Generation Initial Training Program

Dispatch Signal & Locational Marginal Pricing (LMP)

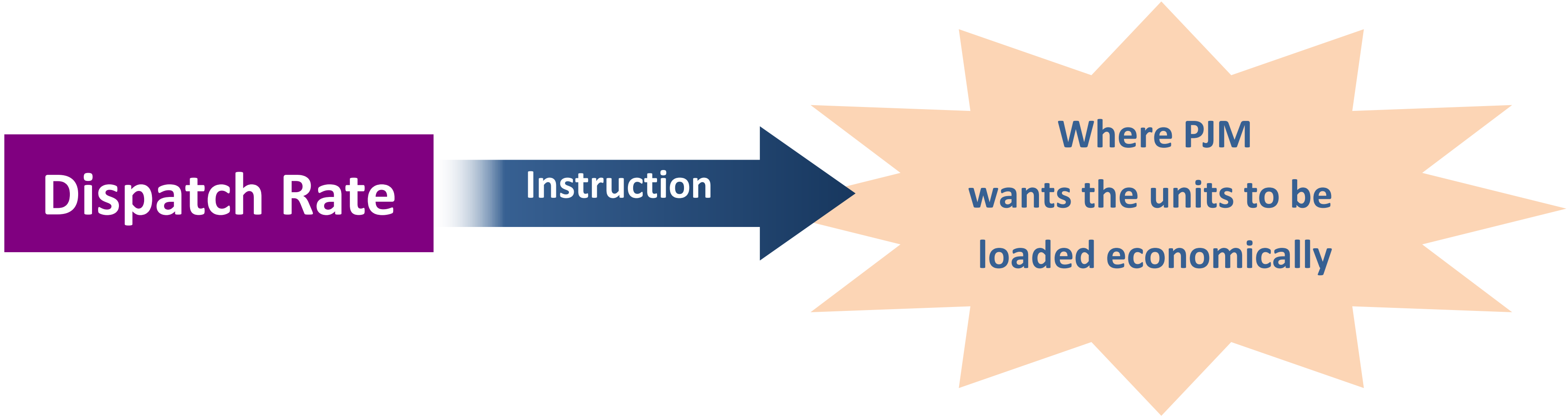
PJM State & Member Training Dept.

Objectives

- Students will be able to:
  - Identify how PJM dispatches & utilizes LMP

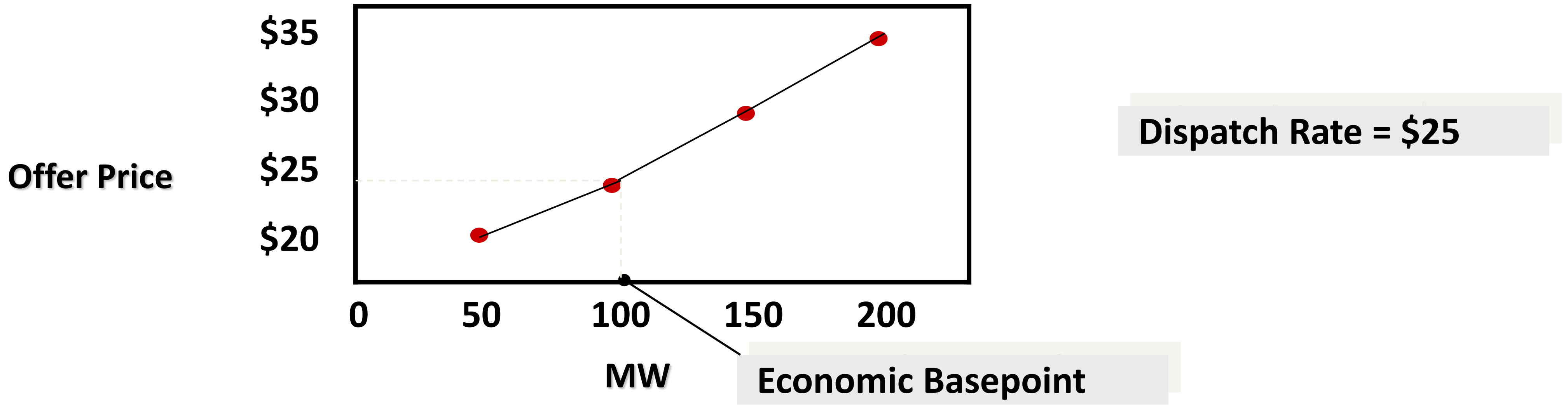
Dispatch Rate

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



Dispatch Rate

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 that indicates to what level the unit should be loaded based on the economic dispatch solution and the unit's incremental price curve

Example: Dispatch Rate: $40 – What are the Economic Basepoints?

$	MW
10	25
14	36
18	46
26	50
40	70

$	MW
8	12
16	20
20	30
26	44
40	60

$	MW
30	30
35	35
40	40
50	50
80	80

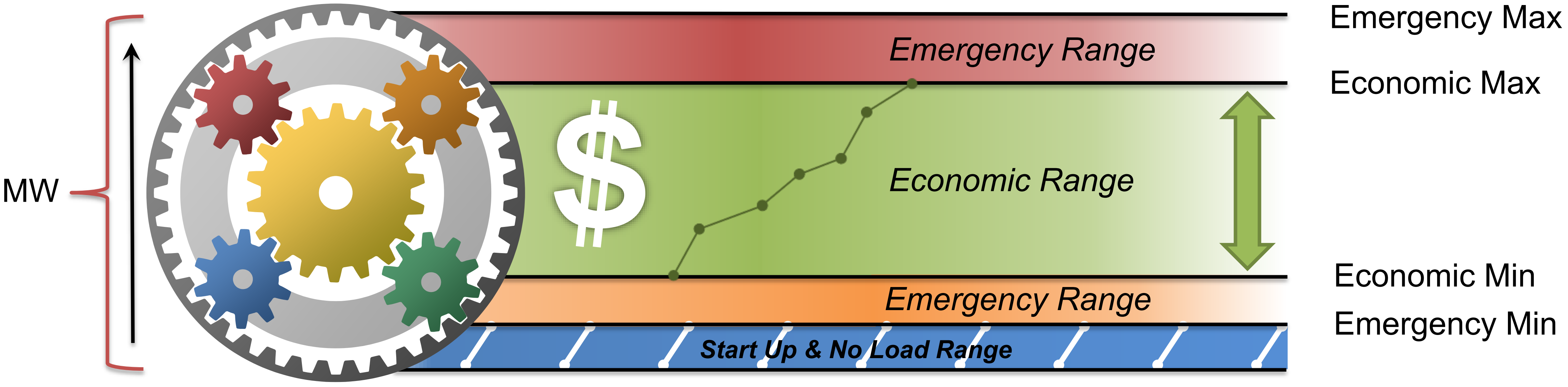
$	MW
10	20
28	60
36	88
40	112
60	130

$	MW
14	32
24	48
40	70
55	90
70	115

$	MW
10	40
20	50
34	68
40	80
60	104

%	MW
20	20
34	36
40	60
56	78
74	90

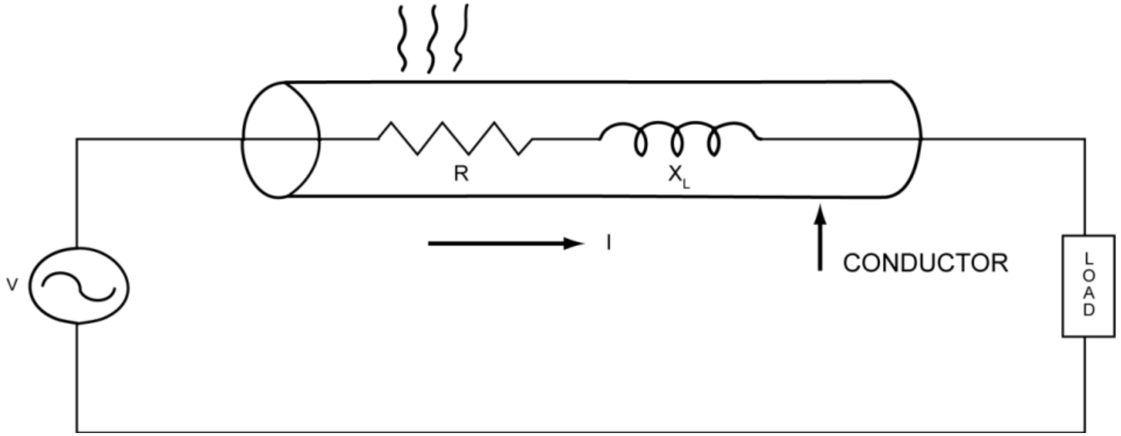
%	MW
10	35
14	46
18	56
26	76
40	90



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

$$Heat\ Disipated = I^2R$$

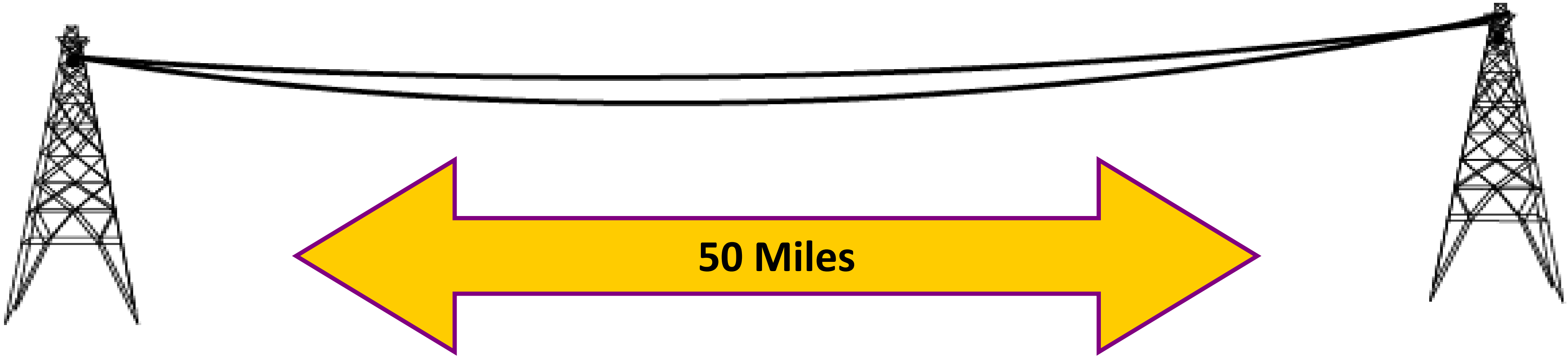


Transmission Losses

- 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

Power = Current * Voltage

Transmission Losses



Power In: 100 MW

Voltage In: 235 KV

Current In: 425.53 A

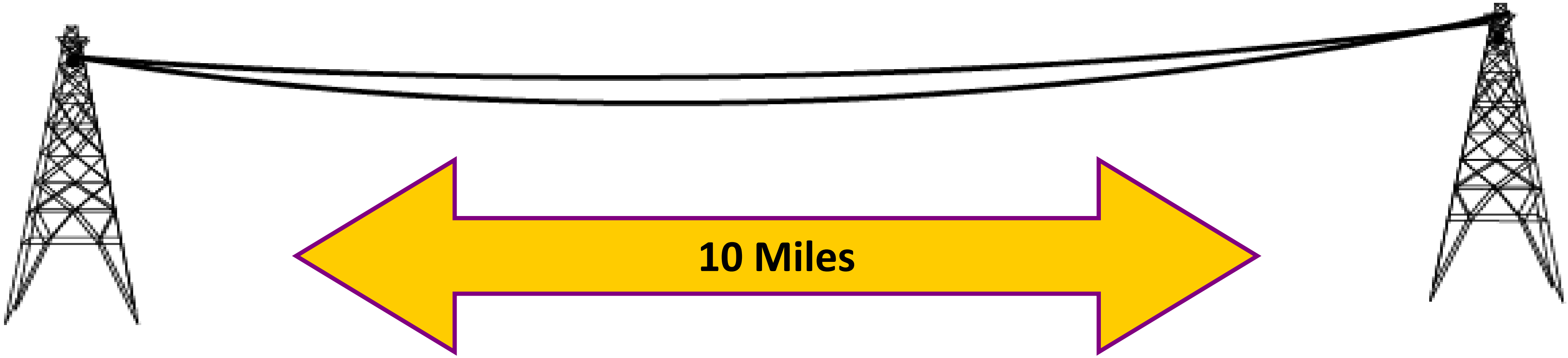
Power Out: 90.946 MW

Power Loss: 9.054 MW

Voltage out: 213.72 KV

Current Out: 425.53 A

Transmission Losses



Power In: 100 MW

Voltage In: 235 KV

Current In: 425.53 A

Power Out: 98.2 MW

Power Loss: 1.8 MW

Voltage out: 230.74 KV

Current Out: 425.53 A

Penalty Factors Effect on Dispatch

- The Incremental Loss for bus i is used to calculate a factor that can be used to include the effect of losses in the dispatch
- This factor is called the Loss Penalty Factor, or Penalty Factor

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

ΔP_L: Change in Losses

ΔP_i: 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 Factors 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

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

Increase in injection will result in higher overall system losses

Penalty Factor

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

Penalty Factors 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

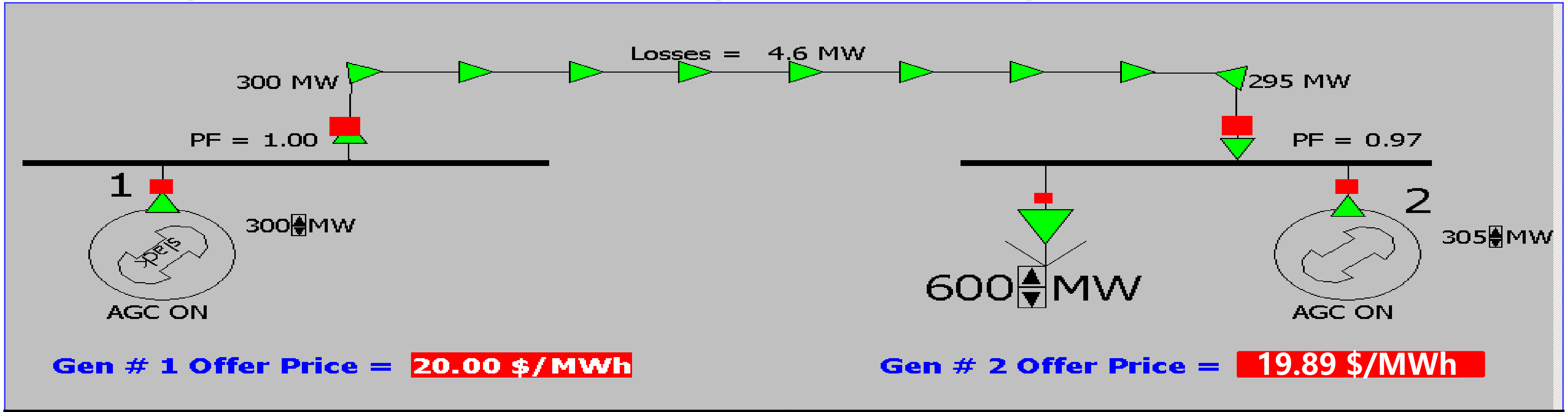
$$0 > \frac{\Delta P_L}{\Delta P_i} > -1$$

Increase in injection will result in lower overall system losses

Penalty Factor

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

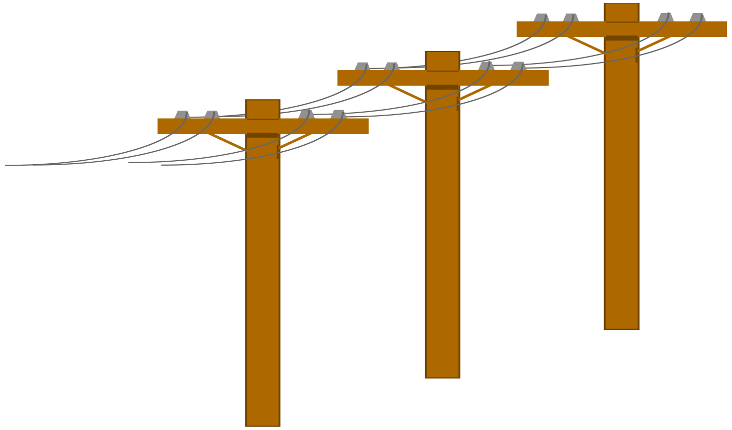
Penalty Factors Effect on Dispatch - Example



Generating Unit # 1	Generating Unit # 2
Offer Price = $ 10.00 ----- 200 MW $ 20.00 ----- 300 MW $ 30.00 ----- 400 MW $ 40.00 ----- 500 MW	Offer Price = $ 10.00 ----- 200 MW $ 20.00 ----- 300 MW $ 30.00 ----- 400 MW $ 40.00 ----- 500 MW
Generating 300 MW	Generating 305 MW
Penalty Factor = 1.00 $20 * 1.00 = $20.00	Penalty Factor = 0.97 $20.50 * 0.97 = $19.89

Operational Limits

- **Thermal Limits -** Thermal limits are due to the heat dissipation capability of power system equipment
- **Voltage Limits -** Utility and customer equipment is designed to operate at a certain supply voltage (or a small range around an ideal voltage)
- **Stability Limits -** Refers to the power system maintaining a state of equilibrium



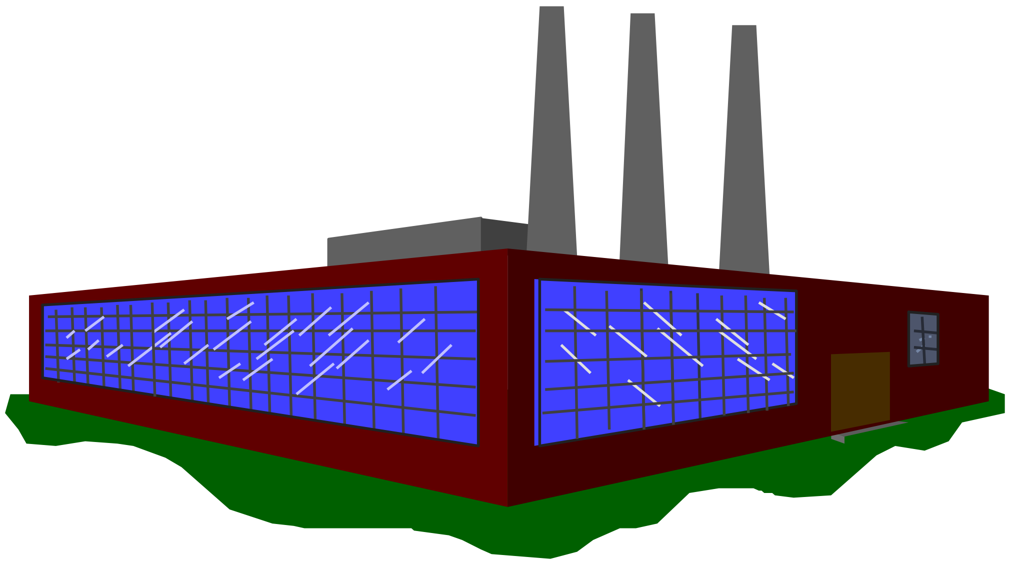
Control Actions

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

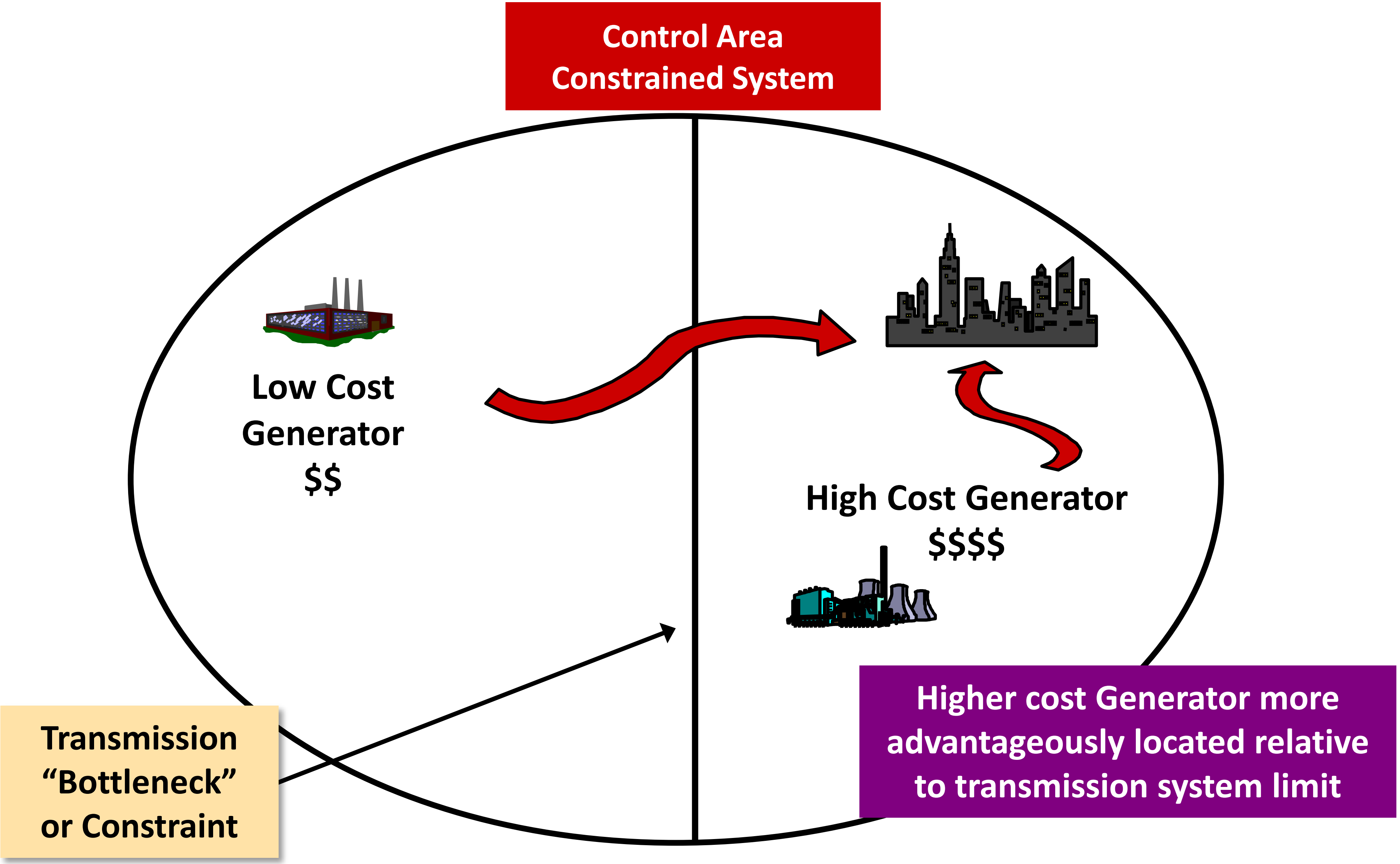
❶ System Reconfiguration

❷ Transaction Curtailments

❸ Redispatch Generation

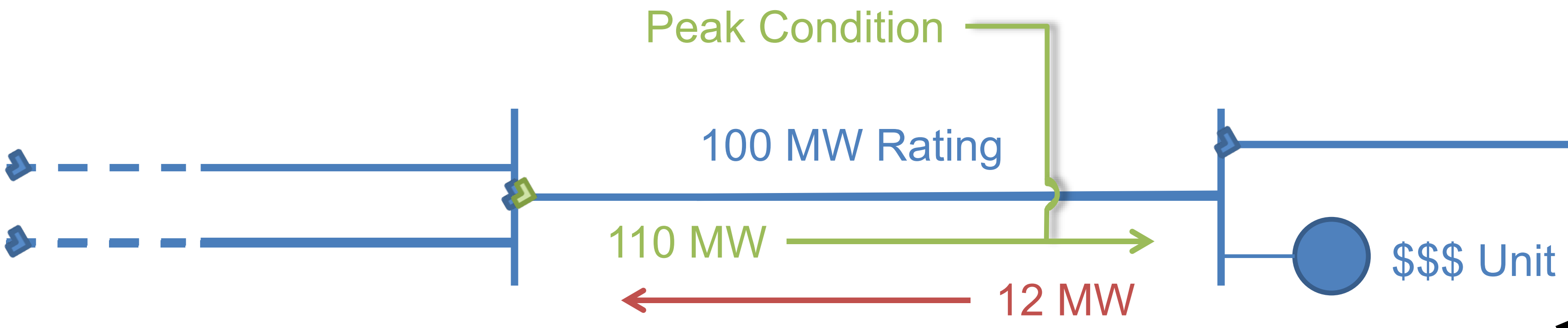


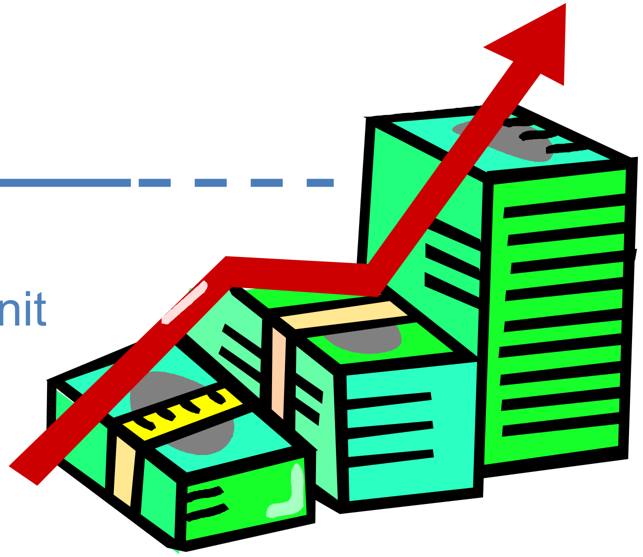
Security Constrained Re-Dispatch



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"





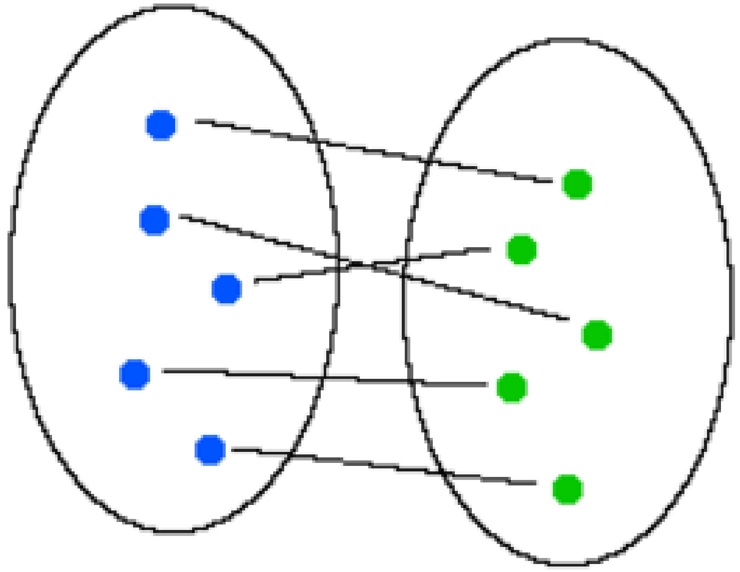
Congestion Effects on LMP and Revenues

- When the bus is **upstream** of a constraint
  - Congestion Component is ***negative***
  - Results in ***negative*** revenues to unit

- When the bus is **downstream** of a constraint
  - Congestion Component is ***positive***
  - Results in ***positive*** revenues to unit

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



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

- 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

- 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

Generation Re-dispatch

For Contingency Analysis

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

- 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

Real Time Contingency Operations

- During Constrained Operations, resources will redispatched cost-effectively based on their bid parameters
- **Cost-effective redispatch** (**$/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.)

Generation Shift Factors

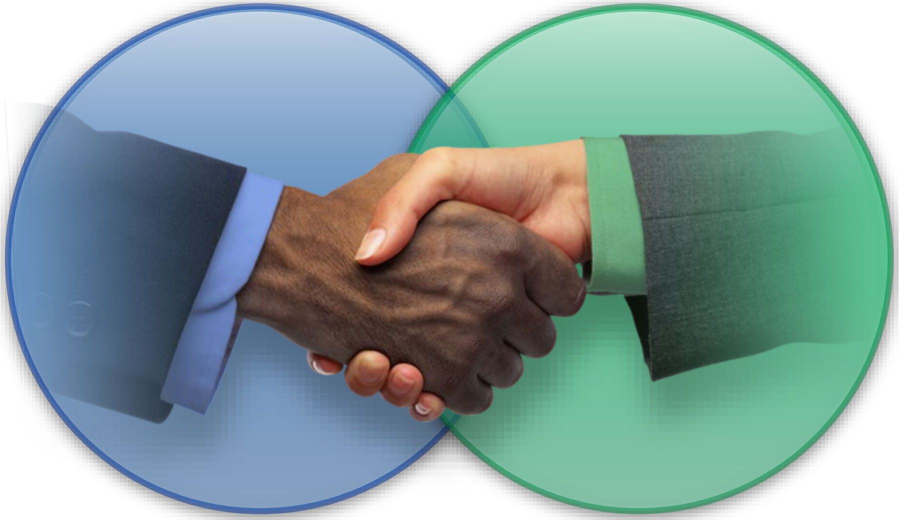
Generation Shift Factors

- The change (or sensitivity) of active power flow in a reference direction on a transmission line with respect to a change in injection at the generator bus and a corresponding change in withdrawal at the reference bus
  - Calculated with a DC Power Flow
- Shift Factors change when:
  - Transmission topology changes
  - Line impedance changes
- Also known as Generation DFax

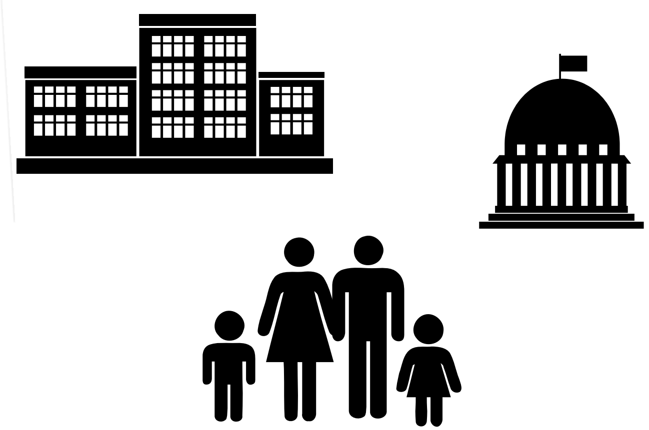
What is LMP?

- Locational Marginal Price
- 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

Generators get paid the LMP



Transactions pay the difference in LMP



Loads pay the LMP

LMP = **System Energy Price** + **Transmission Congestion Cost** + **Cost of Marginal Losses**

Locational Marginal Pricing

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

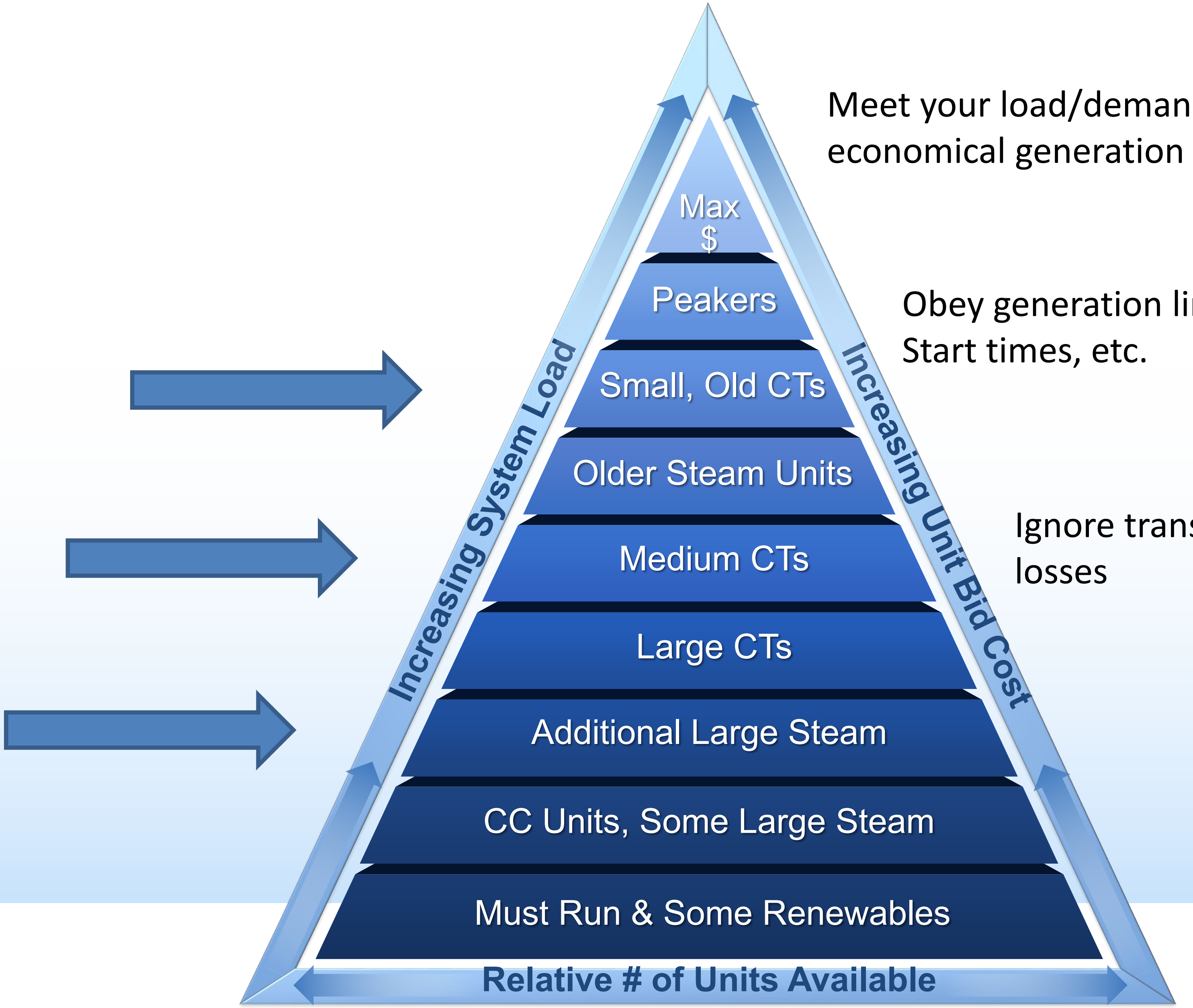
6032

LMP = **System Energy Price** + **Transmission Congestion Cost** + **Cost of Marginal Losses**

Locational Marginal Pricing

System Marginal Price (SMP)

- Incremental price of energy for the system, given the current dispatch, at the load weighted reference bus
- SMP is LMP without losses or congestion
- Same price for every bus in PJM (no locational aspect)



Meet your load/demand with the most economical generation

Obey generation limitations: Max MW, Start times, etc.

Ignore transmission limitations and losses

System Marginal Price: Example

*Unit pricing levels are not necessarily accurate, only an example

LMP Locational Marginal Pricing = **System Energy Price** + **Transmission Congestion Cost** + **Cost of Marginal Losses**

Congestion Component (CLMP)

- Represents price of congestion for binding constraints
- Uses the Shadow Price
- Will be zero in an Unconstrained System
- Varies by electrical “location” if system is constrained
- Load pays Congestion Price, Generation is paid Congestion Price

Congestion effects on LMP and Revenues

- When the bus is **upstream** of a constraint
  - Congestion Component is **negative**
  - Results in **negative** revenues to unit

- When the bus is **downstream** of a constraint
  - Congestion Component is **positive**
  - Results in **positive** revenues to unit

LMP = **System Energy Price** + **Transmission Congestion Cost** + **Cost of Marginal Losses**

Locational Marginal Pricing

Marginal Loss Component (MLMP)

- Represents price of marginal losses
  - Transmission losses are priced according to marginal loss factors which are calculated at a bus and represent the percentage increase in system losses caused by a small increase in power injection or withdrawal. Calculated using penalty factors
- Will vary by location
- Used to price losses
  - Load pays the Loss Price
  - Generation is paid the Loss Price

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

What Would You Expect to See?

Congestion Component of LMP? (-)

Loss Component of LMP? (-)

200 miles

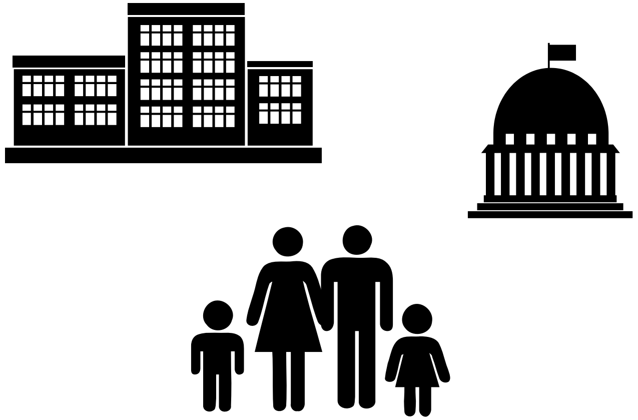
Constraint

30 miles

Congestion Component of LMP? (+)

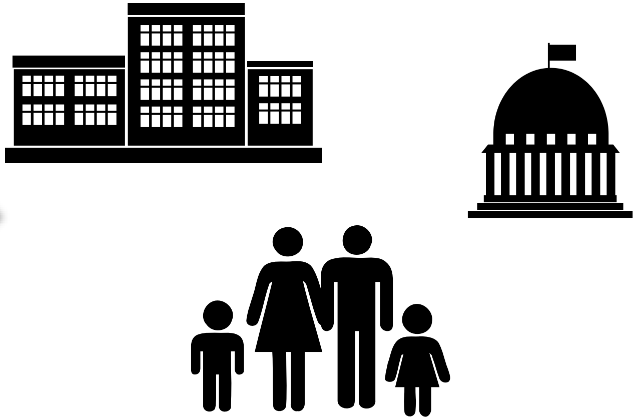
Loss Component of LMP? (+)

Unconstrained Transmission Path



System Energy Price =	SAME
Congestion =	$0*
Losses =	- Effect
Total LMP =	Lower

System Energy Price =	SAME
Congestion =	$0*
Losses =	+ Effect
Total LMP =	Higher



System Energy Price = **SAME**
Congestion = **- Effect***
Losses = **- Effect**

Total LMP = **Lower (Much?)**

System Energy Price = **SAME**
Congestion = **+ Effect***
Losses = **+ Effect**

Total LMP = **Higher (Much?)**

LMP Components – Unconstrained System

System Energy Price = $20.4
Congestion = $ 0.0
Losses = $ 0.0

LMP= $20.4

Installed = 2,000 MW

Dispatch 1500 MW

Loss Penalty Factor = 1.02

Unconstrained Transmission Path

Loss Penalty Factor = 1.0

System Energy Price = $20.4
Congestion = $ 0.0
Losses = -$ 0.4

LMP = $20.0

Installed = 700 MW

Constrained System
LMP Components - System Energy Price

System Energy Price = $50.0
Congestion =
Losses =

LMP= $50.0

Installed = 2,000 MW

Dispatch 1000 MW

Flow = 1000 MW

Limit = 1000 MW

Loss Penalty Factor = 1.02

Loss Penalty Factor = 1.0

System Energy Price = $50.0
Congestion =
Losses =

LMP = $50.0

Dispatch 500 MW

Installed = 700 MW

Constrained System
LMP Components - Congestion

System Energy Price = $50.0
Congestion = $ 0.0
Losses =

LMP= $50.0

Installed = 2,000 MW

Dispatch 1000 MW

Flow = 1000 MW

Limit = 1000 MW

Loss Penalty Factor = 1.02

Loss Penalty Factor = 1.0

System Energy Price = $50.0
Congestion = -$29.0
Losses =

LMP = $21.0

Dispatch 500 MW

Installed = 700 MW

Constrained System
LMP Components Marginal Losses

System Energy Price = $50.0
Congestion = $ 0.0
Losses = $ 0.0

LMP= $50.0

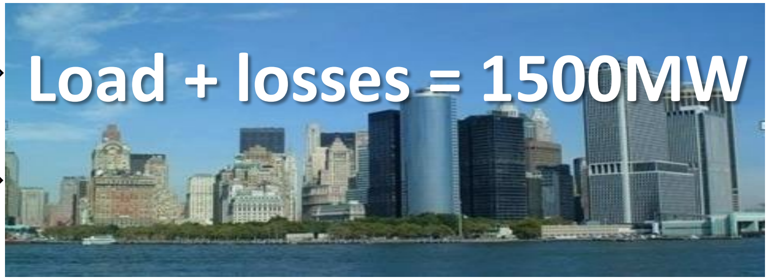
Installed = 2,000 MW

Dispatch 1000 MW

Loss Penalty Factor = 1.02

Flow = 1000 MW

Limit = 1000 MW



Loss Penalty Factor = 1.0

System Energy Price = $50.0
Congestion = -$29.0
Losses = -$ 1.0

LMP = $20.0

Dispatch 500 MW

Installed = 700 MW

Questions?

PJM Client Management & Services

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