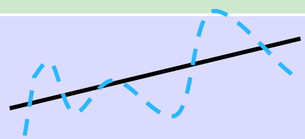
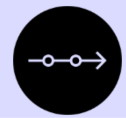
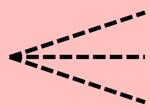
Meeting Operating Reserve Needs Implicitly Through Advanced Scheduling Applications

Three Central Needs for Reserve	Explicit Reserve Requirement	Implicitly Scheduled Flexibility
1. Variability occurring within the interval	Reserve Requirements (e.g., regulation reserve)	Shorter scheduling intervals
2. Variability anticipated beyond the interval	Reserve Requirements (e.g., flexible ramping reserve)	Time-coupled multi-period dispatch w/ longer look-ahead horizons
3. Uncertainty of future conditions	Reserve Requirements (e.g., contingency reserve)	Stochastic or robust unit commitment and dispatch meeting multiple scenarios

Case Study Approach – Three Studies, Three Cases

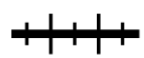
- Study the impact of dynamic reserve and advanced scheduling for each of the three reserve needs
  - **Study 1:** Variability within the scheduling interval (*Intra-Interval Variability*)
  - **Study 2:** Variability beyond the scheduling interval (*Inter-Interval Variability*)
  - **Study 3:** Uncertainty throughout (*Uncertainty*)
- Determine dynamic reserve requirements by using detailed, but attainable data to meet each of the three needs
- **Case 1**: Simulate base case without dynamic reserve or advanced scheduling
- **Case 2**: Simulate the advanced scheduling case
- **Case 3**: Simulate the dynamic reserve case
- Compare the cases in terms of reliability (inability to meet load, *penalties*) and efficiency (*overall production costs*)
- These three studies are first performed on IEEE RTS

Simulation Cases

Cause	Type	Advanced Scheduling Case	Dynamic Reserve Case
Variability	Intra-Interval 		Reserve to meet expected ramp and capacity within interval
Variability	Inter-Interval 		Reserve capacity to meet expected future net load
Uncertainty	Inter-Interval 		Reserve to meet ramp and capacity of uncertain scenarios

Key

 **Multi Period Scheduling with Look Ahead**

 **Shorter Scheduling Intervals**

 **Stochastic Scheduling**

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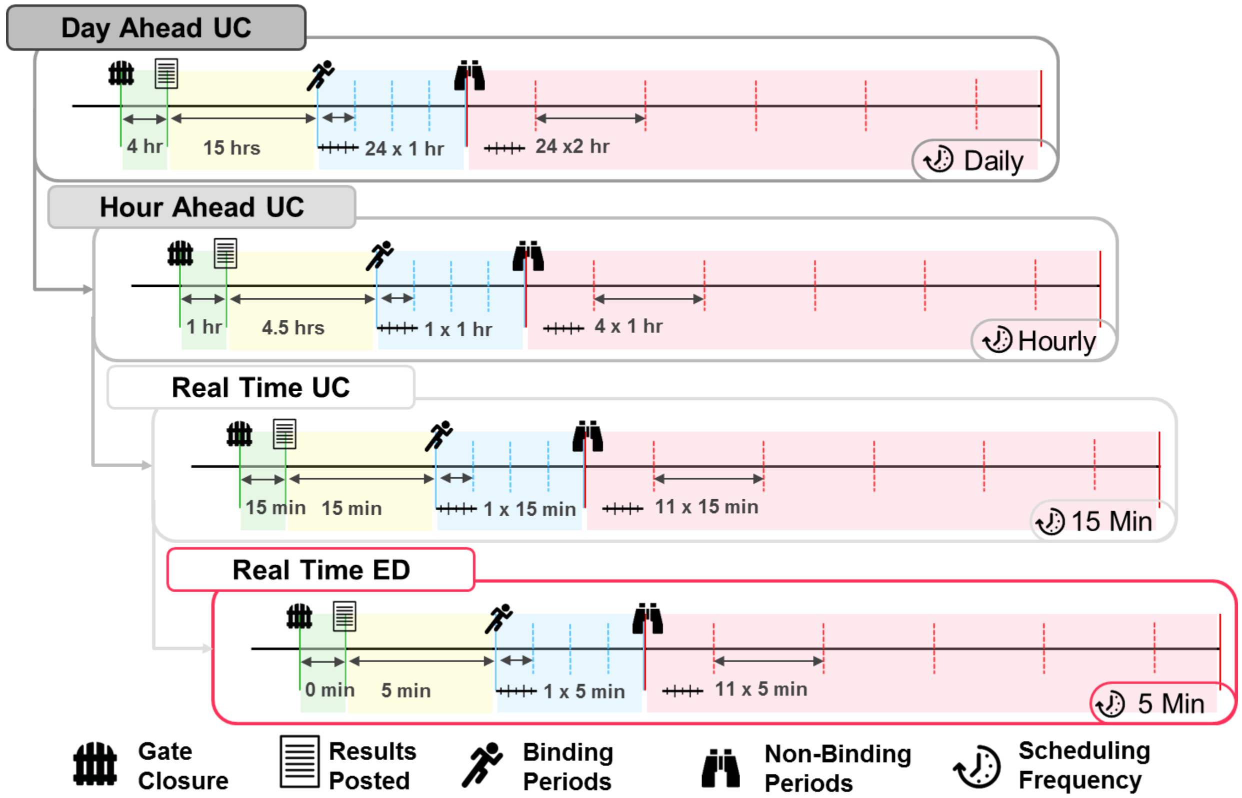
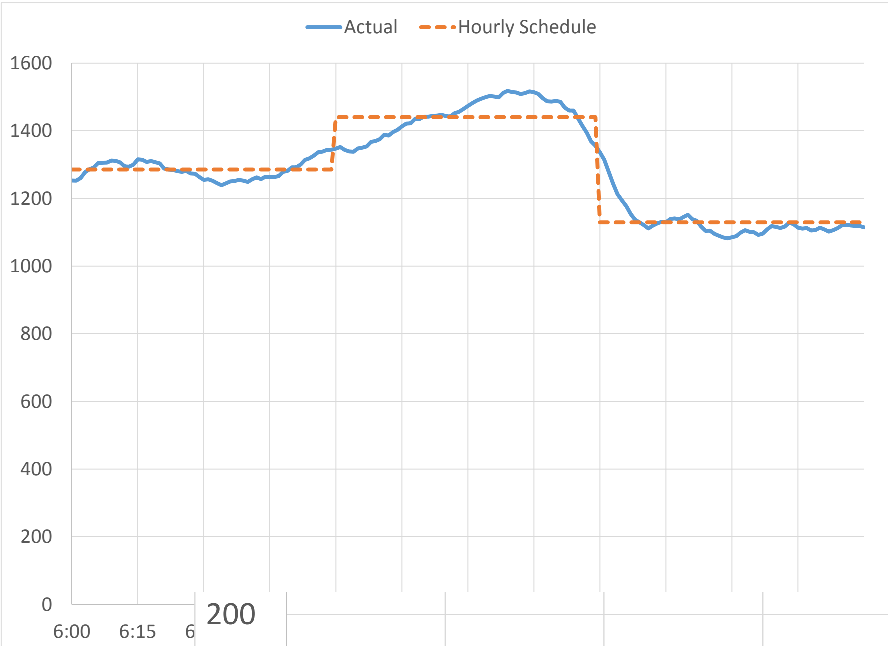
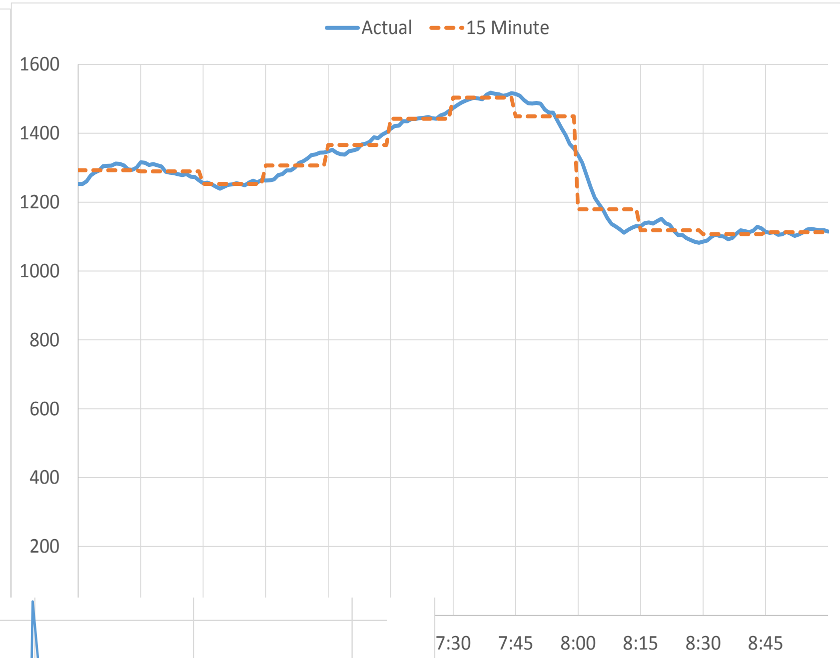
Scheduling Cycle Definitions

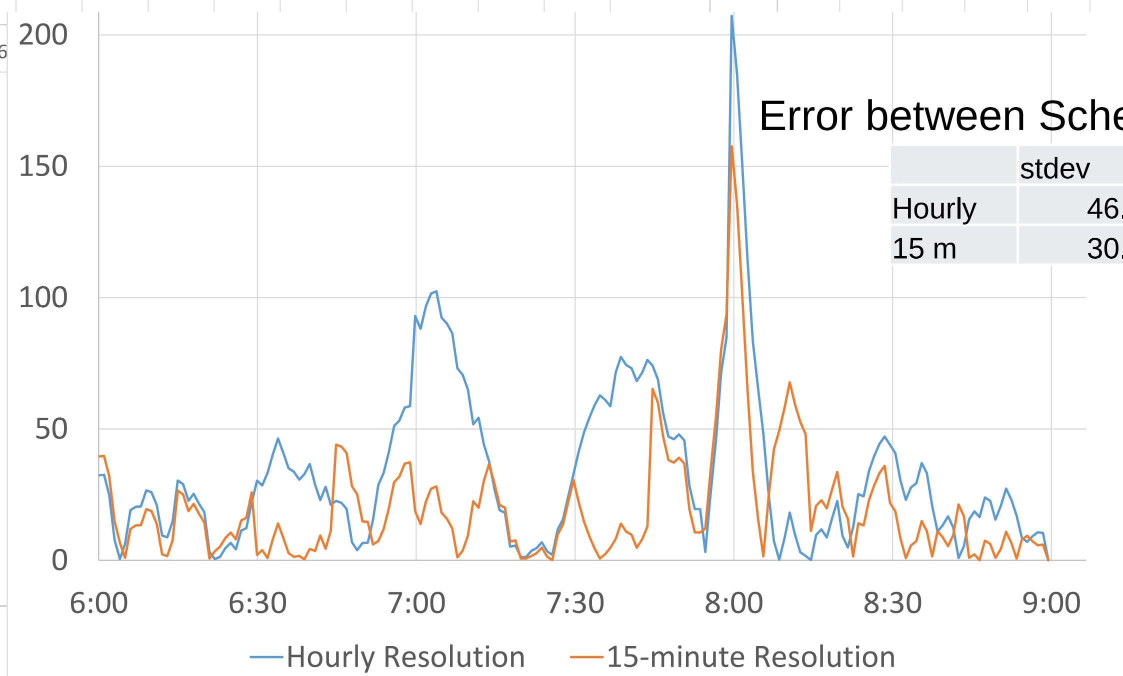


PSO: Power Systems Optimizer

Explicit vs. implicit – Intra-Interval variability





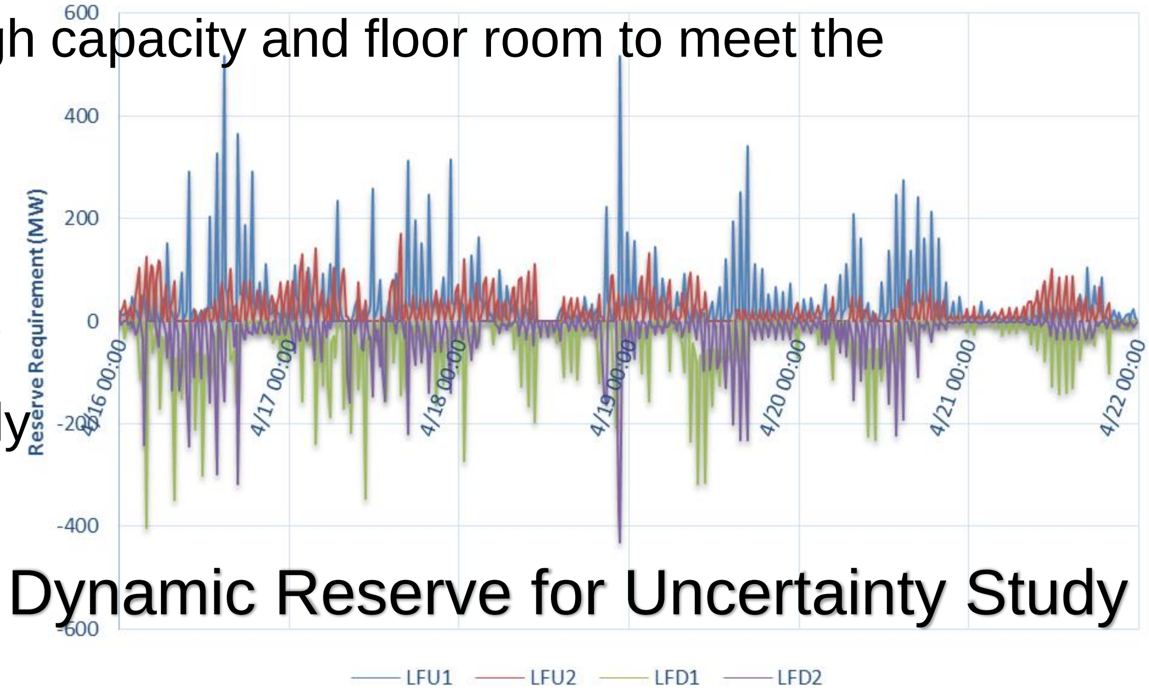


Error between Schedule and Actual

	stdev	Max	Min	MAE	95th %ile
Hourly	46.7	207.2	-102.4	33.9	77.2
15 m	30.0	157.6	-93.6	20.0	49.7

Dynamic Reserve Requirements based on information available to advanced scheduling case

- Dynamic reserve case uses exactly the same information required for the advanced scheduling case but explicitly schedules reserve through reserve constraint
- Example Uncertainty Study: Probabilistic forecast from 3 scenarios of VG forecast used to determine reserve need
- LFU1/LFD1: Ensure enough ramping to meet ramps in all scenarios
- LFU2/LFD2: Ensure enough capacity and floor room to meet the highest/lowest capacity need of all scenarios.
- Adjust load if total capacity excessive (commitment only thing that matters in UC model, and not dispatch



Dynamic Reserve for Uncertainty Study

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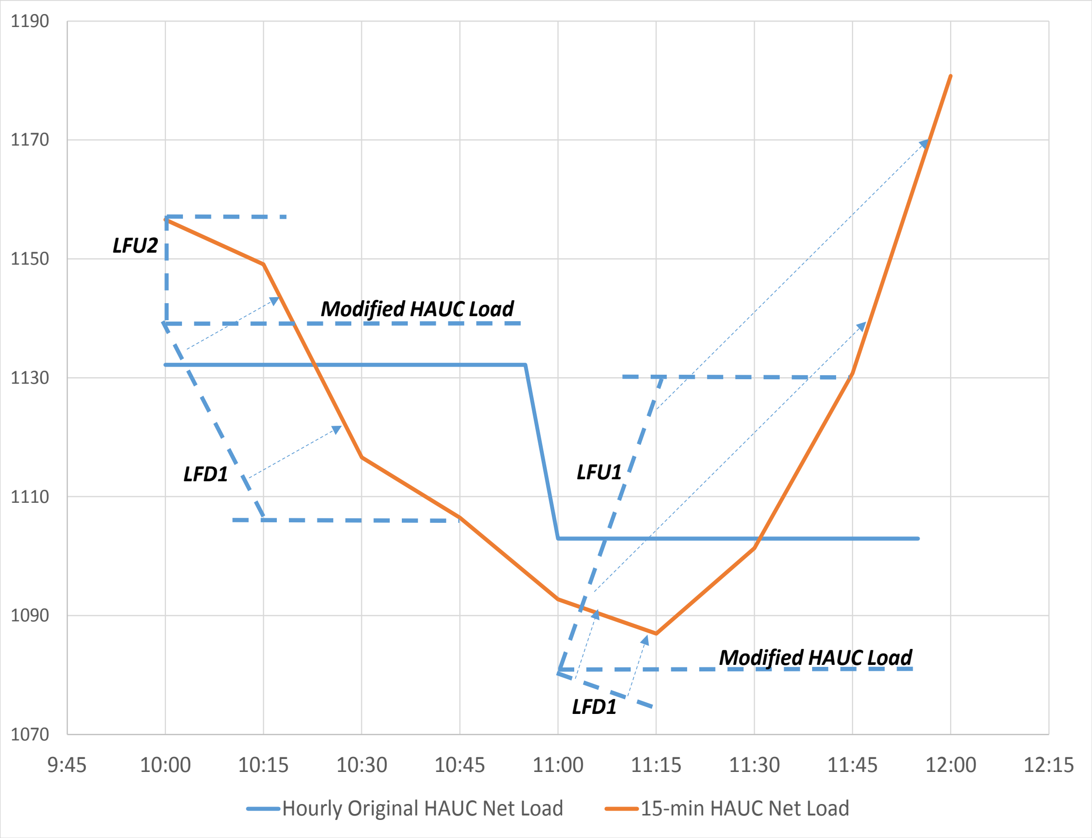
Dynamic Reserve Requirements – Intra-Interval variability

$$\mathbf{LFU1}\ (H) = Max\ \{0\ ,\ NL\ (I_H) - NL\ (I_H\text{-}1)\}\ for\ all\ I_H \in H$$

$$\mathbf{LFU2}\ (H) = Max\{0,\ NL\ (I_H) - NL\ (H) - LFU1\ (H)\}\ for\ all\ I_H \in H$$

$$\mathbf{LFD1}\ (H) = Max\ \{0\ ,\ NL\ (I_H\text{-}1) - NL\ (I_H)\}\ for\ all\ I_H \in H$$

$$\mathbf{LFD2}\ (H) = Max\{0,\ NL\ (H) - NL\ (I_H) - LFD1\ (H)\}\ for\ all\ I_H \in H$$



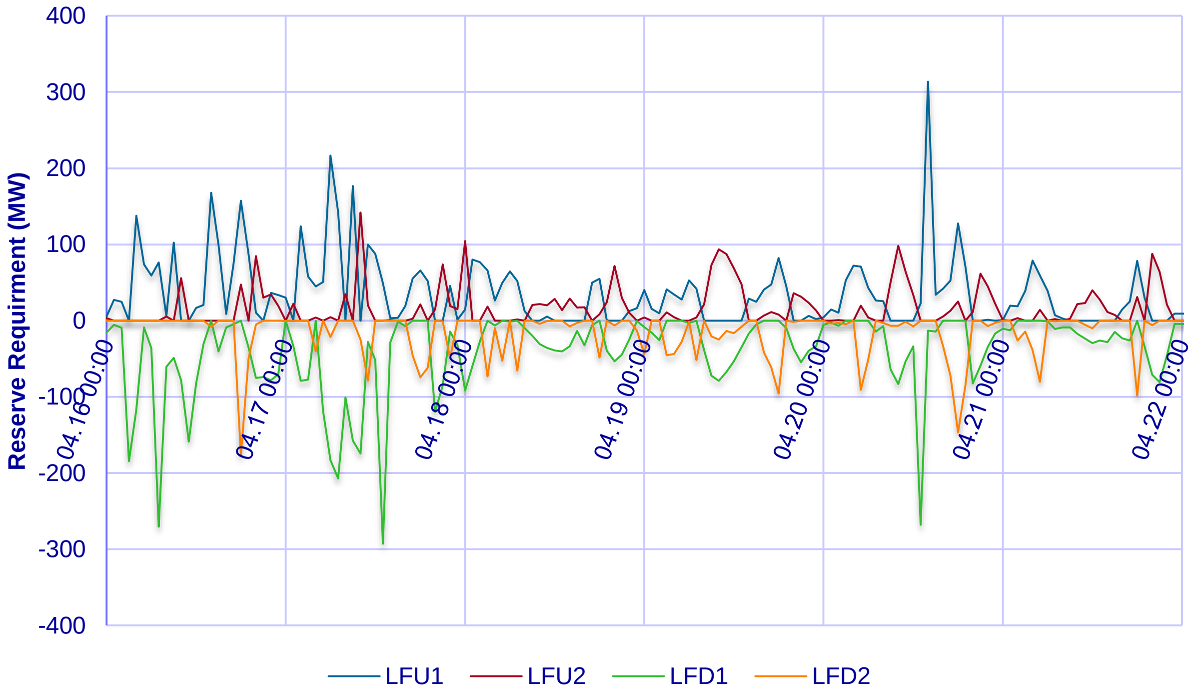
H: Hour index

I_H: 15-minute interval index within H

$$Load\ (H) = Max\{NL\ (I_H) + VG - LFU1 - LFU2\}\ for\ all\ I_H \in H$$

Load of dynamic reserve case only is reduced when LFU1 makes total capacity excessively high. Remember the UC only cares about commitment and not dispatch!

Reserve Requirements – Intra-Interval Variability



System
Peak Load: 2100 MW
Avg. Wind: 450 MW

Time/Cycle Model – Intra-interval Variability Study

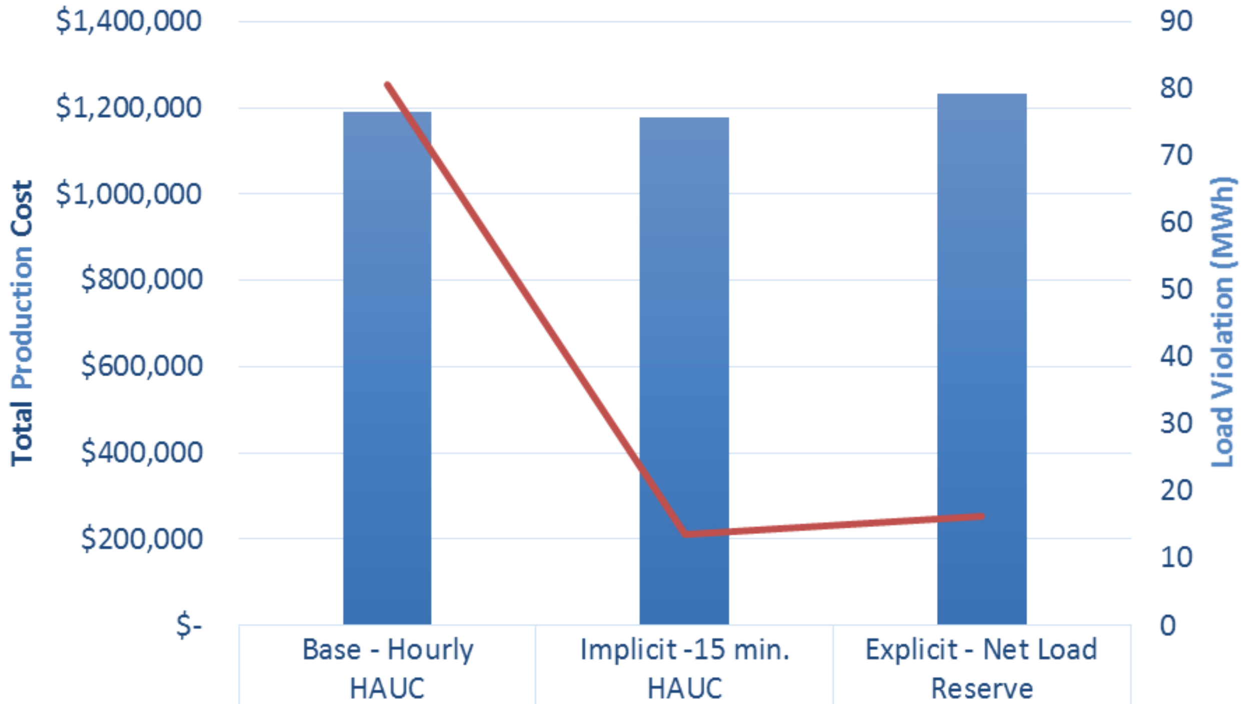
Base Case and Dynamic Reserve Case

Cycle	Decision Time	Binding Time	Horizon Length	Binding Periods in same decision cycle		Non-Binding Periods in same decision cycle	
				Number of Periods	Period Length	Number of Periods	Period Length
DAUC	15 hours 5 minutes	24 hours	48 hours	24	1 hour	12	2 hour
HAUC	4 hours 5 minutes	1 hour	5 hours	**1**	**1 hour**	**4**	**1 hour**
RTUC	35 minutes	15 minutes	3 hours	1	15 minutes	11	15 minutes
RTED	5 minutes	15 minutes	1 hour	3	5 minutes	9	5 minutes

Advanced Scheduling Case

Cycle	Decision Time	Binding Time	Horizon Length	Binding Periods in same decision cycle		Non-Binding Periods in same decision cycle	
				Number of Periods	Period Length	Number of Periods	Period Length
DAUC	15 hours 5 minutes	24 hours	48 hours	24	1 hour	12	2 hour
HAUC	4 hours 5 minutes	1 hour	5 hours	**4**	**15 minutes**	**16**	**15 minutes**
RTUC	35 minutes	15 minutes	3 hours	1	15 minutes	11	15 minutes
RTED	5 minutes	15 minutes	1 hour	3	5 minutes	9	5 minutes

Results – Intra-Interval Variability



	Base - Hourly HAUC	Implicit -15 min. HAUC	Explicit - Net Load Reserve
Costs	$1,190,775.61	$1,176,303	$1,232,672
MWh	80.60	13.57	16.275

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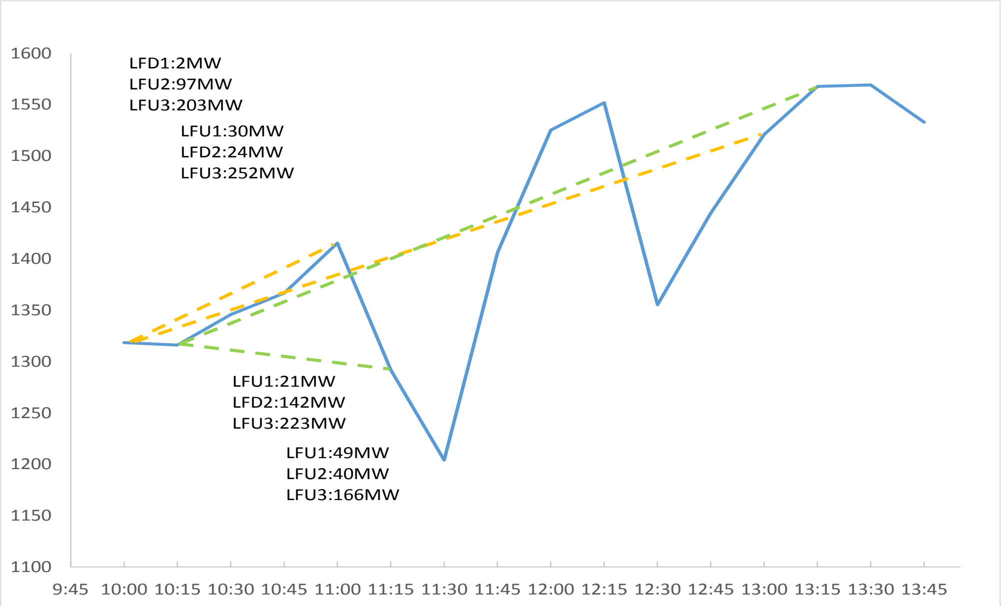
Explicit vs. implicit – Inter-Interval variability

Look-ahead	1-hour reserve	2-hour reserve	3-hour reserve	4-hour reserve
Single snapshot hourly scheduling decision cycle	44 MW	135 MW	334 MW	533 MW
2-hour look-ahead	91 MW	290 MW	489 MW	
3-hour look-ahead	199 MW	398 MW		
4-hour look-ahead	199 MW			



Time/Cycle Model – Inter-Interval Variability

Base Case and Dynamic Reserve Case

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Advanced Scheduling Case

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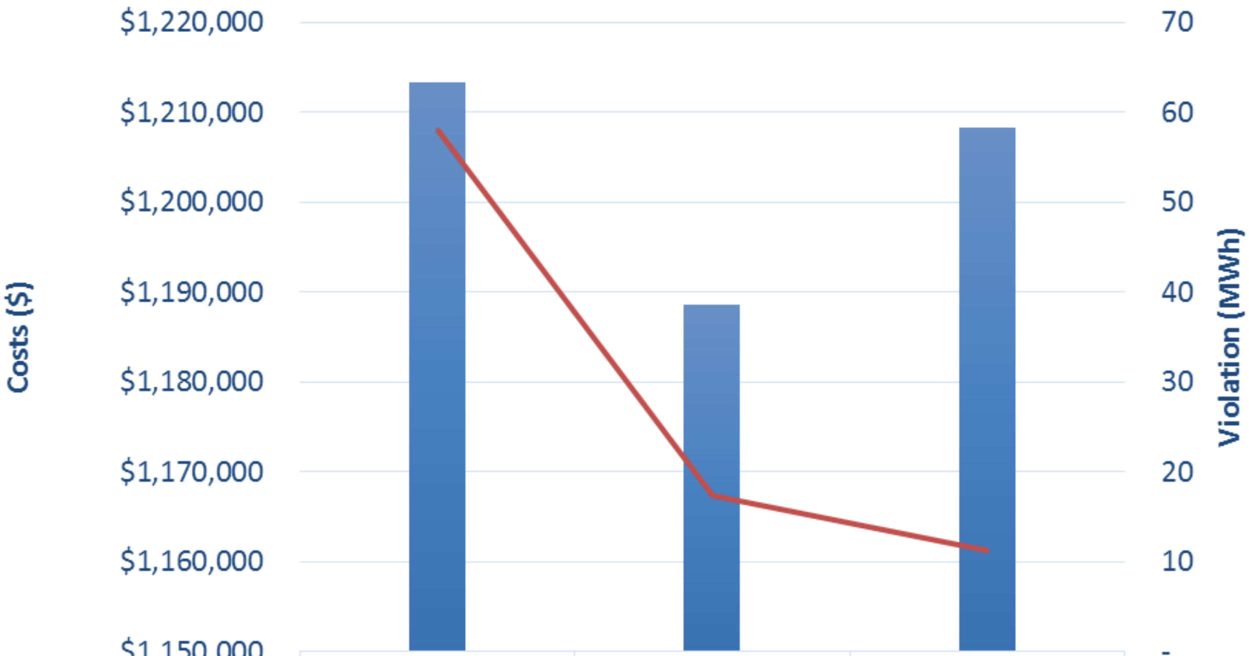
Results – Inter-Interval Variability



	Base - No Look Ahead	Advanced Scheduling Case - 3 Hr LA	Dynamic Reserve Requirement
Costs	$1,213,290	$1,188,597	$1,208,309
% Change		-2%	0%
Violation (MWh)	58	17	11

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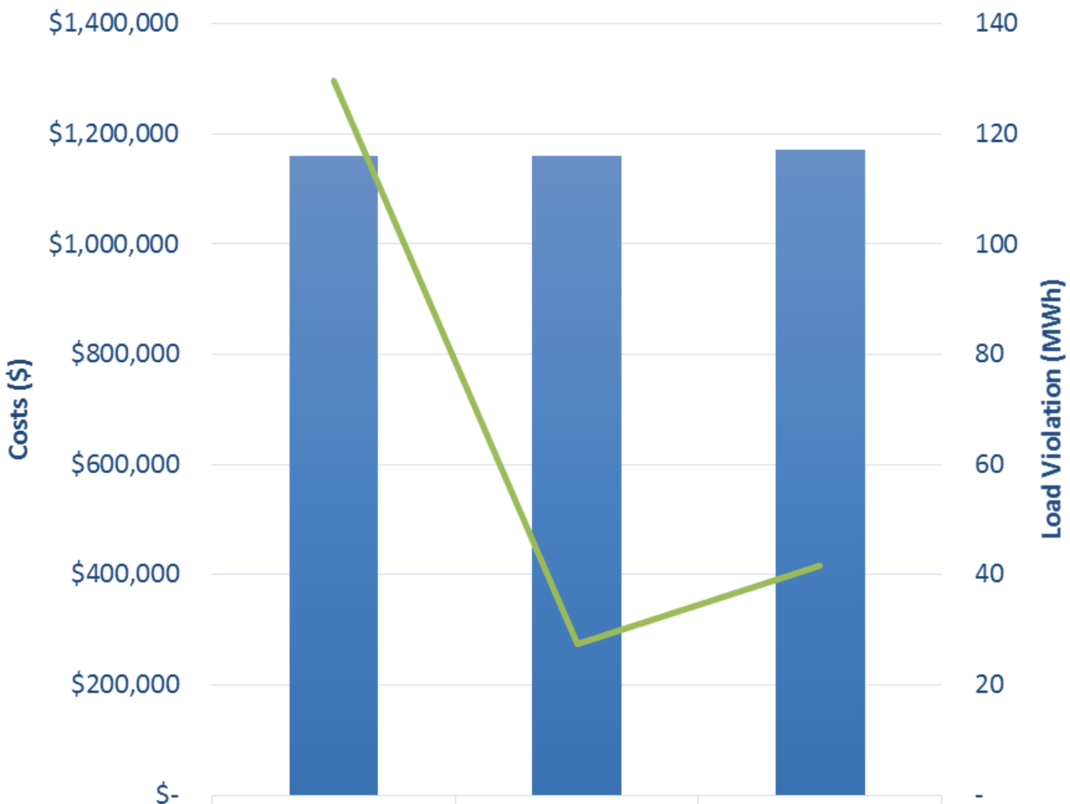
Time/Cycle Model – Uncertainty Case

Used in all cases

Cycle	Decision Time	Binding Time	Horizon Length	Binding Periods in same decision cycle		Non-Binding Periods in same decision cycle	
				Number of Periods	Period Length	Number of Periods	Period Length
DAUC	15 hours, 5 minutes	24 hours	48 hours	24	1 hour	12	2 hour
HAUC	90 minutes	1 hour	5 hours	4	15 minutes	8	30 minutes
RTUC	35 minutes	15 minutes	1 hour	1	15 minutes	3	15 minutes
RTED	5 minutes	15 minutes	15 minutes	3	5 minutes		

In the advanced scheduling case, the HAUC uses stochastic UC with 3 scenarios, a median scenario at 0.7 probability, a low at 0.15, and a high at 0.15. Only VG is stochastic.

Results - Uncertainty



	Base	Advanced Scheduling Case - Stochastic	Dynamic reserve case
Operating Costs	$1,158,623.84	$1,159,343.98	$1,170,118.82
Change from Base	0%	0%	1%
Load Violation	129.58	27.50	41.67

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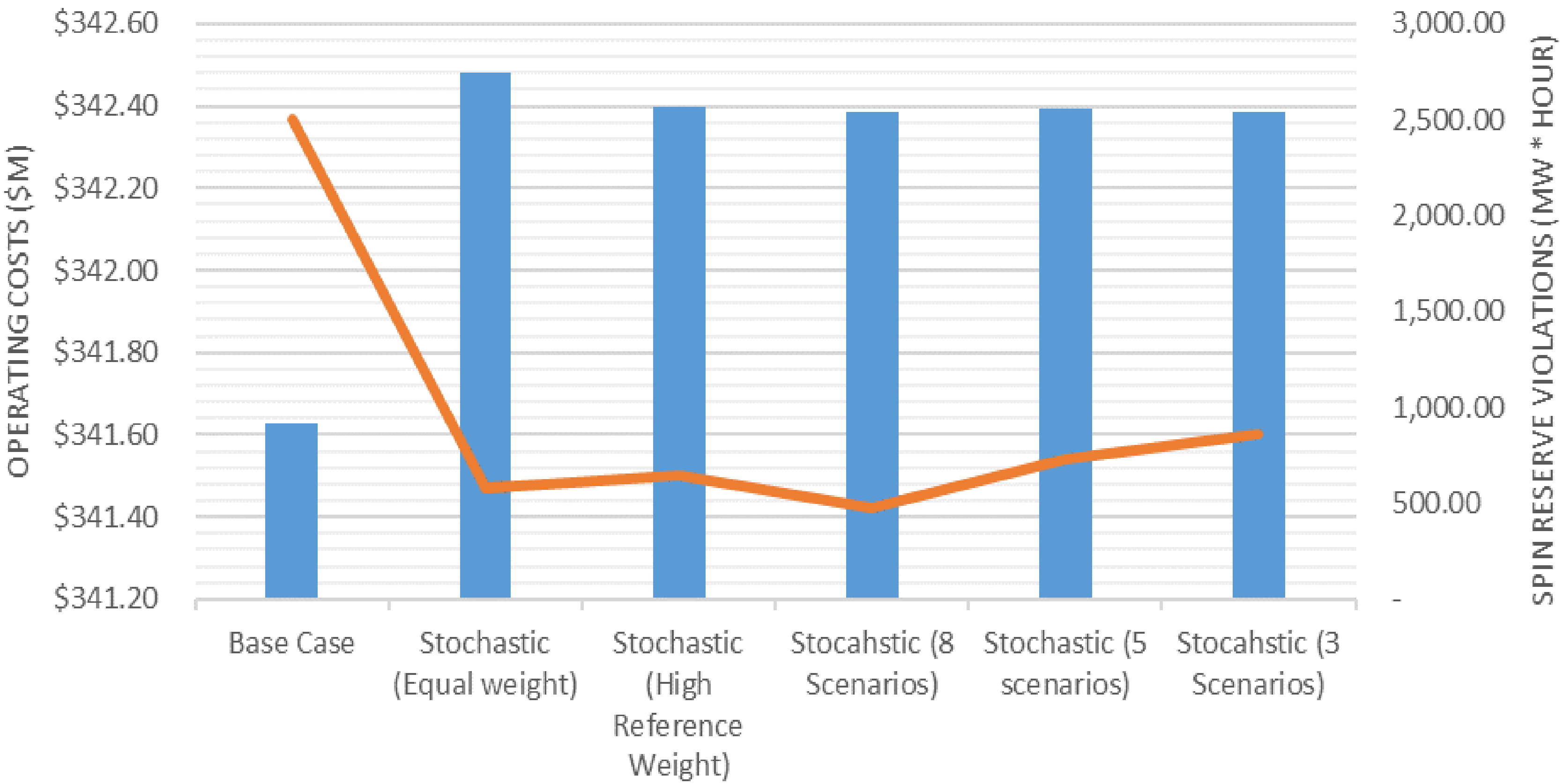
CAISO Case Study

- Perform the exact version of the "Uncertainty Study" on the Western Interconnection, with focus on CAISO system
- Perform several sensitivities to understand additional sensitivity
- Simulating the WI/CAISO system provides new challenges and new understandings
  - Impact of interchange across regions
  - Impact of existing static reserve requirements (e.g., spin and regulation) on dynamic load following / flexibility reserve
  - Impact of more diverse resource mix (e.g., energy limited resources, demand response, etc.)
  - Impact of transmission constraints
  - Scalability of stochastic model on large, practical-sized systems

CAISO STUDY RESULTS: COSTS & RELIABILITY



- Stochastic scheduling increases costs by < 0.25% but reduces contingency reserve depletion by 80%.
- Changing the number of scenarios and scenario weighting impacts the outcome marginally. Further work to determine translation into equivalent reserve needed.

Case Study Results and Takeaways

- In all three studies, advanced scheduling tends to perform the best
  - Sometimes not by large margin and not in both categories
- Hard to compare reliability and costs simultaneously
  - Assuming a "loss of load" cost has its own challenges
- Stochastic case takes at least 5X longer than dynamic reserve case to solve
  - 5-day CAISO/WI simulation with real-time unit commitment cycle using 10 scenarios takes 30 hours to solve using SOA software
  - Deterministic cases takes 5 hours to solve
- Further improvement can be made to the dynamic reserve requirement
  - Locational requirements
  - Deployment costs

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