

PJM Overview of Markets

Georgian Delegation
PUCO Office
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Introduction

Energy Markets

Locational Marginal Pricing - LMP

Two Settlement - Day Ahead / Real time

Ancillary Services

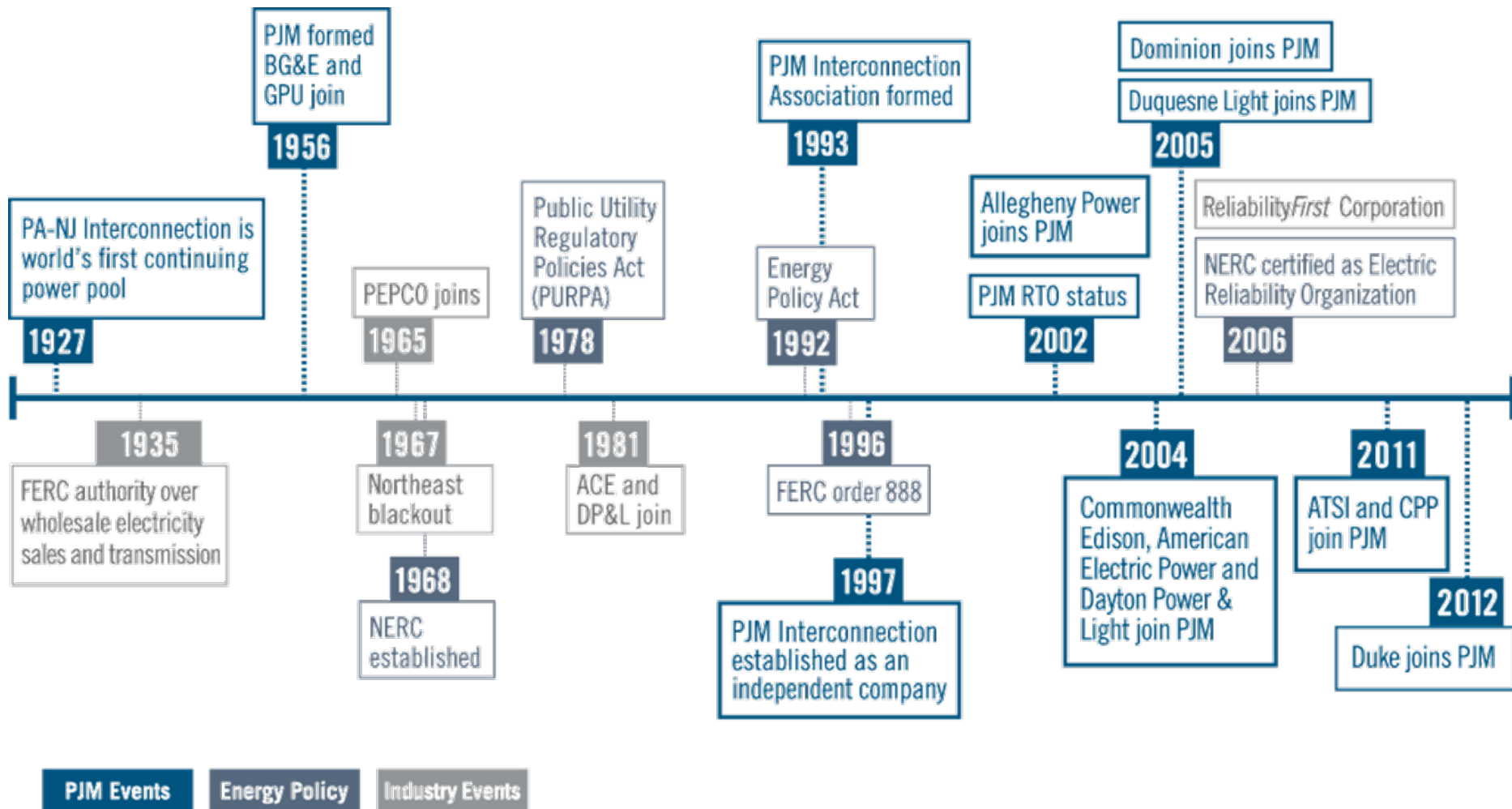
Capacity Market - Reliability Pricing Model



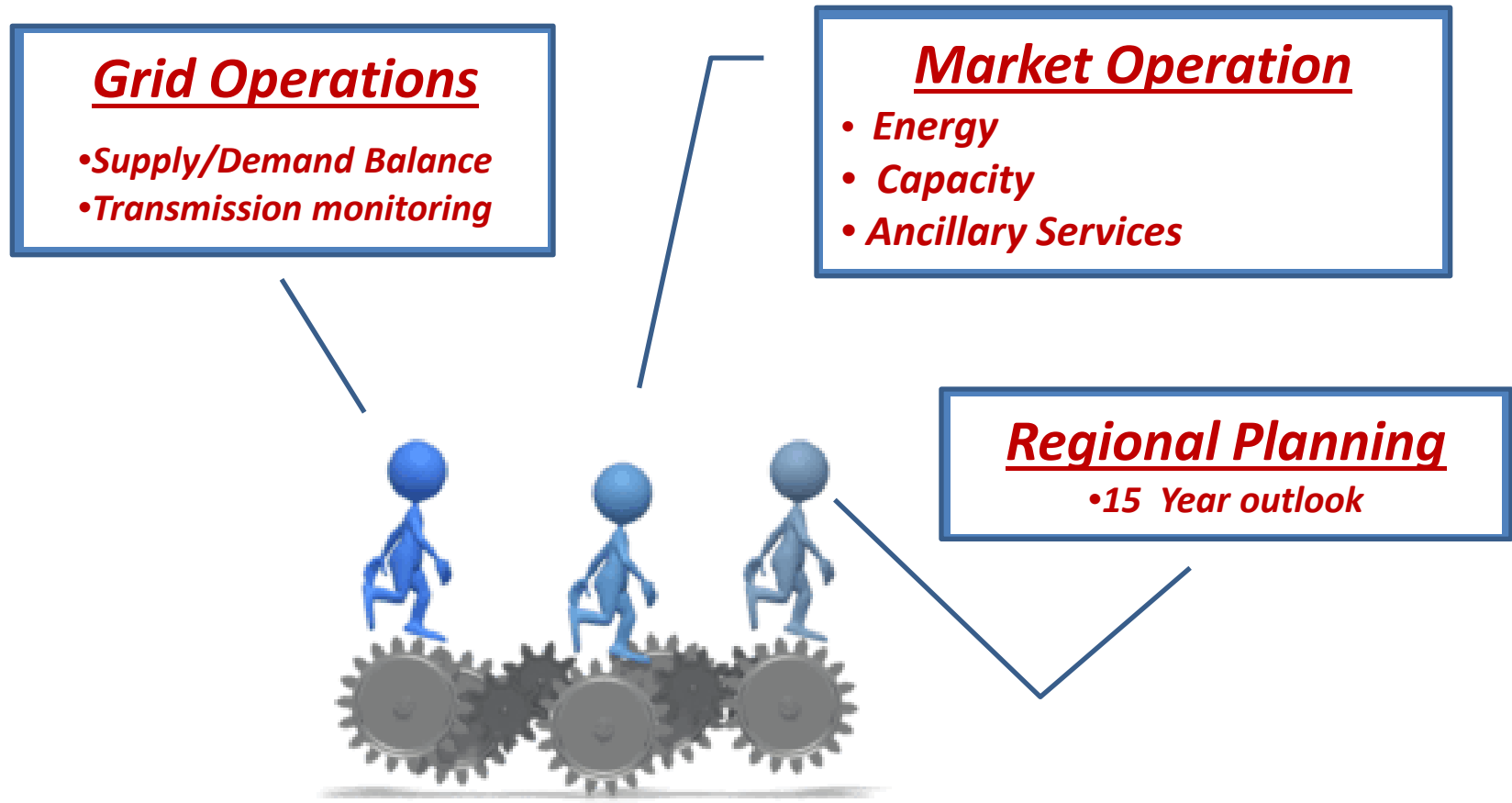


Introduction

The History of PJM



PJM Basic Functions



PJM Demographics

❑ Complexity

- 185,600 MW of Generating Capacity
- Over 65,441 Miles of Transmission Lines
- Over 60 Million People Served

❑ Uniqueness

- Single Control Area in NERC Region
- Area Served: 13 States + DC

❑ Members/Customers

- Member Companies ~ 800 +
- Transmission Svc. Customers ~ 100 +
- 158,448 MW Peak Load

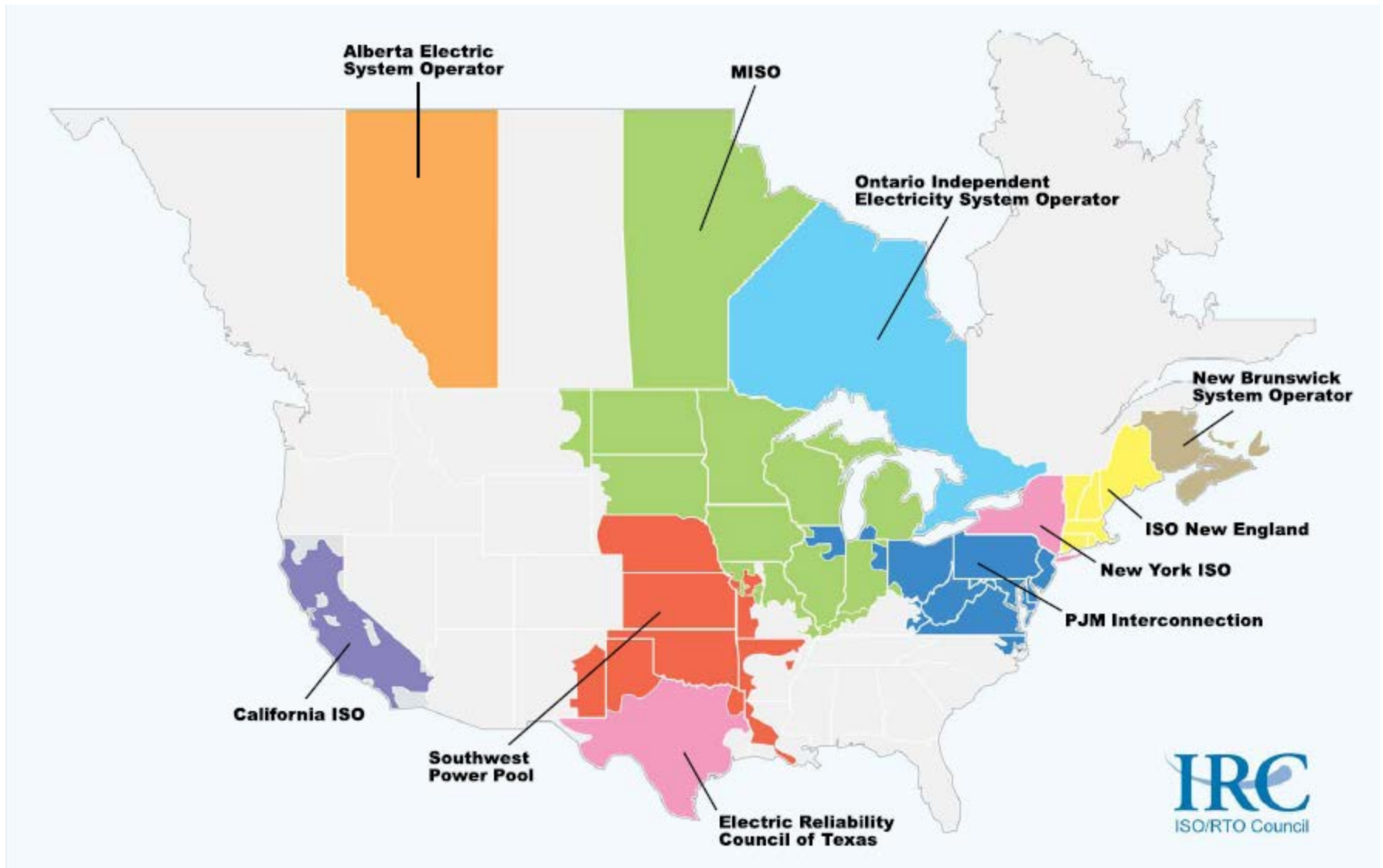


A Regional Transmission Organization (RTO) is:

- Independent from all market participants
- Responsible for grid operations and reliability
- Responsible for transmission service within region



Nine Major North American RTOs / ISOs



How is PJM different from the local utility?

PJM does:

- Direct operation of the transmission system
- Remain profit neutral
- Maintain independence from PJM members
- Coordinate maintenance of grid facilities





Locational Marginal Pricing Basics

➡ Pricing method PJM uses to:

- ⇒ price energy purchases and sales in PJM Market
- ⇒ price transmission congestion costs to move energy within PJM RTO
- ⇒ price losses on the bulk power system

➡ Physical, flow-based pricing system:

- ⇒ how energy actually flows, NOT contract paths



How does PJM Use LMP?

- ☑ Generators get paid at generation bus LMP
- ☑ Loads pay at load bus LMP

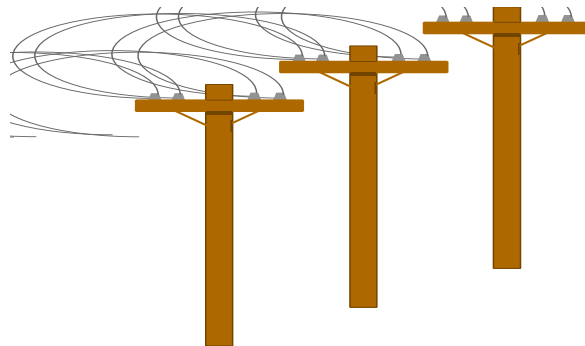


Market Design Consensus

- Locational Marginal Pricing (LMP)
 - LMP is not a new concept to power system operators, For many years, system operators have managed congestion using least-cost security constrained dispatch which is the same program that calculates LMP values
 - An LMP-based market provides an open, transparent and non-discriminatory mechanism to manage transmission congestion under open transmission access

Transmission System Congestion

- Transmission system congestion occurs when available, low cost supply cannot be delivered to the demand location due to transmission limitations
- As Market Participants compete to utilize the scarce transmission resource, the RTO needs an efficient, non-discriminatory mechanism to deal with the congestion problem



Thermal Limits
Voltage Limits
Stability Limits

Locational Marginal Price

$$\text{LMP} = \text{System Energy Price} + \text{Transmission Congestion Cost} + \text{Cost of Marginal Losses}$$

LMP is made up of 3 independent components

LMP Components - System Energy Price

$$\text{LMP} = \text{System Energy Price} + \text{Transmission Congestion Cost} + \text{Cost of Marginal Losses}$$

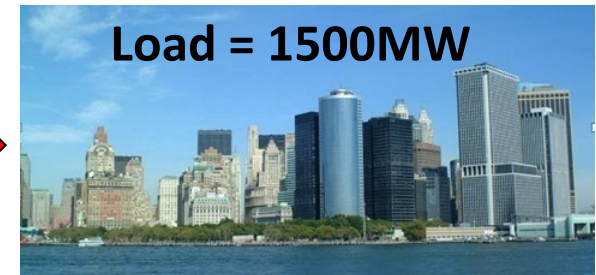
☑ System Energy Price

- Represents optimal dispatch ignoring congestion and losses
- Same price for every bus in PJM
- Calculated both in day ahead and real time

LMP Components – System Energy Price

$$\begin{array}{rcl}
 \text{System Energy Price} & = & \$20 \\
 \text{Congestion} & = & \\
 \text{Losses} & = & \\
 \hline
 \text{LMP} & = & \$20
 \end{array}$$

Dispatch 1500 MW



$$\begin{array}{rcl}
 \text{System Energy Price} & = & \$20 \\
 \text{Congestion} & = & \\
 \text{Losses} & = & \\
 \hline
 \text{LMP} & = & \$20
 \end{array}$$

LMP Components - Congestion

$$\text{LMP} = \text{System Energy Price} + \text{Transmission Congestion Cost} + \text{Cost of Marginal Losses}$$

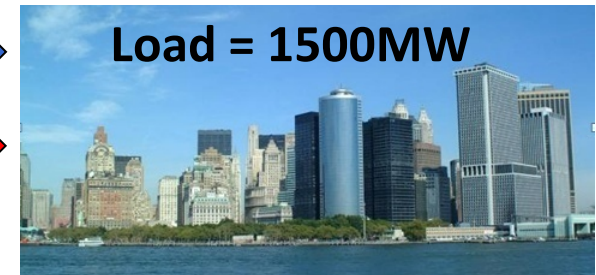
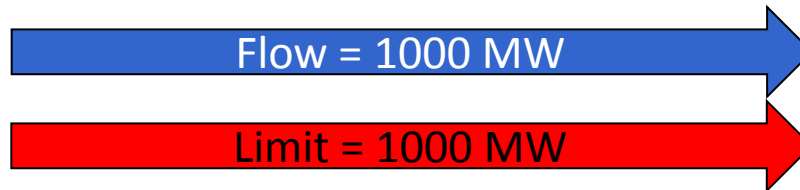
☑ Congestion Price

- Represents price of congestion for binding constraints
 - Calculated using cost of marginal units controlling constraints and sensitivity factors on each bus
- Will be zero if no constraints
 - Will vary by location if system is constrained
- Calculated both in day ahead and real time

LMP Components - Congestion

System Energy Price =	\$20
Congestion =	\$30
Losses =	
LMP=	\$50

Dispatch 1000 MW



System Energy Price =	\$20
Congestion =	\$ 0
Losses =	
LMP =	\$20

Dispatch 500 MW



LMP Components – Marginal Losses

$$\text{LMP} = \text{System Energy Price} + \text{Transmission Congestion Cost} + \text{Cost of Marginal Losses}$$

☑ Loss Price

- Represents price of marginal losses
 - Calculated using penalty factors
 - Will vary by location
- Calculated both in day-ahead and real-time

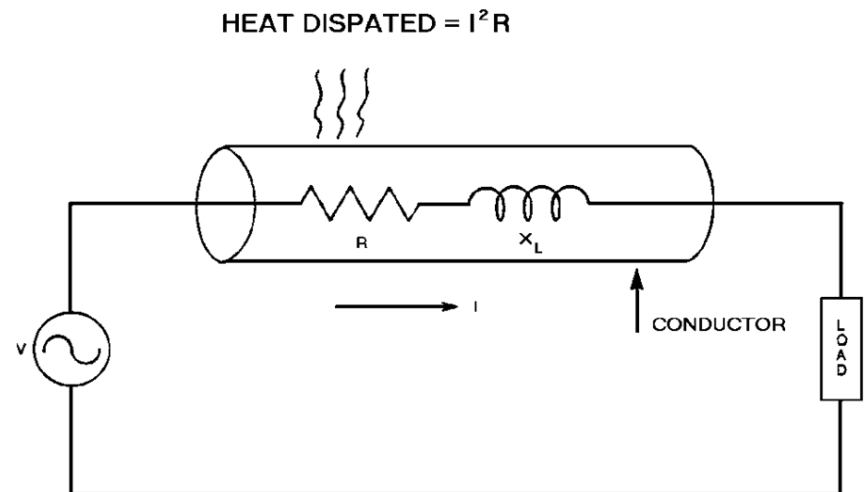
Transmission Losses

- Real Power (MW) Losses

- Power flow converted to heat in transmission equipment
- Heat produced by current (I) flowing through resistance (R)
- Losses equal to I^2R
- Heat loss sets the “thermal rating” of equipment

- Losses increase with:

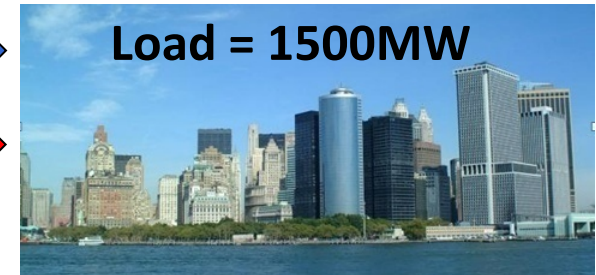
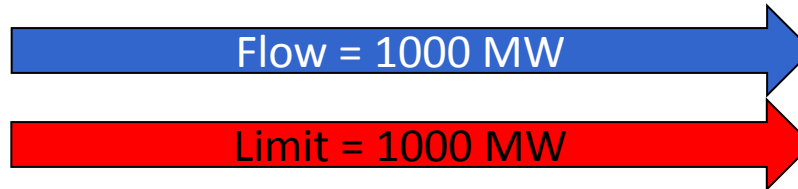
- Lower voltage
- Longer lines
- Higher current



LMP Components Marginal Losses

System Energy Price =	\$20
Congestion =	\$30
Losses =	\$ 2
LMP=	\$52

Dispatch 1000 MW



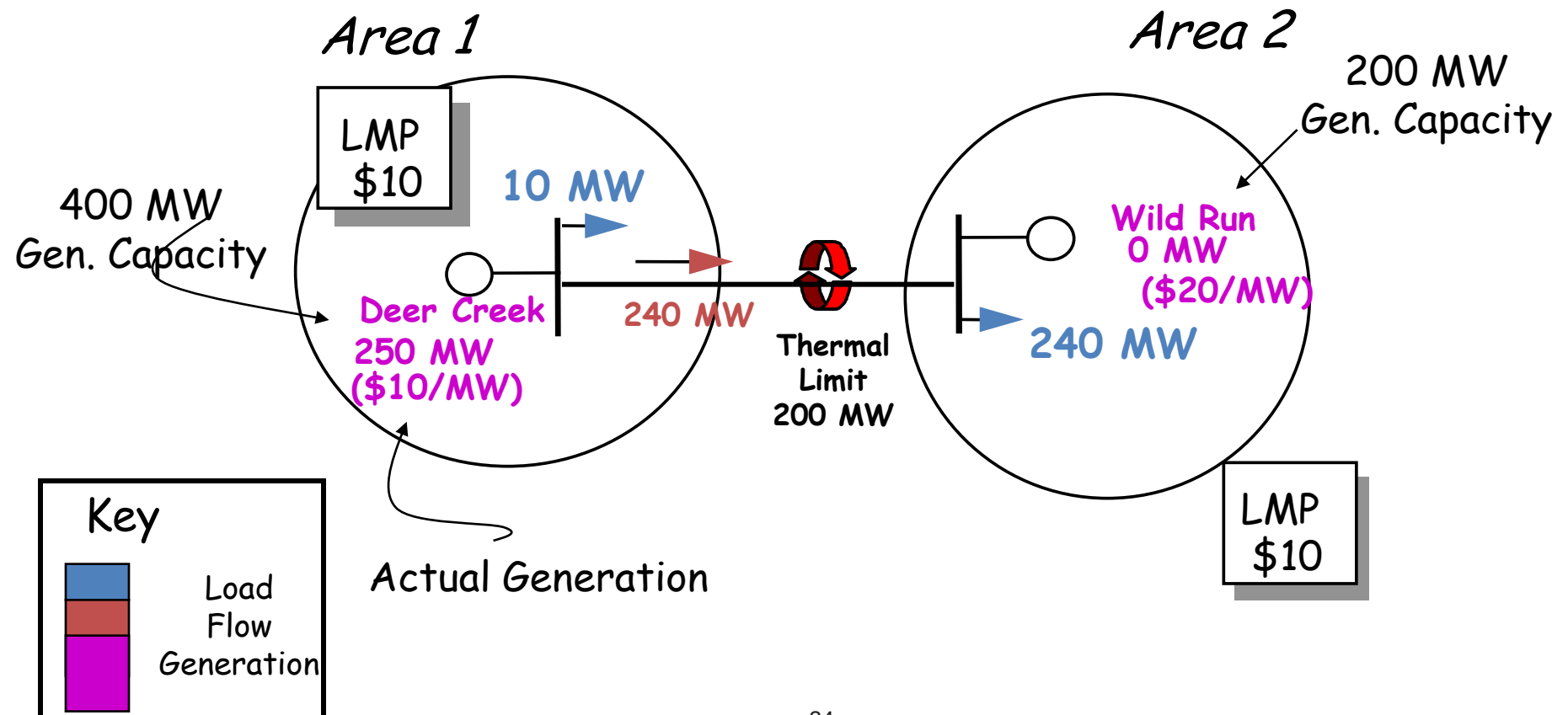
System Energy Price =	\$20
Congestion =	\$ 0
Losses =	(\$ 1)
LMP =	\$19

Dispatch 500 MW



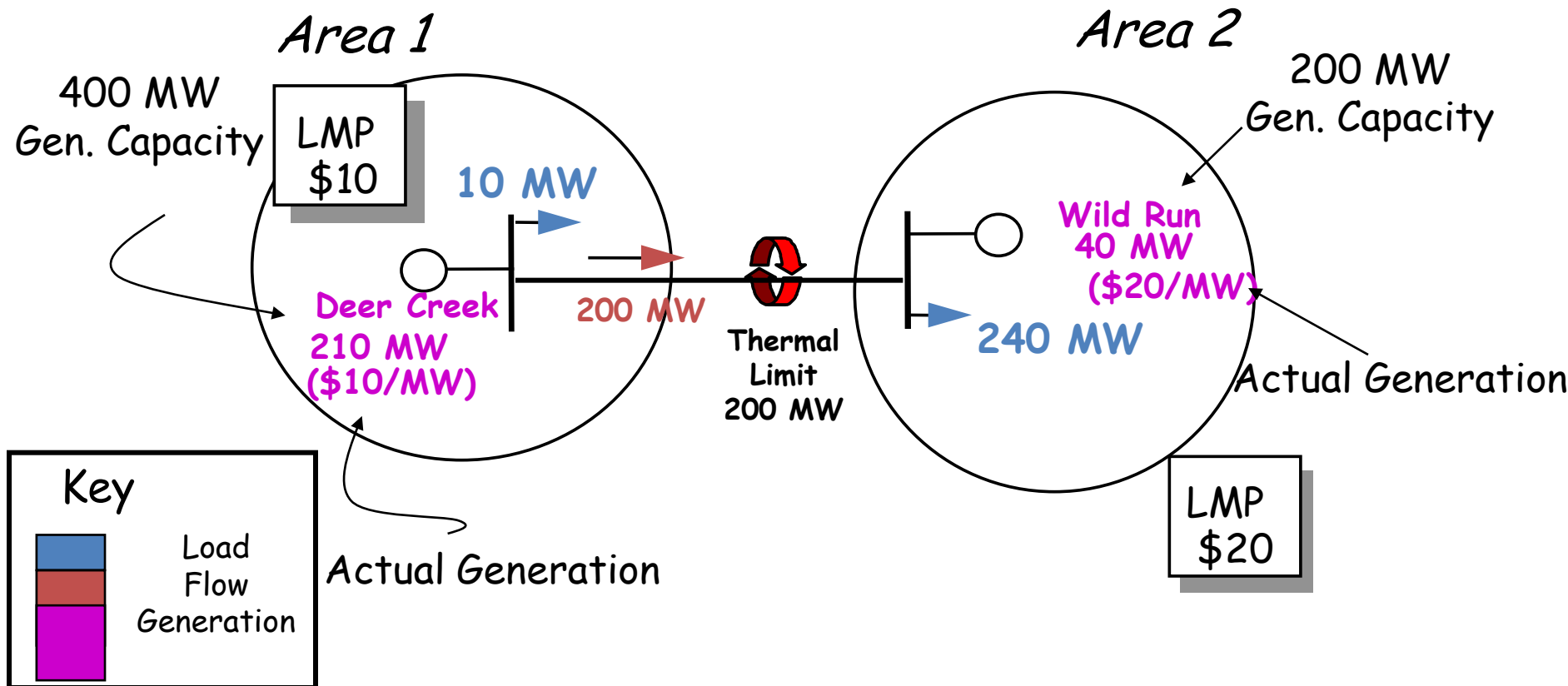
LMP Example - 2 Bus Transmission Grid

Economic Dispatch Ignoring Transmission Limitation



LMP Example - 2 Bus Transmission Grid

Security-Constrained Economic Dispatch



LMP Example - Wholesale Market Settlements

Customer	MW	LMP	Energy ¹ Settlement	Congestion Credit
Area 1 Demand	10	\$10	\$100	-
Area 2 Demand	240	\$20	\$4800	\$2000 ²
Deer Creek	210	\$10	(\$2100)	-
Wild Run	40	\$20	(\$800)	-
Totals	0		\$2000	\$2000

1. Positive indicates charge, negative indicates credit
2. Congestion Credit is due to ownership of 200 MW Financial Transmission Right from Area 1 to Area 2, FTR Settlement = 200 MW (\$20 - \$10)



Two Settlement

What is Two-Settlement?

- It provides PJM Market Participants with the option to participate in a forward market for electric energy in PJM
 - Consists of two markets
 - Separate settlements performed for each market



Two-Settlement Markets

- **Day-ahead Market**

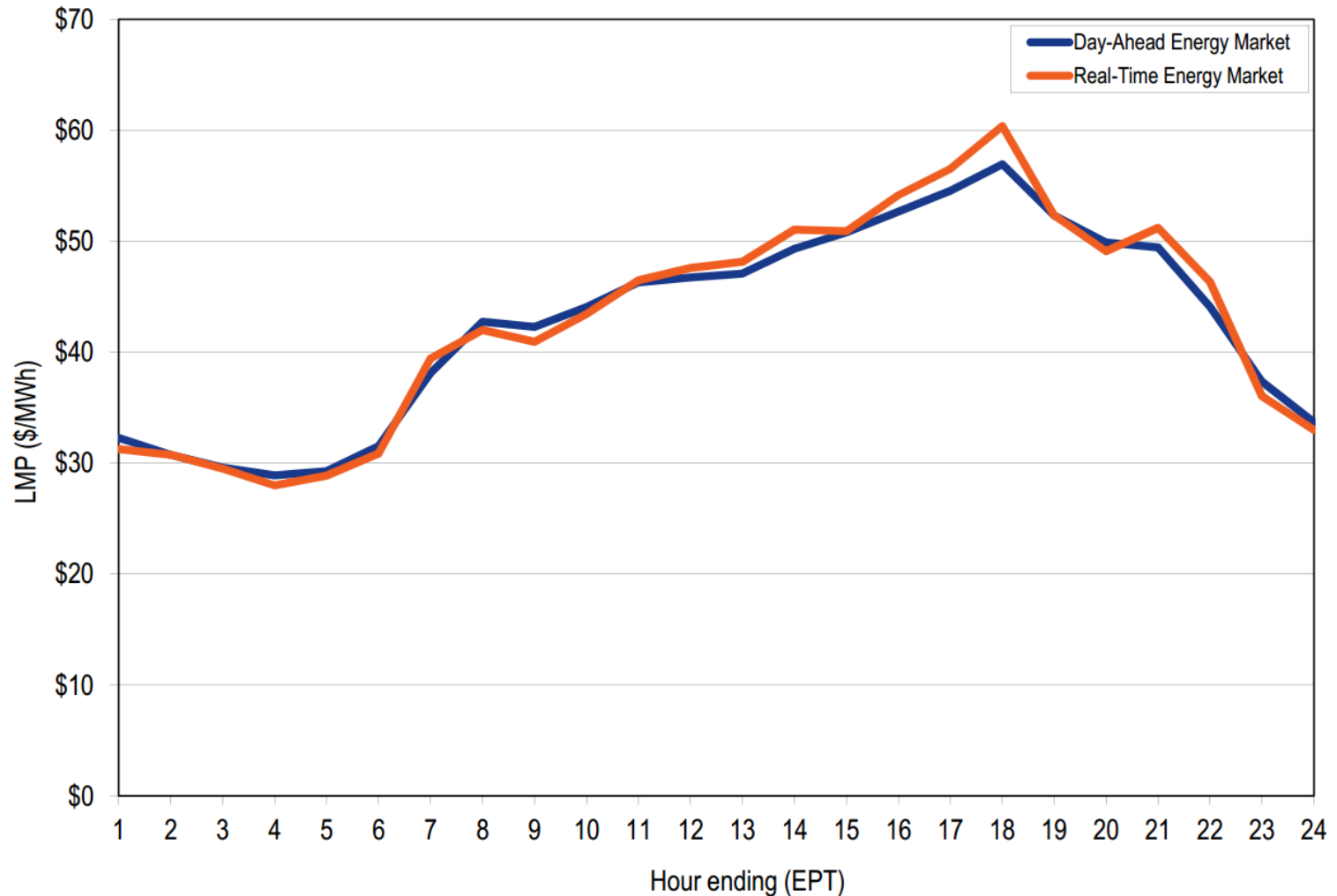
- Financial market using Bid-In Load
- Prices calculated hourly / Hourly settlements
- Includes virtual bids and price sensitive demand



- **Real-time Market**

- Physical Market based on actual system conditions
- Prices calculated every 5 minutes
- Hourly Settlements based on *deviations* from Day-Ahead position

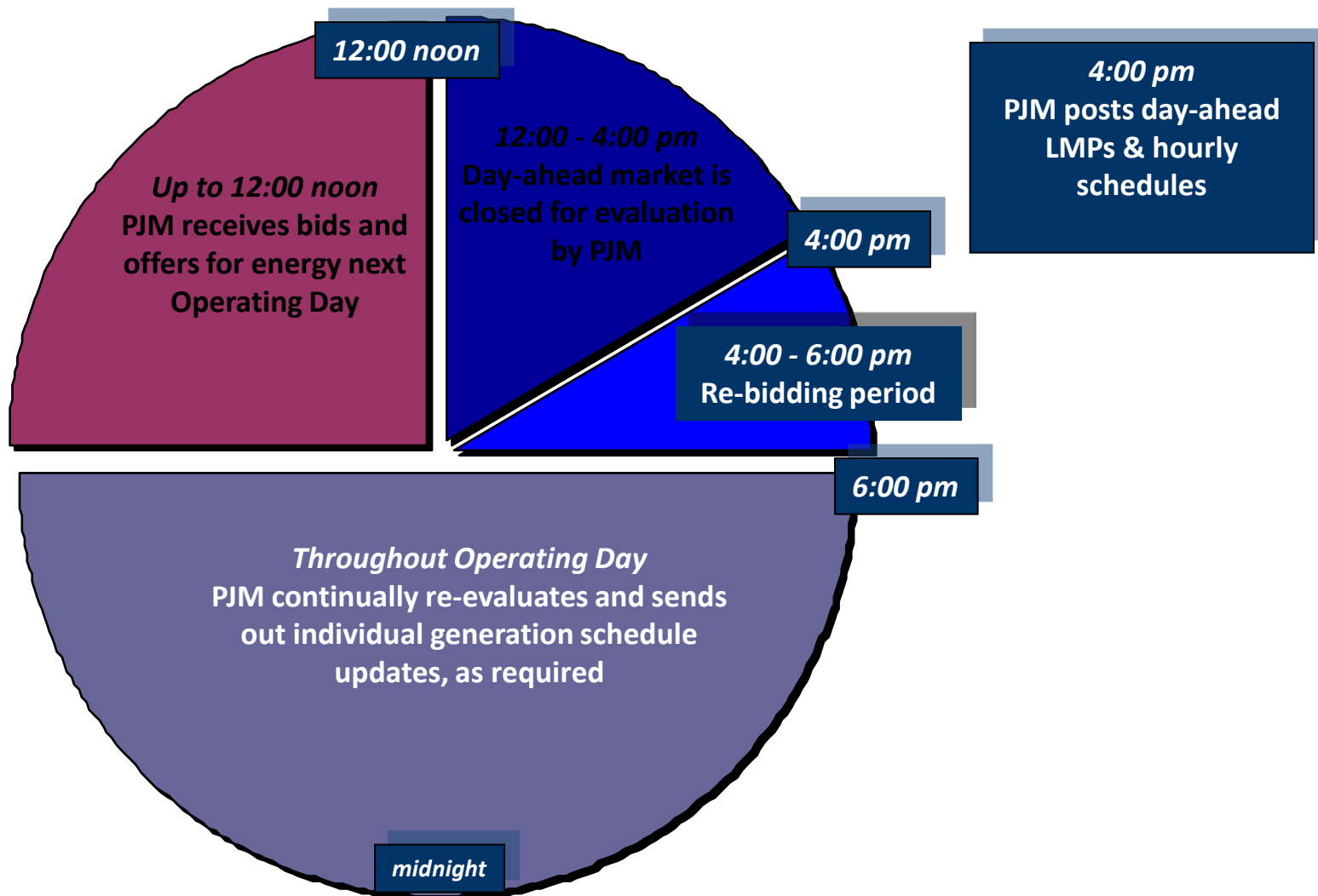
PJM DA vs. RT Prices



Real-time average LMP was greater than day-ahead average LMP for 12 out of 24 hours

Source: Monitoring Analytics 2011 State of the Market Report for PJM

Day-Ahead Market Timeline



Day Ahead Energy Market

Day ahead Market - Unit Commitment

Offers Received from Resources

10MW @\$30

40MW @\$5

20MW @\$10

15MW @\$25

25MW @ \$15



Offers Sorted in Increasing Order

100 MW @ \$90

125MW @\$50

150MW @\$25

175MW @\$20

195MW @\$10

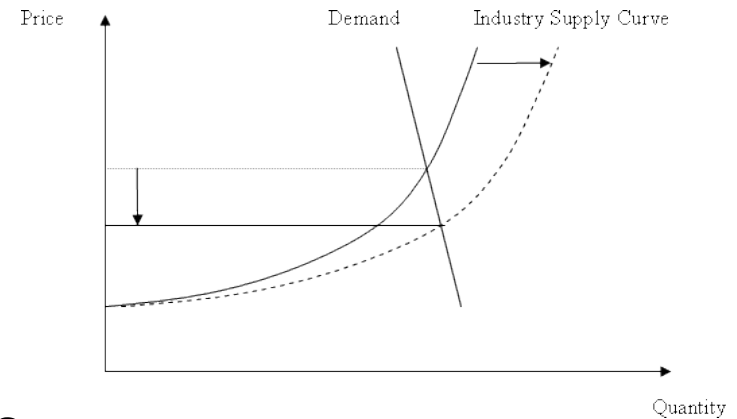
5 Offers

10 Offers

15 Offers

20 Offers

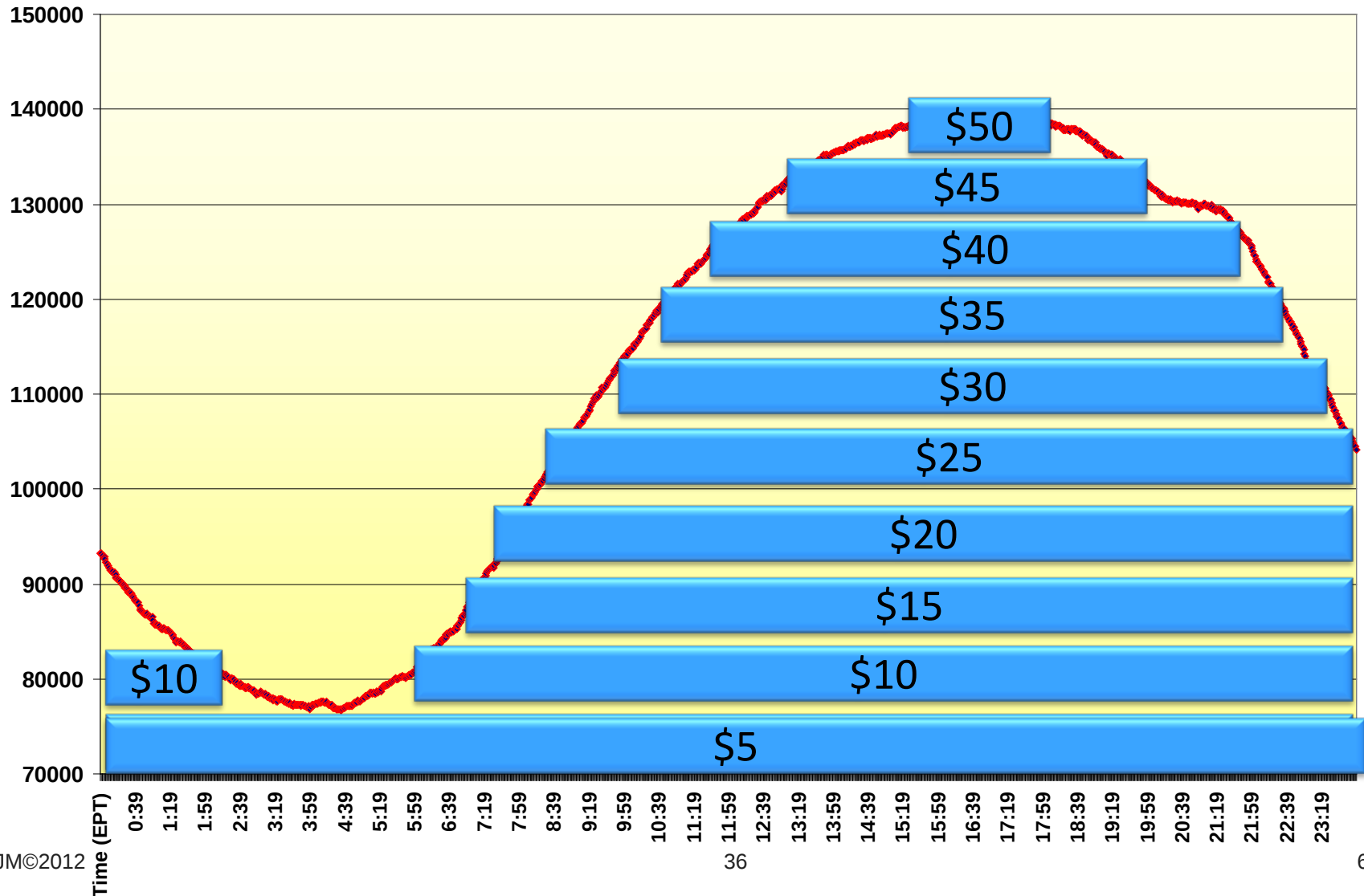
30 Offers



Resources Scheduled to Meet Forecast Demand for the Next Day

Load (MW)

RTO Load (MW)



Real Time Energy Market

Real time System Operation

- Dispatch Resources Committed in the Day Ahead Market in merit order to satisfy demand while respecting transmission limits.
- May need to dispatch generation out of merit order to solve for constraints on the transmission system (Security Constrained Economic Dispatch)

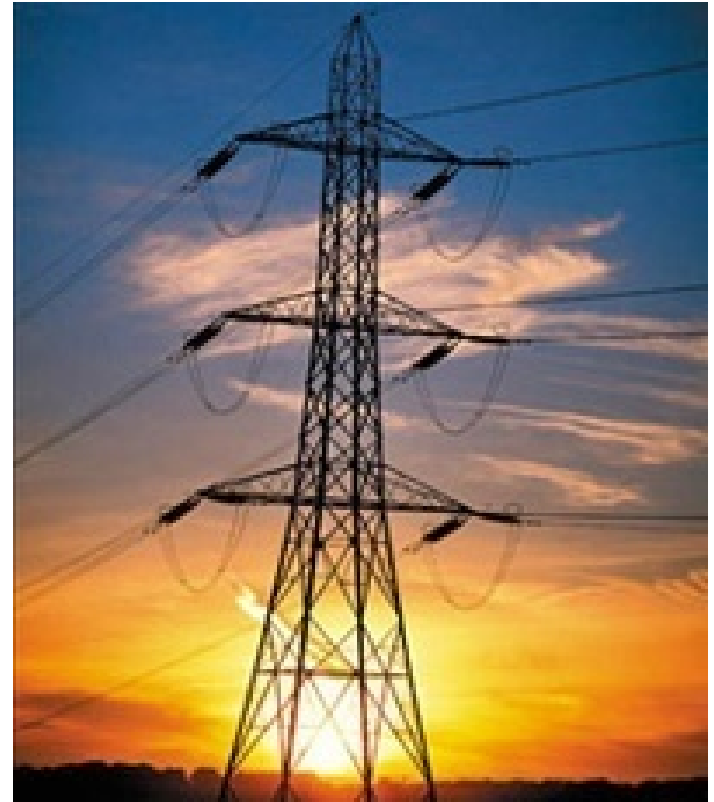


Transmission System Operator

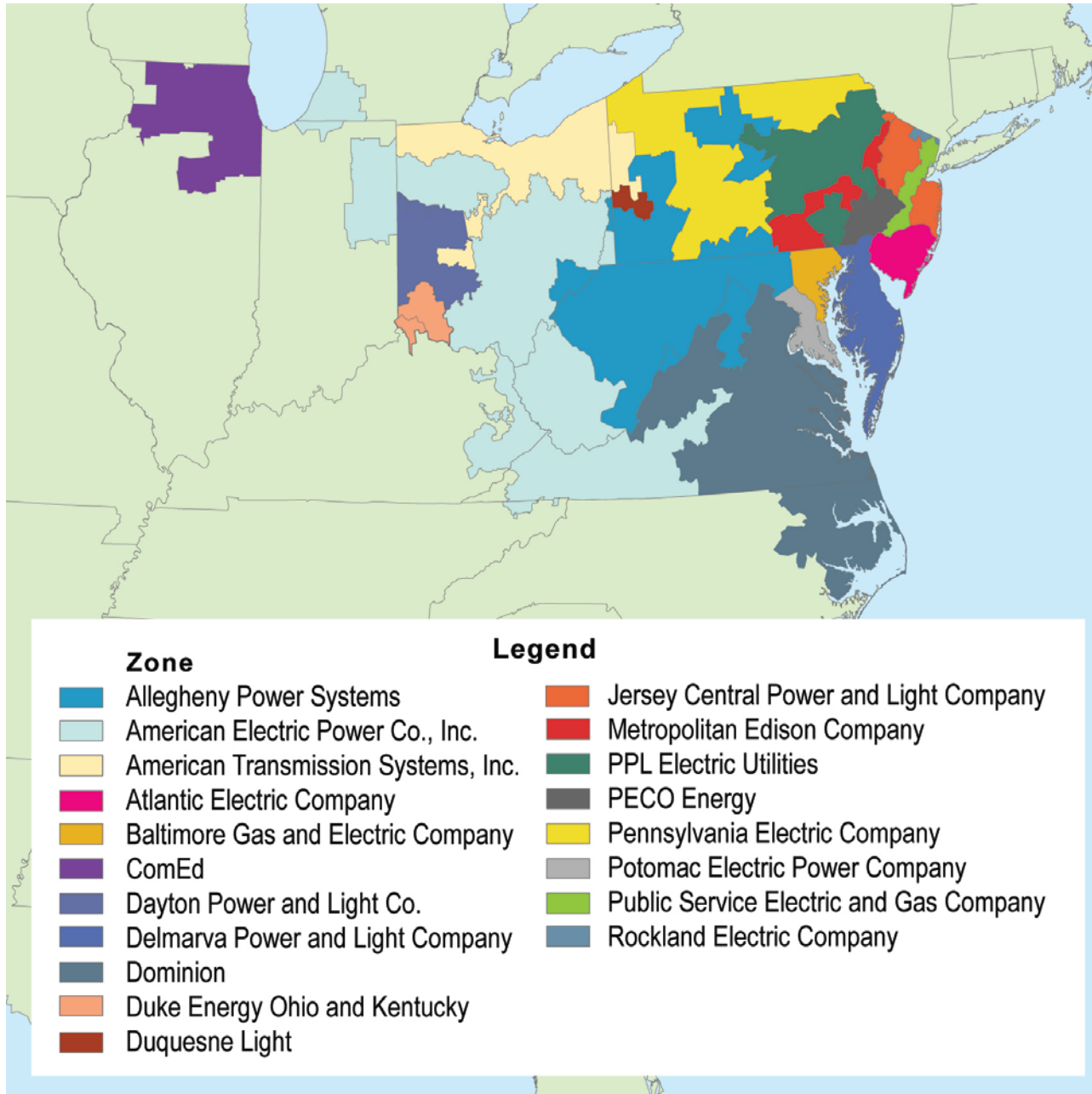


Transmission System Operations

- Ensure Security of the Transmission System
- Monitor Transfer Limitations
- Monitor Thermal Constraints
- Contingency Analysis
- Direct Off-Cost Operations
 - Generation Shifts
 - Contract Curtailments
- Coordinate Switching



PJM Territory by Zones



PJM Operates as a
single Control Area
With free flowing
ties between
Zones



Ancillary Services

- Regulation Market
- Reserve Reserve Market
- Black Start Service
- Reactive Services
- Scheduling, System Control & Dispatch

Purpose: To provide for the continuous balancing of generation and load

- Generation and Demand Response resources
- Transmission customer must provide or purchase
- Resources must be able to respond within 5 minutes
- Resources are paid based on their performance

Purpose: To bring generation and load back in balance after the loss of generation

- LSE's have obligation to purchase based on Load Ratio Share
 - Bilateral
 - Scheduling owned resources
 - Purchase from Reserve Market
- Co-optimized with Regulation Market
- Allows for participation by Demand Side Response resources

- Synchronized Reserves
 - Online resources that can respond within 10 minutes
- Non-Synchronized Reserves
 - Offline resources that can respond within 10 minutes

Purpose: To provide a power source to start critical generation after a system shutdown.

- Transmission Owners, with PJM identify critical Blackstart units
- Generator annual revenue requirements - Cost-based service
- Charges go to Transmission Customers
- Annual Blackstart testing requirements

Reactive Supply & Voltage Control

Purpose: To maintain transmission voltages within acceptable limits.

- FERC approves reactive revenue requirements
- PJM calculates zonal rate
- Paid by transmission customers
- Credits go to generation resources and transmission owners

Scheduling, System Control & Dispatch

Purpose: To provide transmission service and operate the energy market.

- Schedule 9 of PJM Tariff
 - Control Area Administrative Service
 - FTR Administrative Service
 - Market Support Service
 - Regulation Administrative Service
 - Capacity Resource and Obligation Service



Reliability Pricing Model (RPM)

Capacity vs. Energy

Capacity

- A commitment of a resource to provide energy during PJM emergency under the capped energy price.
- Capacity revenues paid to committed resource whether or not energy is produced by resource.
- Daily product

Energy

- Generation of electrical power over a period of time
- Energy revenues paid to resource based on participation in PJM's Day-Ahead & Real-Time Energy Markets
- Hourly product

Capacity, energy & ancillary services revenues are expected, in the long term, to meet the fixed and variable costs of generation resources to ensure that adequate generation is maintained for reliability of the electric grid.

Objectives of RPM

- Resource commitments to meet system peak loads three years in the future
- Three year forward pricing which is aligned with reliability requirements and which adequately values all capacity resources
- Provide transparent information to all participants far enough in advance for actionable response

Purpose of RPM is to enable PJM to obtain sufficient resources to reliably meet the needs of electric consumers within PJM.

Resource Adequacy Requirement

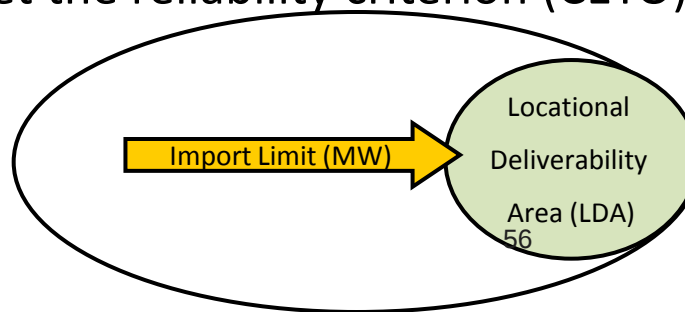
- Determines the amount of capacity resources required to serve the forecast peak load and satisfy the reliability criterion.
- The reliability criterion is based on Loss of Load Expectation (LOLE) not exceeding one event in ten years.

An Installed Reserve Margin (IRM) = 15.4% satisfies the reliability criterion for the 2015/16 Delivery Year.

Resource Adequacy ICAP Requirement = Forecast Peak Load * (1+ IRM)

What are Locational Constraints?

- Locational Constraints are capacity import capability limitations that are caused by
 - transmission facility limitations, or
 - voltage limitations.
- PJM determines constrained sub-regions (i.e., locational deliverability areas) to be included in RPM Auctions to recognize and quantify the locational value of capacity.
- Constrained regions are determined by comparing the import limit of a region (CETL) to the amount of capacity that needs to be imported into a region to meet the reliability criterion (CETO).



CETL = Capacity Emergency Transfer Limit

CETO = Capacity Emergency Transfer Objective

Locational Deliverability Areas

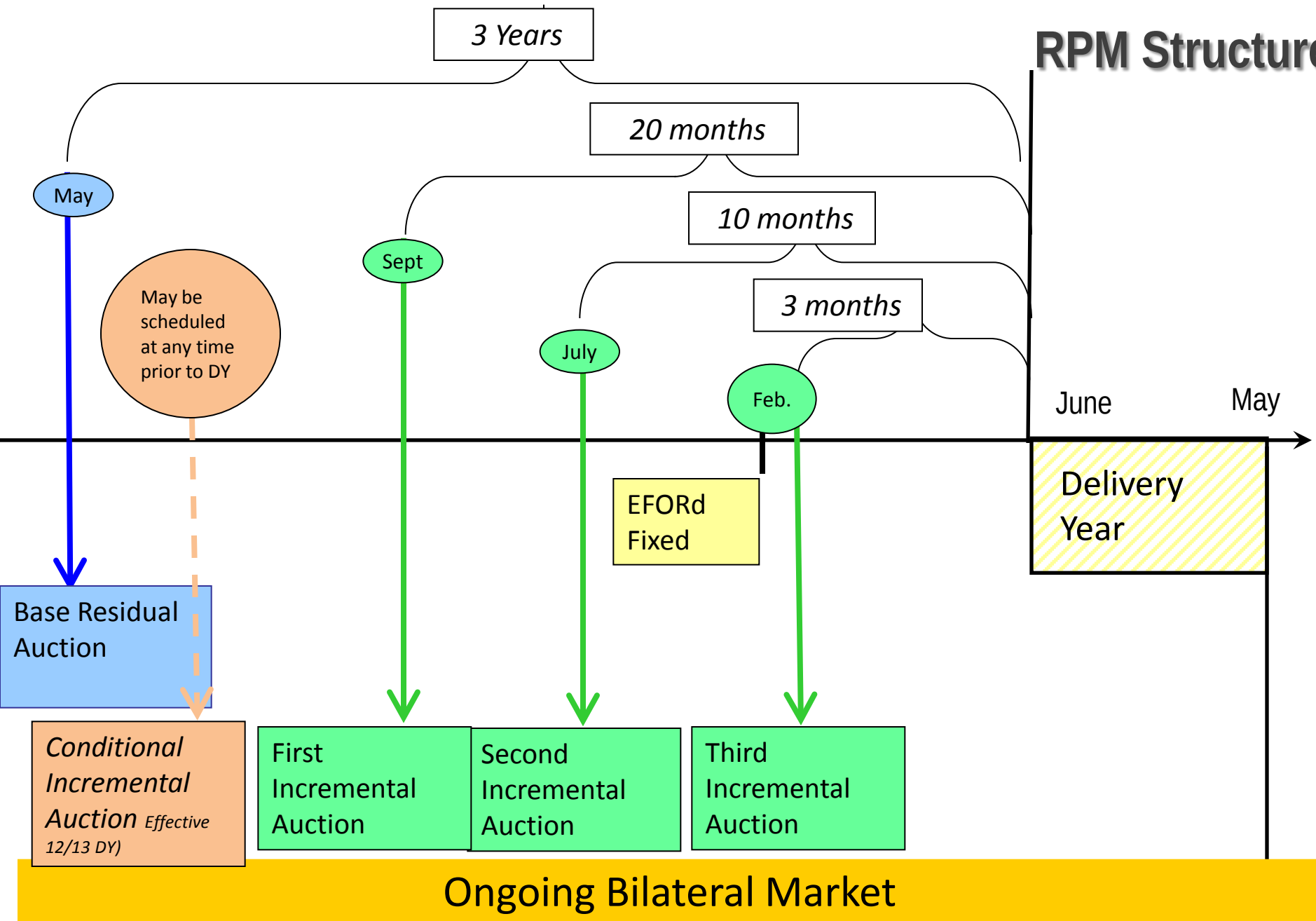
RTEPP has currently identified 25* sub-regions as Locational Deliverability Areas (LDAs) for evaluating the locational constraints.

- Regions
 - Western PJM (ComEd, AEP, Dayton, APS, Duquesne, ATSI, Duke)
 - Mid-Atlantic Area Council (MAAC) Region
 - Eastern MAAC (PSE&G, JCP&L, PECO, AE, DPL & RECO)
 - Southwestern MAAC (PEPCO & BG&E)
 - Western MAAC (Penelec, MetEd, PPL)
- Zones
 - AE, AEP, APS, ATSI, BGE, Comed, Dayton, DUQ, Dominion, DPL, Duke, JCPL, MetEd, PECO, Penelec, PEPCO, PPL, PSEG
- Sub-Zones
 - PSEG Northern Region (north of Linden substation)
 - DPL Southern Region (south of Chesapeake and Delaware Channel)

**Includes ATSI effective with 13/14 DY and Duke effective with 14/15 DY.*

PJM required to make a filing with FERC before adding a new LDA.

RPM Structure



RPM Auctions (Starting with 12/13 DY)

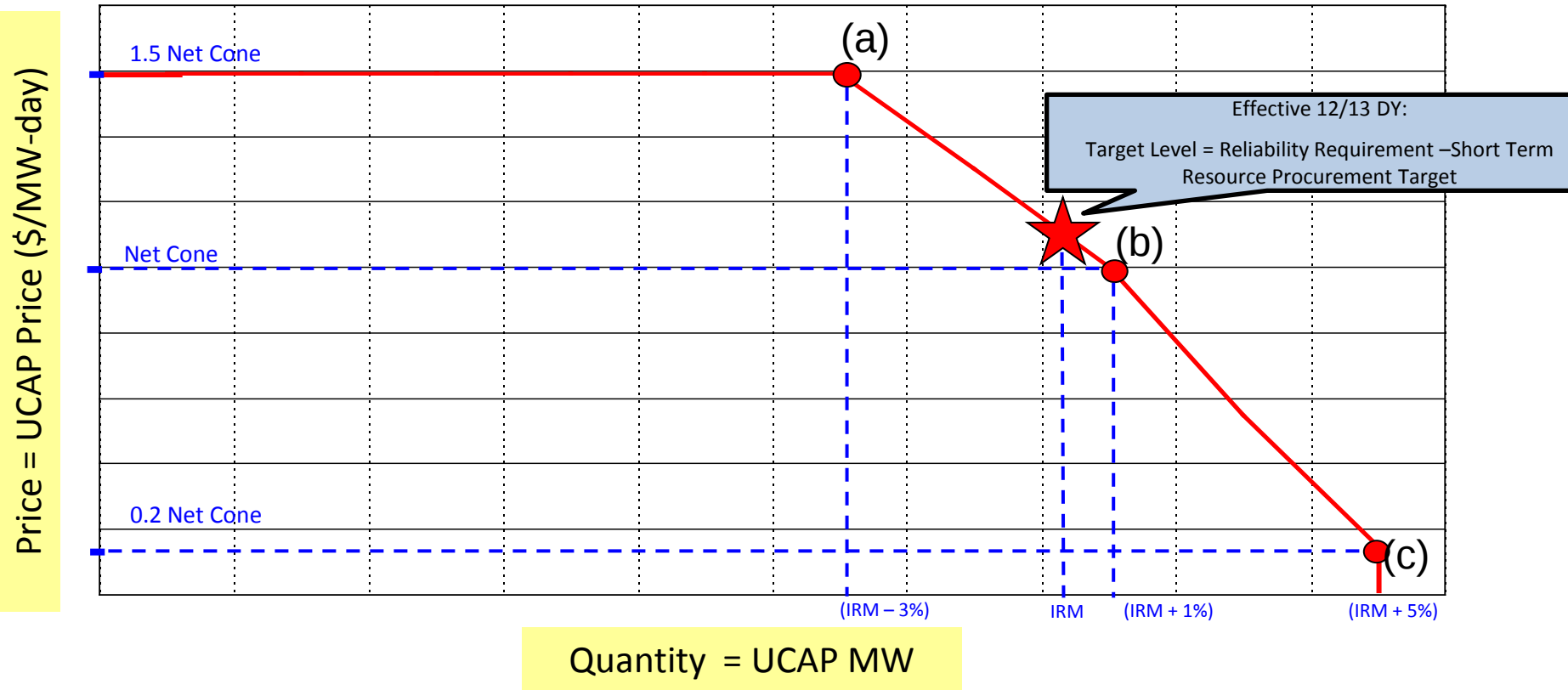
Activity	Purpose	Cost of Procurement
Base Residual Auction	Procurement of RTO Obligation less an amount reserved for short term resources, less FRR Obligation	Allocated to LSEs through Locational Reliability Charge
1 st Incremental Auction	Allows for: (1) replacement resource procurement (2) increases and decreases in resource commitments due to reliability requirement adjustments; and (3) deferred short-term resource procurement	Allocated to resource providers that purchased replacement resources and LSEs through Locational Reliability Charge
2 nd Incremental Auction		
3 rd Incremental Auction		
Conditional Incremental Auction	Procurement of additional capacity in a LDA to address reliability problem that is caused by a significant transmission line delay	Allocated to LSEs through Locational Reliability Charge

What is the VRR?

The Variable Resource Requirement (VRR) Curve is a downward sloping demand curve that relates the maximum price for a given level of capacity resource commitment relative to reliability requirements.

- The price is higher when the resources are less than the reliability requirement and lower when the resources are in excess.
- VRR Curves are defined for the PJM RTO and for each constrained Locational Deliverability Area (LDA) within the PJM region.

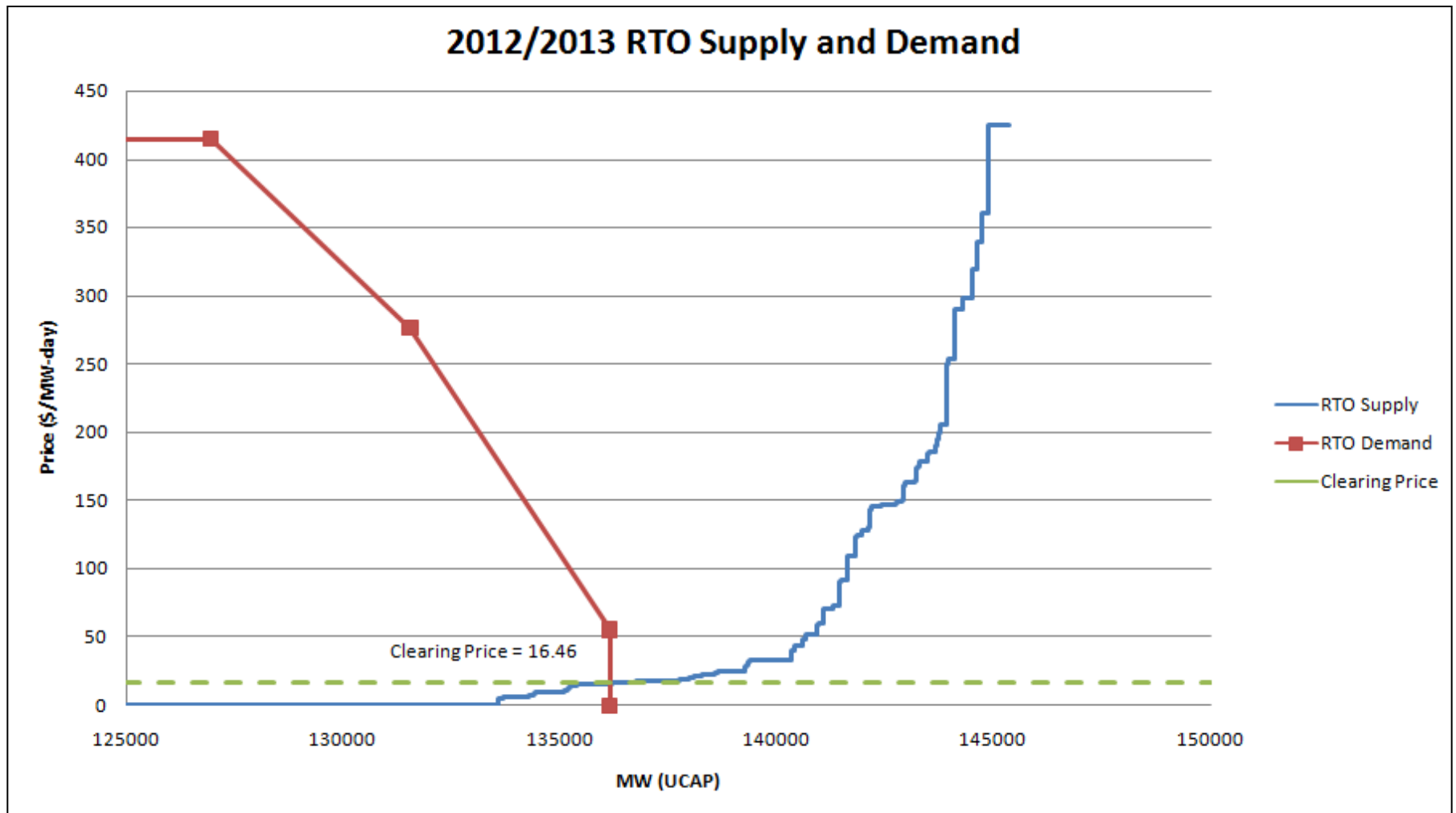
Illustrative Example of a VRR Curve



A VRR Curve is defined for the PJM Region.

Individual VRR Curves are defined for each Constrained LDA.

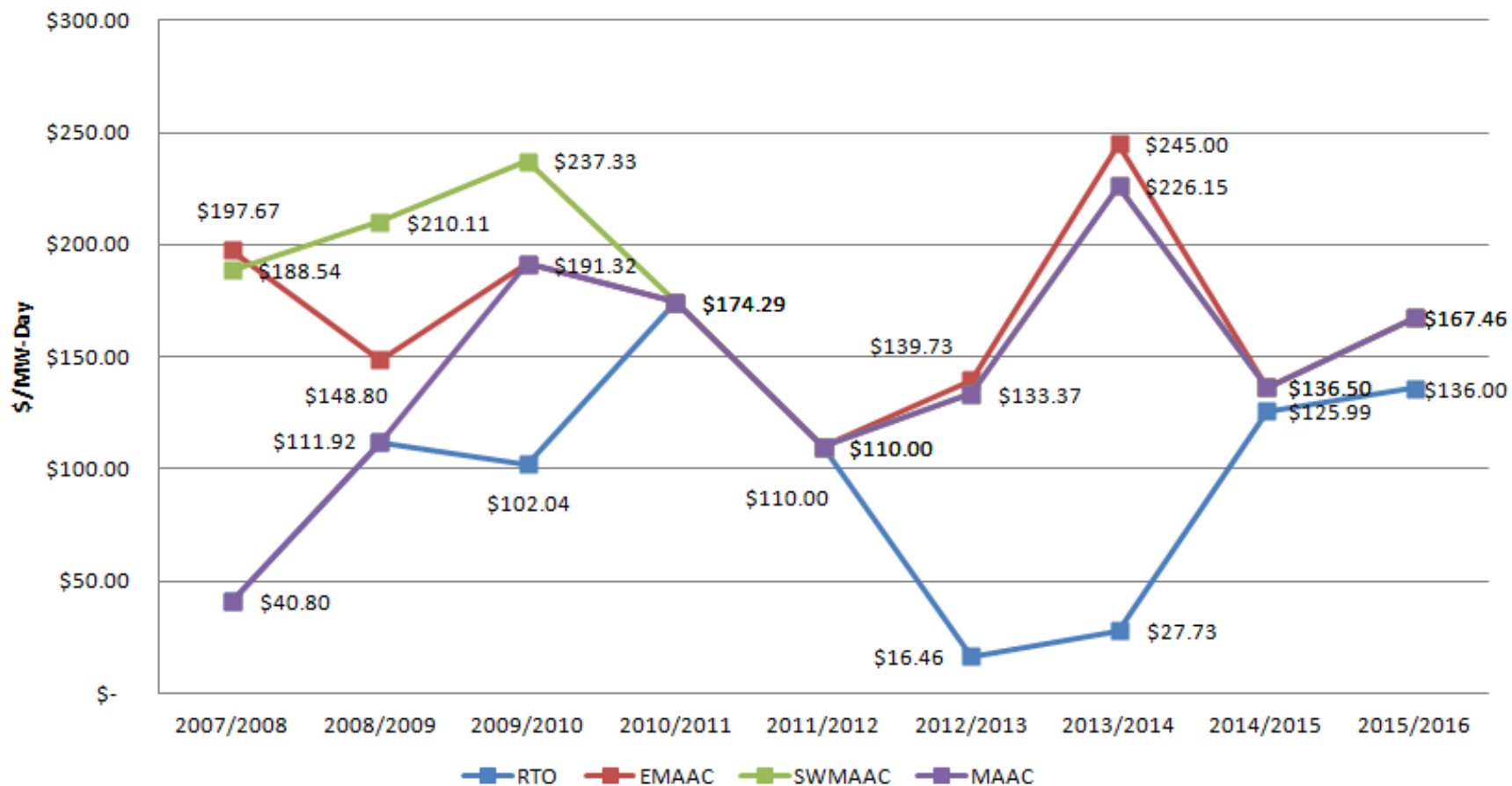
Clearing 2012/2013 Base Residual Auction



Clearing determined by the intersection of the supply and the demand curves.

Base Residual Auction

**RPM Base Residual Auction
Resource Clearing Prices (RCP)**



What is a Supply Resource in RPM?

In RPM, Resources are =

Generation
Resources

Demand
Resources
(DR)

Energy
Efficiency
Resources
(EE)
(Effective with 11/12 DY)

Qualifying
Transmission
Upgrades
(QTU)



