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September 25, 2024

Energy and Reserve Co-Optimization

Intermediate Wholesale Electricity Markets (IWEM)

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Why Do We Need Reserves?

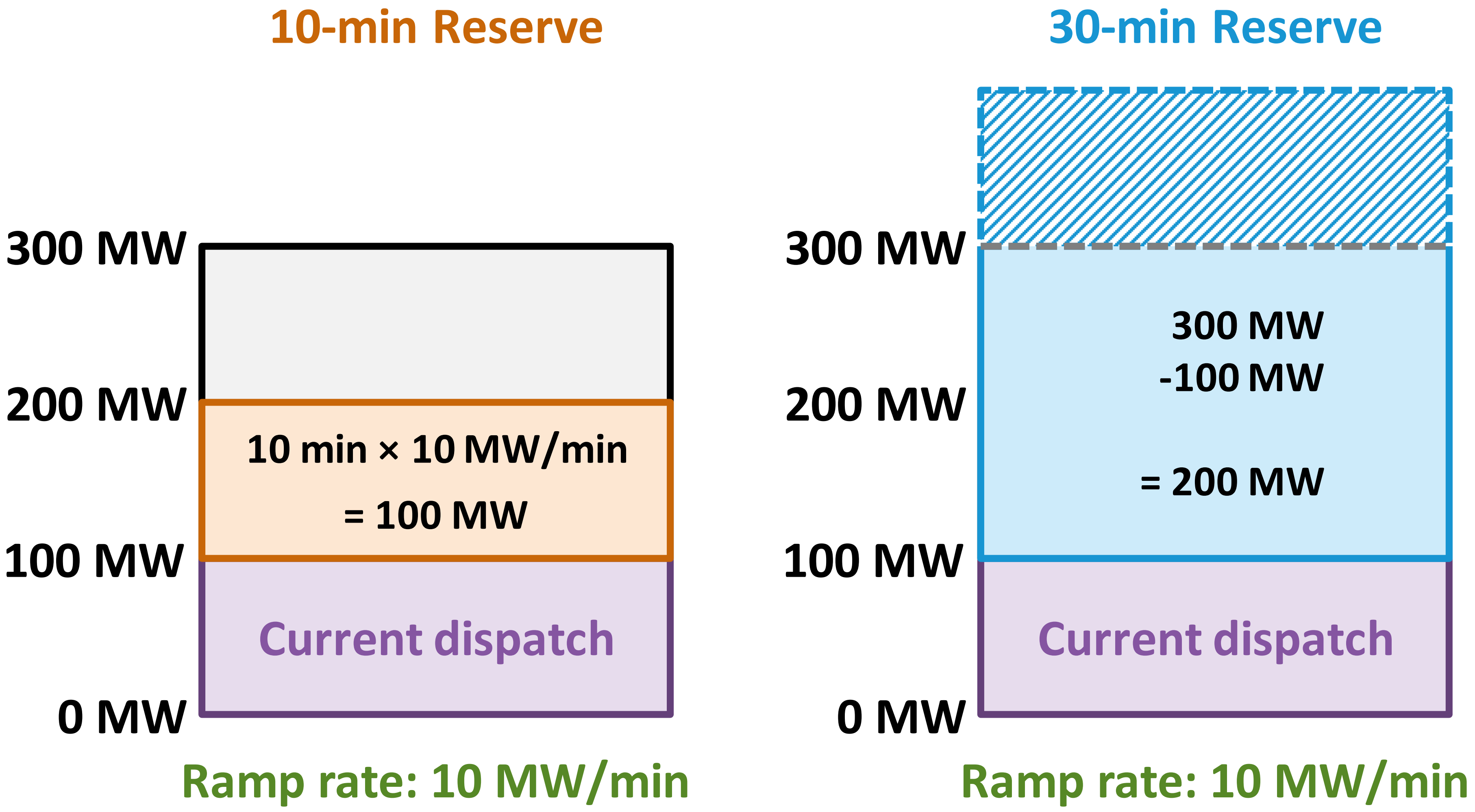
- Reserves provide insurance against potential sudden and unexpected changes in the power system that could impact reliability
  - Generator forced outage
  - Transmission fault
  - Problems in neighboring control areas

- ISO is required to maintain specific levels of reserves to meet reliability requirements established by both NERC and NPCC:
  - NERC Standard BAL-002-3
  - NPCC Directory 5 requirements

- ISO-NE continuously tracks three reserve types – 10 minute spinning, 10 minute non-synchronized, and 30 minute operating reserves

Energy and Reserve Co-Optimization

Introduction: Resource with 300 MW Maximum Output



Objectives

At the end of this section you will be able to:

- Describe the reserve requirements and products
- Describe how reserves are modeled and designated
- Explain the relationship between energy and reserve prices and cleared quantities
- Explain how reserve penalty factors influence market clearing prices

Topics

- Reserve Requirements and Products
- Determining Reserve Designations
- Following ISO Dispatch
- Reserve Constraint Penalty Factors
- Co-Optimization Examples

What is Energy-Reserve Co-Optimization?

- Real-time operational goals:
  1. Meet energy demand
  2. Meet reserve requirements (reliability)
- Real-time energy-reserve co-optimization jointly clears the energy and reserve markets in a least-cost fashion

Why Co-Optimization?

- Energy and reserve are naturally coupled
  - A trade-off may have to be made when energy and reserve is provided by the same physical resource

- Clearing energy and reserve in a sequential way (pre-Standard Market Design) failed to:
  - Maximize total social welfare
  - Reveal the coupling effect between energy and reserve prices
  - Provide incentives for resources to follow dispatch instructions

Benefits of Co-Optimization

System Operator's Perspective

- Provides the least cost way of meeting energy demand while maintaining system reliability (reserve requirements)
- Effectively and simultaneously determines the market clearing prices for both:
  - Energy [locational marginal price (LMP)], and
  - Reserve [reserve market clearing price (RMCP)]
- Provides incentive for resources to follow dispatch

Benefits of Co-Optimization

Market Participant's Perspective

- Produces an energy and reserve allocation that maximizes:
  - Total as-bid profit (if generating resource)
  - Total as-bid benefit (if dispatchable load)
- Provides a financial incentive to follow ISO dispatch

Reserve Requirements and Products

Three Main Real-Time Reserve Requirements

Purpose:

- Meet North American Electric Reliability Corporation (NERC) and Northeast Power Coordinating Council (NPCC) requirements

10-Minute Spinning Reserve Requirement	10-Minute Reserve Requirement	Total Reserve Requirement
Minimum unloaded capacity on all **online** units that can be converted to energy in **10 minutes or less**	Minimum capacity on all units (online or offline) that can be converted to energy in **10 minutes or less**	Minimum capacity on all units (online or offline) that can be converted to energy in **30 minutes or less**

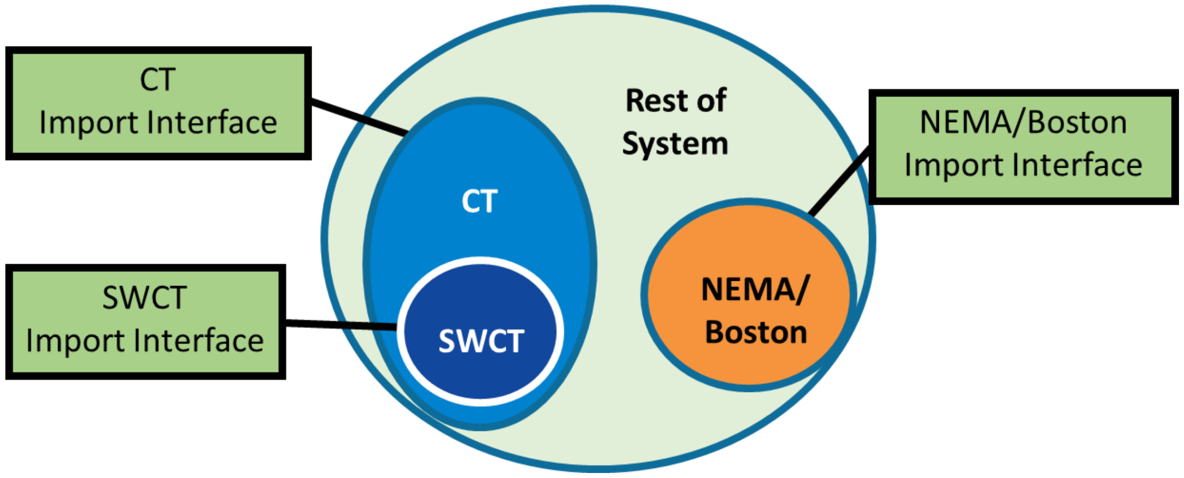
The reserve ***products*** and reserve ***requirements*** are **not** the same

System Reserve Requirements

- 10-minute spinning reserve requirement = 25% of 10-minute reserve requirement
- 10-minute reserve requirement = largest system contingency x contingency reserve adjustment (CRA) factor for the last quarter (currently 1.20)
- Total reserve requirement = 10-minute reserve requirement + 50% of the second largest system contingency

Zonal Reserve Requirements

- Current zones: Northeastern Massachusetts/ Boston (NEMA/Boston), Connecticut (CT), and Southwest Connecticut (SWCT)
- No 10-minute reserve requirement based on assumption that local largest first contingency recovery requirements can be met by operating at the (N-1) import interface limit
- 30-minute zonal reserve requirement = 100% of local second contingency recovery needs subject to the (N-1) import interface limit



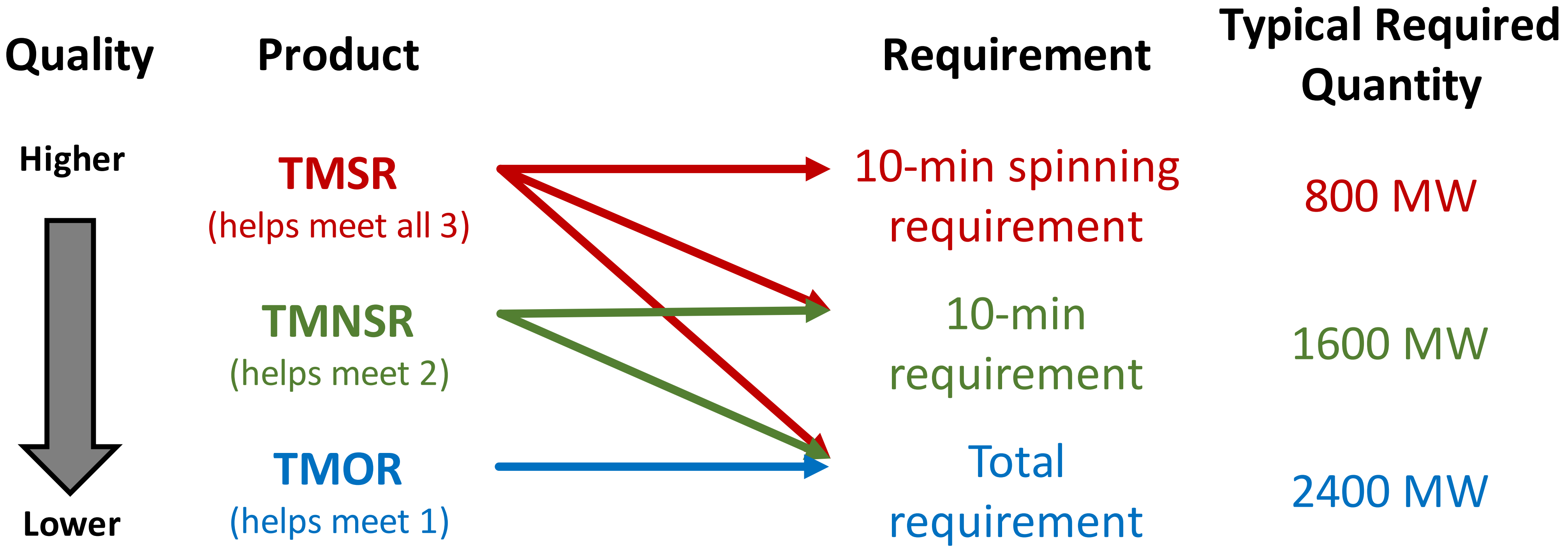
Reserve Products

Resources can provide one or more of the following reserve products:

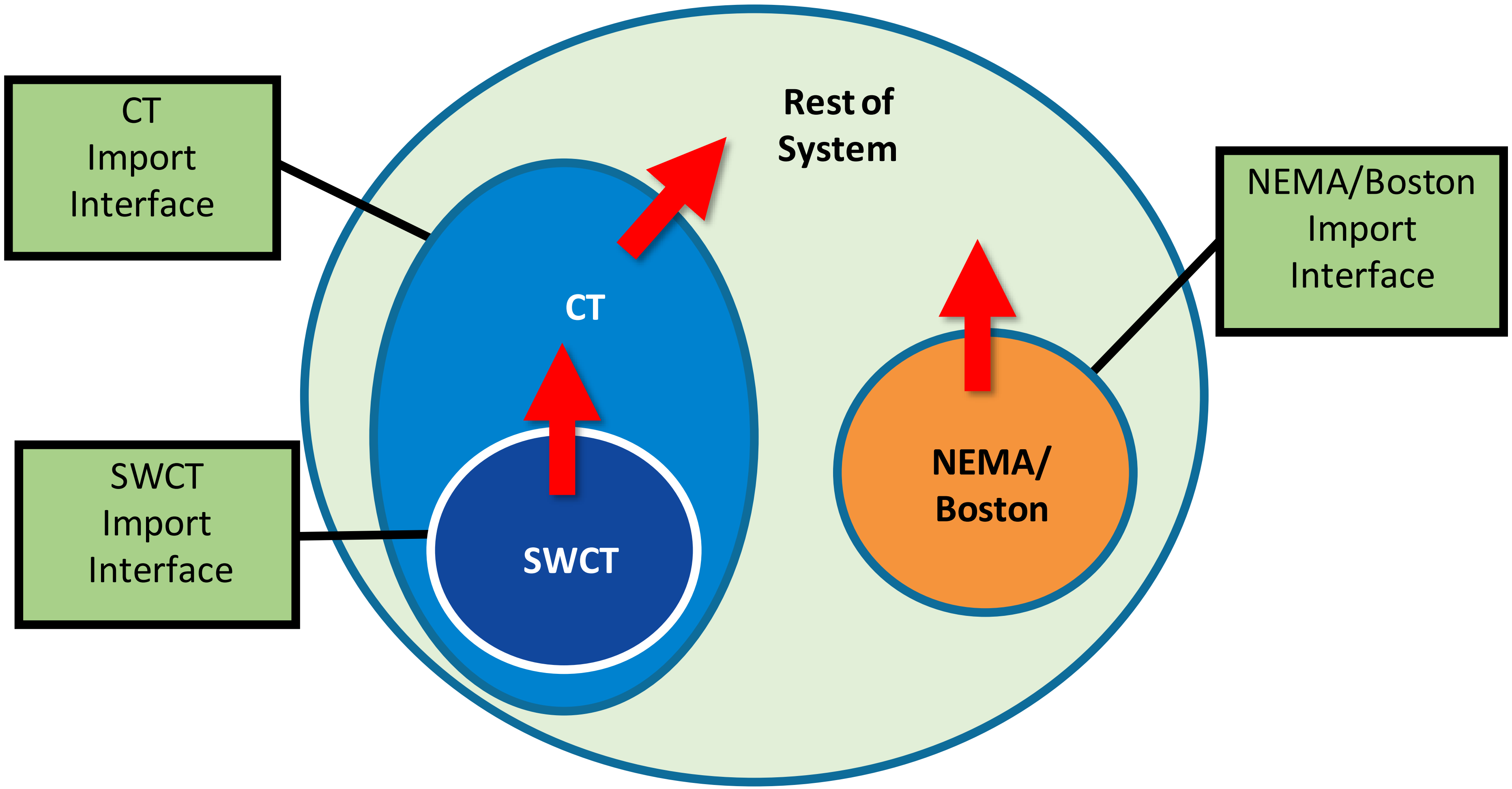
- **TMSR** – ***10-minute spinning reserve*** can be provided by resources that are **online**
- **TMNSR** – ***10-minute non-spinning reserve*** can be provided by **offline** resources that can be online within 10 minutes
- **TMOR** – ***30-minute operating reserve*** can be provided by **online** resources and **offline** resources that can be online within 30 minutes

How Reserve Products Meet Requirements

Reserves that count toward multiple requirements are more valuable to the ISO, so reserve prices "cascade up" from TMOR → TMNSR → TMSR



Reserve Zones and Pricing



Zonal reserve prices "cascade" in a manner similar to reserve product prices
(reserves that count toward more requirements are more valuable)

Questions?

Determining Reserve Designations

How Much Reserve Can a Resource Supply?

Maximum amount of reserves is designated on each resource

Reserve from a resource is limited by either:

- Ramping capability

  or

- Unloaded capacity

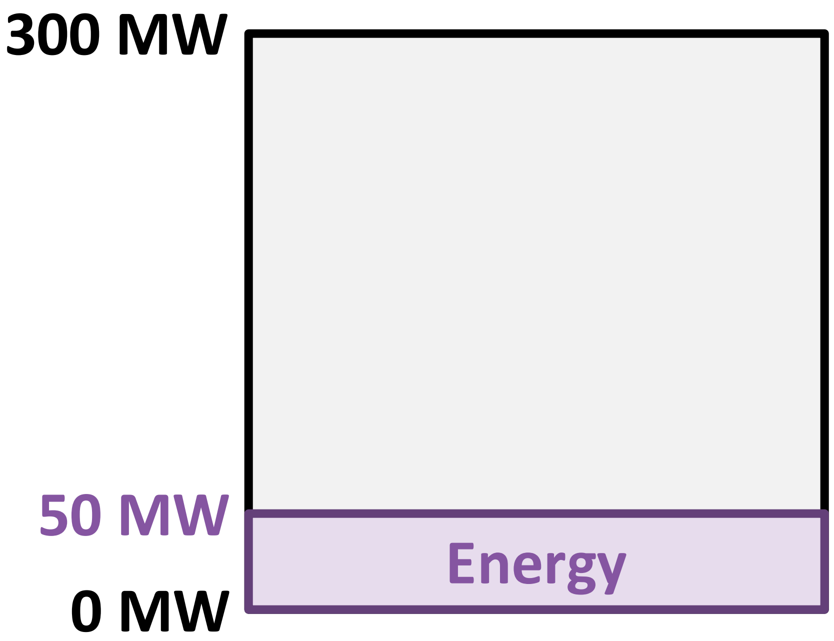
Reserve Resources Limited by Ramping Capability

	Resource ramp rate (MW/min)
×	Time period (min)
=	Ramp limitation (MW)

Reserve Resources Limited by Unloaded Capacity

	Ecomax (MW)
-	Dispatch point (MW)
=	Unloaded capacity (MW)

Calculate 10-Minute Spinning Reserve: Case A



Current output = 50 MW

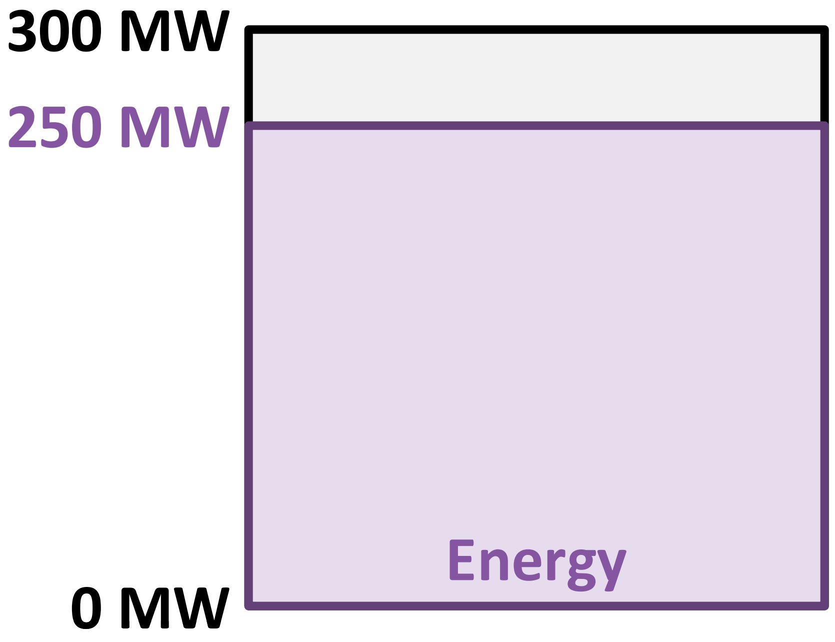
Ramp rate = 10 MW/min

Ecomax = 300 MW

Case A	
Unloaded capacity Ecomax – Dispatch point	
Ramping capability Time period × Ramp rate	
Spinning reserve Take the minimum	

Calculate 10-Minute Spinning Reserve: Case B

Instructions: *Using the current output and ramp rate, calculate the spinning reserve.*



Current output = 250 MW

Ramp rate = 10 MW/min

Ecomax = 300 MW

Case B	
Unloaded capacity Ecomax – Dispatch point	
Ramping capability Time period × Ramp rate	
Spinning reserve Take the minimum	

Following ISO Dispatch

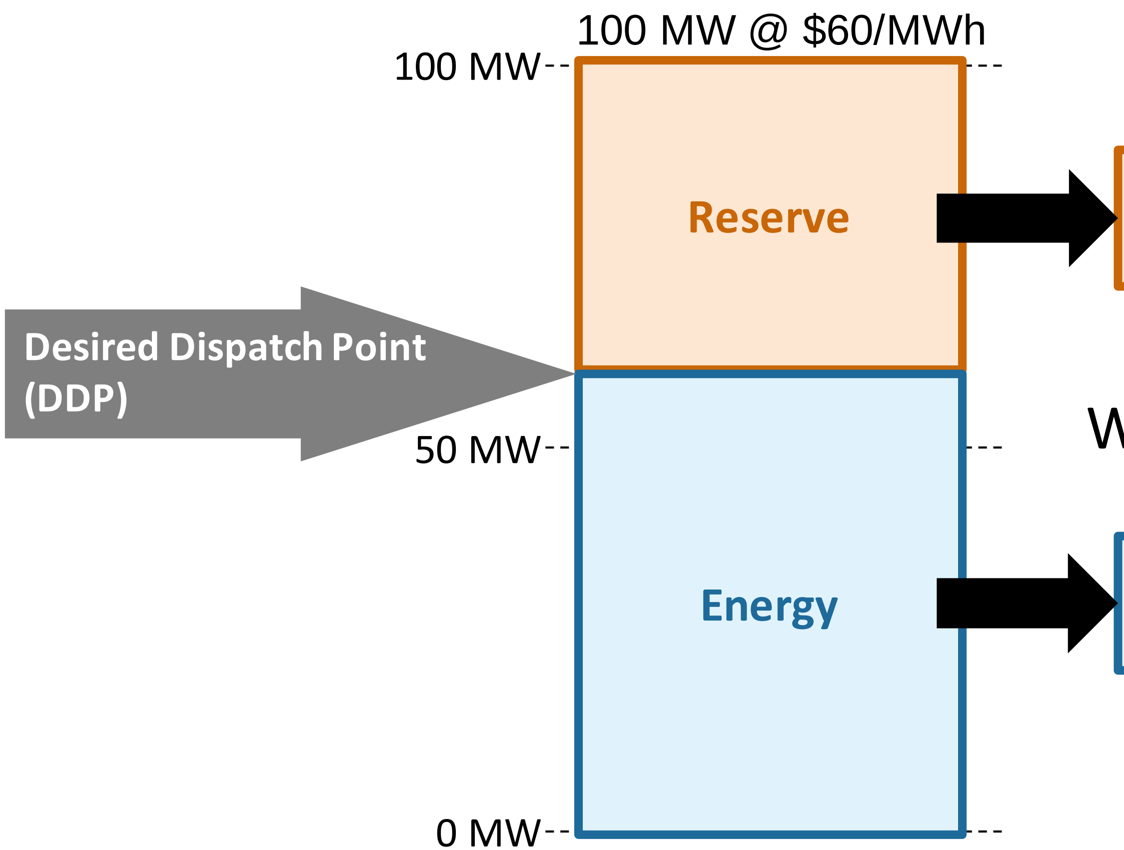
Incentive to Follow

Trade-Off Between Energy and Reserve

- If not constrained by ramping capability, every potential MW of energy is a trade-off for a potential MW of reserve provided by the same resource
- Profit maximization should drive the resource's decision about producing energy vs. providing reserve
- Energy-reserve co-optimization provides ISO operations with the modeling capability to dispatch both energy and reserve optimally and simultaneously
- Optimal solution provides the best outcome to all resources

Trade-Off Between Energy and Reserve

Conceptual Illustration



Incremental Reserve Profit = Reserve Market Clearing Price (RMCP)

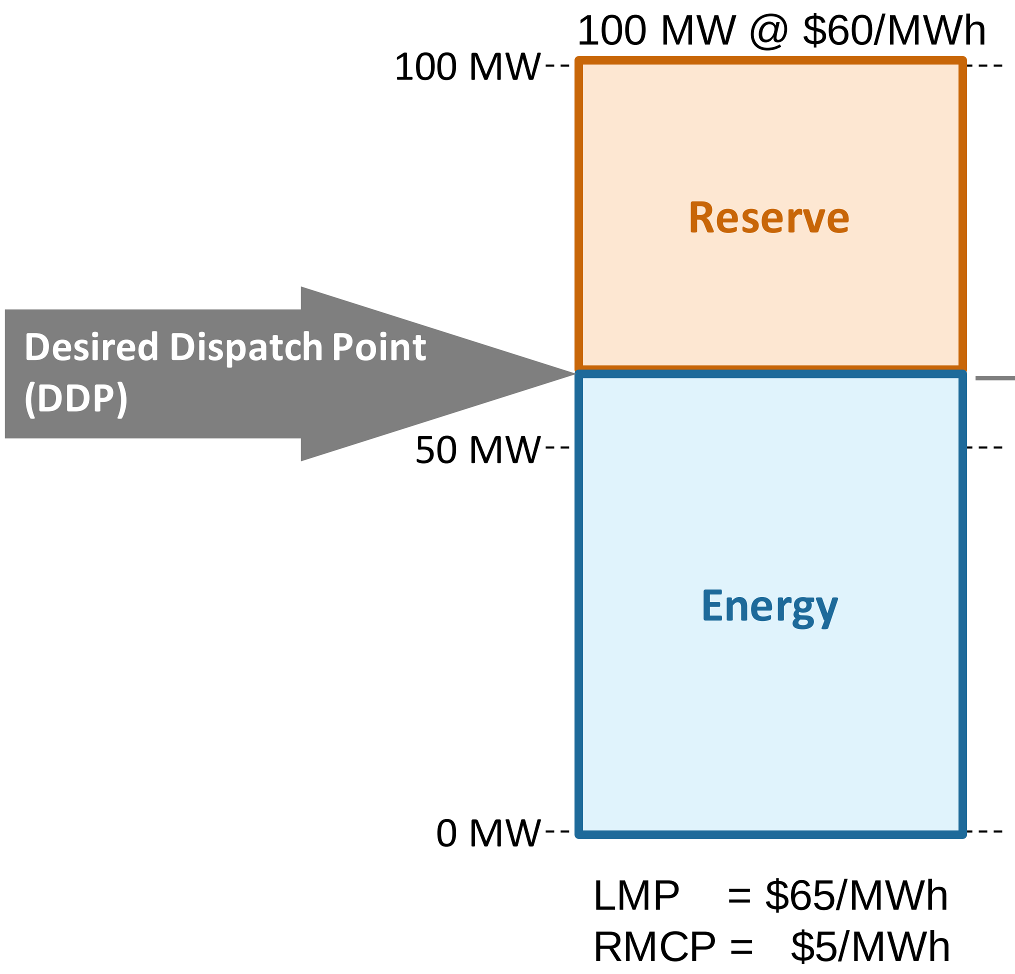
Which product is more profitable: **energy** or **reserve**?

Incremental Energy Profit = LMP - Marginal Cost

Energy-reserve *co-optimization* provides the optimal allocation of energy and reserve for each unit.

Trade-Off Between Energy and Reserve

Base Case Example



- **Increase energy output by 1MW**

Δ Reserve Profit = -$5/MWh

Δ Energy Profit = 65 – 60 = $5/MWh

Profit change

-5 + 5 = $0/MWh

5 - 5 = $0/MWh

- **Decrease energy output by 1MW**

Δ Reserve Profit = $5/MWh

Δ Energy Profit = -65 + 60 = -$5/MWh

Unit maximizes its profit when operating at **DDP**

Questions?

Reserve Constraint Penalty Factors

Reserve Constraint Penalty Factor (RCPF)

- RCPF is the cost of reserves from “virtual reserve resources” that the ISO can deploy when there is a reserve shortage

- Penalty factors are used to prevent infeasibility of the ISO’s optimization problem
  - Penalty factors, including RCPFs, can affect market clearing and pricing

RCPF Values	Constraint
$50	10-min Spinning Reserve Requirement
$1,500	10-min Reserve Requirement
$1,000	Total Reserve Requirement
$250	Total Reserve Requirement (replacement reserve step)
$250	Zonal Reserve Requirement

Reserve Constraint Penalty Factor (RCPF) In Practice

- RCPF represents two values:
  - Administratively-set reserve offer price when reserve supply does not meet reserve requirement
  - Cap on the re-dispatch cost that the system will incur before going short of reserves

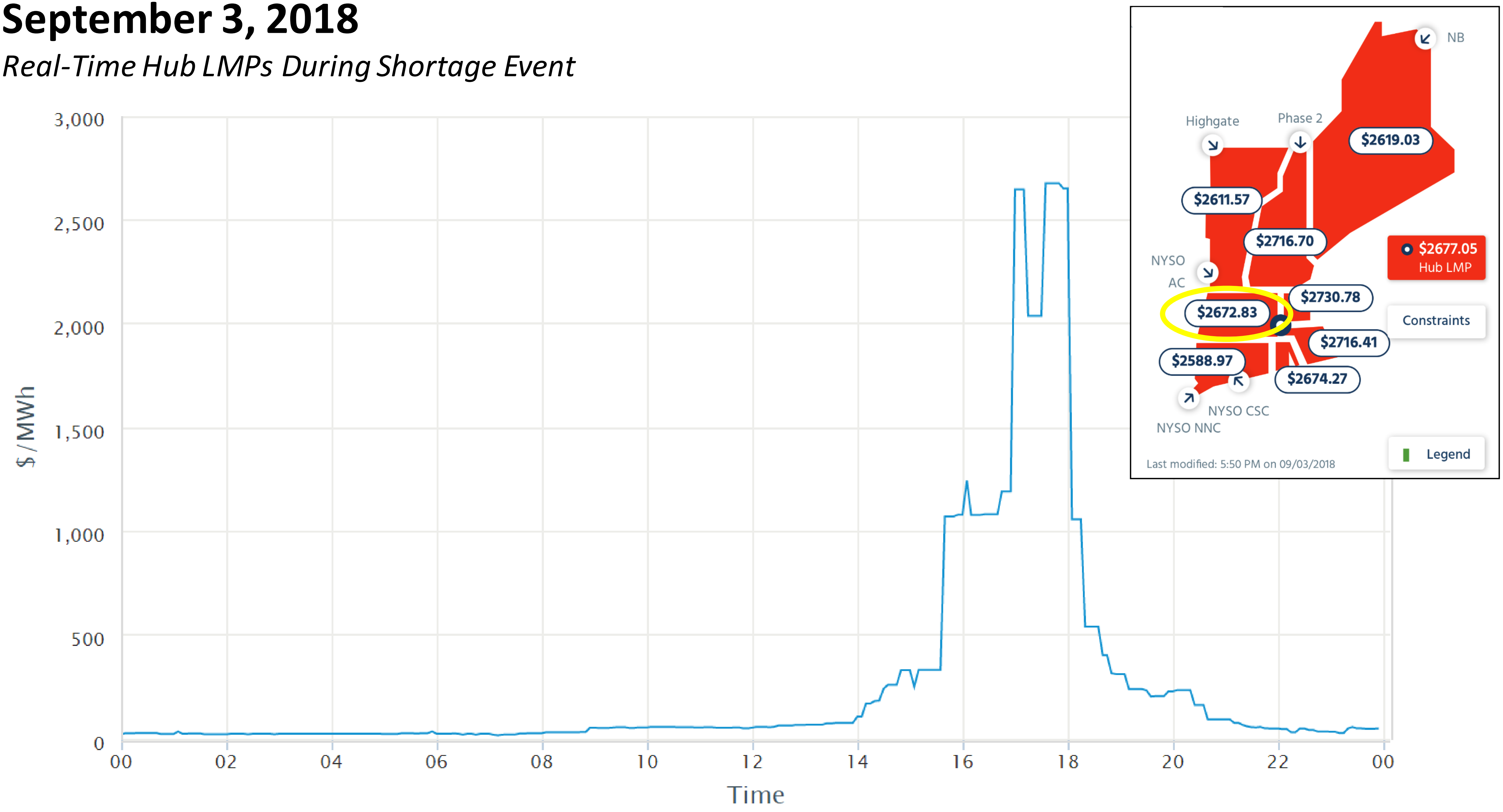
Example

- $1500/MWh RCPF of the 10-minute reserve requirement means that ISO is willing to incur at most $1500/MWh in higher production cost (i.e., due to redispatch) to meet the requirement

- If redispatch is not possible or is more expensive than $1500/MWh:
  - "Virtual reserve resource" will be cleared,
  - TMSR and TMNSR will be paid at least $1500/MWh, and
  - ISO will be in a reserve shortage

September 3, 2018

Real-Time Hub LMPs During Shortage Event

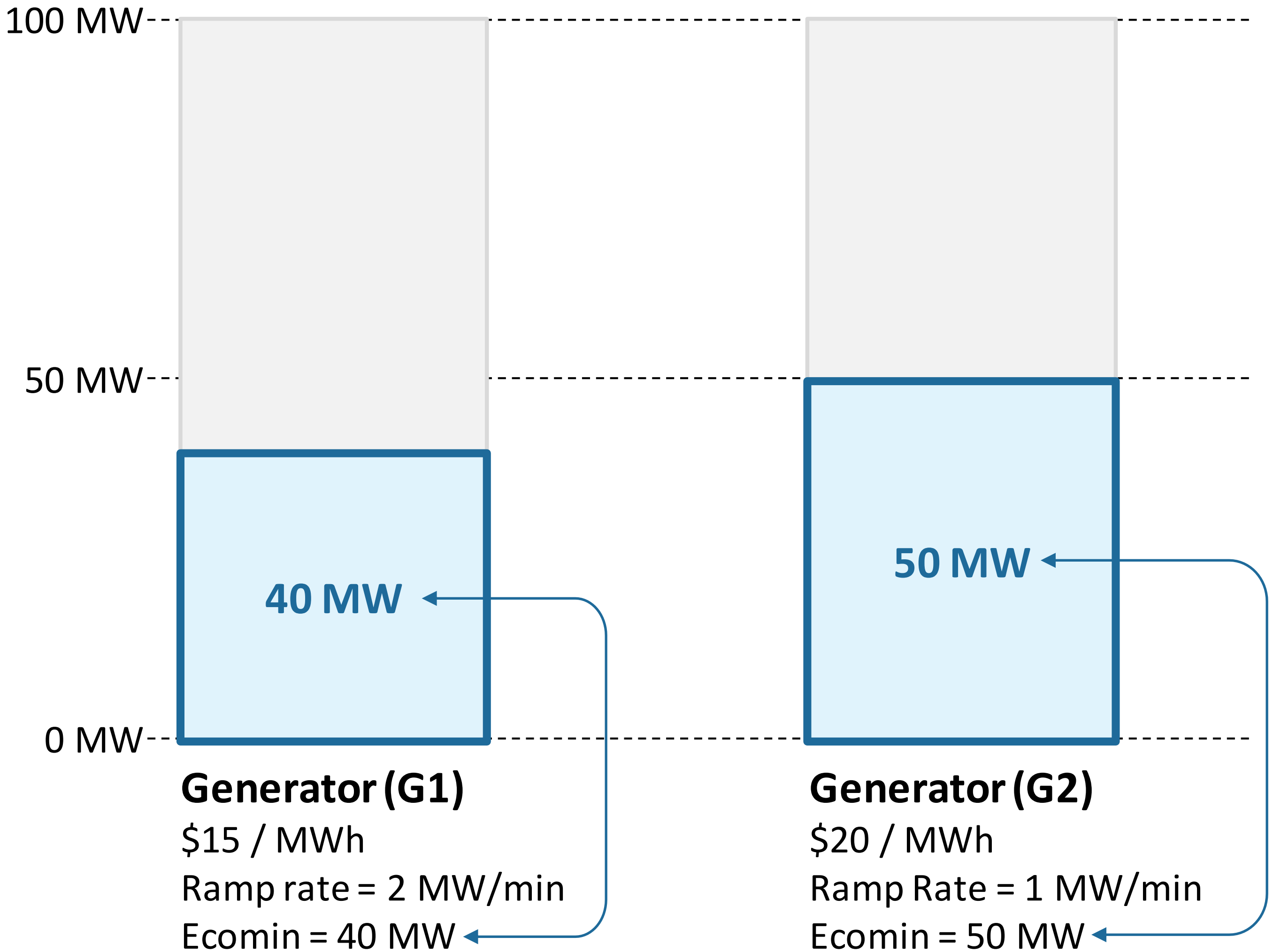


Co-Optimization Examples

Putting Everything Together

Energy-Reserve Co-Optimization Base Case

Two Generators With Differing Offer Prices and Ramp Rates



Generator (G1)
$15 / MWh
Ramp rate = 2 MW/min
Ecomin = 40 MW
Ecomax = 100 MW

Generator (G2)
$20 / MWh
Ramp Rate = 1 MW/min
Ecomin = 50 MW
Ecomax = 100 MW

Base Case:

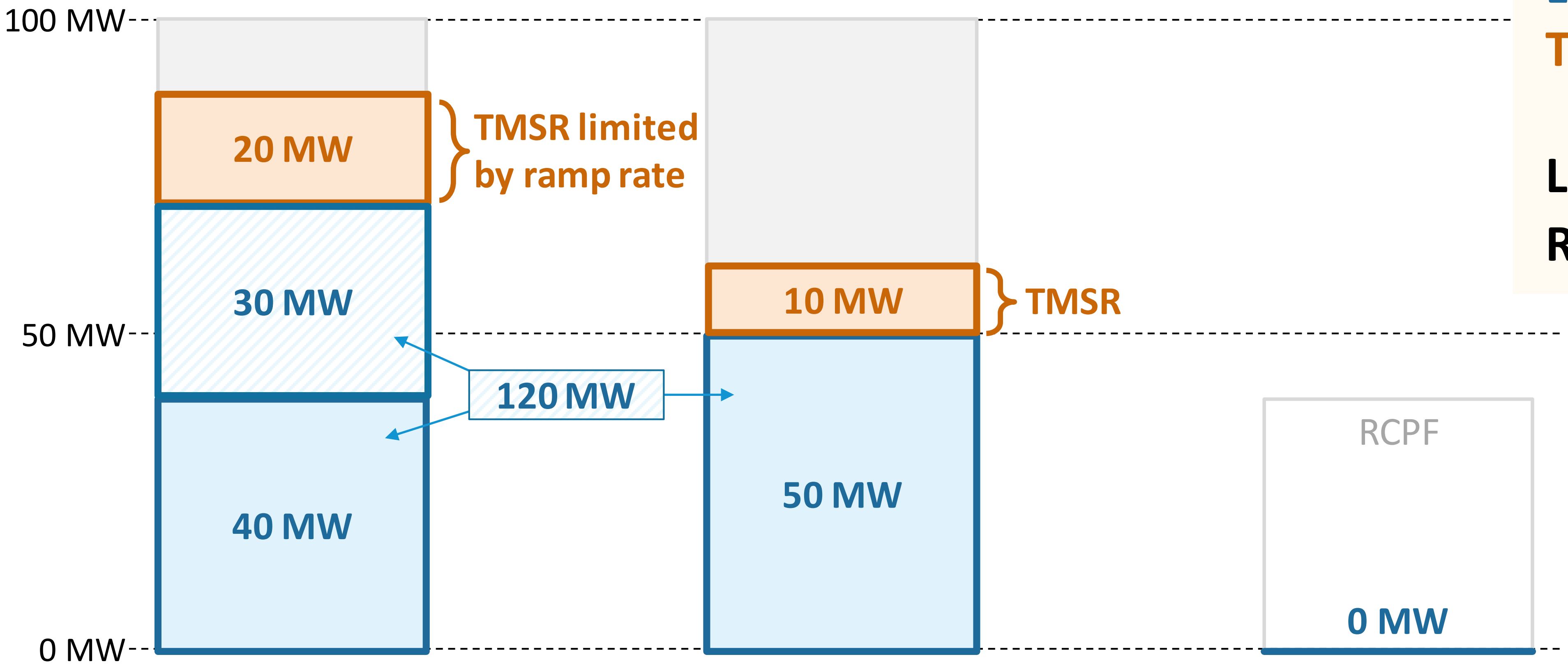
Ecomin = 90 MW
TMSR = 25 MW

In the next examples, we will:

- Co-optimize **load** and **10-min spinning reserve (TMSR)**
- Find the LMP and RMCP

Find LMP and RMCP

Case A: Load = 120 MW; $TMSR_{REQ}$ = 25 MW



Case A:

Load = 120 MW

TMSR = 25 MW

LMP = $______

RMCP = $______

Generator (G1)
$15 / MWh
Ramp rate = 2 MW/min
Ecomin = 40 MW
Ecomax = 100 MW

Ramp rate$_{10\ min}$ = 20 MW

Generator (G2)
$20 / MWh
Ramp Rate = 1 MW/min
Ecomin = 50 MW
Ecomax = 100 MW

Reserve Constraint Penalty Factor (Virtual)
$50 / MWh

5

Find LMP and RMCP

Case B: Load = 145 MW; $TMSR_{REQ}$ = 25 MW

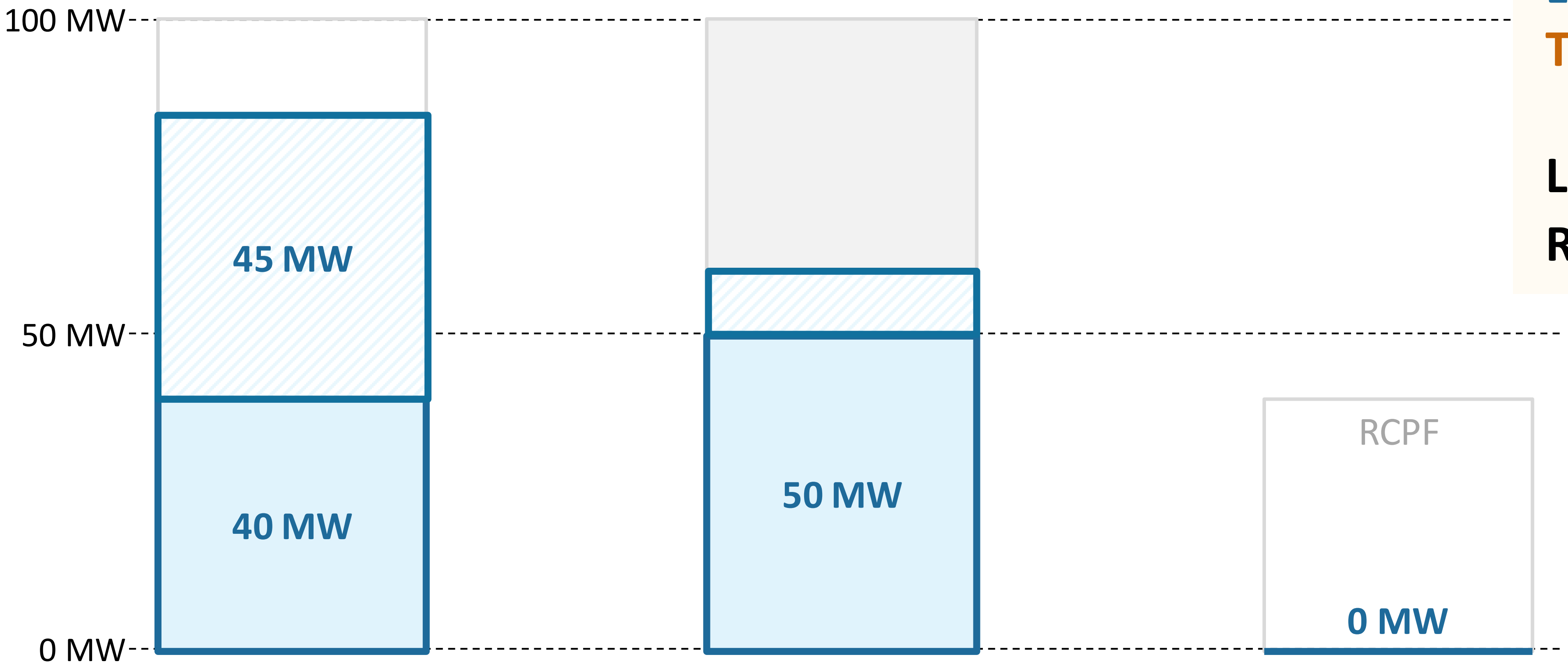
Case B:

Load = 145 MW

TMSR = 25 MW

LMP = $______

RMCP = $______



Generator (G1)
$15 / MWh
Ramp rate = 2 MW/min
Ecomin = 40 MW
Ecomax = 100 MW

Generator (G2)
$20 / MWh
Ramp Rate = 1 MW/min
Ecomin = 50 MW
Ecomax = 100 MW

Ramp rate$_{10\ min}$ = 10 MW

Reserve Constraint Penalty Factor (Virtual)
$50 / MWh

RCPF Triggered and Reserve Price Greater than Energy Price

How can the following be true system-wide?

Reserve Price = RCPF
Reserve Price > LMP

- System must:
  - Be ramp-limited
  - Not be capacity-limited

That means that another MW of load can be met from the available resources without reducing reserve, but resources cannot create more reserve

Find LMP and RMCP

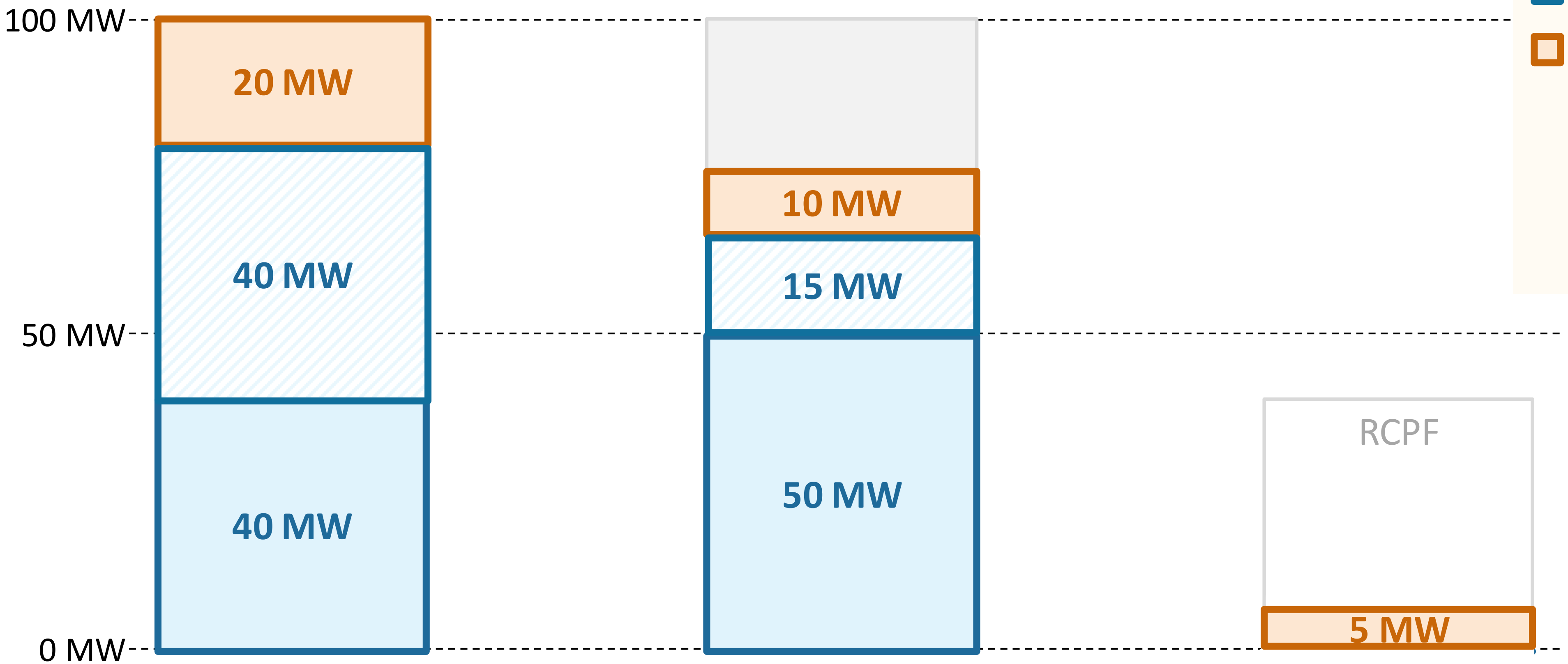
Case C: Load = 145 MW; $TMSR_{REQ}$ = 35 MW

Case C:

- **Load = 145 MW**
- **TMSR = 35 MW**

LMP = $______

RMCP = $______



Generator (G1)
$15 / MWh
Ramp rate = 2 MW/min
Ecomin = 40 MW
Ecomax = 100 MW

Ramp rate$_{10\ min}$ = 20 MW

Generator (G2)
$20 / MWh
Ramp Rate = 1 MW/min
Ecomin = 50 MW
Ecomax = 100 MW

Ramp rate$_{10\ min}$ = 10 MW

Reserve Constraint Penalty Factor (Virtual)
$50 / MWh

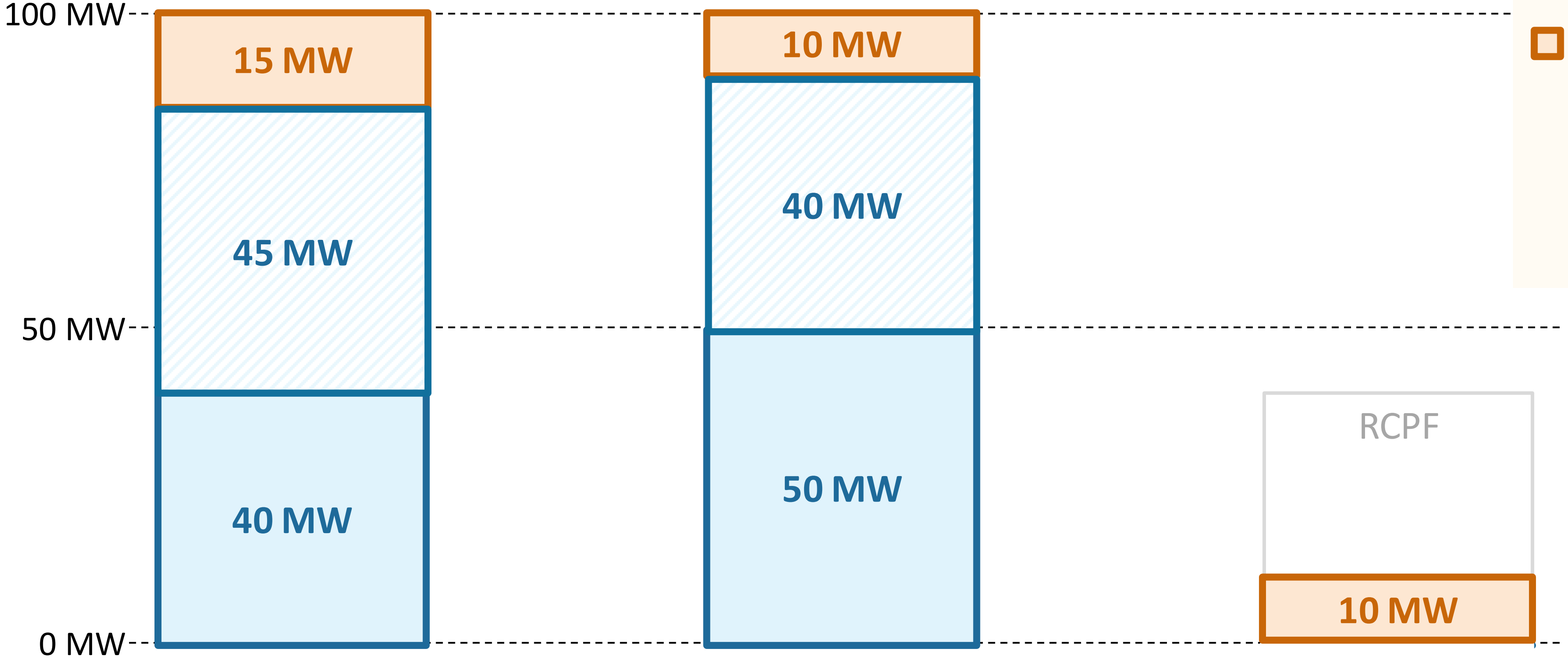
5

Reserve Price > Energy Price

- Under these conditions, every online resource is providing its maximum amount of reserves but NOT its maximum amount of energy
- Therefore, **reserves** are limited but **energy** is not so the RCPF only affects the reserve clearing price

Find LMP and RMCP

Case D: Load = 175 MW; $TMSR_{REQ}$ = 35 MW



Generator (G1)
$15 / MWh
Ramp rate = 2 MW/min
Ecomin = 40 MW
Ecomax = 100 MW

$\text{Ramp rate}_{10\ min}$ = 20 MW

Generator (G2)
$20 / MWh
Ramp Rate = 1 MW/min
Ecomin = 50 MW
Ecomax = 100 MW

$\text{Ramp rate}_{10\ min}$ = 10 MW

Reserve Constraint Penalty Factor (Virtual)
$50 / MWh

Case D:

- **Load = 175 MW**
- **TMSR = 35 MW**

LMP = $______

RMCP = $______

RCPF Triggered and Energy Price > Reserve Price

- If not enough reserve is available
  - RCPF is triggered
  - Next increment of reserve would be supplied from virtual reserve resource at the RCPF
- Providing next increment of energy increases output of cheapest unit ($15/MWh)
- Effects
  - Decrease reserves from cheapest unit
  - Reserves must now be supplied from a virtual reserve resource at the RCPF
  - LMP also includes reserve price RCPF

Summary

In this module, you have learned about the following:

- Reserve requirements and products
- Reserve modeling and designation
- Relationship between energy and reserve prices and the corresponding cleared quantities
- Reserve penalty factor influence on market clearing prices

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