Exploring the Impacts of Price Formation Enhancements in PJM's Wholesale Energy Markets

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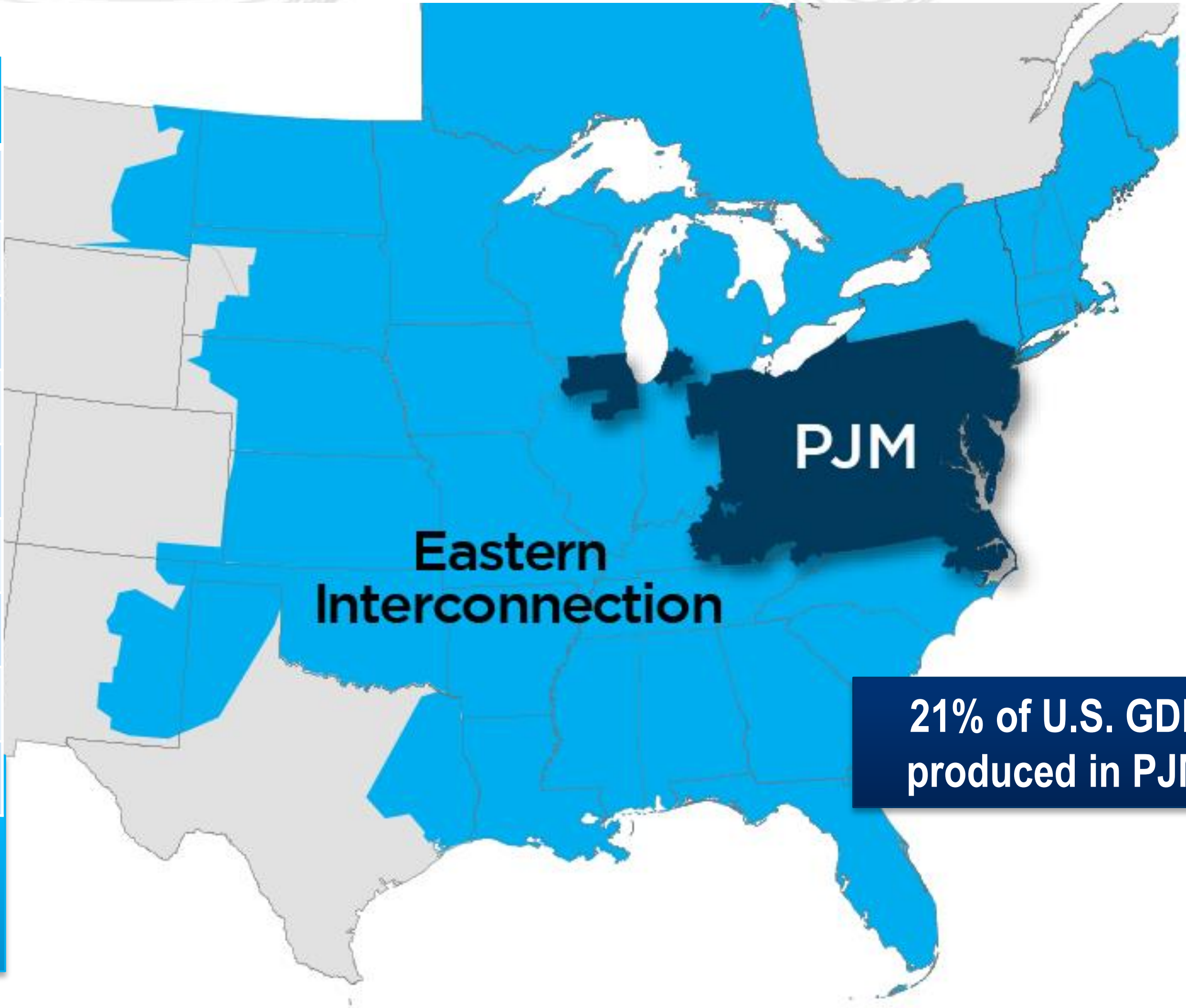
PJM as Part of the Eastern Interconnection

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



21% of U.S. GDP produced in PJM

As of 2/2018

Agenda

- Fast-Start Pricing
- PJM Day-Ahead Market Clearing
- PJM Real-Time Market Clearing
- Integer Relaxation Simulations
- Results
- Questions

Fast-Start Pricing

What Is a Fast-Start Resource?

Fast-start resources can start up quickly and typically have shorter minimum run times than other resources.

Definitions of fast-start resources vary across ISOs/RTOs

PJM Combustion Turbine Special-Pricing Treatment

CTs are usually offered as inflexible
(i.e., block-loaded, where economic minimum = economic maximum).
This means they cannot set price naturally.

- For block-loaded CTs that are eligible to set price, relax their economic minimum by a specific factor (currently 0.8)
- The wider the relaxed dispatchable range, the better chance a resource has to set price
  - But with a wider dispatchable range, the dispatch solution may be far below its economic minimum

Shortcomings of Current Methodology

- Combustion turbines are generally unable to set price even though they are committed and dispatched economically

- Relaxing economic minimum values in the dispatch solution distorts the system energy balance and can lead to inefficient system dispatch

- Distortions must be managed by regulation at potentially higher cost than a balanced energy dispatch

ISO/RTO Fast-Start Pricing Summary

	PJM	CAISO	ISO-NE	MISO	NYISO
Separate Pricing and Dispatch Runs			●	●	●
Economic Minimum Relaxation	○	●	●	●	●
Includes Start-up and No-Load Costs		○	●	●	○

Definitive Points from PJM FERC Order on Fast-Start Pricing

- PJM is required to implement fast-start pricing
  - Separate dispatch and pricing runs
  - Define fast-start resources as those with a total time to start (TTS) and minimum run time (MRT) of less than or equal to one hour
  - Use lost opportunity cost (LOC) use to remove incentive to deviate from dispatch
  - Implement in day-ahead and real-time markets whenever a fast-start unit is committed and running
  - Amortize start-up and no-load in “effective” offer using **integer relaxation**

Single Period Integer Relaxation

- Solve the pricing run using a single-time period optimization similar to the dispatch run
- Allows resources to be partially committed for pricing calculations
  - Equivalently, resources are allowed to be fully dispatchable between 0 and their economic maximums
- Start-up and No-load offers are considered in setting the price
  - Equivalently, the bid blocks of resources can be modified to incorporate the proportional start-up and no-load offers

- For example, under integer relaxation with a single offer block, in the pricing run the total offer cost of dispatching a resource is:

$$Total\ Offer\ Cost = \ Incremental\ Energy\ Cost \times Dispatch + Startup\ Cost \times Commitment\ Status + Noload\ Cost \times Commitment\ Status$$

Where:

$$Commitment\ Status = \frac{Dispatch}{Economic\ Maximum}$$

- As a result, the total offer cost of dispatching a resource in the pricing run can be rewritten as:

$$Total\ Offer\ Costs = \boxed{Incremental\ Energy\ Cost} \times Dispatch + \boxed{\frac{Startup\ Cost}{Economic\ Maximum}} \times Dispatch + \boxed{\frac{Noload\ Cost}{Economic\ Maximum}} \times Dispatch$$

- A resource's "effective" offer is equal to the sum of all three components in the boxes above

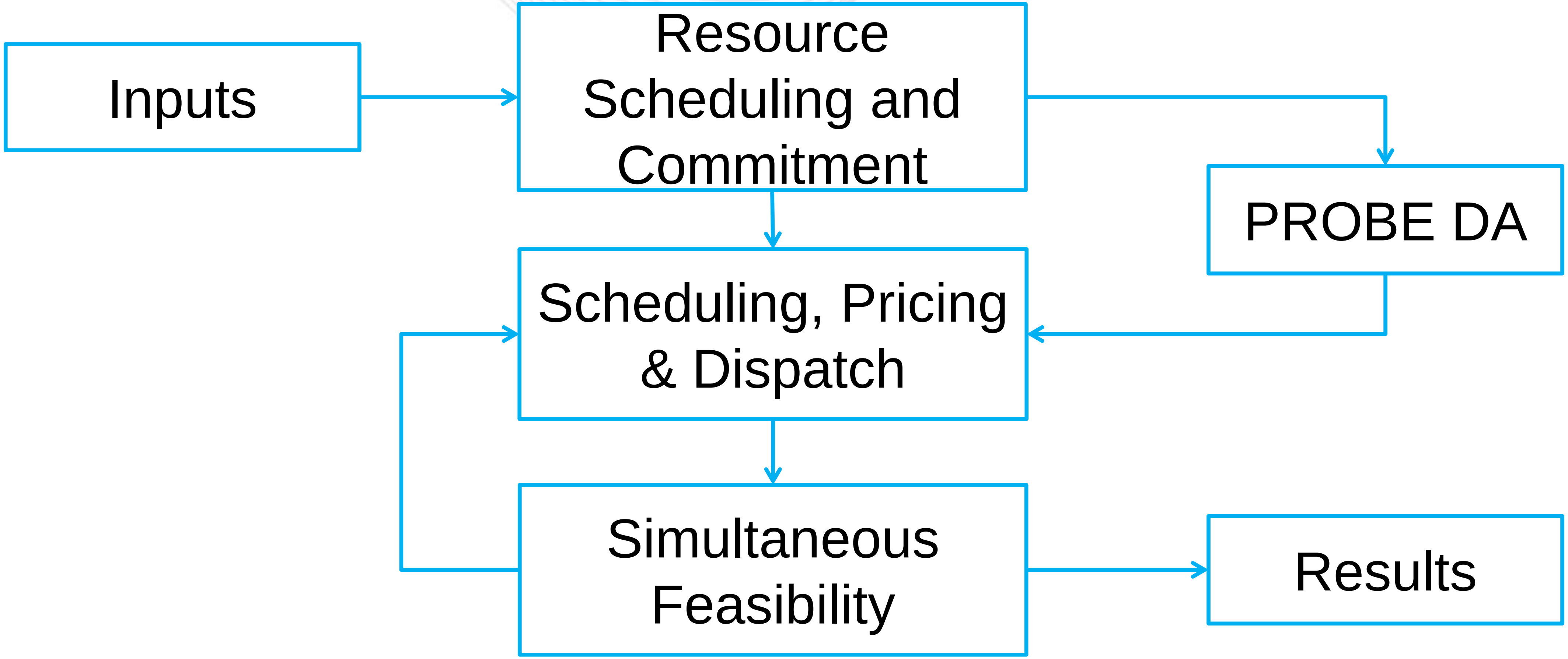
PJM Day-Ahead Market Clearing

Objective:

Develop a set of least-cost financial schedules that are physically feasible subject to:

- Full transmission system model
- Reserve requirements
- Unit commitment constraints

Using bid-in supply offers and demand bids


Inputs
Resource Scheduling and Commitment
PROBE DA
Scheduling, Pricing & Dispatch
Simultaneous Feasibility
Results

Use of PROBE DA in Day-Ahead Market Clearing

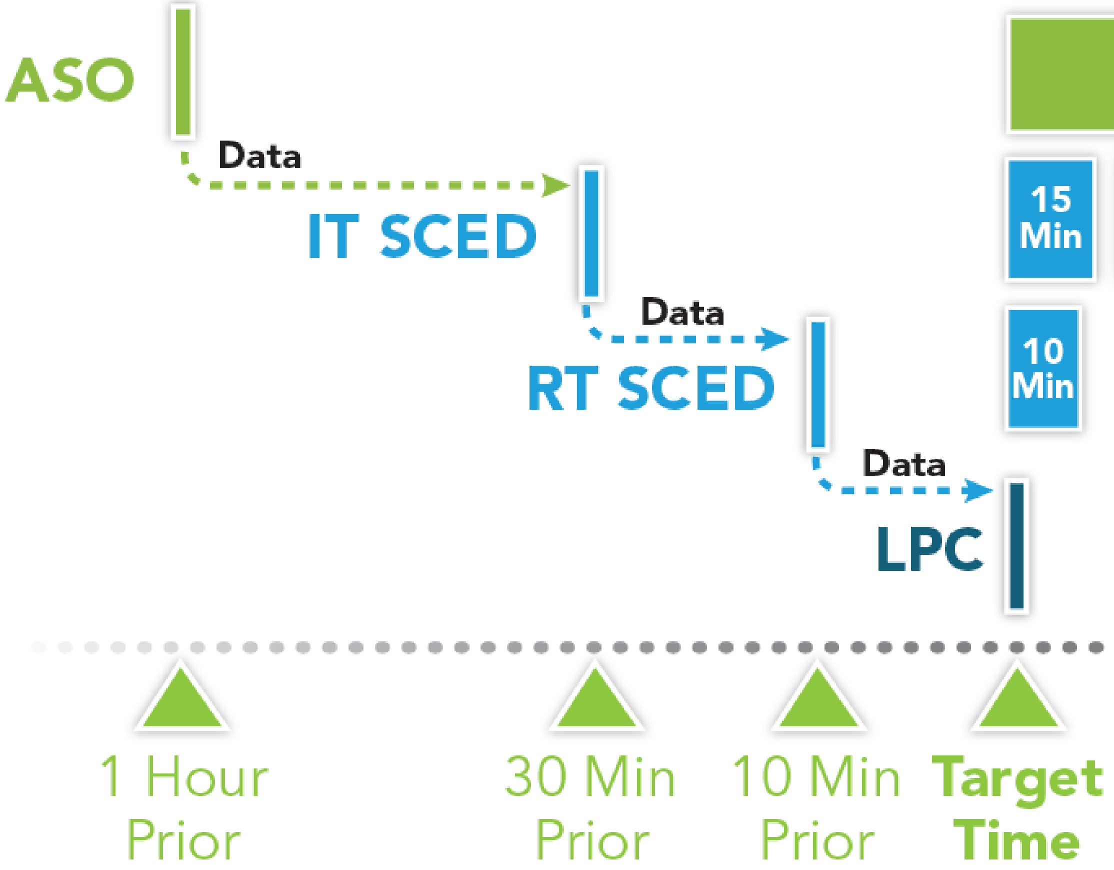
- Provides optimized least-cost solution to aid DA Market Operator
- Performs a Three Pivotal Supplier (TPS) test for market power mitigation
- Considers:
  - All constraints
  - PAR limits
  - Unit parameters
  - Submitted transactions (including virtual bids)
  - Zonal factors

PJM Real-Time Market Clearing

PJM Real-Time Market Clearing, Dispatching and Pricing Engines

Ancillary Services Optimizer (ASO)
Clearing and assignment of regulation and inflexible reserve resources (Solved 60 minutes prior to target time, looks ahead 60 minutes beyond target time)

Intermediate-Term Security Constrained Economic Dispatch (IT SCED)
Demand Trajectory, generator loading strategy, Demand Response commitment for energy, CT commitment and inflexible synchronized reserve recommendations (Solved 30 minutes prior to target time, producing 4 solution intervals that looks ahead 15, 45, 45 and 120 minutes beyond target time)



Real-Time Security Constrained Economic Dispatch (RT SCED)
Final dispatch contour and assignment of non-synchronized reserve and flexible synchronized reserve resources (Solved 10 minutes prior to target time, looks ahead 10 minutes beyond target time)

Locational Pricing Calculator (LPC)
5 minute energy and ancillary service prices

PROBE Perfect Dispatch (PD)

- Performs “re-optimization” in retrospect starting from the actual real-time PJM grid dispatch
- Designed to provide a baseline measure of grid operational performance
- Minimizes total system bid production cost
- Provides optimal N-1 security-constrained unit commitment and dispatch
  - Assuming all system conditions are know in advance

Integer Relaxation Simulations

Integer Relaxation Simulations

- Used PROBE DA and PD to simulate the effects of Integer Relaxation in the pricing run in the DA and RT markets

- Minimum Run Time (MRT) and Total Time to Start (TTS) eligibility for Integer Relaxation treatment:

Day Ahead (MRT and TTS <=)	Real Time (Perfect Dispatch) (MRT and TTS <=)
None	None
2 hours	2 hours
24 hours	24 hours

PROBE Day-Ahead Integer Relaxation Assumptions

- Integer Relaxation treatment is not applied to reserves
- Integer Relaxation treatment is not applied to self-scheduled units
- Ramping constraints are not enforced in the pricing run for units receiving Integer Relaxation treatment
- Pump Storage unit's dispatch is fixed in the pricing run to be the same as the dispatch run
- Start-up offer based on the unit's state at the time of its starting is used and applied to all the following intervals during each commitment period
- Each unit's start-up offer is equally divided among its minimum run time (MRT) intervals
- Each unit's minimum run time is rounded up to the next integer

PROBE Perfect Dispatch Integer Relaxation Assumptions

- Same Integer Relaxation assumptions and start-up and no-load cost treatment as in PROBE DA except for rounding each unit's MRT to the nearest integer

- Only allow the recommitment of CTs and diesel units to mimic the operation of IT SCED during the operating day

2018 Simulation Results

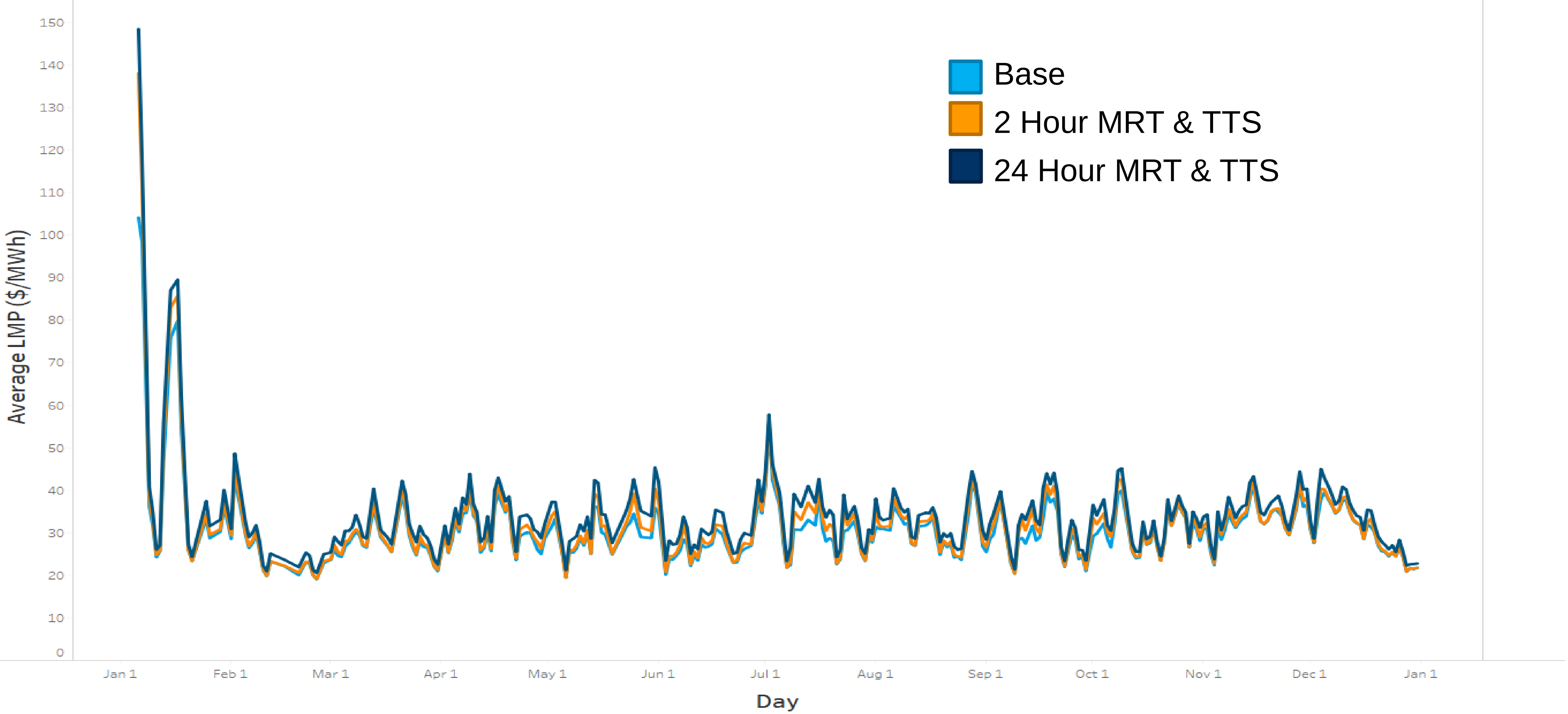
Day Ahead
(298 days)

Case	Average Gen. Weighted LMP	% Change	Uplift	% Change
Base	$31.09	-	$156,268.63	-
2 Hour MRT/TTS	$32.40	4.2	$149,952.94	-4.0
24 Hour MRT/TTS	$34.57	11.2	$26,997.12	-82.7

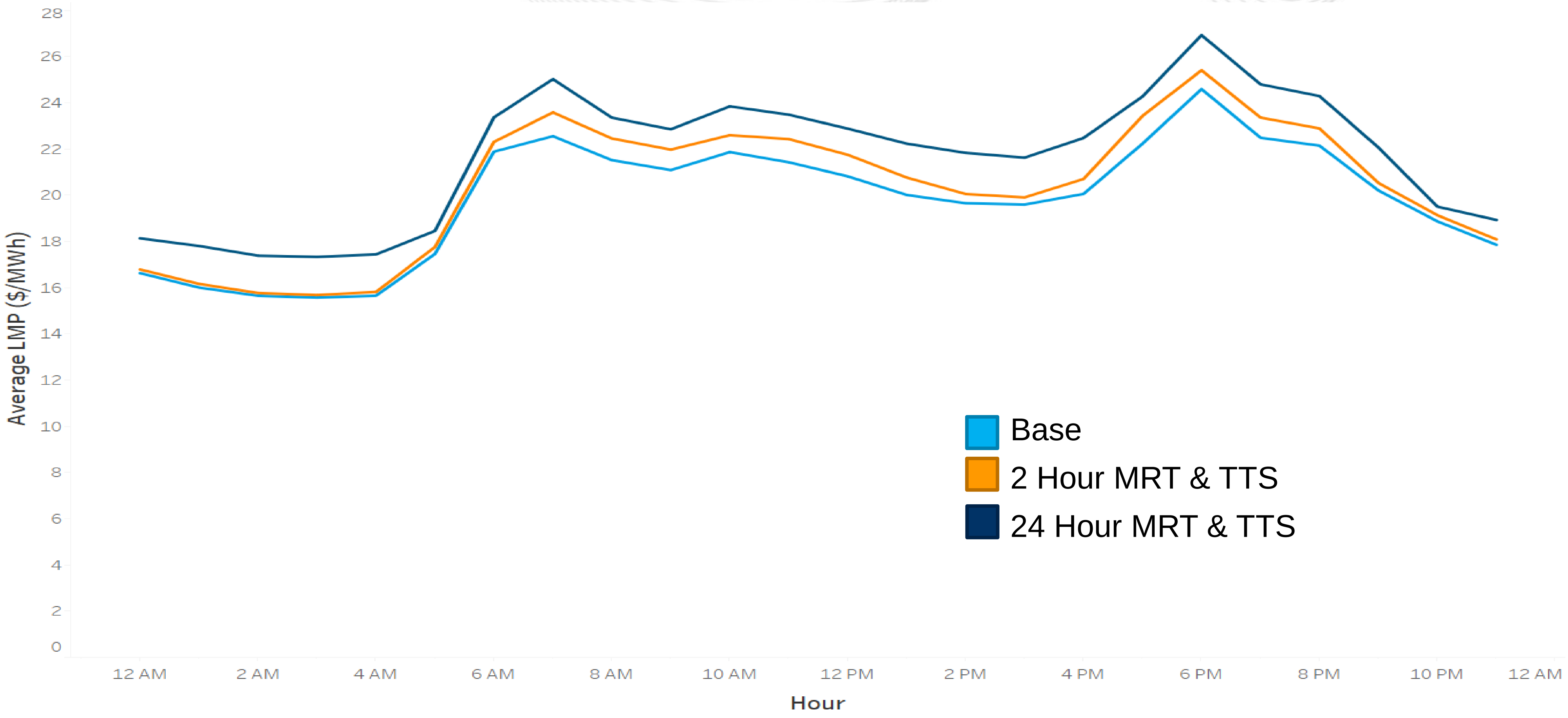
Real Time
(355 days)

Case	Average Gen. Weighted LMP	% Change	Uplift	% Change
Base	$31.86	-	$263,159.17	-
2 Hour MRT/TTS	$33.65	5.6	$207,325.59	-21.2
24 Hour MRT/TTS	$35.39	11.1	$52,416.94	-80.1

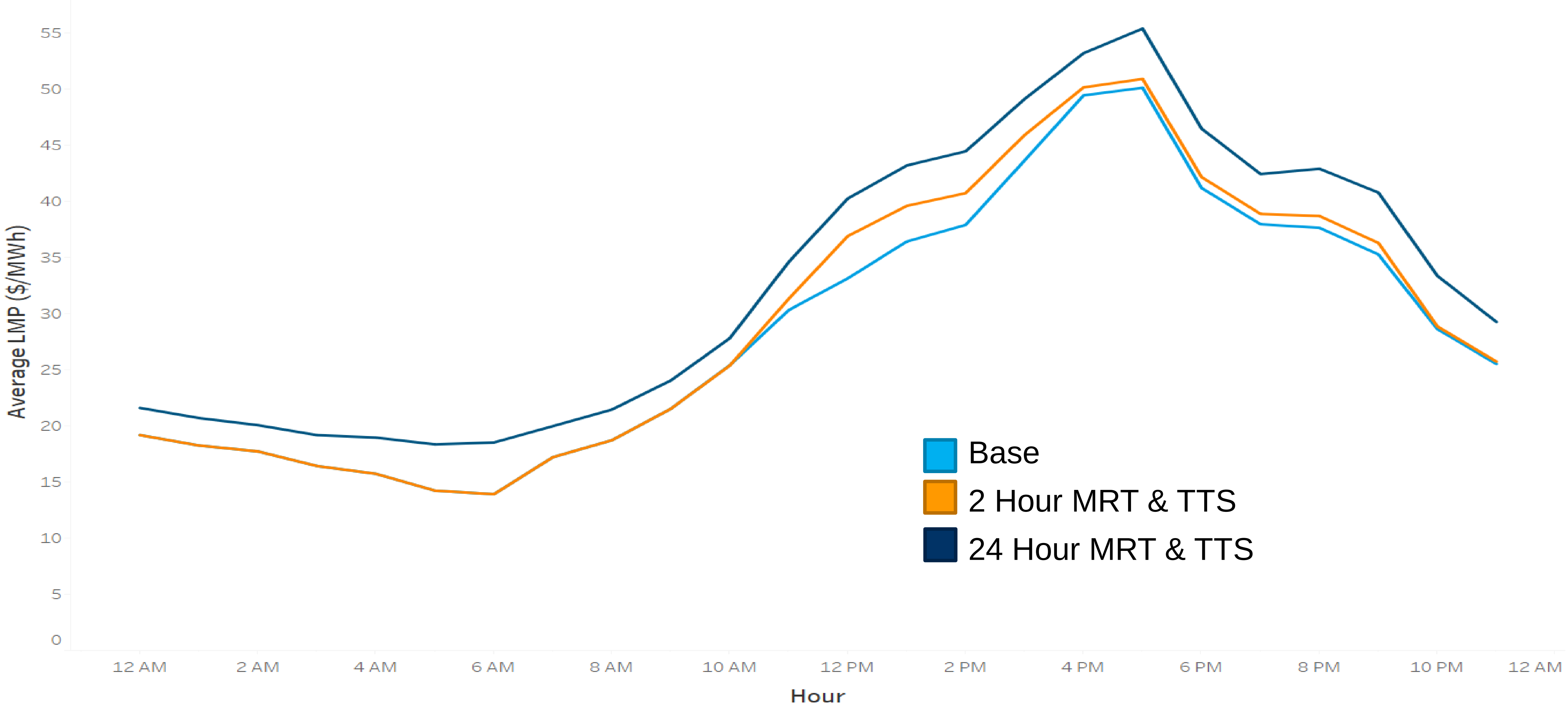
2018 Day-Ahead Average Daily Generator Weighted LMPs



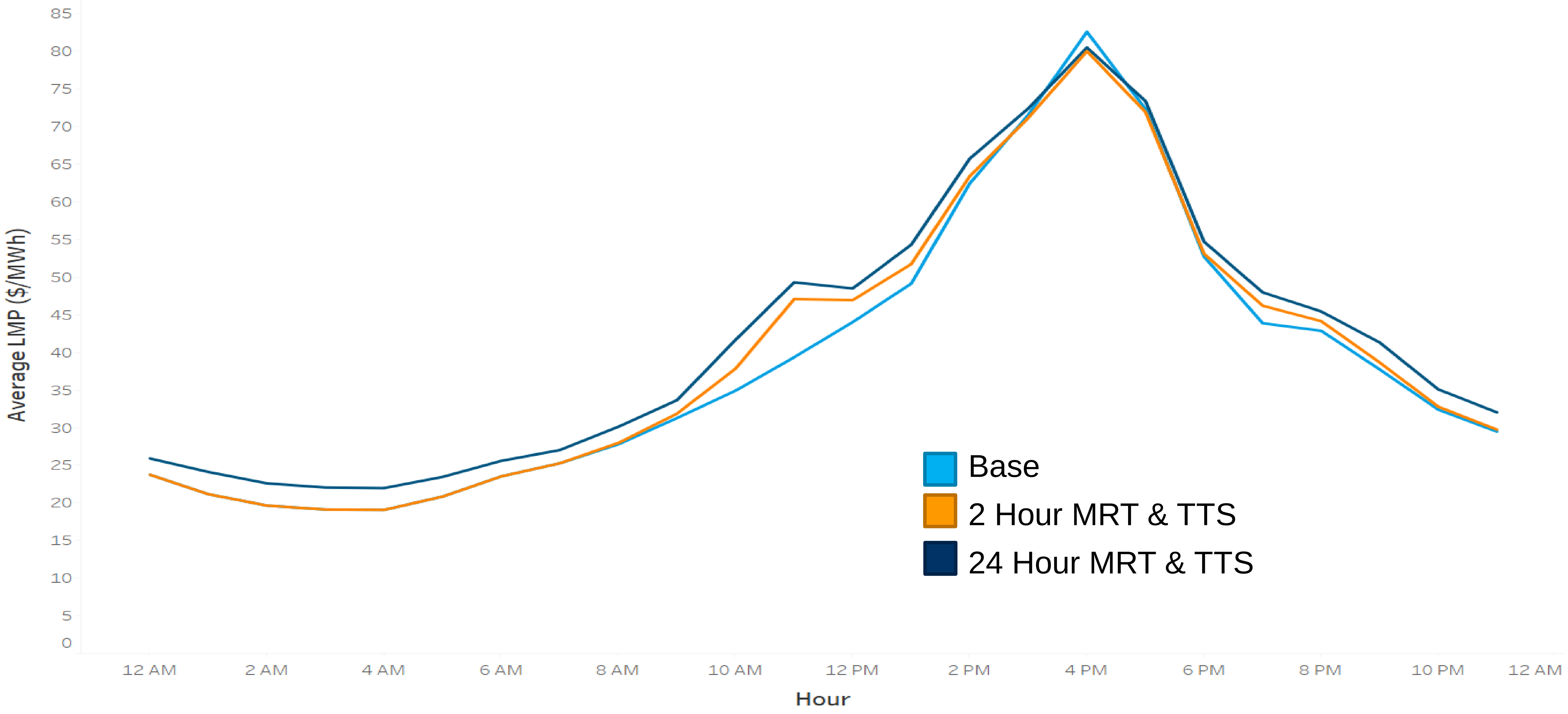
Day-Ahead Average Generator Weighted LMPs on February 20, 2018



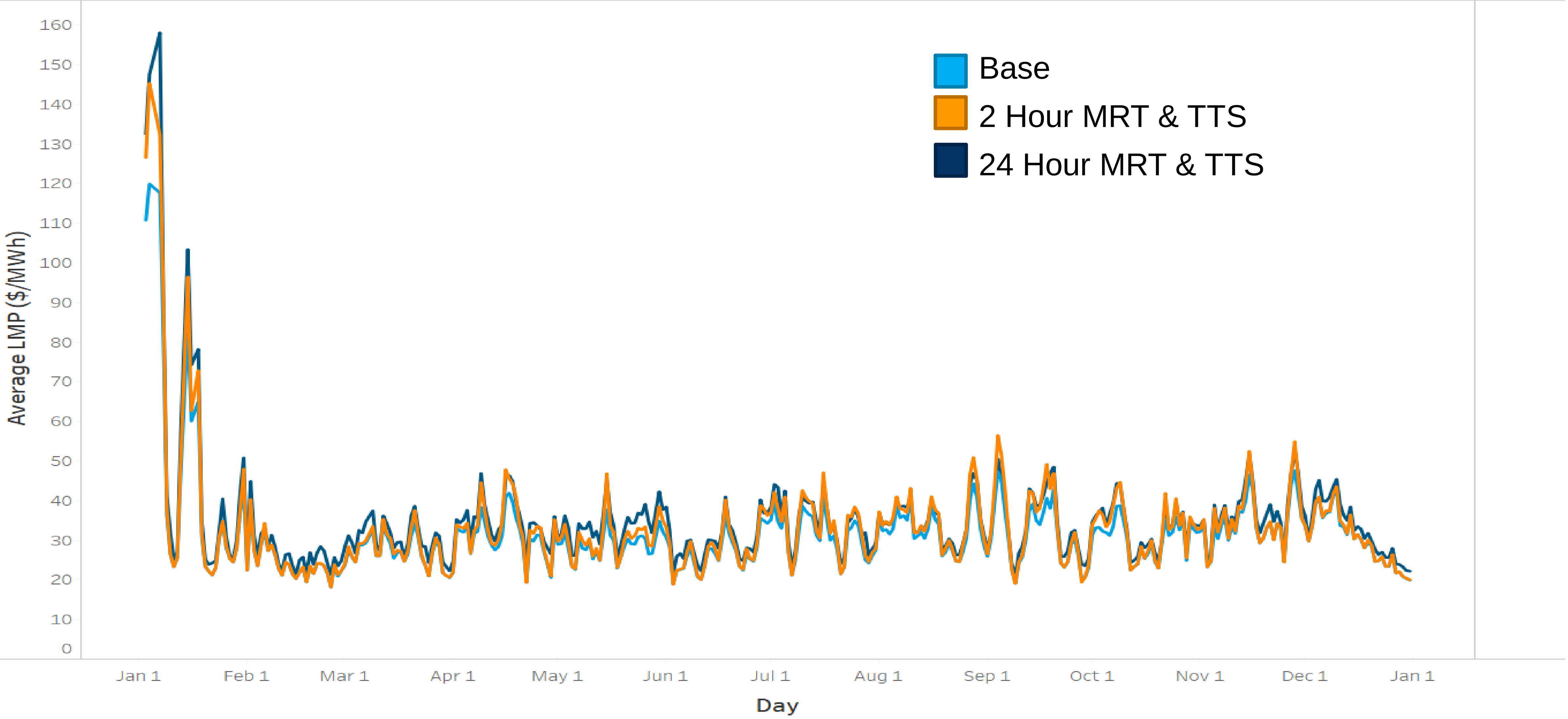
Day-Ahead Average Generator Weighted LMPs on June 17, 2018



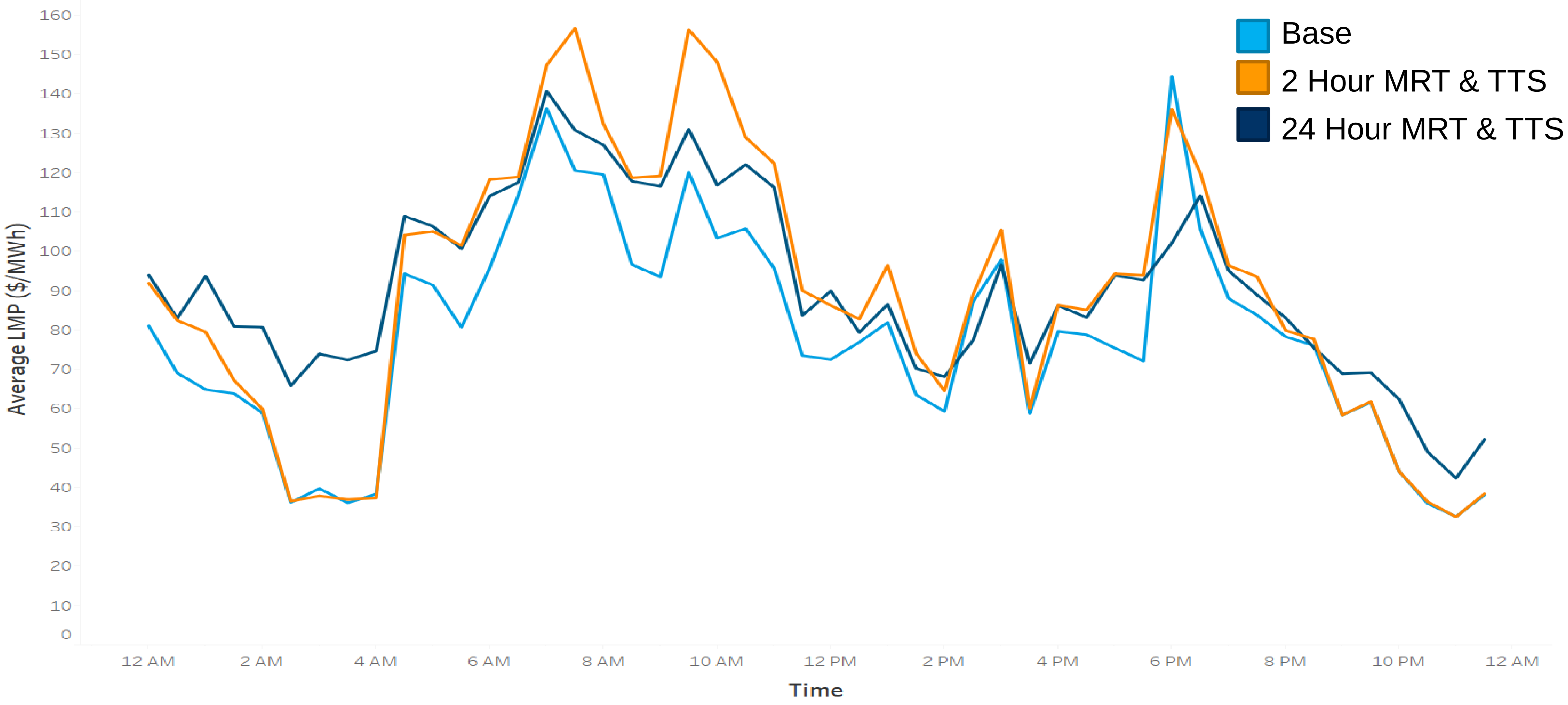
Day-Ahead Average Generator Weighted LMPs on August 28, 2018



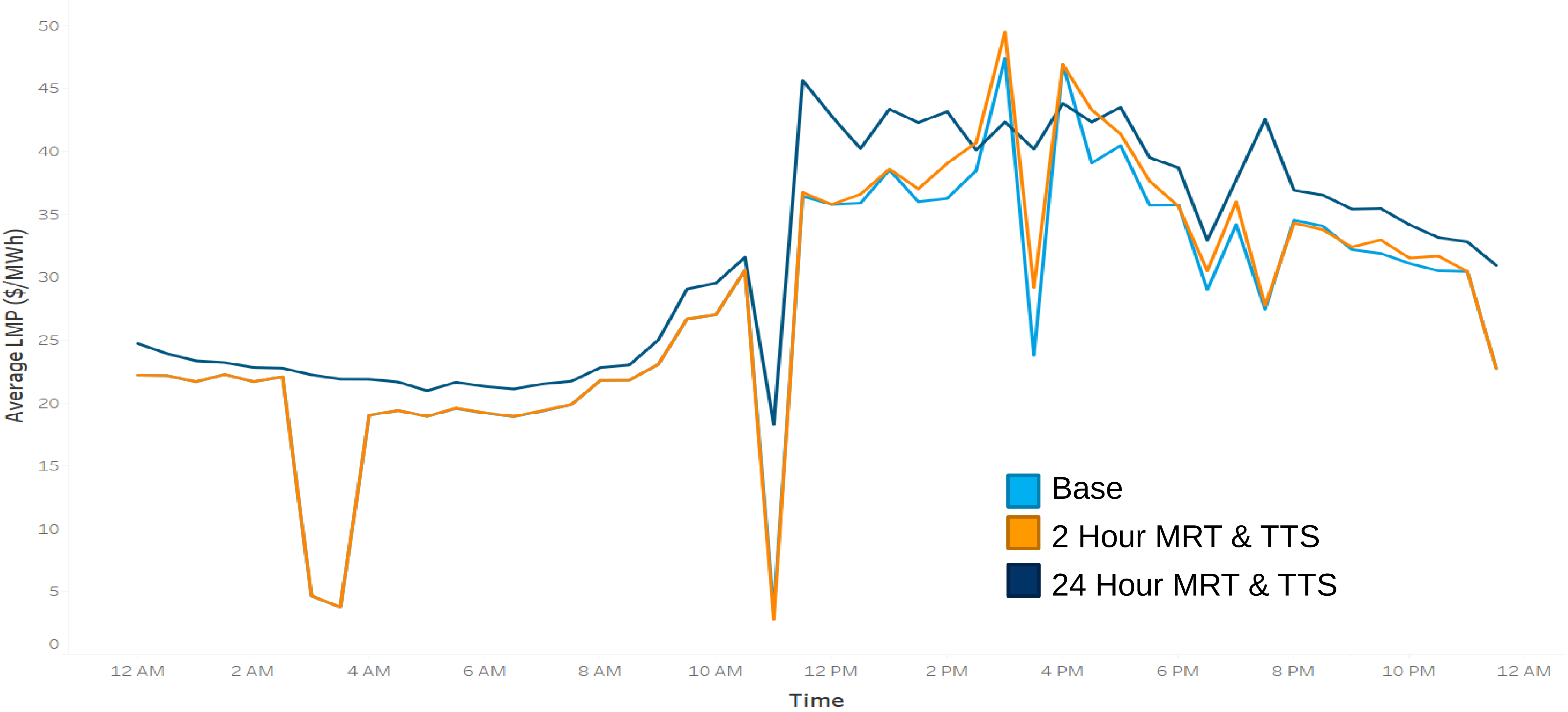
2018 Real-Time Average Daily Generator Weighted LMPs



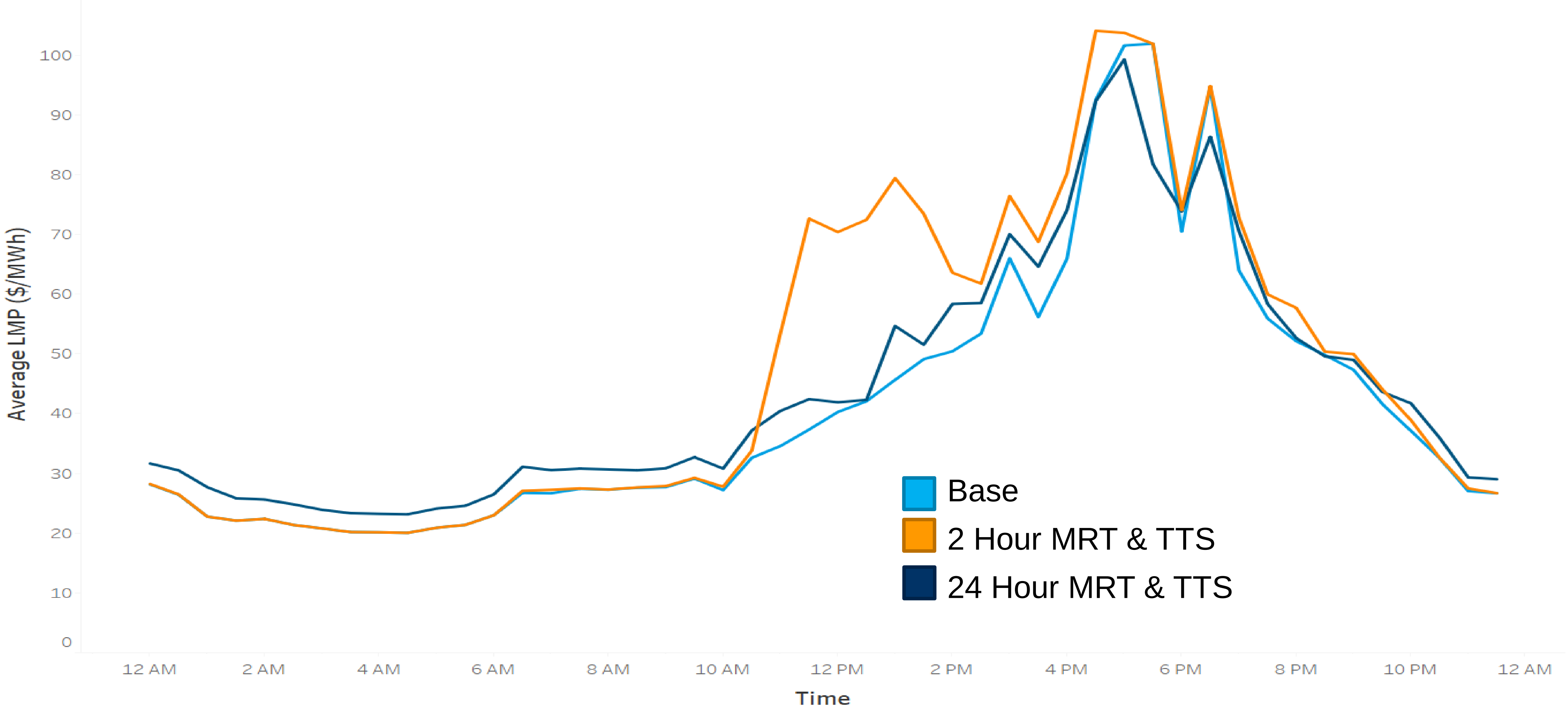
Real-Time Average Generator Weighted LMPs on January 8, 2018



Real-Time Average Generator Weighted LMPs on June 2, 2018



Real-Time Average Generator Weighted LMPs on August 28, 2018



Summary

- PROBE Day-Ahead and Perfect Dispatch were used to simulate the impacts of integer relaxation treatment in the pricing run for the day-ahead and real-time markets, respectively

- Expanding the number of units eligible for integer relaxation treatment results, on average, in increases in the LMP and decreases in uplift

- Expanding integer relaxation treatment to units that have longer total time to start and minimum run times results in consistently higher off-peak prices but potentially lower on-peak prices

Future Work

- Current pricing run implementation optimizes over a single period
- Multi-period integer relaxation solves the pricing problem looking forward over multiple periods
- Allows start-up and no-load costs to be allocated non-uniformly over a resource’s operating hours
- For example, start-up costs can be allocated to peak load hours in order to minimize uplift payments

