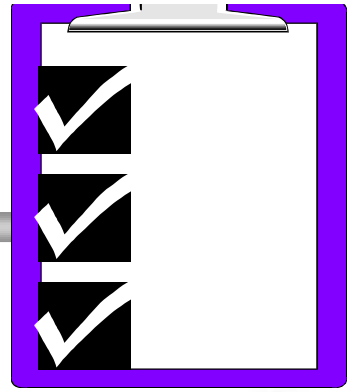
PJM LMP & FTR Refresher Course

August 2000

Agenda



- ✓ Understanding LMP
- ✓ Understanding FTRs
- ✓ Market Operations Example
- ✓ Actual LMP Results
- ✓ Transaction Modeling

Note: intent is to explain LMP & FTR concepts; we are not differentiating between day-ahead and real-time markets

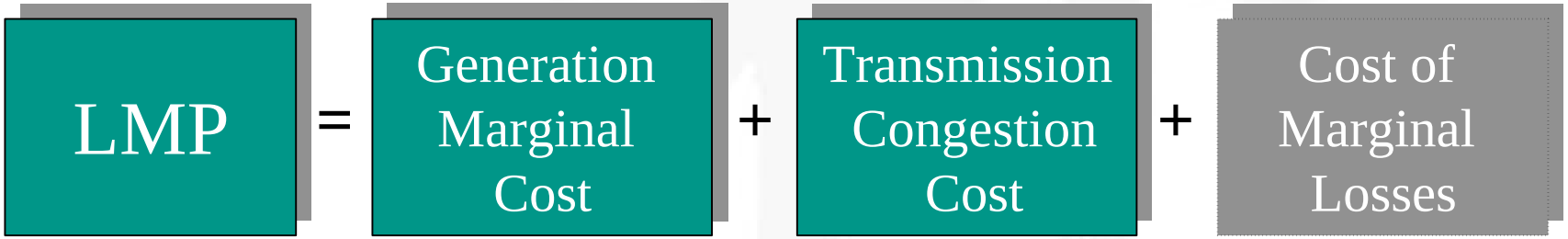
Understanding LMP

What is LMP?

- Pricing method PJM uses to …
  - price energy purchases and sales in PJM Market
  - prices transmission congestion costs to move energy within PJM Control Area
- Physical, flow-based pricing system
  - how energy actually flows, NOT contract paths

Definition: Locational Marginal Pricing

Cost of supplying next MW of load at a specific location , considering generation marginal cost, cost of transmission congestion, and losses.



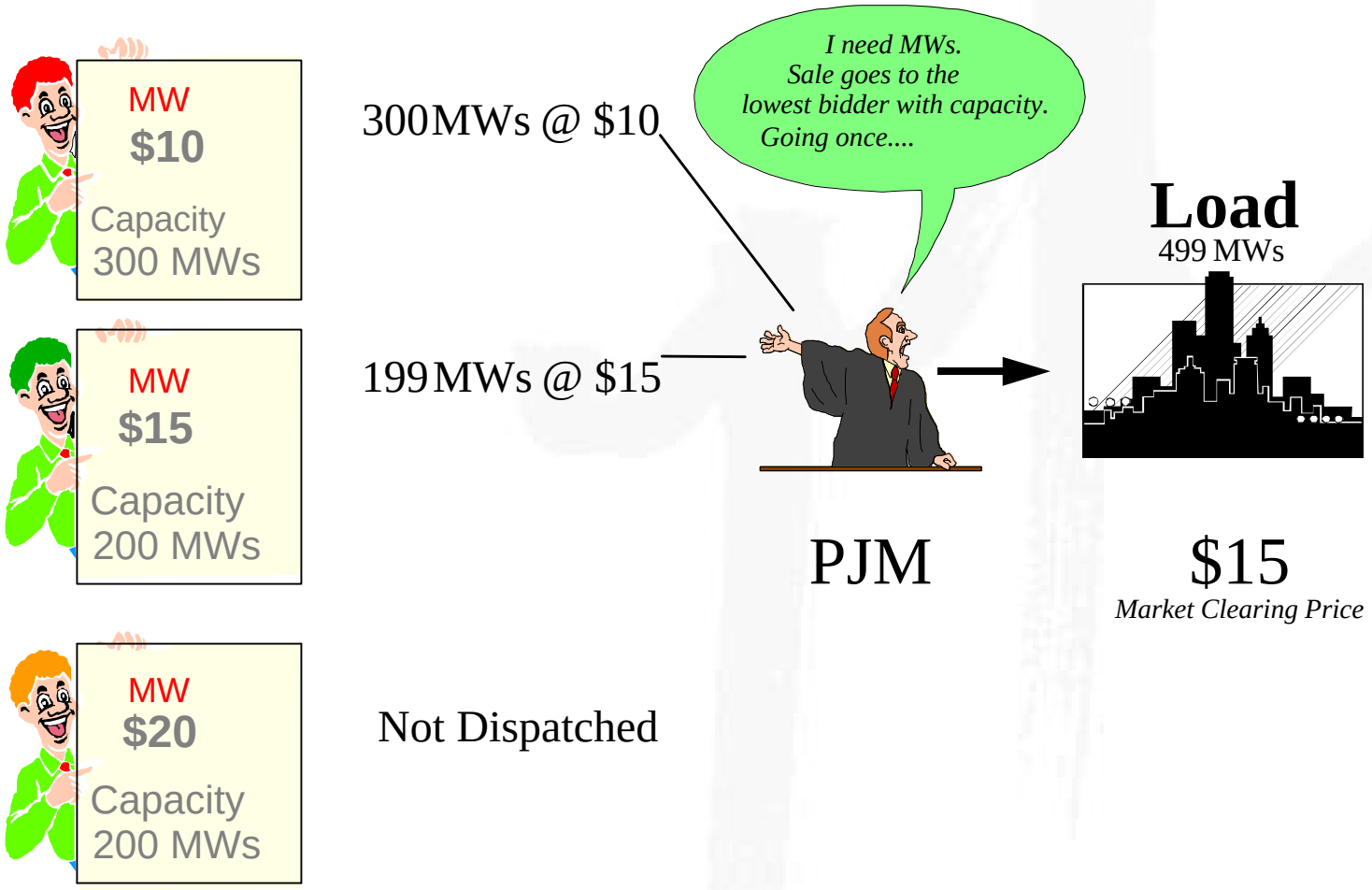
Cost of Marginal Losses = Not currently implemented

Said Another Way…

- The marginal cost to provide energy at a specific location depends on:
  - marginal cost to operate generation
  - total load (demand)
  - cost of delivery on transmission system

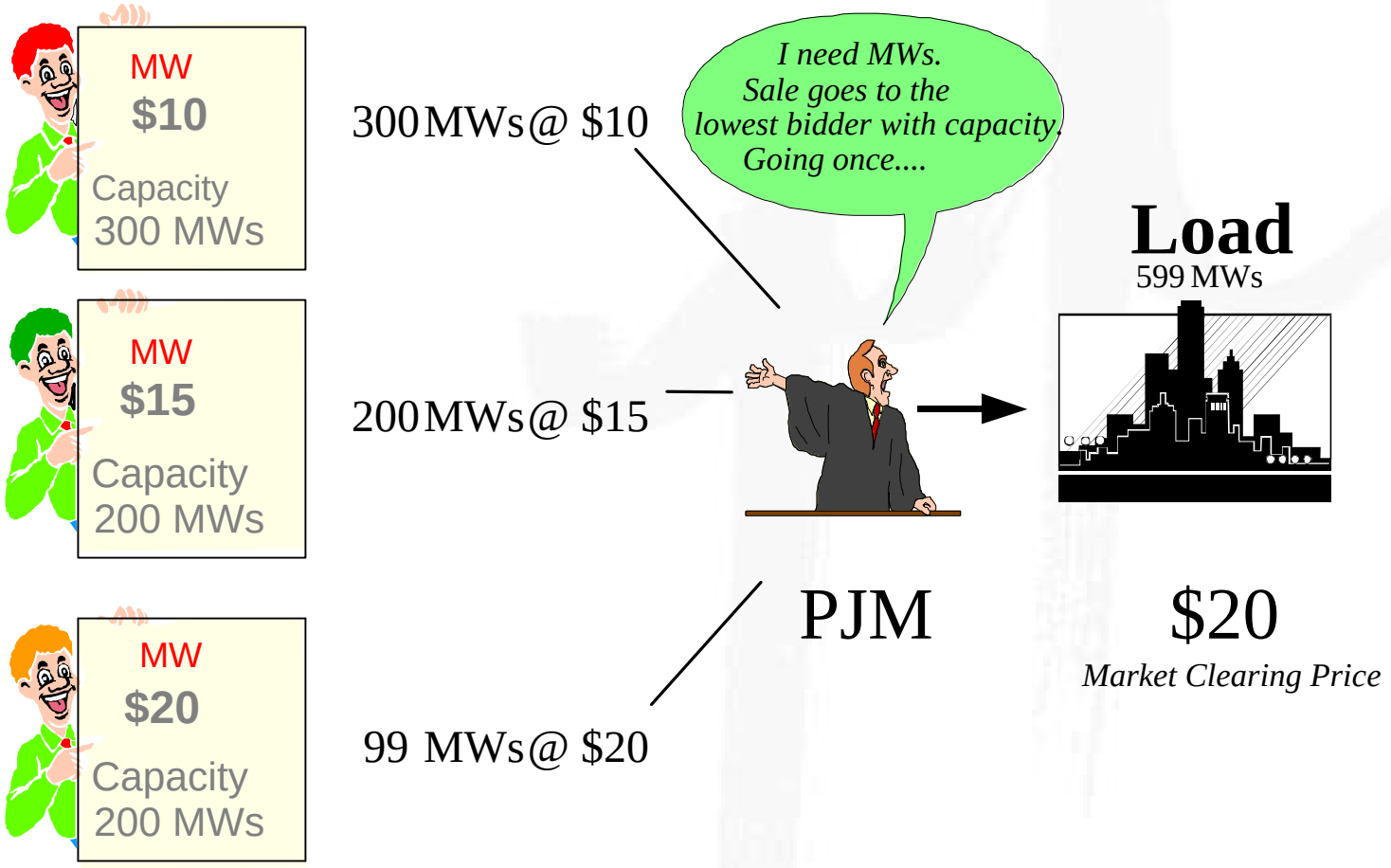
Economic Dispatch

Highest Cost Generator Not Dispatched

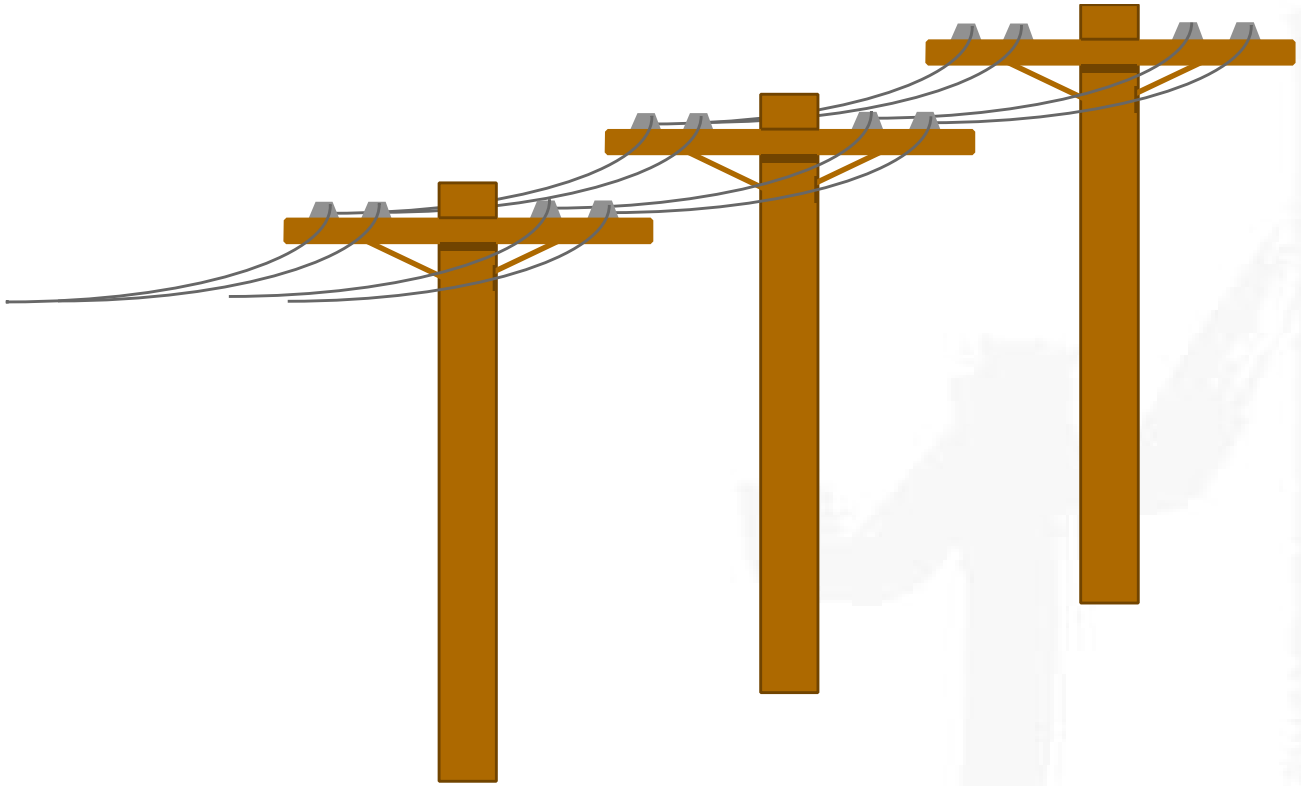


Economic Dispatch

Highest Cost Generator Sets Price

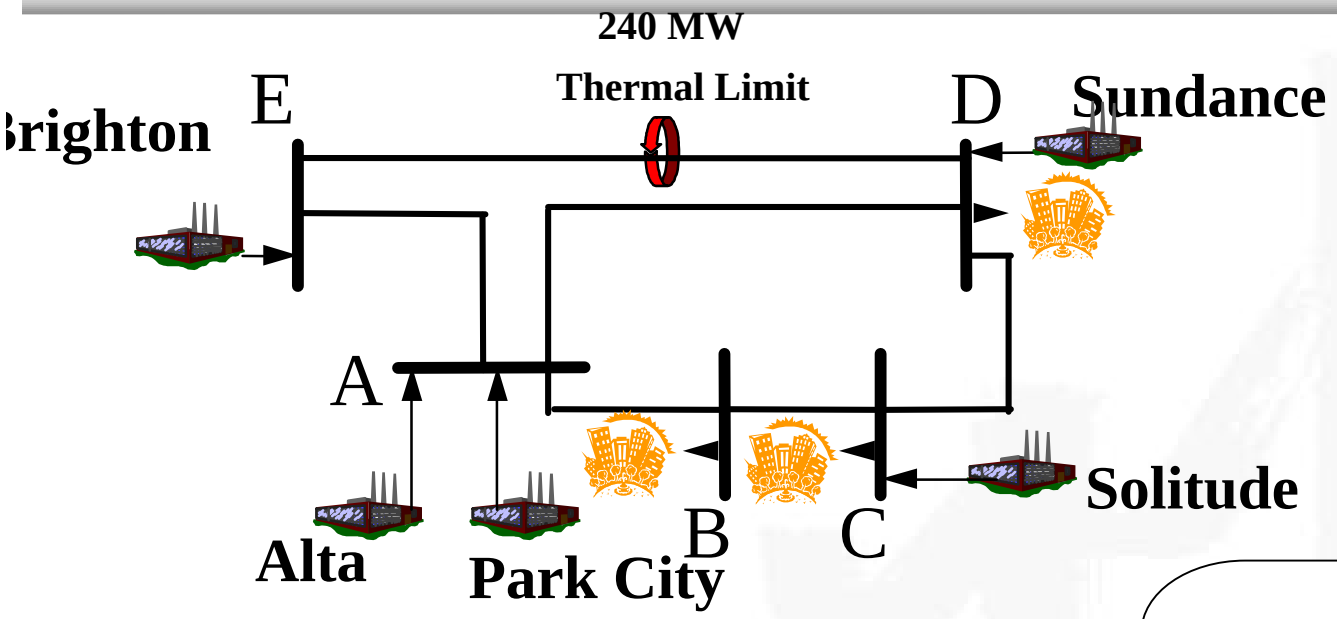


Power Transfer Limits



Thermal Limits
Voltage Limits
Stability Limits

Control Actions



System Reconfiguration

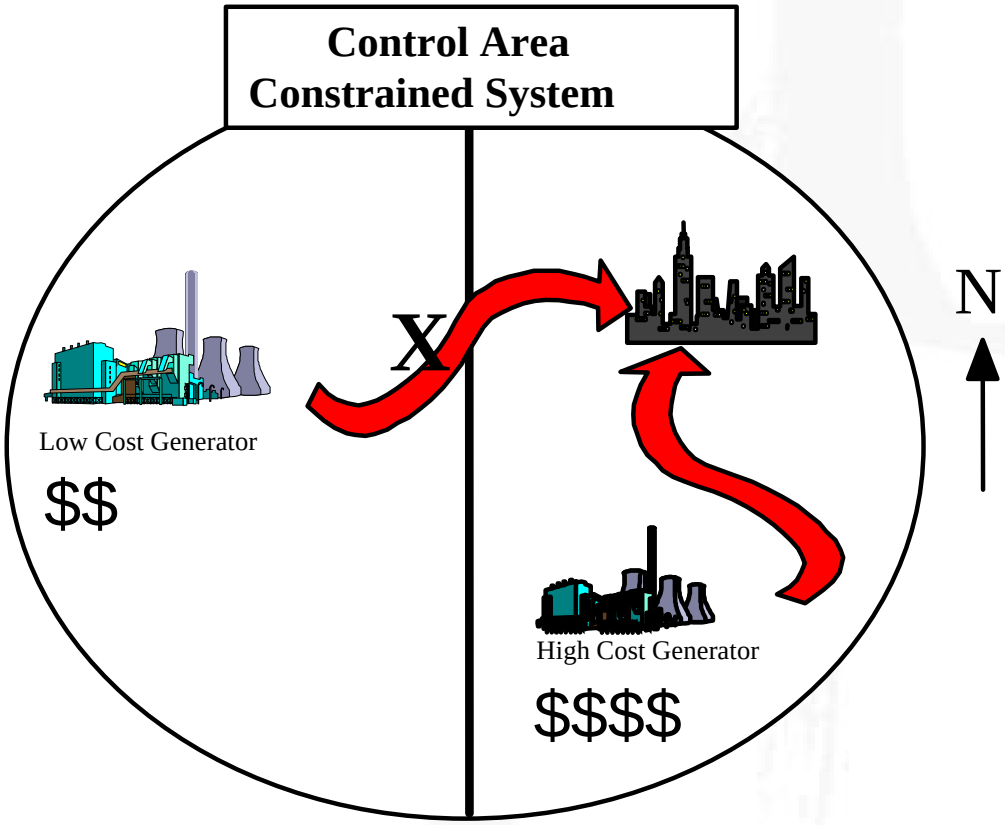
Transaction Curtailments

Re-dispatch Generation

When Constraints Occur

- Delivery limitations prevent use of “next least-cost generator”
- Higher cost generator closer to load must be used to meet demand
- Cost expressed as “security constrained redispatch cost”

Security Constrained Re-Dispatch



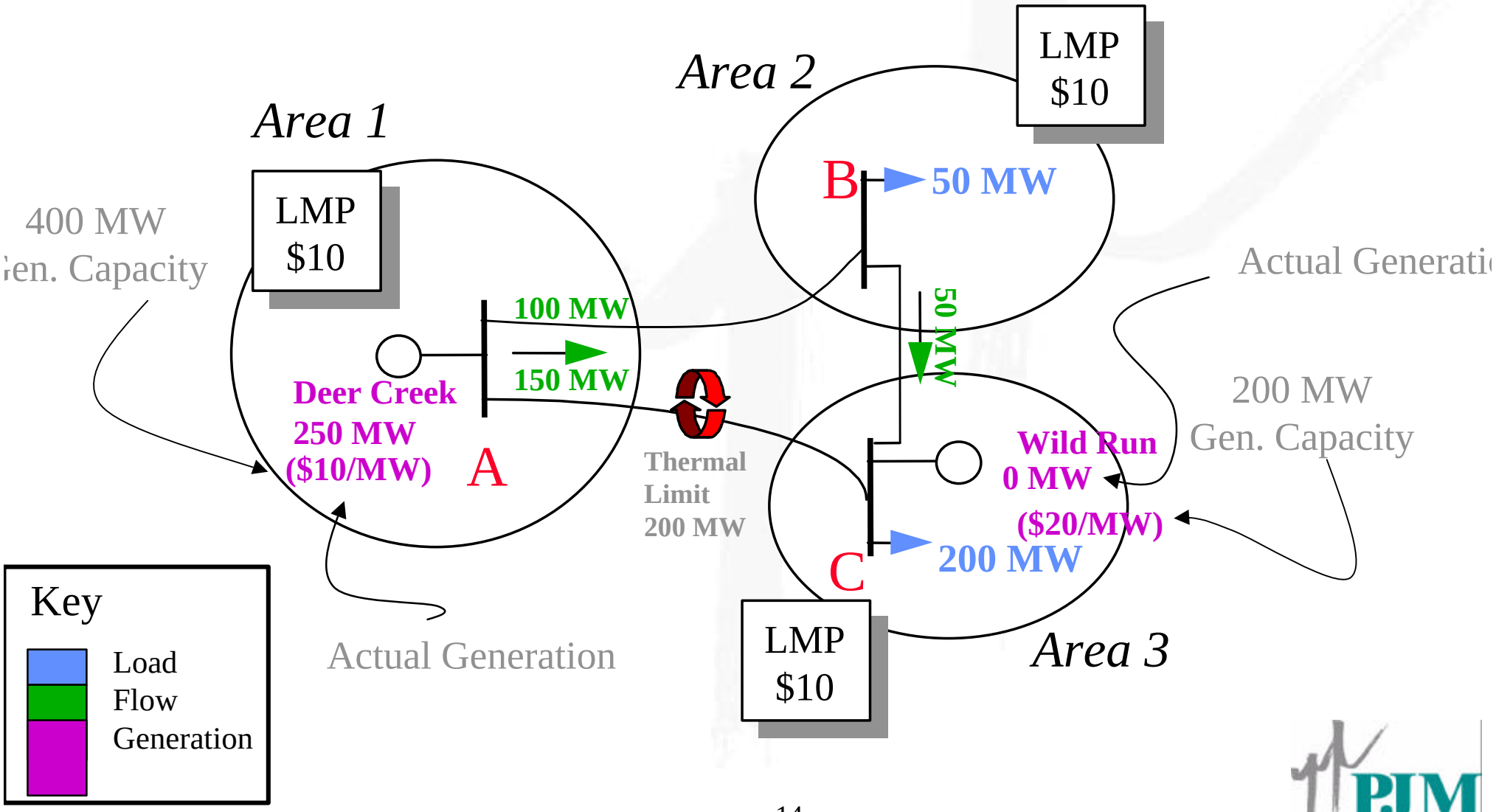
LMP Characteristics

- Based on …
  - actual flow of energy
  - actual system operating conditions
- LMPs …
  - are equal when transmission system is unconstrained
  - vary by location when transmission system is constrained

3 Bus Transmission Grid

Hour 0200

Unconstrained System

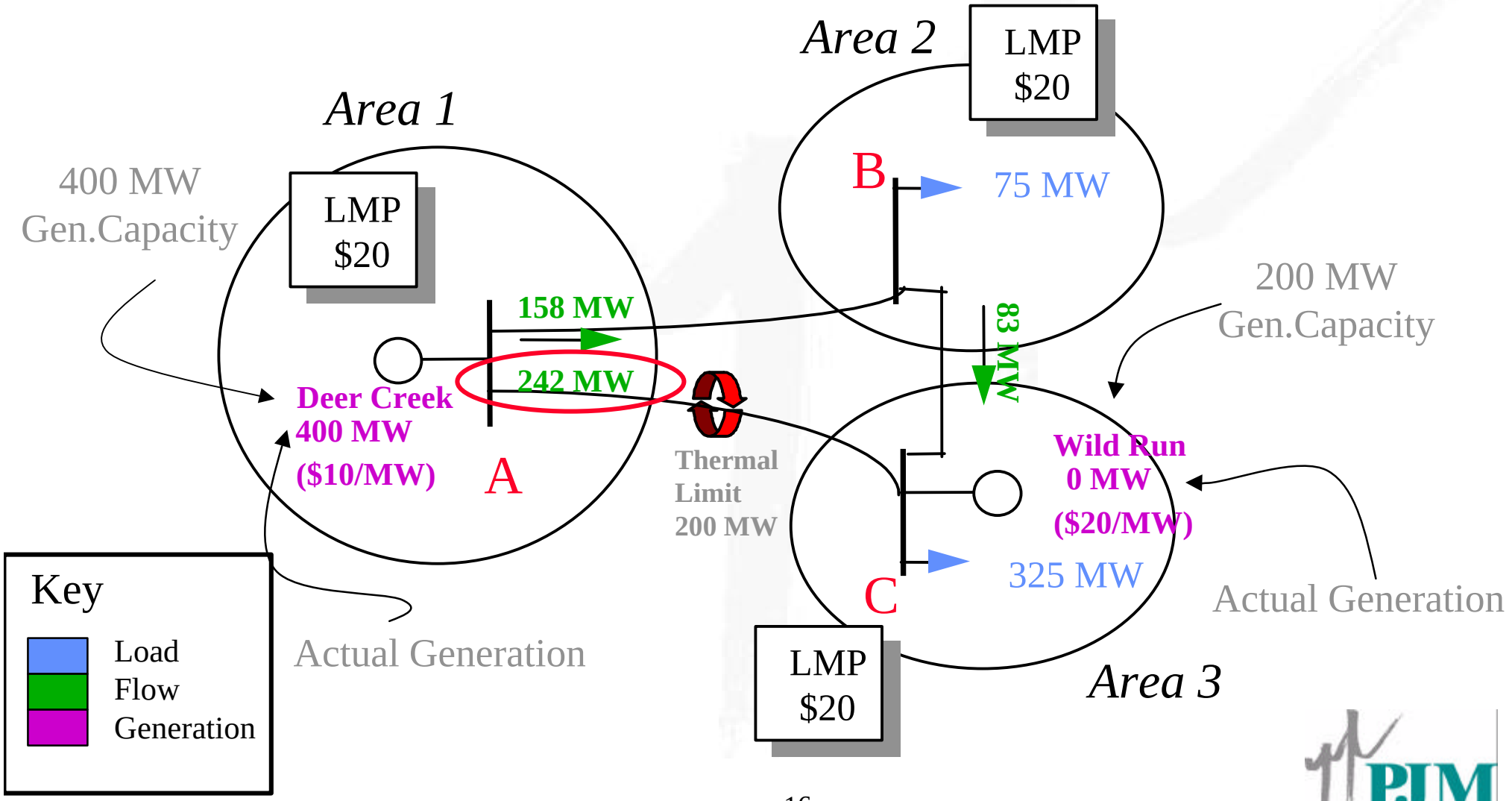


Unconstrained Example

- Total load 250 MW
  - Bus B 50 MW
  - Bus C 200 MW
- Constraint on line A-C (200 MW thermal limit)
- Deer Creek dispatched to meet load
- Deer Creek generation capacity is 400 MW
- Wild Run generation capacity is 200 MW
- Same LMPs at each bus

3 Bus Transmission System

Hour 1300 **Dispatched Ignoring Thermal Limit**



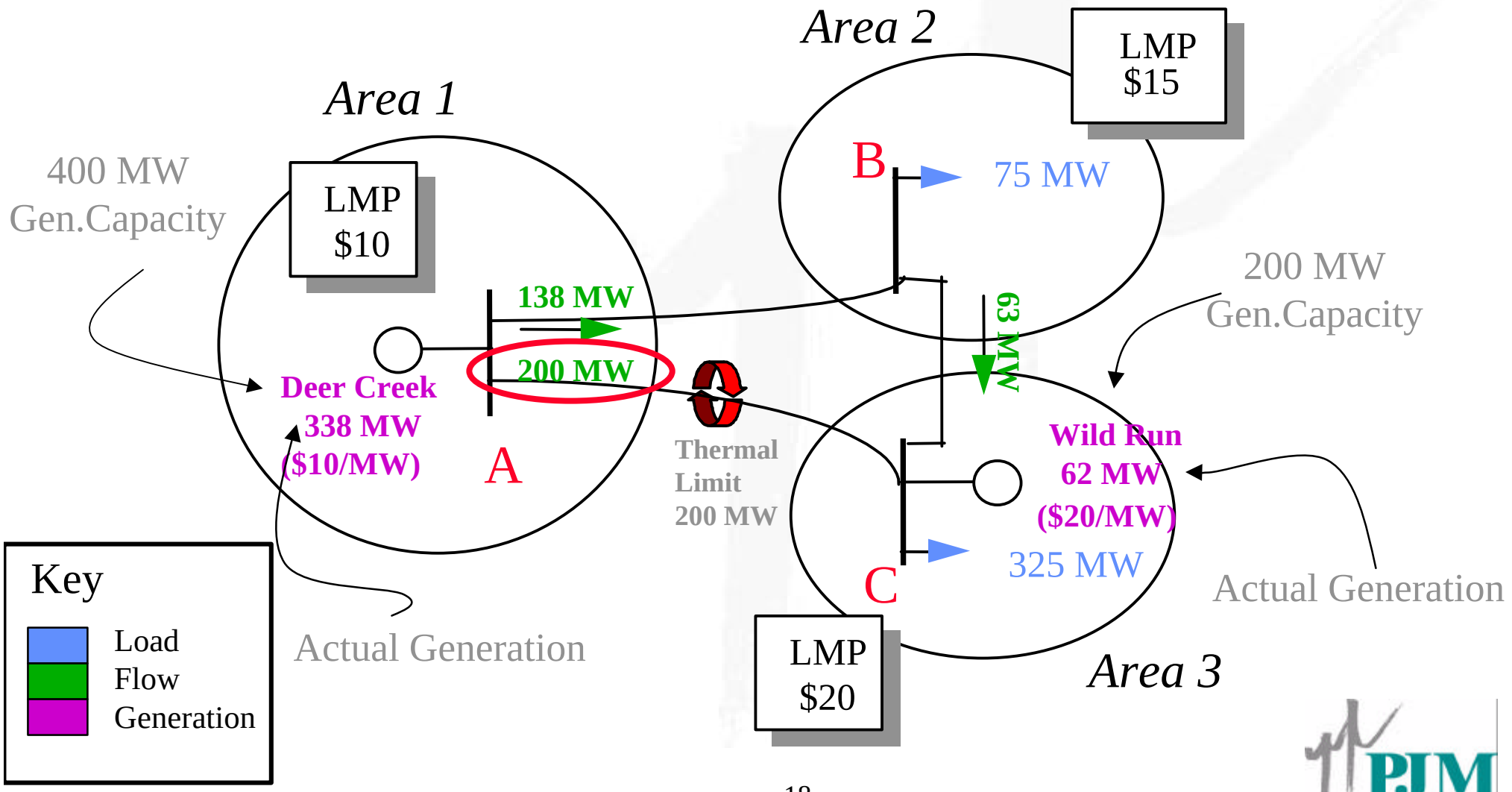
Dispatch Ignoring Transmission Limits

- Same case - different hour
- Increased load by 150 MW
  - Bus B from 50 to 80 MW
  - Bus C from 200 to 325 MW
- Limit ignored on line A-C (200 MW thermal limit)
- Deer Creek ramped up
- Wild Run not run

3 Bus Transmission System

Hour 1300

Constrained System



Constrained Example

- Same case - maintaining flow under limit
- Keep increased load at 150 MW
  - Bus B from 50 to 80 MW
  - Bus C from 200 to 325 MW
- Constraint on line A-C (200 MW thermal limit)
- Wild Run dispatched
- Deer Creek ramped down
- LMPs different at each bus

LMP & Sensitivity Factors

- Wild Run & Deer Creek supply the next increment of load
- Resulting sensitivity factors determine LMPs
  - contributions from each marginal unit
- Calculates least expensive way to service load, while respecting transmission limit

Constrained System LMPs

- To maintain reliability and economic dispatch, 50% of added load (1 MW) served from Deer Creek at $10; 50% served from Wild Run at $20
- LMP at B = (.5 * $10) + (.5 * $20) = $15.00
- LMPs depend on flow characteristics of transmission system
- LMPs reflect proportional delivery cost from marginal generators and cost of delivering power to location

How Does PJM Do It?

- Factors that Affect LMP
- Simplifying Assumptions
- LMP Characteristics
- Functional Overview
- LMP Model

Factors That Affect LMP

- Energy Demand
- Economic Dispatch
- Available Flexible Generating Units
- Network Topology
- Binding Transmission Limits

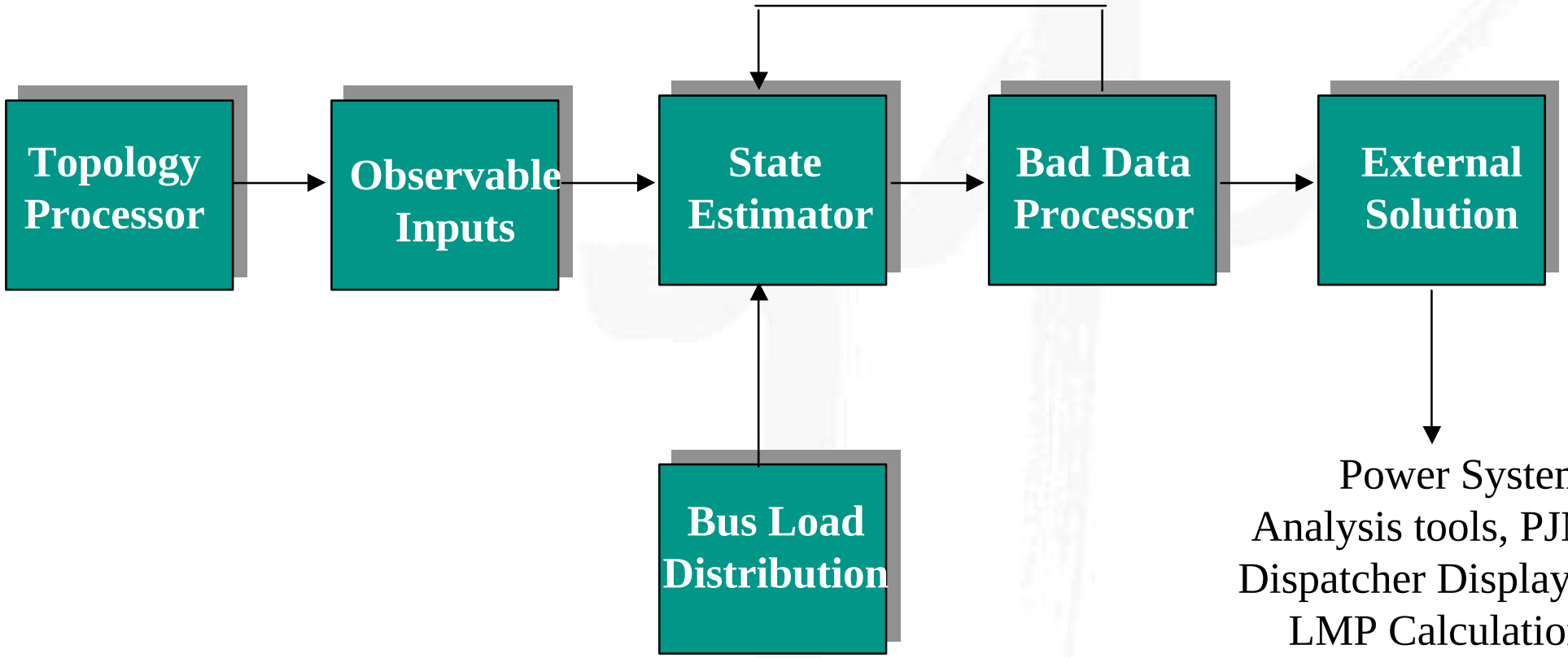
Simplifying Assumptions

- The PJM real-time economic dispatch solution is the basis for calculating the real-time energy prices
- The price of energy is based on actual PJM operating conditions, as described by the PJM state estimator
- The price of energy is calculated at five minute intervals and is based on the concept of Locational Marginal Pricing (LMP)
- Day-ahead and balancing settlements are performed based on hourly integrated LMPs

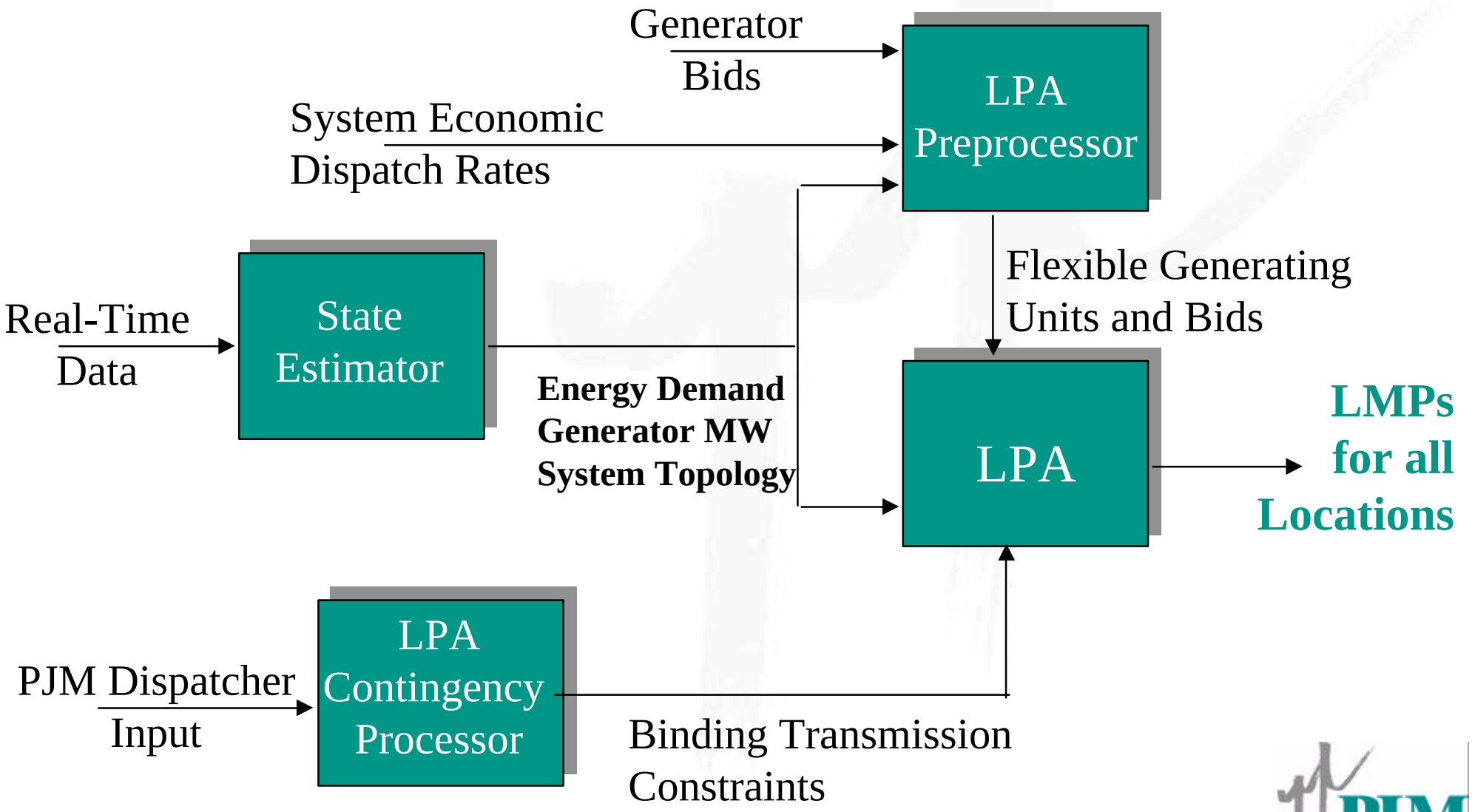
LMP Characteristics

- Single Market Clearing Price when system is unconstrained
- Under constrained conditions, the marginal cost of energy varies by location as low cost supply cannot reach all demand
- LMPs reflect increased cost to deliver energy when insufficient transmission exists
- Under constrained conditions, LMPs can be quite different from the economic dispatch rates due to costs to delivery energy from marginal generating units to load buses

PJM State Estimator Functional Overview



Locational Marginal Pricing Model



LMP Execution Steps

1. Determine current system conditions
   - energy demand
   - generator MW values
   - system topology
2. Process generator bids & dispatch rates to determine flexible generators
3. Collect current system constraint data
4. Execute Locational Price Algorithm

How does PJM use LMP?

- Generators get paid at generation bus LMP
- Loads pay at load bus LMP
- Transactions pay congestion charges equal to the differential in source and sink LMPs
- Covered in more detail in Transaction Modeling

Understanding FTRs

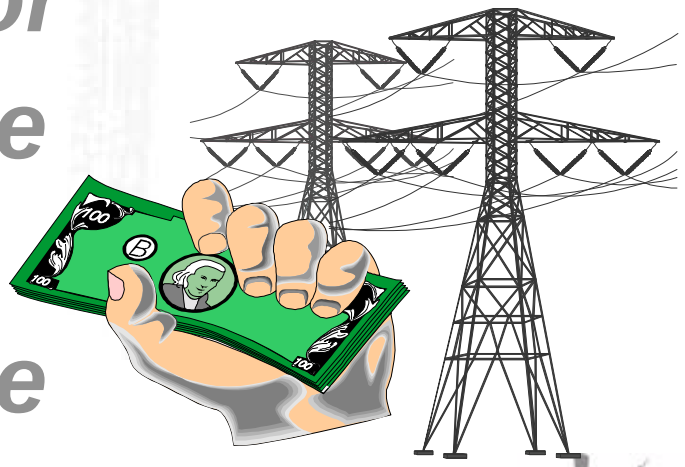
Why Do We Need FTRs?

- Challenge:
  - LMP exposes PJM Market Participants to price uncertainty for congestion cost charges
  - During constrained conditions, PJM Market collects more from loads than it pays generators
- Solution:
  - Provides ability to have price certainty
  - FTRs provide hedging mechanism that can be traded separately from transmission service

What Are FTRs?

Fixed Transmission Rights are …

a financial contract that entitles holder to a stream of revenues (or charges) based on the hourly energy price differences across the path



Why Use FTRs?

- To create a financial hedge that provides price certainty to Market Participants when delivering energy across the PJM system
- To provide firm transmission service without congestion cost
- To provide methodology to allocate congestion charges to those who pay the fixed cost of the PJM transmission system

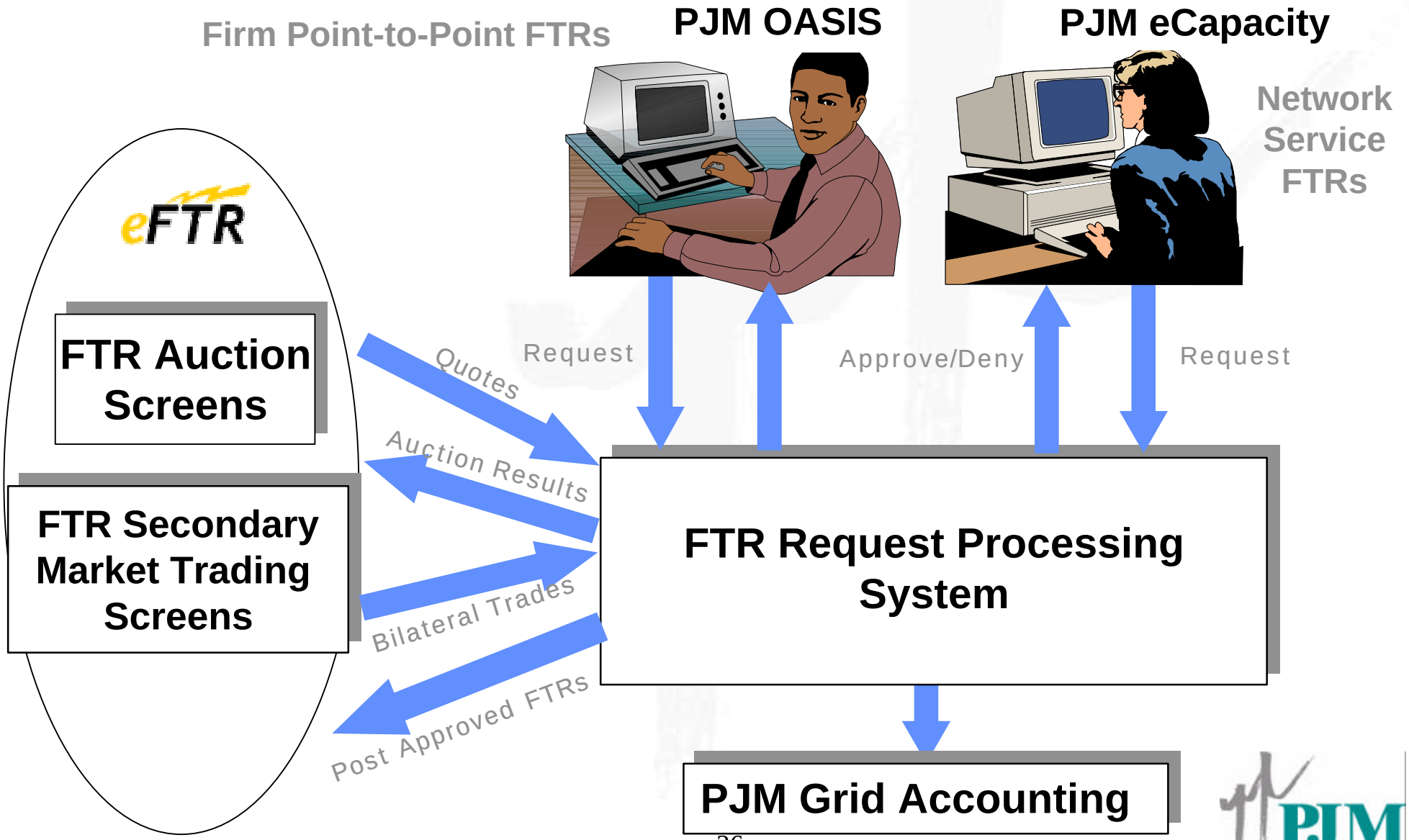
Purpose of FTRs

- To protect firm transmission customers from increased cost due to transmission congestion, when energy deliveries are consistent firm reservations
- To allow energy traders to purchase protection from transmission congestion charges on a specified path
- To facilitate a forward energy market by providing a mechanism to manage basis risk caused by LMP differences during periods of transmission congestion

Obtaining FTRs

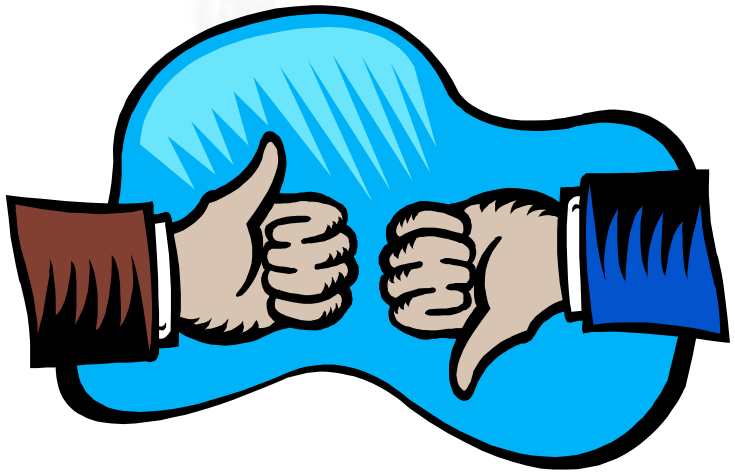
- Network service
  - based on annual peak load
  - designated from resources to aggregate loads
- Firm point-to-point service
  - may be requested with transmission reservation
  - designated from source to sink
- Secondary market -- bilateral trading
  - FTRs that exist are bought or sold
- FTR Auction -- centralized market
  - purchase “left over” capability

PJM FTR System



What are FTRs Worth?

- Economic value determined by hourly LMPs
- Benefit (Credit)
  - same direction as congested flow
- Liability (Charge)
  - opposite direction as congested flow



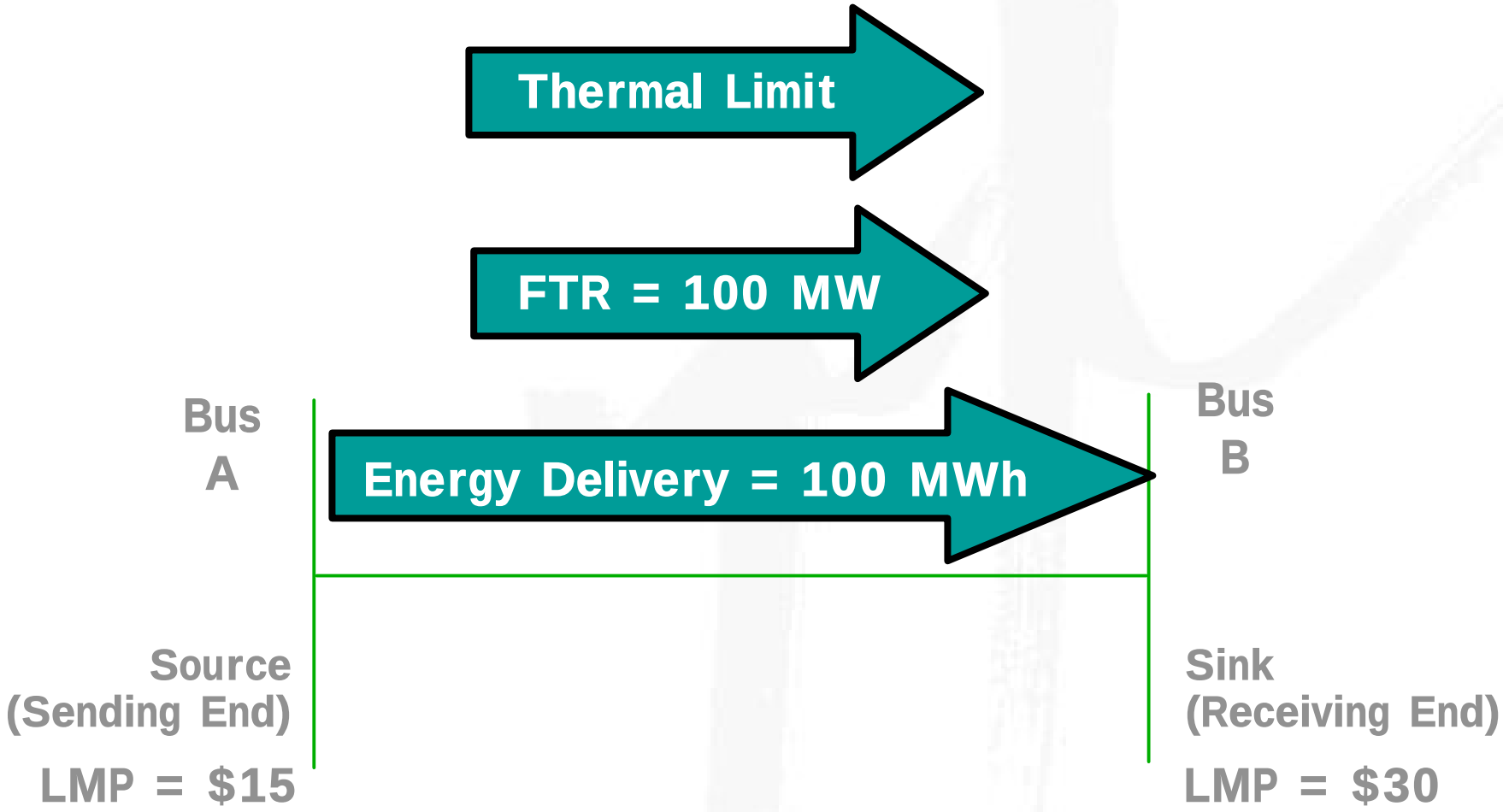
FTRs and Congestion Charges

Congestion Charge =

MWh * (Day-ahead Sink LMP - Day-ahead Source LMP)

- Point-to-Point FTR Credit
  - MW * (Day-ahead Sink LMP - Day-ahead Source LMP)
- Network Service FTR Credit
  - MW * (Day-ahead Aggregate Load LMP - Day-ahead Generation Bus LMPs)

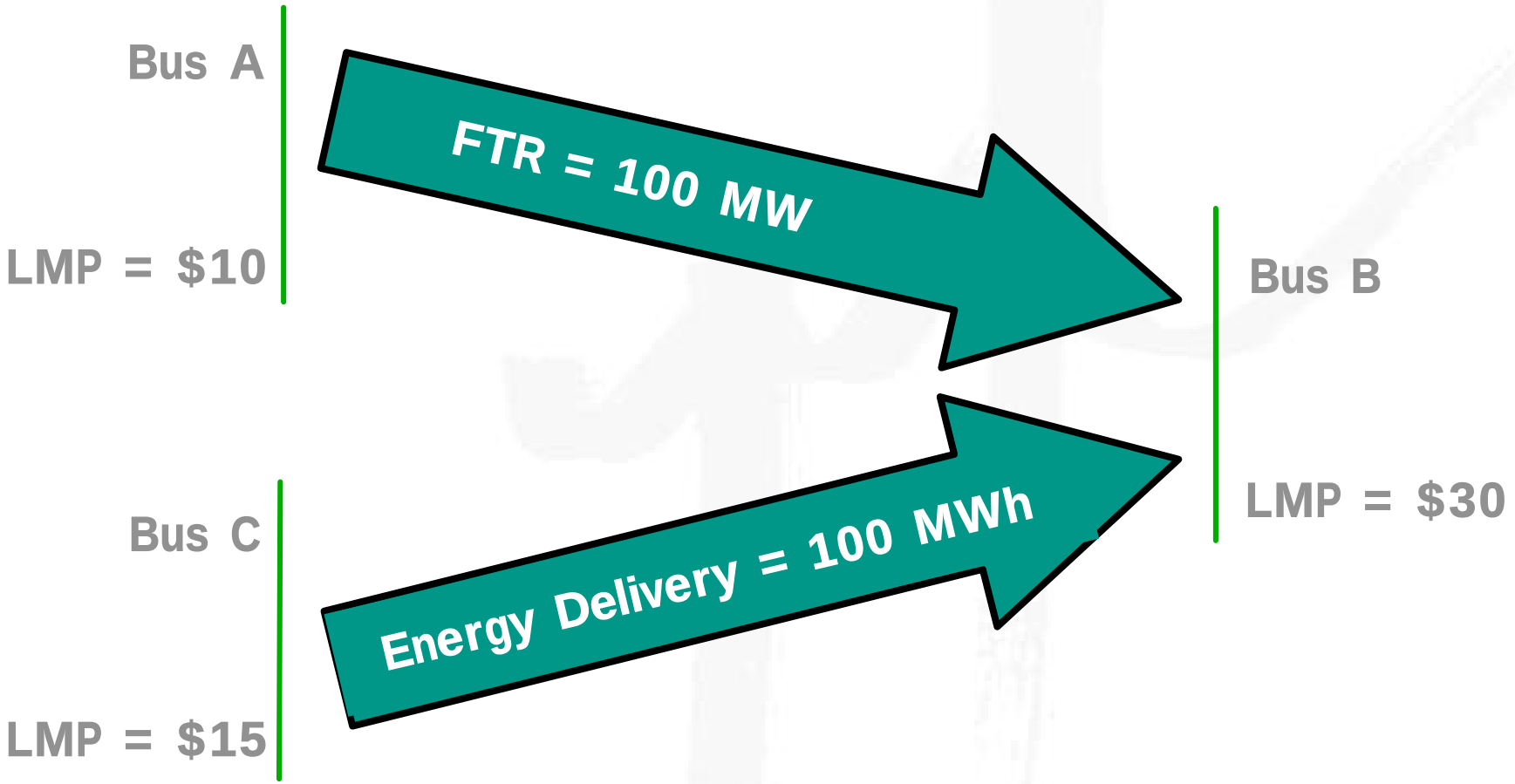
Energy Delivery *Consistent* with FTR



Congestion Charge = 100 MWh * ($30-$15) = $1500

FTR Credit = 100 MW * ($30-$15) = $1500

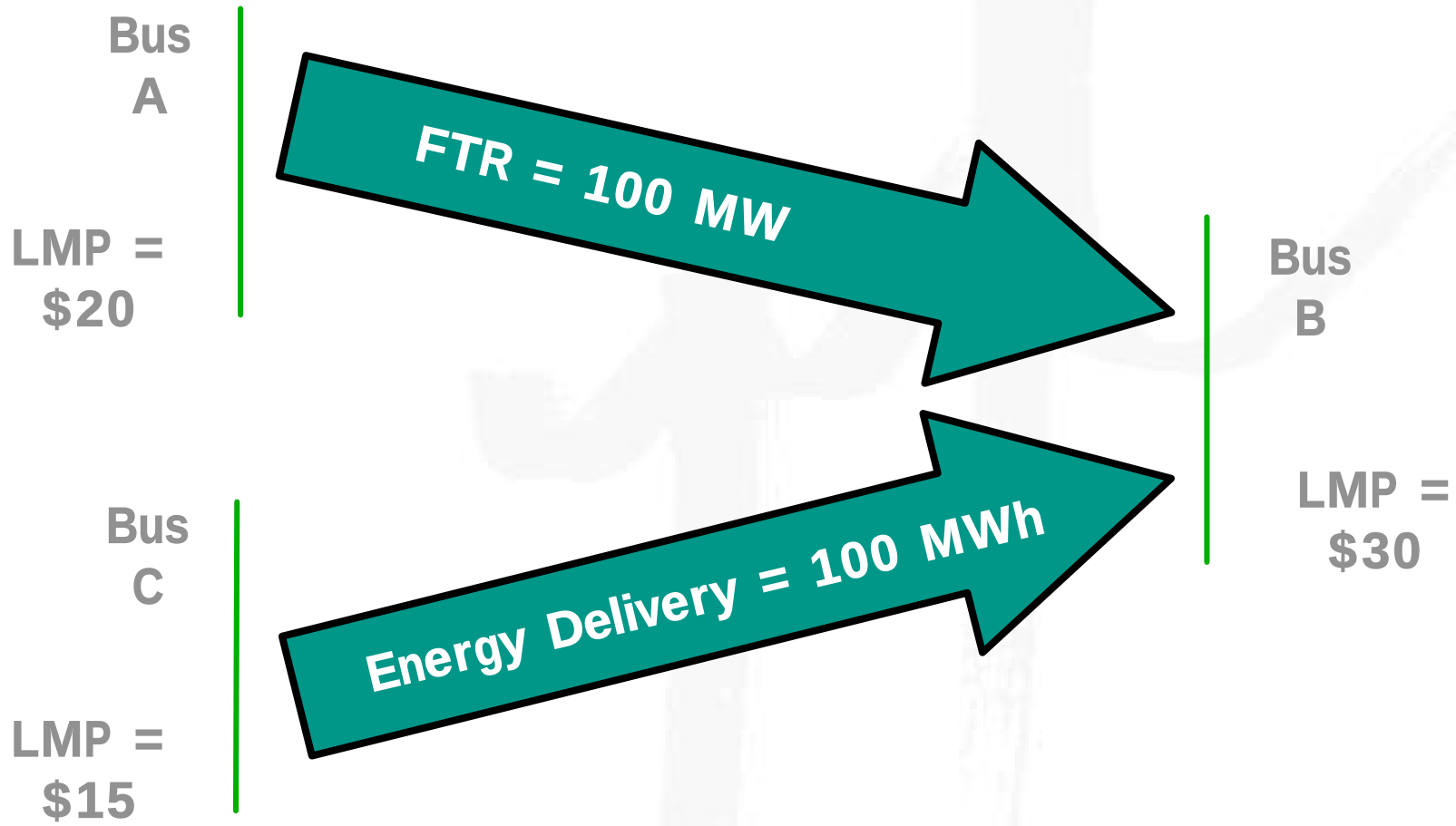
Energy Delivery *Not Consistent* with FTR (I)



Congestion Charge = 100 MWh * ($30-$15) = $1500

FTR Credit = 100 MW * ($30-$10) = $2000

Energy Delivery *Not Consistent* with FTR (II)



Congestion Charge = 100 MWh * ($30-$15) = $1500

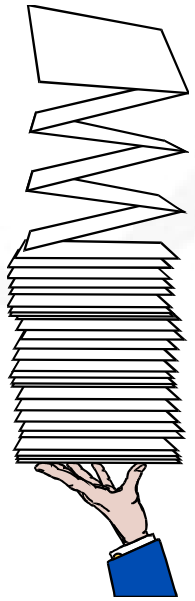
FTR Credit = 100 MW * ($30-$20) = $1000

Characteristics of FTRs

- Defined from source to sink
- MW level based on transmission reservation
- Financially binding
- Financial entitlement, *not* physical right
- Independent of energy delivery

FTR Simultaneous Feasibility Test

- Test Description
  - What is it?
  - Overview of Test Conditions
  - Required Inputs
  - Network Assumptions
  - Testing Criteria
- Logistics
  - Periodicity of Test
  - Notification Requirements (PJM, Customer)
  - Details



What is an SFT?

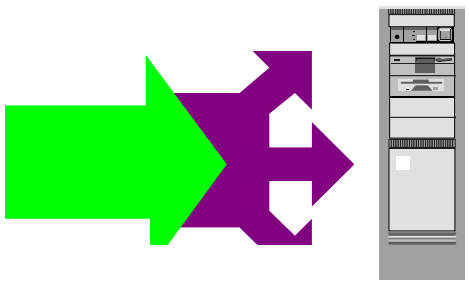
- Test to ensure that all subscribed transmission entitlements (FTRs) are within the capability of the existing transmission system
- Test to ensure the PJM Energy Market is revenue adequate under normal system conditions
- NOT a System Reliability Test
- NOT intended to model actual system conditions

Overview of Test Conditions

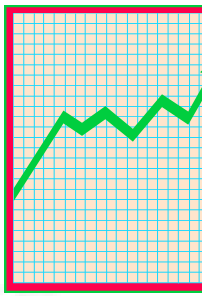
- Model all requested FTRs for the study period in a DC powerflow analysis.
- FTRs for Point-to-Point service are modeled as generation at the receipt (source) point(s) and load at the delivery (sink) point(s).
- FTRs for Network Service are modeled as a set of generators at the receipt (source) point and a network load at the delivery (sink) point.

Required Inputs to the Model

- All newly requested FTRs for the study period
- All existing FTRs defined at any time in the study period
- Transmission line outage schedules
- Thermal operating limits for transmission lines
- PJM reactive interface limits that are valid for the study period
- Estimates of uncompensated parallel power flow circulation through PJM from other control areas

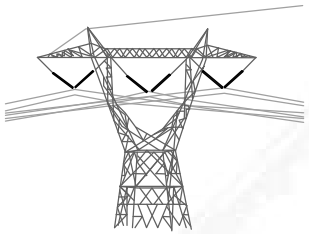


Network Topology Assumptions



- SFT uses power flow model that accurately as possible models expected network topology (facilities status) during time period being analyzed
- Annual case assumes all bulk facilities in service unless there is a known long-term equipment outage
- Monthly cases assume worst-case bulk facilities outage scenario (i.e, scheduled facilities will be modeled as out-of service)
- Near-term cases incorporate more definitive bulk facilities outages

Testing Criteria



- Single contingency test criteria
- Perform DC powerflow analysis to:
  - evaluate ability of all system facilities to remain within normal thermal ratings
  - evaluate ability to sustain the loss of any single contingency event with all system facilities remaining within applicable short-term, emergency ratings
  - evaluate ability to maintain acceptable bulk system voltage performance by imposing 500 kV reactive interface limits

FTR Request & Approval Process

- FTR Analysis Timeframes
- Network Service
  - as requested on PJM eCapacity
- Firm Point-to-Point
  - annual
  - monthly
  - weekly
  - daily

FTR Request & Approval Process

PJM's Responsibilities

- Timestamp and acknowledge receipt of Transmission Service Requests (TSR)
- Analyze and determine both reliability impact and market feasibility of TSRs within required time period
- Notify customers of disposition of request and assign FTRs to all approved TSRs within required time period
- Incorporate FTRs into PJM eFTR database

FTR Request & Approval Process

Customers' Responsibilities

- Submit TSRs during proper windows
- For Point-to-Point Service, specify MW amount and transaction receipt (source) and delivery (sink) points
- For Network Service, specify designated network generating resources (sources) up to value of peak load
- Delivery points are by default the aggregate company load, as determined by data in PJM OI databases

FTR Request & Approval Process

Network Service Process Summary

- Covers year from June 1 through May 31
- Submit desired FTRs during April 1-30 enrollment window.
  - All requests received during enrollment window are deemed to have arrived simultaneously.
  - Continuing Network Service and active Point-to-Point TSRs have priority
    - » This priority ends on 6/1/2001

FTR Request & Approval Process

Network Service Process Summary (cont'd)

- Changes made via PJM eCapacity
  - any time for any length of time
  - subject to feasibility test

FTR Request and Approval Process

Point-to-Point Transmission Service Facts

- FTRs are for same duration as associated firm point-to-point transmission service
- Annual service TSRs and FTRs may begin at start of any month and run for twelve complete months
- Other TSRs and FTRs are for one complete calendar period, e.g.,
  - monthly service can be for August 1-31, but not July 15-August 15
  - weekly service runs Monday through Sunday
  - daily service is for hours 0 through 23

FTR Request and Approval Process

Point to Point Transmission Service Key Dates

	Annual	Monthly	Weekly	Daily
Earliest Request	-	17 months	2 weeks	3 days
Latest Request	per tariff	14 days	7 days	2 days
OI Respond	Per tariff	Per tariff	2 days	4 hours
Customer Confirm	15 days after PJM approves OR By 12:00 noon on the day prior to service commencemnt			

FTR Secondary Market

- Bilateral trading of FTRs provided on PJM eFTR
  - mark FTRs for sale
  - offer to buy FTRs
  - accept offers to buy FTRs
- FTR trades specified by path, not be individual FTR
- Only PJM Members and Transmission Service Customers may purchase FTRs through Secondary Market
  - Cannot sell FTR you do not own

FTRs & Full Customer Choice

- Market Participants use PJM eCapacity to meet their obligations through capacity transactions
  - buy capacity to meet obligation with FTRs
  - modify FTRs (additions or reductions)
- Total FTRs for unit cannot be greater than unit's installed capacity
- FTR data passed from PJM eCapacity to PJM eFTR
- All FTR requests and modifications subject to feasibility test