

Dispatch Signal and Locational Marginal Pricing


PJM Initial Training Program

Student Guide

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Table of Contents



Introduction	3
Objectives	4
Dispatch Rate	4
Dispatch Rate	5
Dispatch Rate Cont.	6
Transmission Losses	7
Transmission Losses	8
Transmission Losses Example	9
Transmission Losses Example	10
Penalty Factor Effect on Dispatch	11
Penalty Factor Effect on Dispatch	12
Penalty Factor Effect on Dispatch	13
Penalty Factor Effect on Dispatch - Example	14
Operational Limits.....	15
Control Actions	16
Security Constrained Re-Dispatch.....	17
When Constraints Occur	18
Constraints & Marginal Units	19
Contingency Analysis	20
Contingency Analysis Cont.....	21
How Contingency Analysis Works	22
Generation Re-Dispatch	22
PJM Real Time Contingency Operations.....	23
PJM Real Time Contingency Operations.....	24

PJM Real Time Contingency Operations.....	25
LMP	25
What is LMP?	26
What is LMP?	27
How is LMP Applied?	28
LMP Components.....	29
System Marginal Energy Price	30
System Marginal Price - Example.....	31
Congestion Component.....	32
Congestion Effects on LMP and Revenues	33
Marginal Loss Component.....	34
Marginal Loss Effects on LMP and Revenues.....	35
LMP - Example 1	36
LMP - Example 2	37
Wrap-Up.....	38
 Knowledge Check!	39
Questions	40

Objectives

Objectives

Identify how PJM dispatches & utilizes LMP

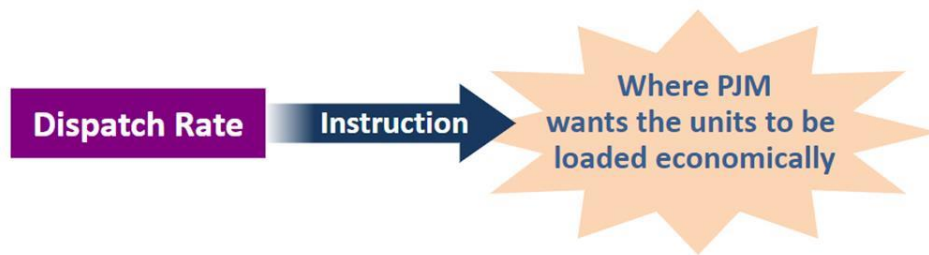


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Dispatch Rate

Dispatch Rate

The **Dispatch Rate** is expressed in dollars per MWh, calculated and transmitted to each generator, to direct the output level of all generation resources dispatched by PJM based on the incremental offer data which was previously received from the generators



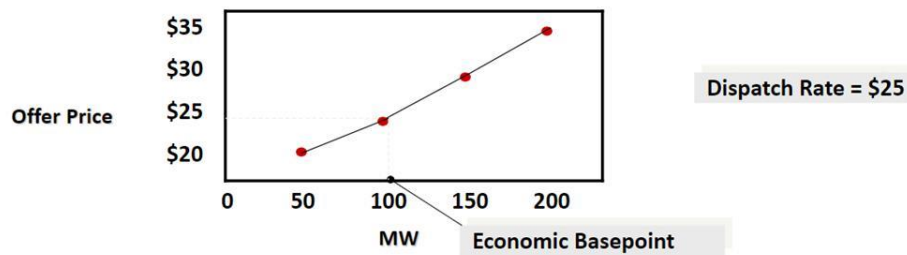
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Dispatch Rate Cont.

Dispatch Rate Cont.

The **Dispatch Rate** is determined by the PJM economic dispatch solution as calculated by PJM's Security Constrained Economic Dispatch program (SCED).

The **Economic Basepoint** is the MW value sent to the generating unit. It indicates what level the unit should be loaded based on the economic dispatch solution and the unit's incremental price curve.

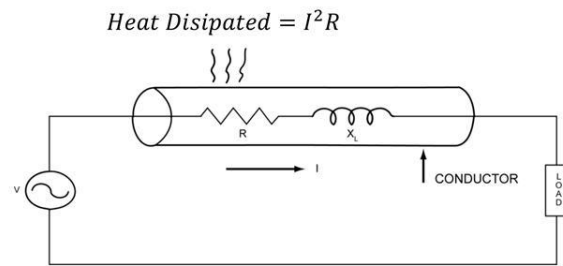


Transmission Losses

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



4

Transmission Losses

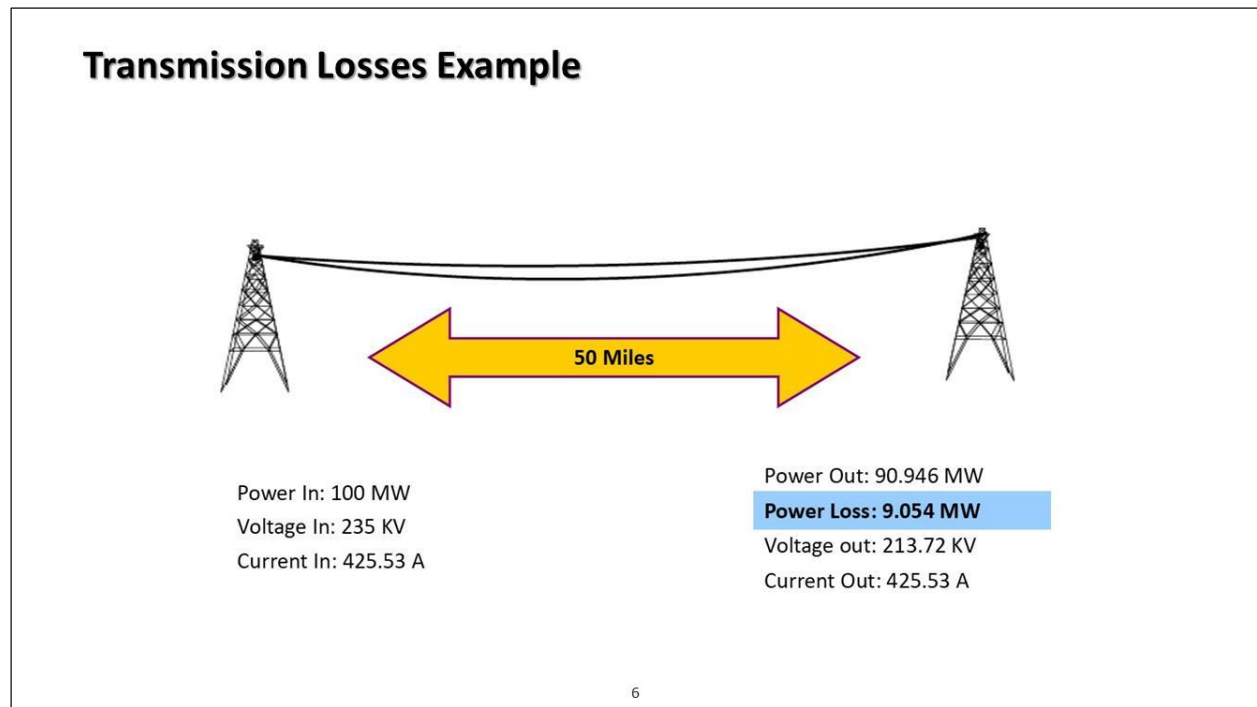
Transmission Losses

Real Power (MW) Losses

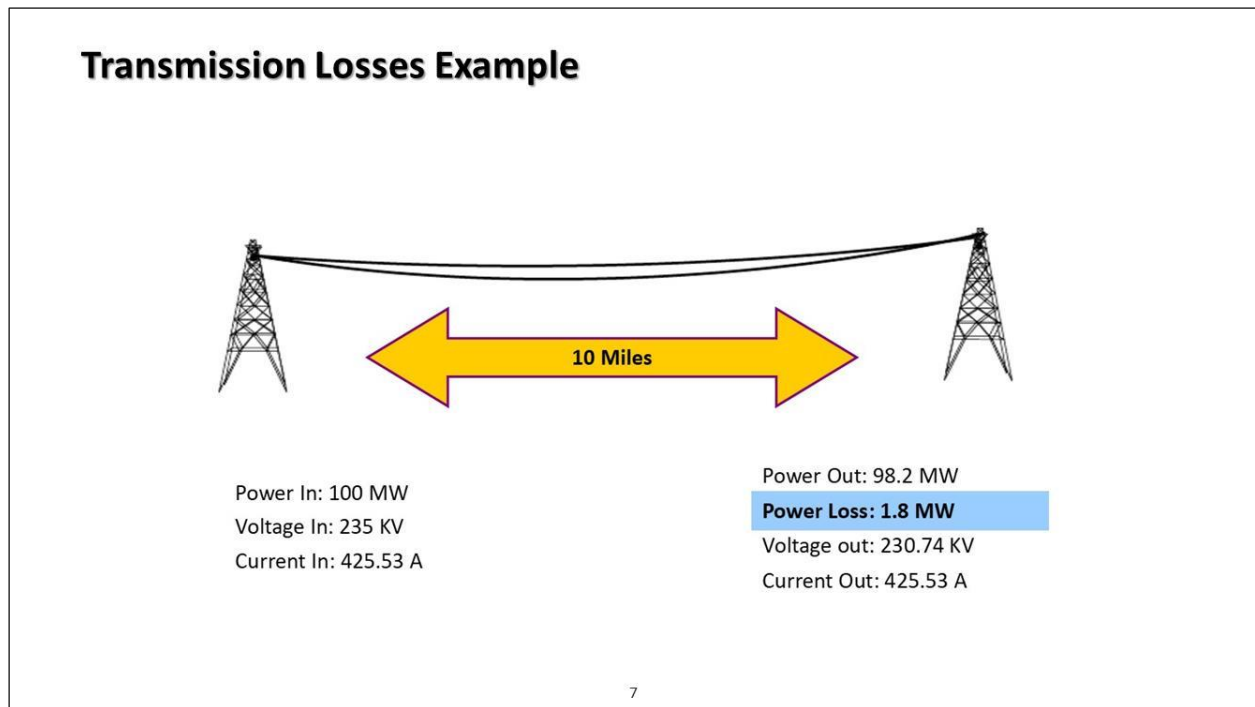
- Increase with line length
 - Increased R
- Increase with increased current flow (I)
- Increase at lower voltages due to those higher currents

$$\text{Power} = \text{Current} * \text{Voltage}$$

Transmission Losses Example



Transmission Losses Example



Penalty Factor Effect on Dispatch

Penalty Factor Effect on Dispatch

The incremental loss for a bus used to calculate a factor that can be used to include the effect of losses in the dispatch. It adjusts the incremental cost of each resource to include the effects of losses.

This factor is called the Loss Penalty Factor, or Penalty Factor

$$Pf_i = \frac{1}{\left(1 - \frac{\Delta P_L}{\Delta P_i}\right)}$$

Change in Losses

Change in Unit's MW Output

The Penalty Factors adjust the incremental cost of each generator so as to include the effects of losses

Penalty factors applied to each and every location

- Including generation, load, virtual transaction

Penalty Factor Effect on Dispatch

Penalty Factor Effect on Dispatch

If an increase in generation results in an increase in system losses then:

- Penalty factor is greater than 1
- Units offer curve is adjusted higher
 - Unit offer curve is multiplied by penalty factor
 - Unit looks less attractive to dispatch

Loss Factor

$$0 < \frac{\Delta P_L}{\Delta P_i} < 1$$

Penalty Factor

$$Pf_i = \frac{1}{\left(1 - \frac{\Delta P_L}{\Delta P_i}\right)} > 1.0$$

Penalty Factor Effect on Dispatch

Penalty Factor Effect on Dispatch

If an increase in generation results in a decrease in system losses then:

- Penalty factor is less than 1
- Units offer curve is adjusted lower
- Unit offer curve is multiplied by penalty factor
 - Unit looks more attractive to dispatch
- Total LMP would still at least equal unit's original offer

Loss Factor

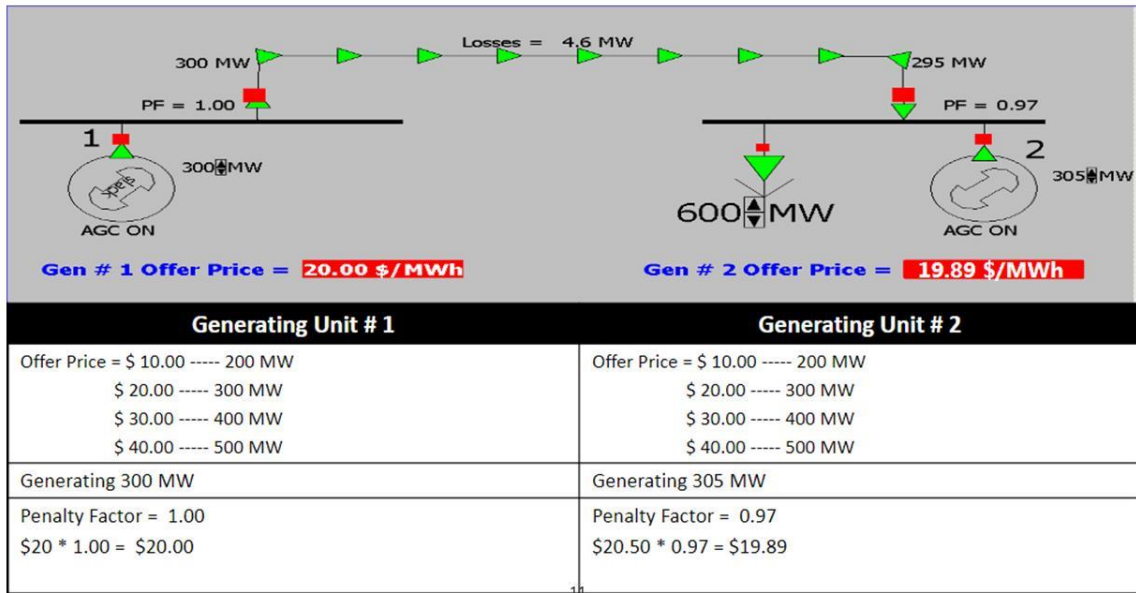
$$0 > \frac{\Delta P_L}{\Delta P_i} > -1$$

Penalty Factor

$$Pf_i = \frac{1}{\left(1 - \frac{\Delta P_L}{\Delta P_i}\right)} < 1.0$$

Penalty Factor Effect on Dispatch - Example

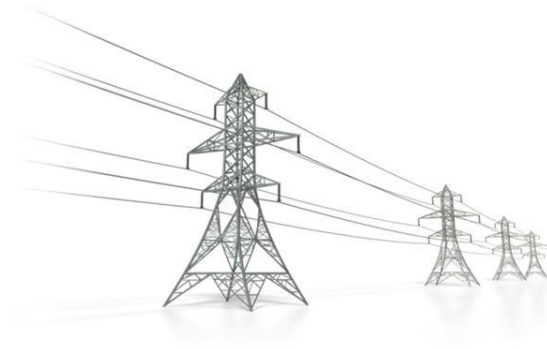
Penalty Factor Effect on Dispatch - Example



Operational Limits

Operational Limits

- Thermal Limits
- Voltage Limits
- Stability Limits



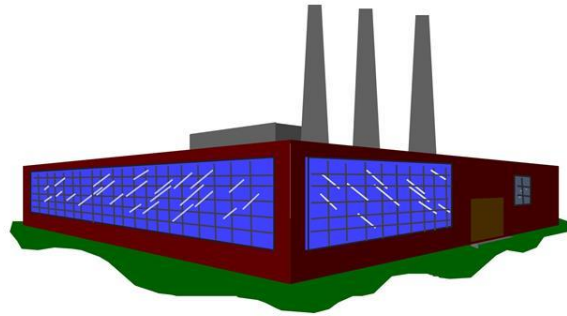
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Control Actions

Control Actions

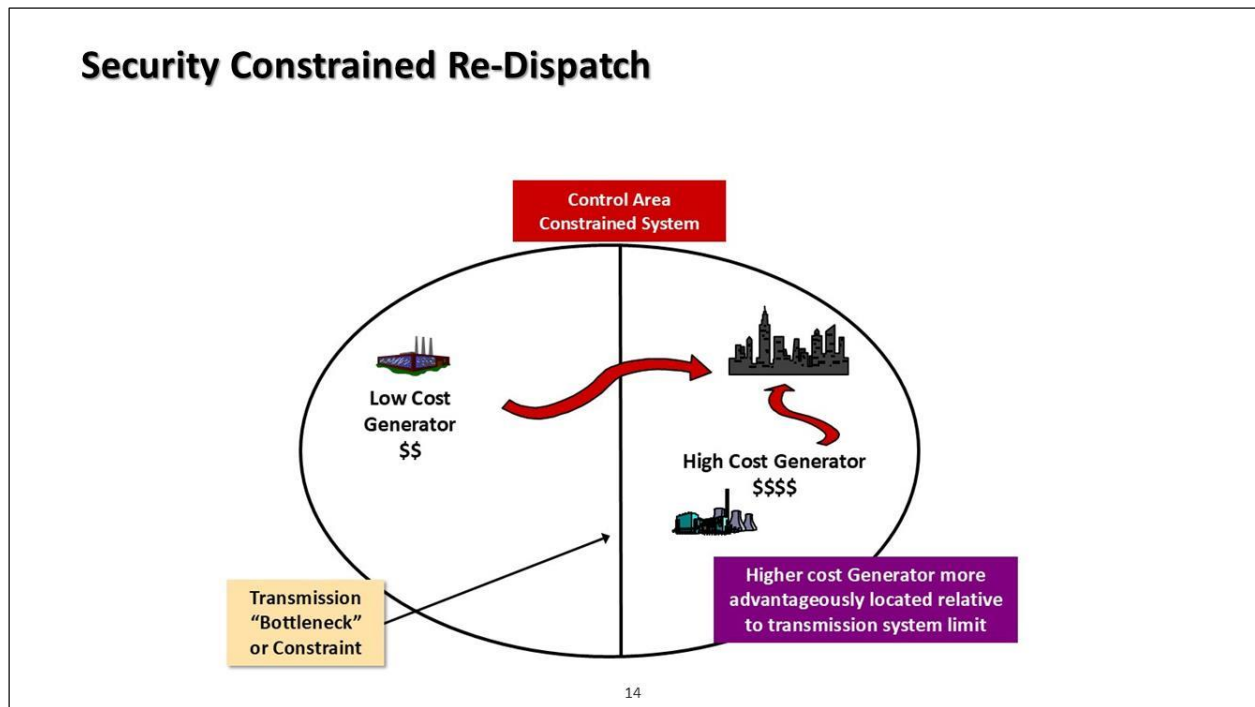
There are three basic types of actions that can be performed to control the flow of power on the electric system:

- System Reconfiguration
- Transaction Curtailments
- Generation Redispatch



13

Security Constrained Re-Dispatch



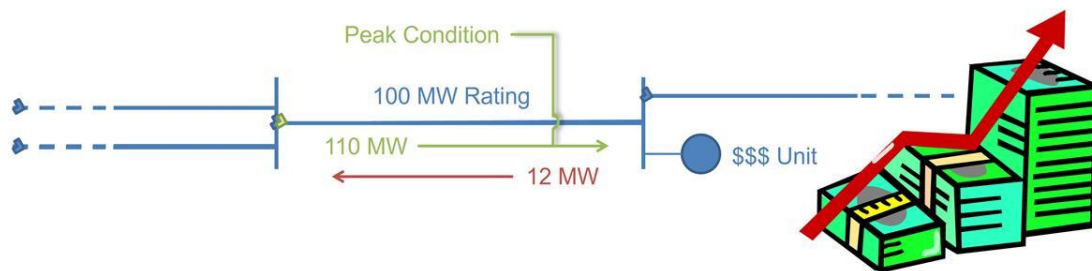
When Constraints Occur

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”

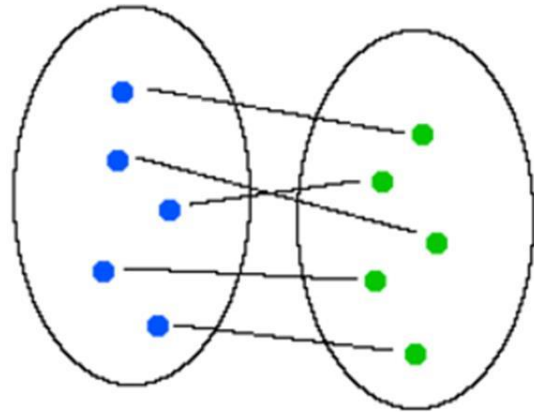


15

Constraints & Marginal Units

Constraints & Marginal Units

- There will always be at least one marginal unit
 - System Energy Unit
- There will be an additional marginal unit for each binding constraint
- It is possible, and in fact likely, that there will be multiple marginal units for a given time interval



16

Contingency Analysis

Contingency Analysis

“What if” scenario simulator that evaluates, provides and prioritizes the impacts on an electric power system when problems occur.

- A contingency is a provision for an unforeseen event or circumstance
 - Loss or failure of a *small* part of the power system (e.g. a transmission line)
 - Loss or failure of individual equipment such as a generator or transformer

A computer application that uses a simulated model of the power system

- Evaluates the effects of an outage event
- Calculates any overloads that may result

This is referred to as maintaining system security

Contingency Analysis Cont.

Contingency Analysis Cont.

Contingency Analysis is essentially a "preview" analysis tool

- It simulates and quantifies the results of problems that could occur in the power system in the immediate future

Contingency Analysis is used as a study tool for the off-line analysis of contingency events, and as an on-line tool to show operators what would be the effects of future outages

- This allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

How Contingency Analysis Works

How Contingency Analysis Works

Executes a power flow analysis for each potential problem that is defined on a contingency list

- A contingency list contains each of the elements that will be removed from the network model, one by one, to test the effects for possible overloads of the remaining elements
- The failure or outage of each element in the contingency list is simulated in the network model by removing that element
- The resulting network model is solved to calculate the resulting power flows, voltages, and currents for the remaining elements of the model

PJM Real Time Contingency Operations

PJM Real Time Contingency Operations

Review available controlling actions and the distribution factor (DFax) effect on the overloaded facility.

- Consider whether there are sufficient resources available to control transmission facilities within acceptable limits.

Initiate off-cost if reasonable controlling actions are available

SCED works best when the impacts are 5% or greater but can still be utilized when only lower DFax values exist

PJM Real Time Contingency Operations

PJM Real Time Contingency Operations

Once off-cost is initiated, RT-SCED will redispatch generation based on its dollar per MW effect, considering all on-line flexible units with an impact of ~1% or greater

- –This percentage may be adjusted on a case by case basis

Initiate a Post Contingency Local Load Relief Warning/Action if post-contingency flows exceed designated ratings and insufficient resources are available to control the overloaded facilities

PJM Real Time Contingency Operations

PJM Real Time Contingency Operations

During Constrained Operations, resources will re-dispatched cost-effectively based on their bid parameters

Cost-effective re-dispatch (\$/MW Effect) = (Current Dispatch Rate – Unit Bid)/Unit Shift Factor

- SMP and Marginal Cost of Unit values are the result of optimization

Units with lowest \$/MW effect are used to re-dispatched when the system is constrained

Unit parameters are taken into account and honored(i.e. eco min, eco max, min run time, etc.)

DFAX sign	\$/MW Effect for Raising Output	\$/MW Effect for Lowering Output
Negative DFAX = Raise Help	Choose Lowest	Choose Highest
Positive DFAX = Lower Help	Choose Highest	Choose Lowest

What is LMP?

Generation Shift Factors

Generation Shift Factor: Fraction of change in generation MW output that will appear on a line or facility

- Used to predict the effect of generation changes on transmission line flow

Generation Shift Factors vs. Distribution Factors

- Similar to distribution factors
 - Decimal value
 - Used to analyze the effect of generation shifts on MW flow
- Unlike distribution factors
 - **Do not** add up to zero

23

What is LMP?

What is LMP?

Locational Marginal Pricing (LMP) is the pricing mechanism used in PJM.

LMP is used to price:

- Energy purchases and sales
- Transmission congestion
- System losses

Physical, flow-based pricing system:

- How energy actually flows, NOT contract paths



How is LMP Applied?

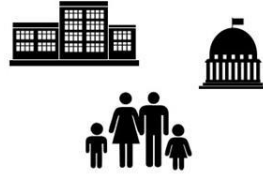
How is LMP Applied?



Generators get paid the LMP



Transactions pay the difference in LMP



Loads pay the LMP

LMP Components

LMP Components

LMP =
Locational Marginal
Pricing

System
Energy
Price



Transmission
Congestion
Cost



Cost of
Marginal
Losses

All components are calculated as part of both the Real-Time and Day-Ahead LMP

System Marginal Energy Price

System Marginal Energy Price

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

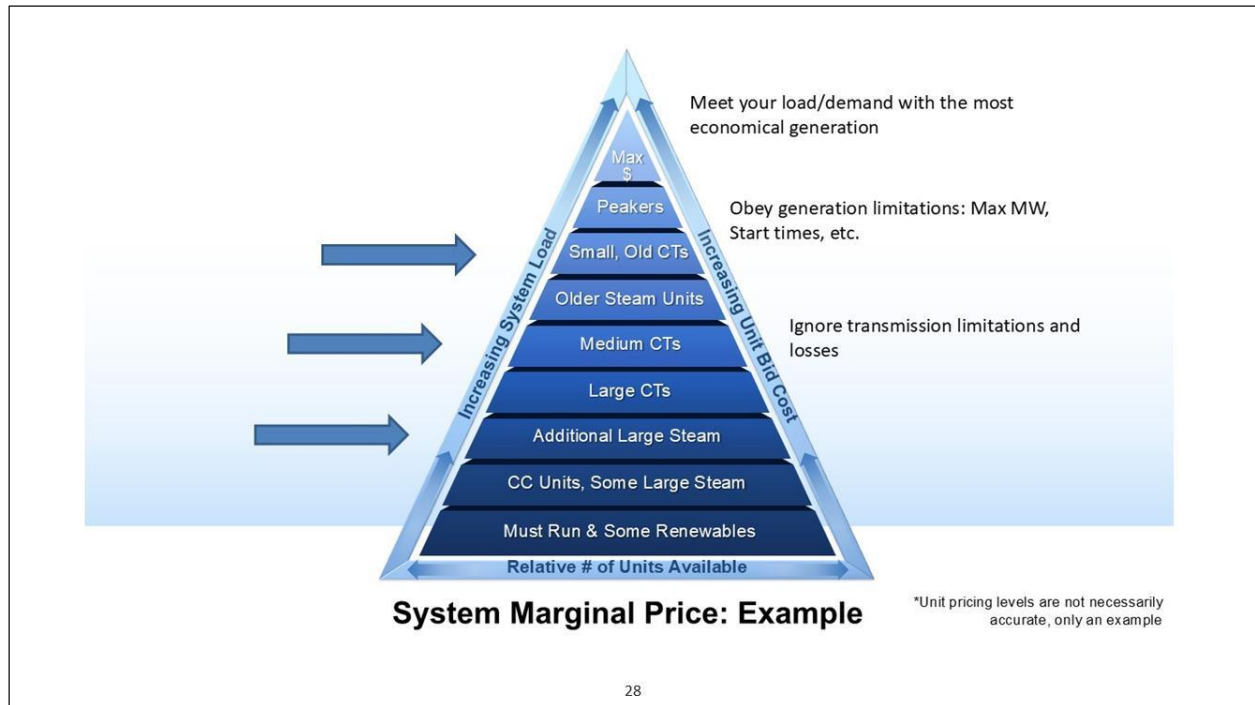
Locational Marginal Pricing

System Marginal Price

- Incremental cost to meet the demand on the system without considering losses or congestion
- SMP is LMP without losses or congestion
- Same for every bus on the system (no locational aspect)

27

System Marginal Price - Example



28

Congestion Component

Congestion Component

LMP =
Locational Marginal
Pricing



Transmission Congestion Cost

- Takes into account all congested constraints on the system
- Shadow price and distribution factors are used to determine that electrical location from a constraint
- If there are no constraints on the system, this component is ZERO
- Varies by electrical "location" if the system is constrained
- Loads pay Congestion Price, Generators get paid Congestion Price

29

Congestion Effects on LMP and Revenues

Congestion Effects on LMP and Revenues

When **upstream** of constraint...

- Congestion component is **negative**
- Results in **negative** revenues to unit



When **downstream** of constraint...

- Congestion component is **positive**
- Results in **positive** revenues to unit



Marginal Loss Component

Marginal Loss Component

LMP =
Locational Marginal
Pricing

System
Energy
Price



Transmission
Congestion
Cost



Cost of
Marginal
Losses

Cost of Marginal Losses

- Priced according to marginal loss factors
 - Calculated at every bus and represent a percentage increase in system losses caused by a increase in power injection or withdrawal
 - Calculated using penalty factors
- Varies by distance away from the system "load center"
- Loads pay the Loss Price, Generators get paid the Loss Price

31

Marginal Loss Effects on LMP and Revenues

Marginal Loss Effects on LMP and Revenues

When the bus is electrically **distant** from the load

- Marginal Loss Component is **negative**
- Results in **negative** revenues to unit



When the bus is electrically **close** to the load

- Marginal Loss Component is **positive**
- Results in **positive** revenues to unit



LMP - Example 1

LMP - Example 1

What Would You Expect to See?



Congestion Component of LMP?

Loss Component of LMP?

Constraint

200 miles



Congestion Component of LMP?

Loss Component of LMP?

30 miles



33

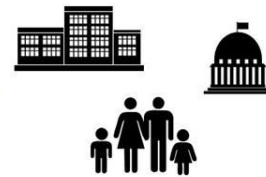
LMP - Example 2

LMP - Example 2



System Energy Price =
Congestion =
Losses =
Total LMP =

Unconstrained Transmission Path



System Energy Price =
Congestion =
Losses =
Total LMP =

34

LMP - Example 2



System Energy Price =
Congestion =
Losses =
Total LMP =

Constrained Transmission Path



System Energy Price =
Congestion =
Losses =
Total LMP =

35



Knowledge Check!

- 1. What is the primary purpose of the dispatch rate calculated by PJM?**
 - a. To determine transmission line ratings*
 - b. To assign congestion costs across the footprint*
 - c. To direct generator output based on submitted offers*
 - d. To calculate market clearing prices*

- 2. In the context of Locational Marginal Pricing (LMP), what does the congestion component represent?**
 - a. The price impact of system constraints*
 - b. The marginal unit's minimum run time*
 - c. The change in voltage due to increased load*
 - d. The cost of energy at the reference bus*

- 3. When is the penalty factor for a generator typically less than one?**
 - a. When the generator is electrically distant from the load*
 - b. When the generator is upstream of a constraint*
 - c. When the generator causes an increase in system losses*
 - d. When the generator reduces total system losses*

Questions

Questions?

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