Optimizing Synchronous Condensers in PJM's Day-Ahead Energy Market Using a Hybrid Multiple Configuration Resource Model

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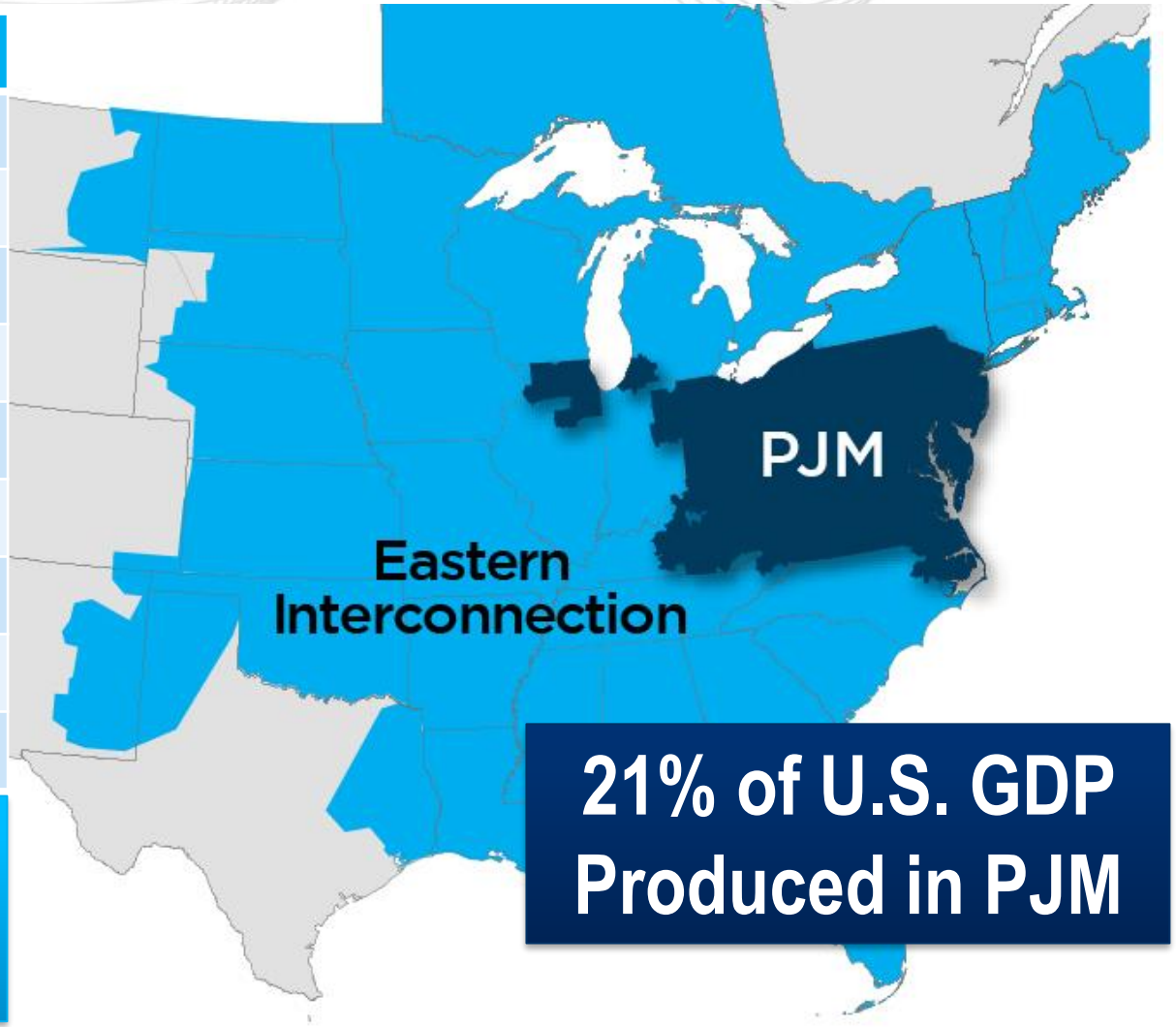
FERC Technical Conference
July 9, 2024

PJM as Part of the Eastern Interconnection

Key Statistics	
Member companies	1,090
Millions of people served	65+
Peak load in megawatts	165,563
Megawatts of generating capacity	180,785
Miles of transmission lines	88,185
Gigawatt hours of annual energy	770
Generation sources	1,439
Square miles of territory	368,906
States served	13 + DC

- 26% of generation in Eastern Interconnection
- 25% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection



As of 2/2024

Outline

1 Synchronous Condensers Overview

2 Multiple Configuration Resource Model

3 PJM Day-Ahead and Real-Time Market Clearing

4 Market Observations

5 Simulations

6 Questions

Synchronous Condensers Overview

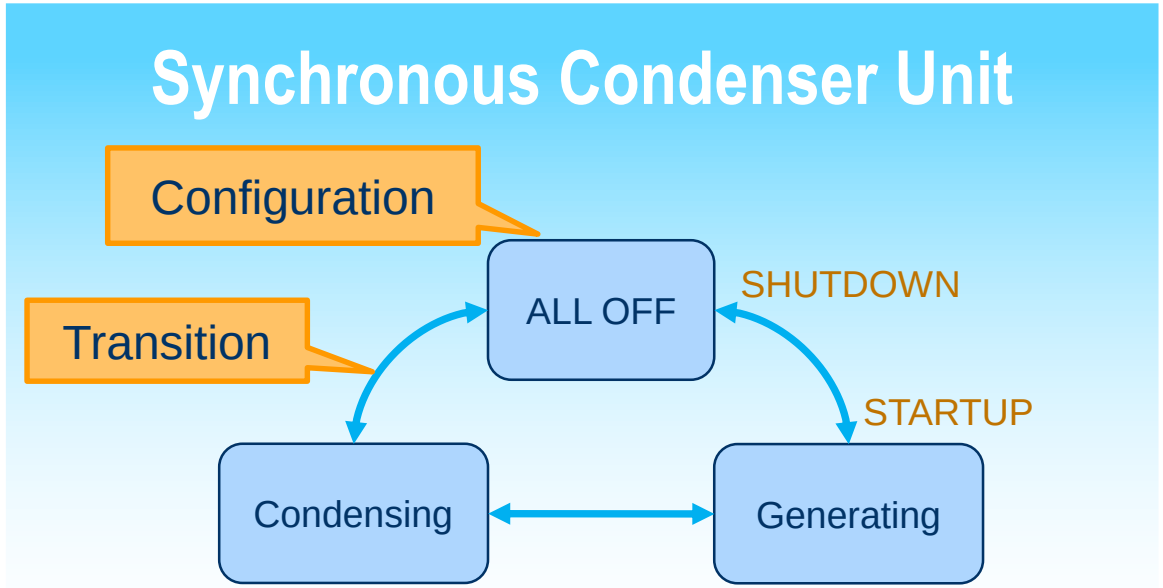
A synchronous machine whose shaft is not attached to any driving equipment and is able to provide reactive power support

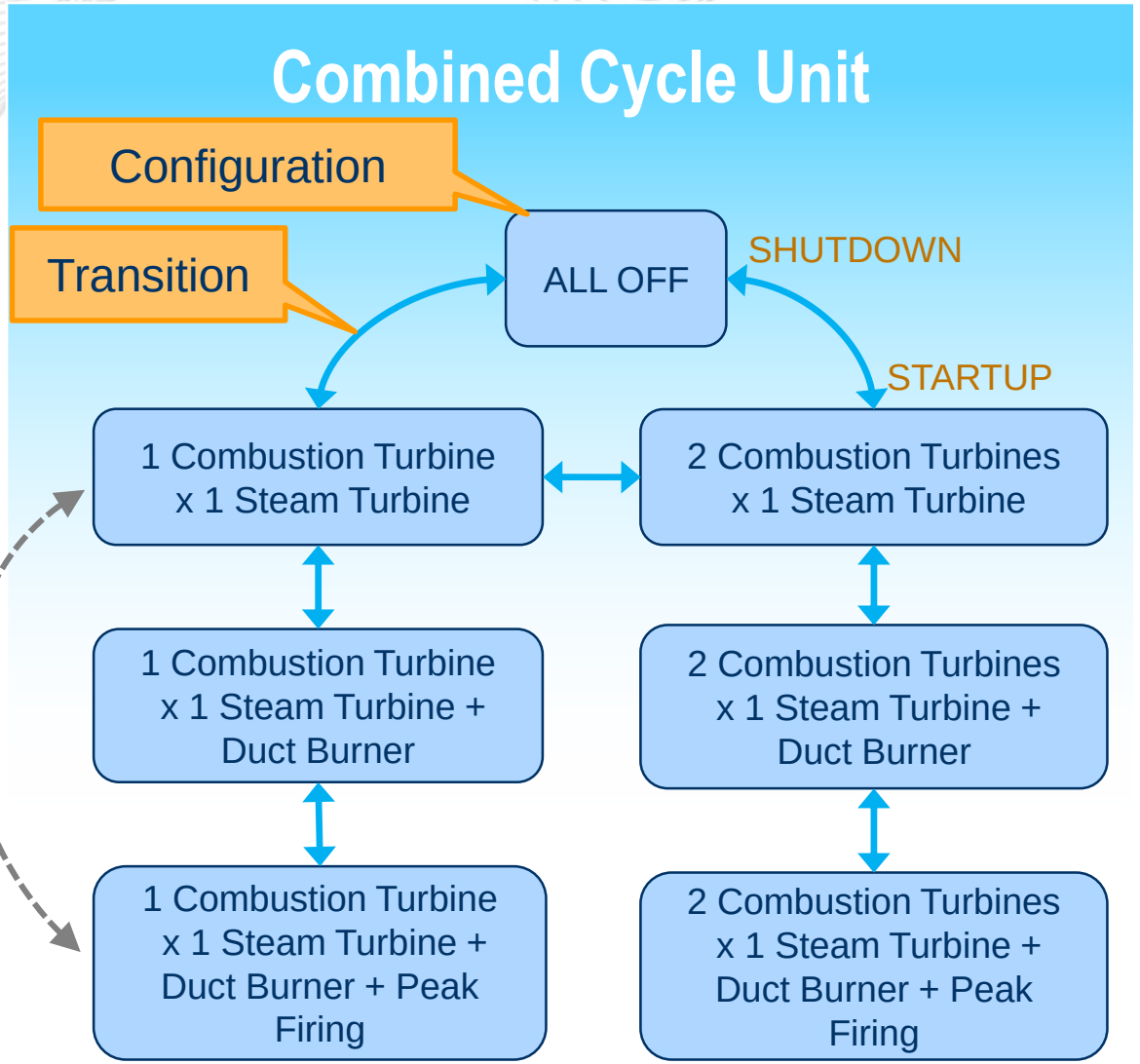
40+ CT and hydro units offer condensing capability in the Day-Ahead Energy Market.

Condensing Mode	Generating Mode
• Consumes a small amount of real power • Able to provide synchronized reserves	Able to provide energy or reserves

Optimizing Synchronous Condensers Is Similar to Combined Cycle Units

Multiple Configuration Resource (MCR) Model:
Allows for the individual modeling of each "operating mode" and its transitions





Multiple Configuration Resource (MCR) Model Development

2018

MISO market R&D department completed an Enhanced Combined Cycle (ECC) conceptual design.

2020

PJM, MISO and PowerGEM started a multiyear joint R&D project to implement the MCR model within PowerGEM's PROBE software.

- Started with MISO's MCR model
- Completely different implementation
  Doesn't use any commercial MIP solver

2023

PJM, MISO and PowerGEM presented details of the MCR model development at the June FERC Technical Conference:

Overview of MISO and PJM Hybrid Multiple Configuration Resource Model Implementation within PROBE software (https://www.ferc.gov/media/qun-gu-powergem-clifton-park-ny)

Optimizing Combined Cycle Units in PJM's Wholesale Energy Markets Using a Hybrid Multiple Configuration Resource Model (https://www.ferc.gov/media/anthony-giacomoni-pjm-interconnection-audubon-pa)

PROBE MCR Model Key Features

1	A hybrid configuration/component-based model • Most of the physical/economic operational characteristics are defined at the configuration level. • Minimum run/down time can be defined at the component (turbine) level.
2	PROBE can simultaneously enforce minimum run/down times at both levels.
3	No limitation on the maximum number of configurations
4	Capable of modeling three offline thermal status (hot, intermediate or cold) with different startup cost/time
5	Hourly multiple-segment ramp curves defined by configurations
6	Advanced ancillary service modeling capabilities

Synchronous Condenser Mode Optimization

Condensing capable units can operate **in two online modes:**	
Condensing	**Generating**
Units provide additional input bids/ characteristics for condensing:	**Transition cost/time from** Offline → Condensing → Generating
	Condensing energy usage (equivalent to a small negative generation)

Condenser Parameters:

Offline to Condensing Start-up cost	**Condensing Notification Time**	**Condensing** to **Generating** Transition cost/time ***Generating*** *to* ***Condensing*** *Transition cost/time is always assumed to be 0.*	**Condensing Energy Usage** Negative fixed megawatt value that is modeled as negative generation

Synchronous Condenser Mode Optimization Design

Condensing mode optimization problem can be easily modeled with the MCR model.

- **Two online configurations** (Generating and Condensing)
- **Condensing mode's** EconMin = EconMax = – Energy Usage MW
- Units are not allowed to self-schedule to be in condensing mode.

Transition Table	Offline	Generating	Condensing
Offline		X	X
Generating	X		X
Condensing	X	X	

- Full Three Pivotal Supplier (TPS) test capability (can accommodate multiple-schedule bids)

First implementation of the MCR model in production in PROBE DA

Went live on Oct. 3, 2023

To date, there has been minimal impact on performance.

Use of PROBE DA in Day-Ahead Market Clearing

Provides	Performs a Three Pivotal Supplier (TPS) test for	Optimizes
unit commitment suggestions to aid Day-Ahead Market operators	**market power mitigation**	**hydro pumped storage schedules**

High-performance SCUC engine

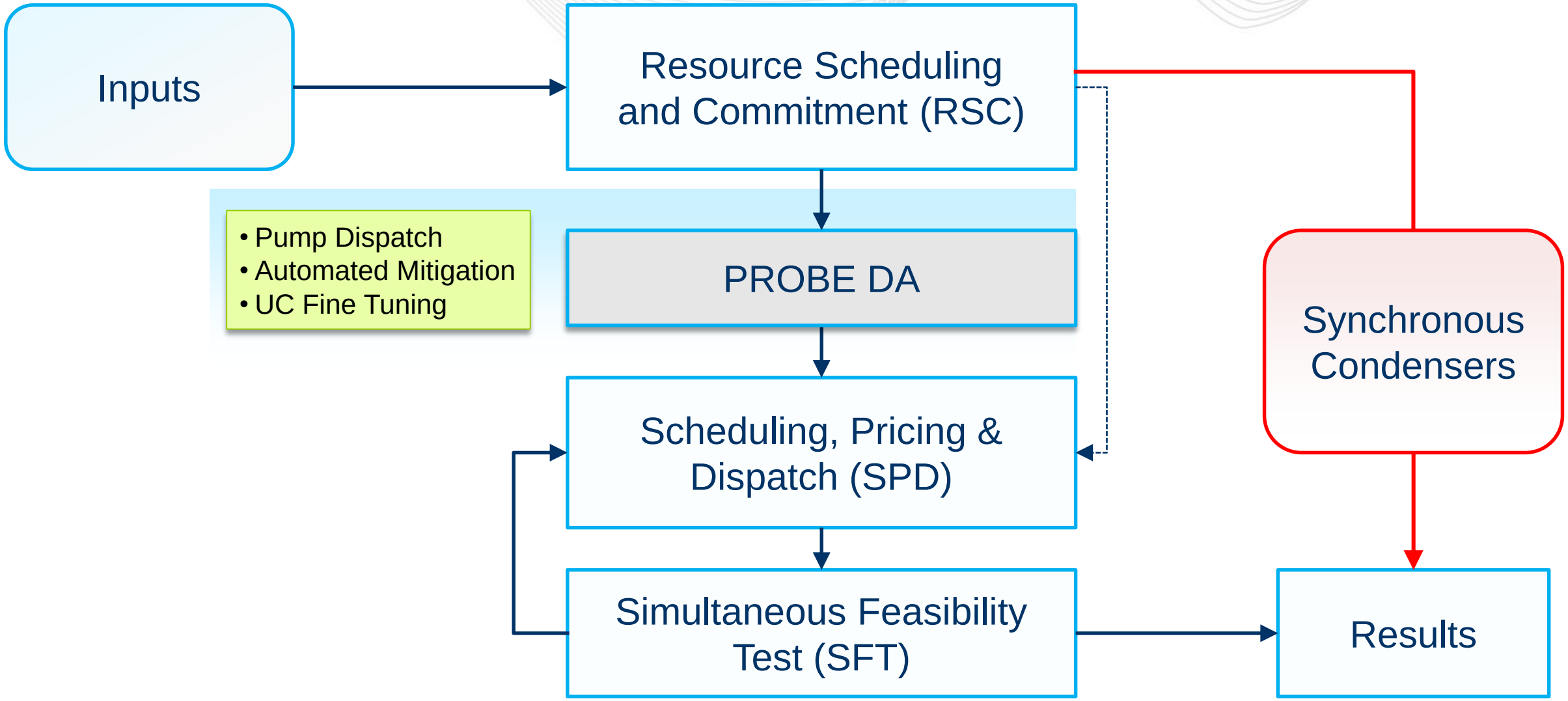
- Does not use third-party solvers
- Typically 1–5 minutes to solve

CONSIDERS:

- All N-1 constraints, thousands of monitored branches and contingencies
- Network and market-to-market flowgates
- Iterative load flow with marginal losses updates
- Ancillary services – system-wide and zonal
- PAR optimization
- All DA unit parameters
- Submitted transactions
- Virtual bids including large volumes of up-to-congestion (UTC) transactions
- DFAX computed on the fly

Day-Ahead Market Clearing Overview

Prior to Oct. 3, 2023



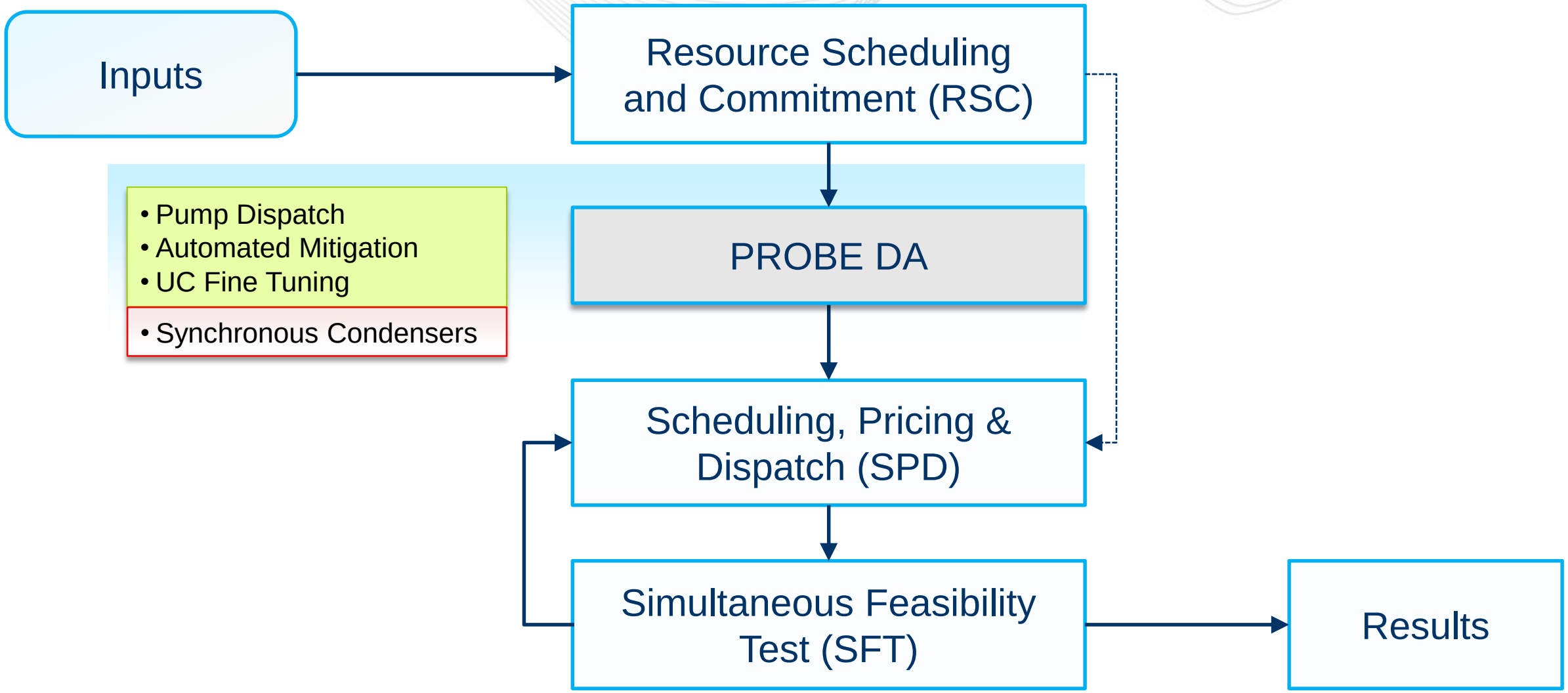
Synchronous Condenser Mode Determination

Prior to Oct 3, 2023

1. Resource Scheduling and Commitment (RSC) engine chose the configuration for the resource.
2. Units committed in condensing mode by RSC went directly into the approved day-ahead case (bypassed PROBE DA).
3. Not fully transparent how these decisions were being made.
4. Often resources in condensing mode were losing money.

Day-Ahead Market Clearing Overview

Beginning Oct. 3, 2023



PROBE DA Results

Oct. 27, 2023

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D PROBE decommits unit (RSC committed unit for energy).

C PROBE commits unit to condensing mode from offline.

R PROBE commits unit for energy.

. **^** **c** RSC and PROBE agree on unit status, no change.

d PROBE decommits unit from condensing mode (RSC committed unit in condensing mode).

= Synchronous condenser changes

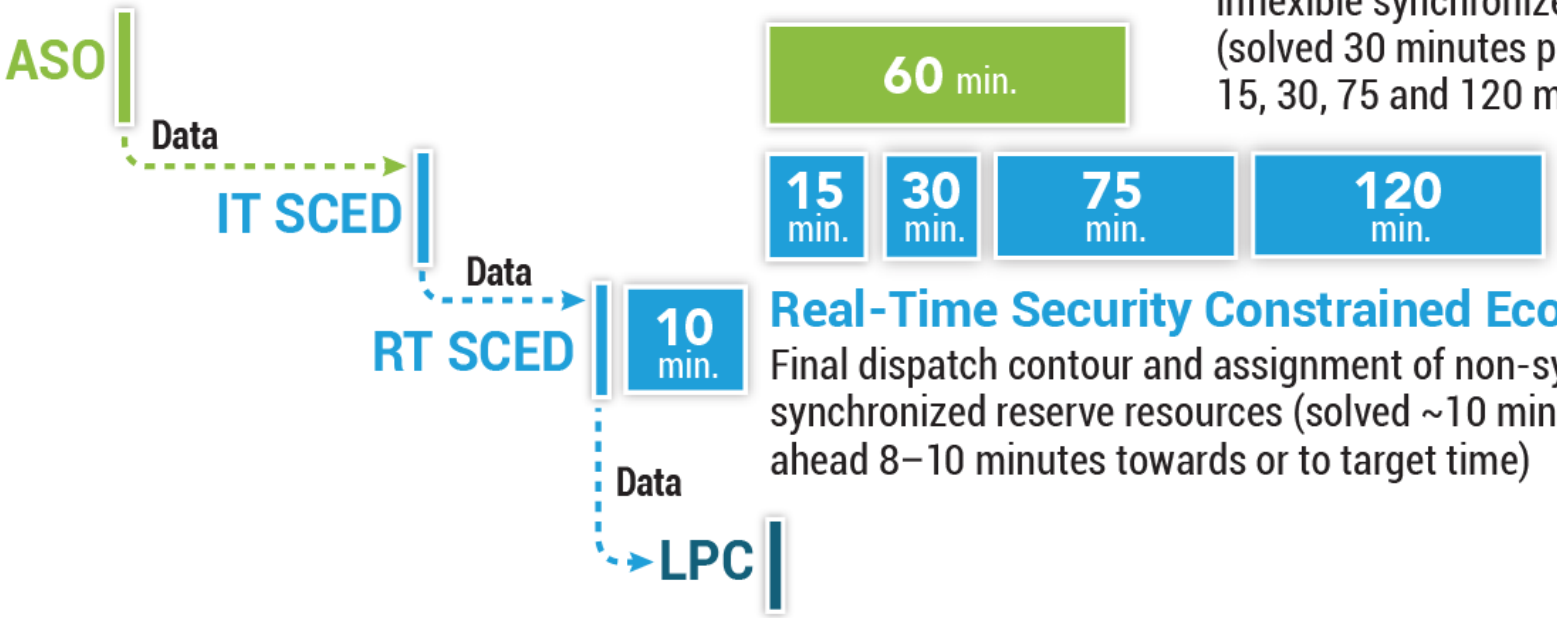
PJM Real-Time Market Clearing Process

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, looks ahead 15, 30, 75 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 8–10 minutes towards or to target time)

Locational Pricing Calculator (LPC)

5-minute energy and ancillary service prices
Based on latest approved RT SCED case

PJM Real-Time Inflexible Reserve Assignments

PJM Ancillary Services Optimizer (ASO) will honor inflexible reserve resource assignments (i.e., synchronous condensers) from the Day-Ahead Market (DAM)

except in the following cases:

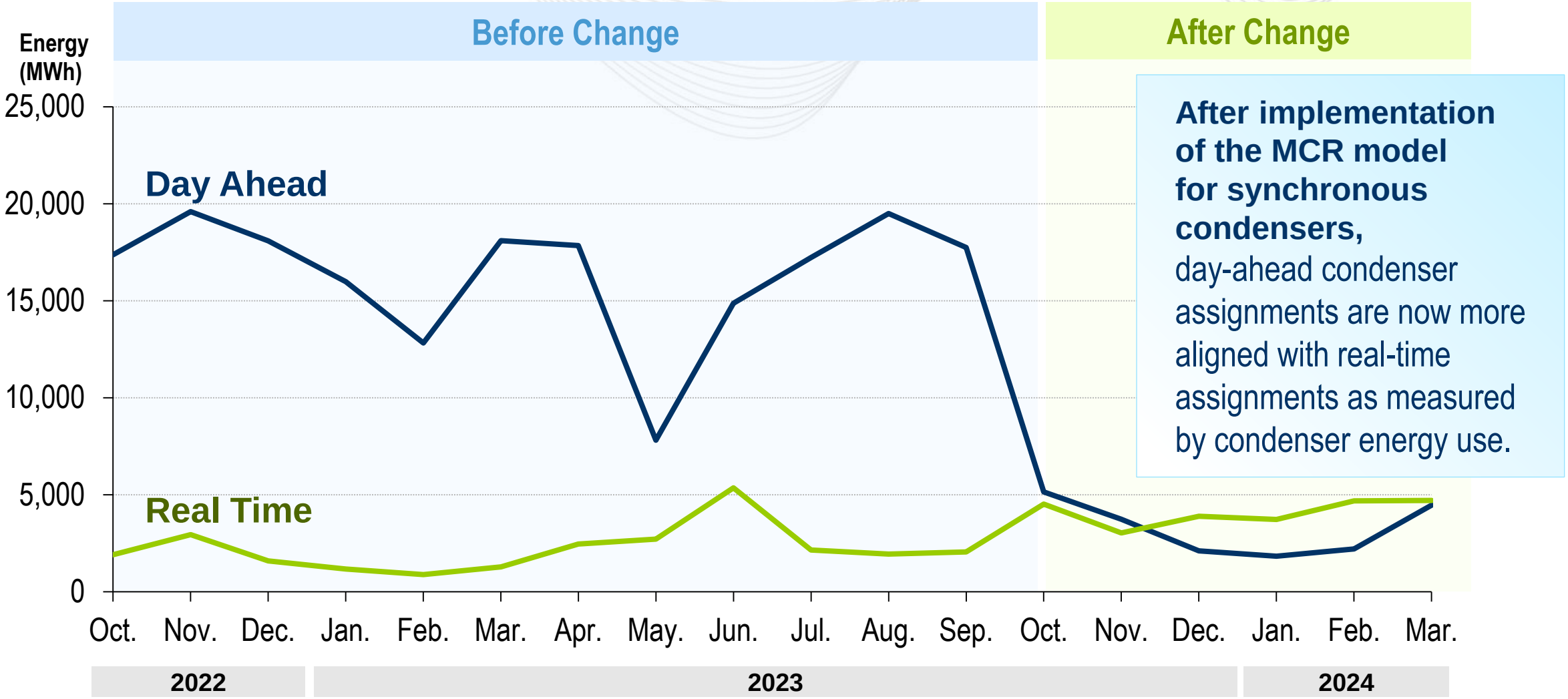
1

Unit is committed by ASO for regulation

2

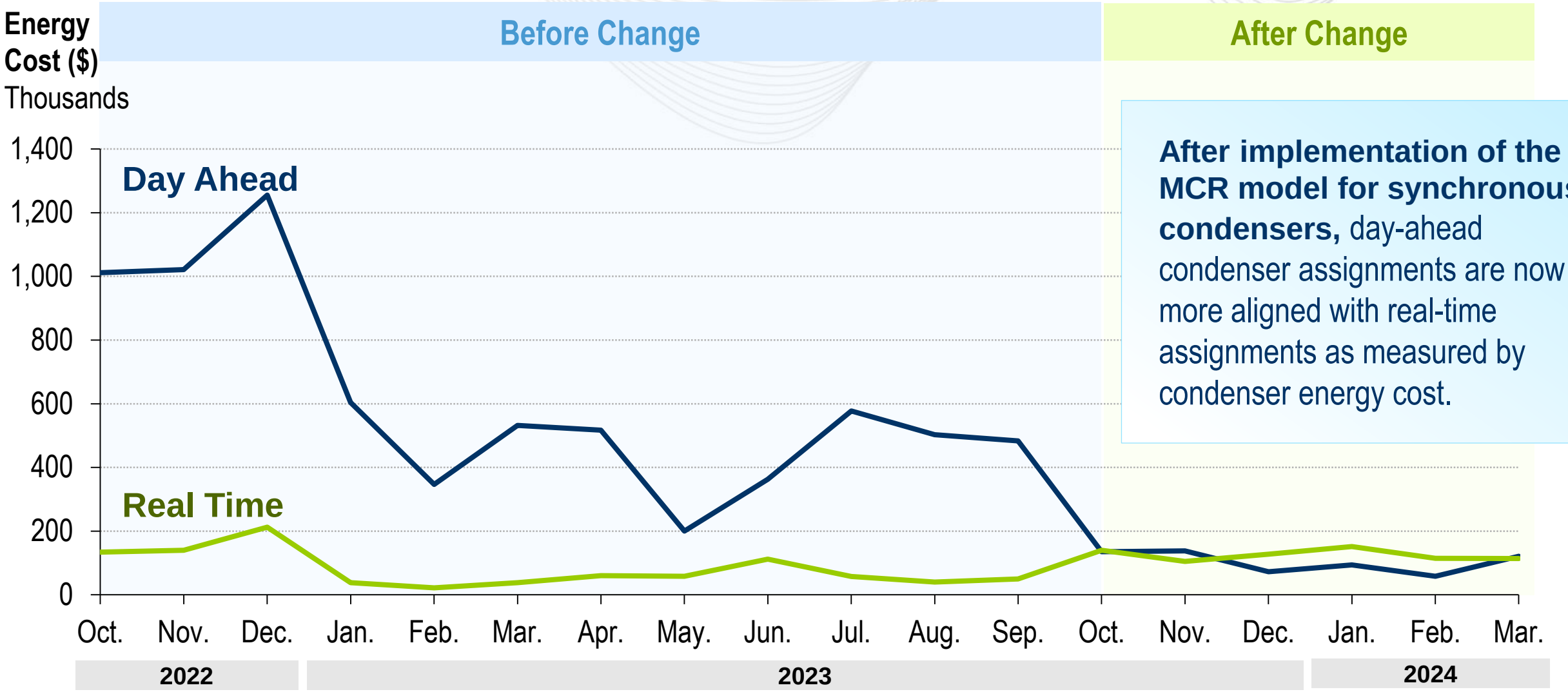
Unit changes any of its offer parameters after the DAM

Synchronous Condenser Energy Use



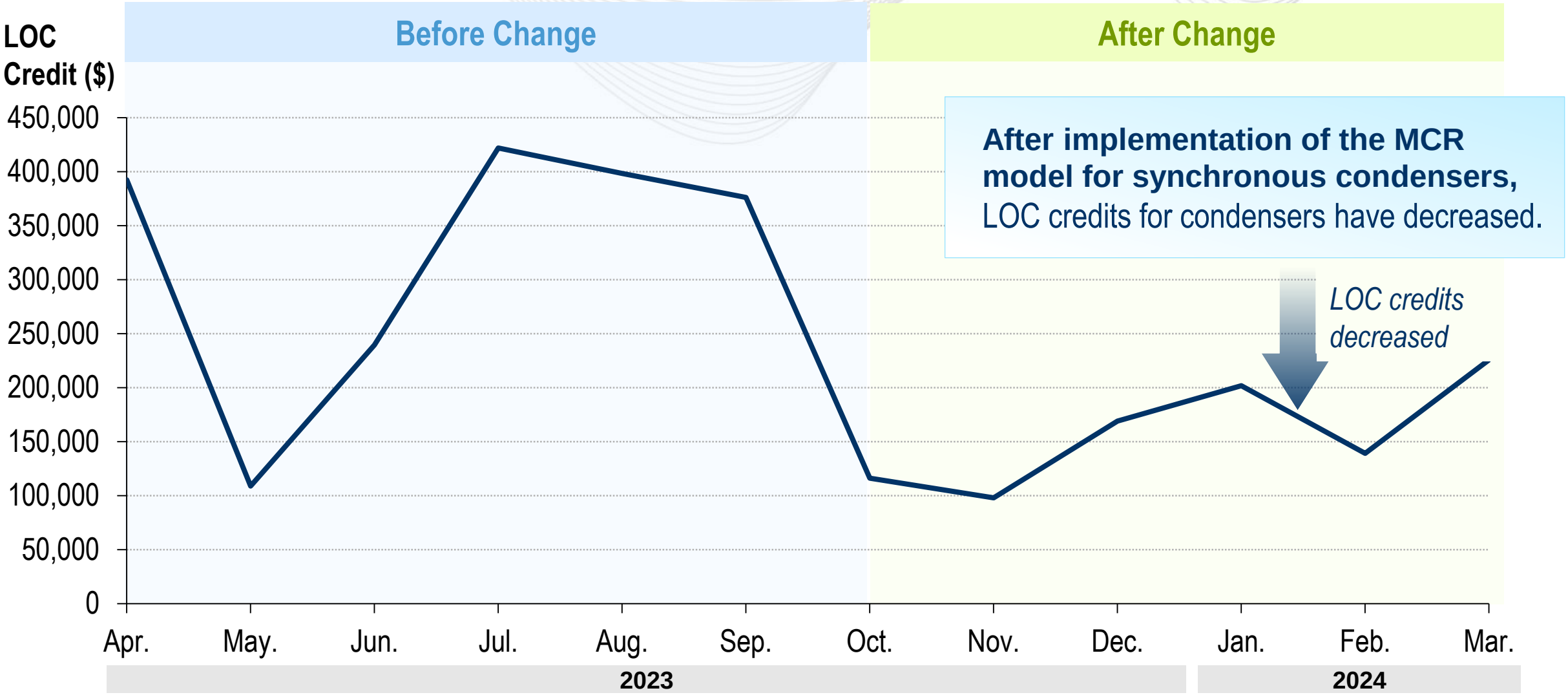
After implementation of the MCR model for synchronous condensers, day-ahead condenser assignments are now more aligned with real-time assignments as measured by condenser energy use.

Synchronous Condenser Energy Use Cost



After implementation of the MCR model for synchronous condensers, day-ahead condenser assignments are now more aligned with real-time assignments as measured by condenser energy cost.

Synchronous Condenser Lost Opportunity Cost (LOC) Credits



Simulation Methodology Overview

To estimate the benefits from the additional flexibility provided by the synchronous condenser mode optimization in the PJM Day-Ahead Market, simulations were run using the PROBE DA Market clearing software.

Two cases were simulated,
and the differences between the two were measured to estimate the impacts on social welfare:

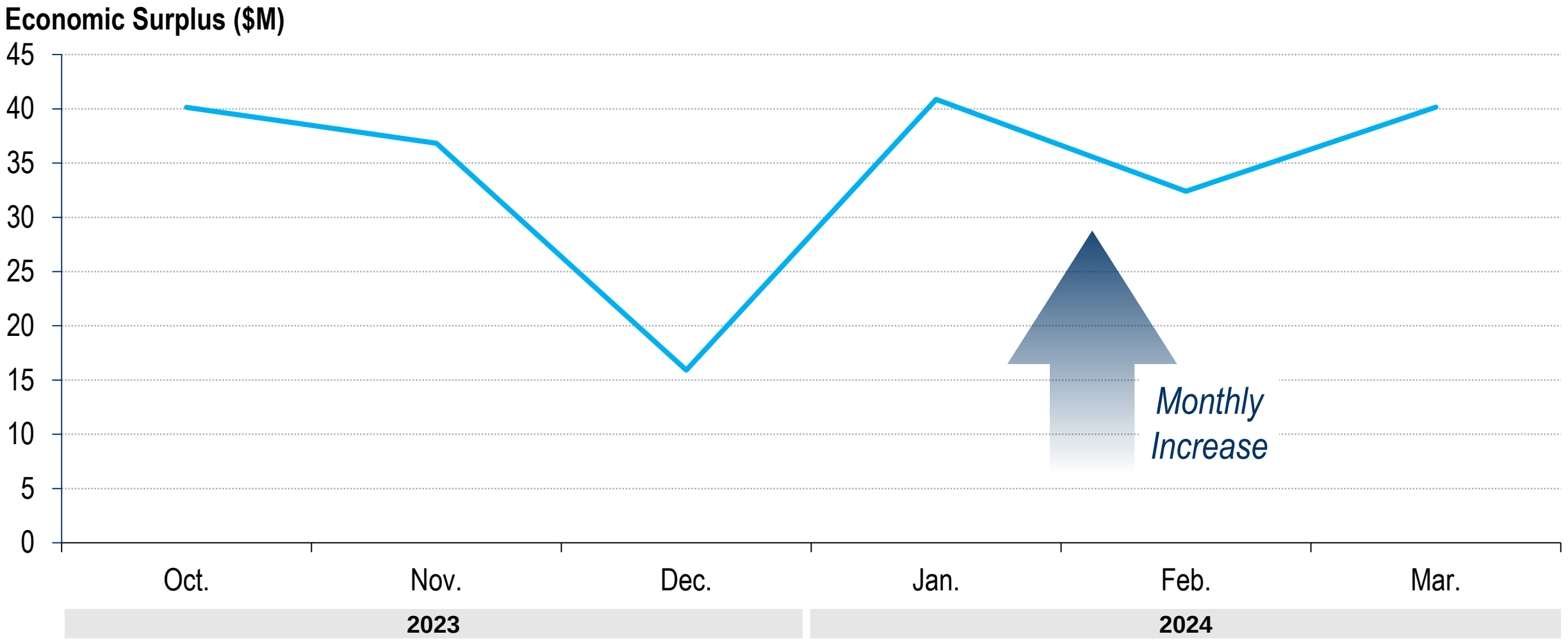
BASE CASE:	SYNCHRONOUS CONDENSER (SC) CASE:
Generators are not allowed to run in condensing mode.	Condensing mode optimization is implemented using the MCR model.

All other variables were held constant between the two cases.

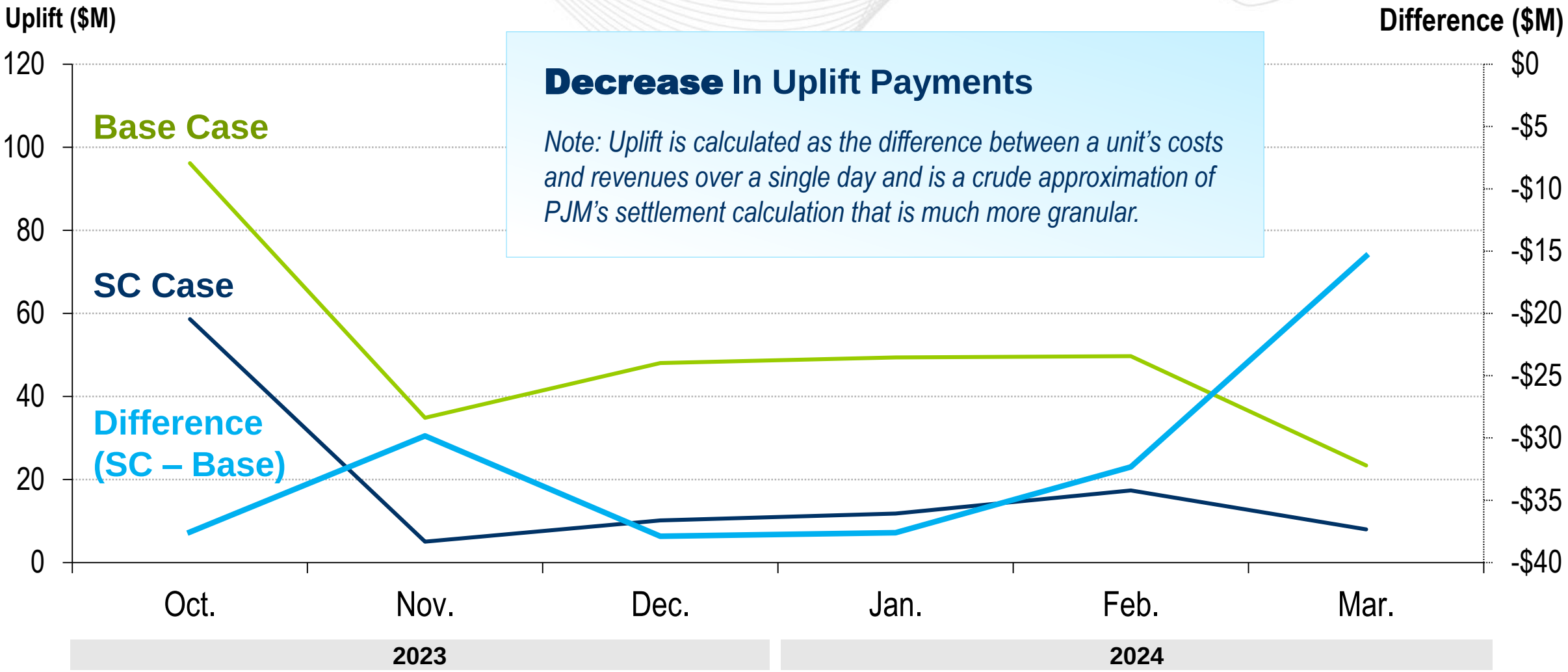
175 days were simulated
from Oct. 3, 2023, through March 31, 2024.

Six days were excluded
due to data issues.

Simulation Results – Monthly Increase in Economic Surplus (Benefits – Costs) from Condensing Mode Optimization



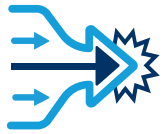
Simulation Results – Uplift Payments



Decrease In Uplift Payments

Note: Uplift is calculated as the difference between a unit's costs and revenues over a single day and is a crude approximation of PJM's settlement calculation that is much more granular.

Using the MCR model for condensing mode optimization:

	Day-ahead synchronous condenser assignments are now aligned with real-time assignments.
	LOC payments to synchronous condensers have decreased.

Synchronous condenser mode optimization increases
economic surplus by approximately $30-40M/month
and reduces uplift in the Day-Ahead Market.