

# Solving the ISO “Seams” Problem for Uniform Boundary LMP’s

Bruce Wollenberg

University of Minnesota



# Central Market Designs

- PJM and NYISO are central markets based on Locational Marginal Price
- No identification of individual transactions
- Each generator and each load bids to sell (buy) from a central exchange.
- Central exchange calculates the bus Locational Marginal Prices (LMP's) which determine payments and transmission charges



# Locational Marginal Price (LMP)

- Requires a Security Constrained Optimal Power Flow
- Usually coupled with Unit Commitment (SCUC)
- The only transmission management scheme now in use that uses full AC network model

# Optimal Power Flow (linearized)

$$\min \left[ \sum_i C_i(P_{G_i}) - \sum_i W_i(P_{E_i}) \right]$$

**Gen Bid Cost – Load Bid Cost**

$$\left[ \mathbf{B}_x \right] \left[ \begin{array}{c} \mathbf{q}_1 \\ \vdots \\ \mathbf{q}_n \end{array} \right] - \left[ \begin{array}{c} P_{G_1} - P_{E_1} \\ \vdots \\ P_{G_n} - P_{E_n} \end{array} \right] = \left[ \begin{array}{c} -P_{D_1} \\ \vdots \\ -P_{D_n} \end{array} \right]$$

**Transmission System Power Balance Constraint**

$$\frac{1}{x_{ij}} (\mathbf{q}_i - \mathbf{q}_j) + s_{ij} = P_{ij}^{\max}$$

**Transmission line limits**

$$\frac{1}{x_{ij}} (\mathbf{q}_i - \mathbf{q}_j) + LODF_{ij,mn} \cdot \frac{1}{x_{mn}} (\mathbf{q}_m - \mathbf{q}_n) + s_{ij,mn} = 1.1 \cdot P_{ij}^{\max}$$

**Transmission contingency constraints**



# Real World OPF

- 10,000 bus, 15,000 line model
- 20,000 dependent variables
- 300-500 generation bids
- ~ 8000 load bids
- 15,000 line limits
- Very large number of contingency limits



# Security Constrained Unit Commitment

- 1/0 problem with generator on/off status added to the Security Constrained OPF
- Solved for 24 hours of the day ahead

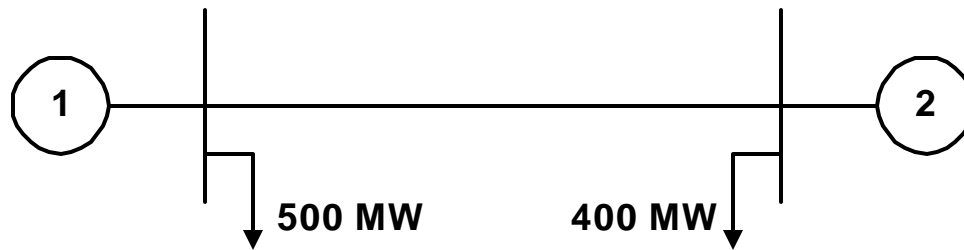


# Data to drive the OPF

- ~ 20,000 bus measurements
- ~ 30,000 line flow measurements
- ~ 100,000 circuit breaker open/closed status values
- ~ 5000 independent transactions data
- Gather the above data and solve a state estimation every 5 minutes
- Gather generation and load bids for every hour
- Solve OPF for each hour



## CASE 1



### Generator 1

Asks	MW	Price
A	400	5.00
B	400	7.50

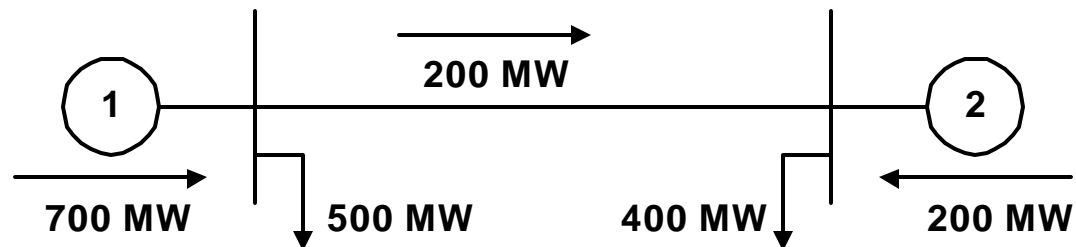
### Generator 2

Asks	MW	Price
C	200	6.50
D	200	8.00

## CASE 1 (cont)

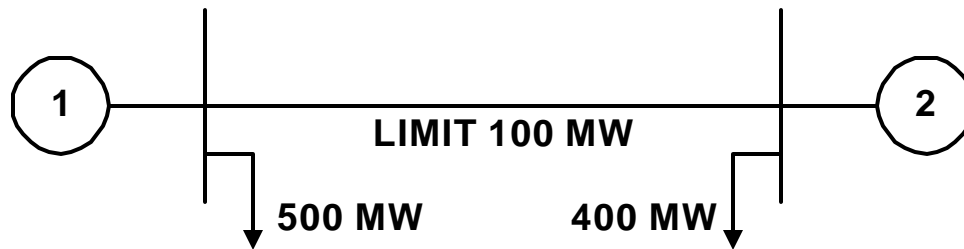
Schedule of generation:

Ask	MW	Price
A	400	5.00
C	200	6.50
B	300	7.50 clearing price (same for both buses)



The next MW purchased at either bus will be taken from the B segment of generator 1 for a price of 7.50 \$/MWh

## CASE 2



Generator 1

Ask	MW	Price
A	400	5.0
B	200	7.50

Generator 2

Ask	MW	Price
C	200	6.50
D	100	8.00

## CASE 2 (cont)

clearing price at bus 1 = 7.50

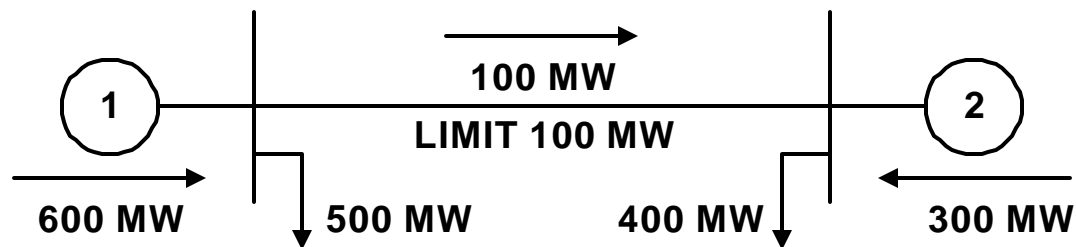
clearing price at bus 2 = 8.00

Bus 1 generation schedule

Ask	MW	Price
A	400	5.0
B	200	7.50 clearing price

Bus 2 generation schedule

Ask	MW	Price
C	200	6.50
D	100	8.00 clearing



The next MW purchased at bus 1 will come from the B segment of generator 1 for a price of 7.50 \$/MWh, but the next MW purchased at bus 2 must come from the D segment of generator 2 at 8.00 \$/MWh since the line is at capacity.

# Case 1 Accounting

Revenue Collected from Loads	Revenue paid to generators and Transmission Owners
Load 1: $500 \times 7.50 = 3750$	Gen 1: $700 \times 7.50 = 5250$
Load 2: $400 \times 7.50 = 3000$	Gen 2: $200 \times 7.50 = 1500$ Transmission = 0
Total: 6750	Total: 6750

# Case 2 Accounting

Revenue Collected from Loads	Revenue paid to generators and Transmission Owners
Load 1: $500 \times 7.50 = 3750$	Gen 1: $600 \times 7.50 = 4500$
Load 2: $400 \times 8.00 = 3200$	Gen 2: $300 \times 8.00 = 2400$
	Transmission $100(8.00-7.50) = 50$
Total:           6950	Total:           6950



# Financial Transmission Right (FTR)

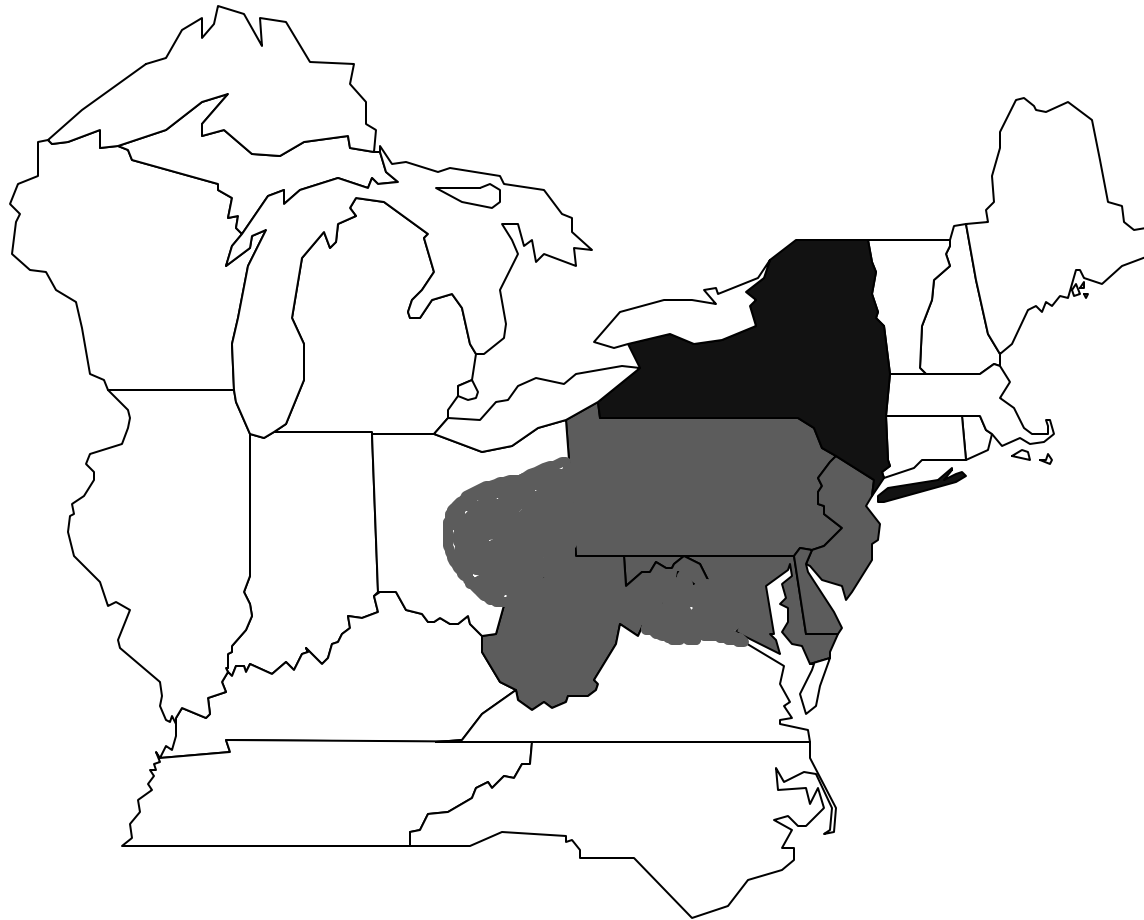
- Transmission charge in an LPM market is:
  - $(LPM_i - LMP_j) * MW_{flow}$
- Holder of FTR receives credit of:
  - $(LPM_i - LMP_j) * MW_{flow}$
  - Where  $MW_{flow}$  is the “amount” purchased
- Holder can transfer the amount of the FTR from location  $i$  to  $j$  at no charge (credit cancels transmission charge)



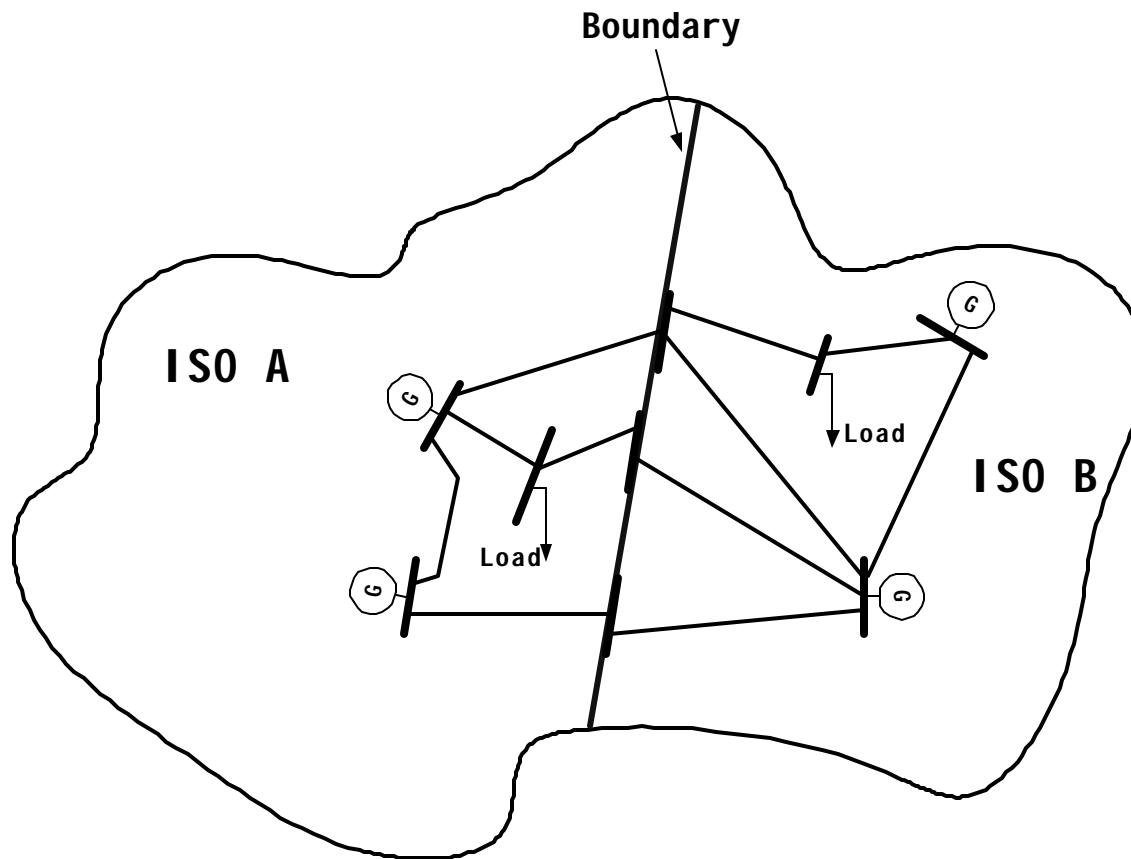
# FERC Standard Market Design

- FERC's proposal mirrors the PJM and NY ISO market designs
- Key elements of SMD
  - LMP based congestion management
  - Financial Transmission Rights
  - Financially binding day-ahead energy markets
  - Real time balancing markets
  - Capacity markets (initial reluctance, gradual acceptance)
  - Market power mitigation

# The New York – PJM Seam



# Seams Problem



**Both regions A and B operate by LPM calculations.**

**They will get different costs along the boundary or seam between them**

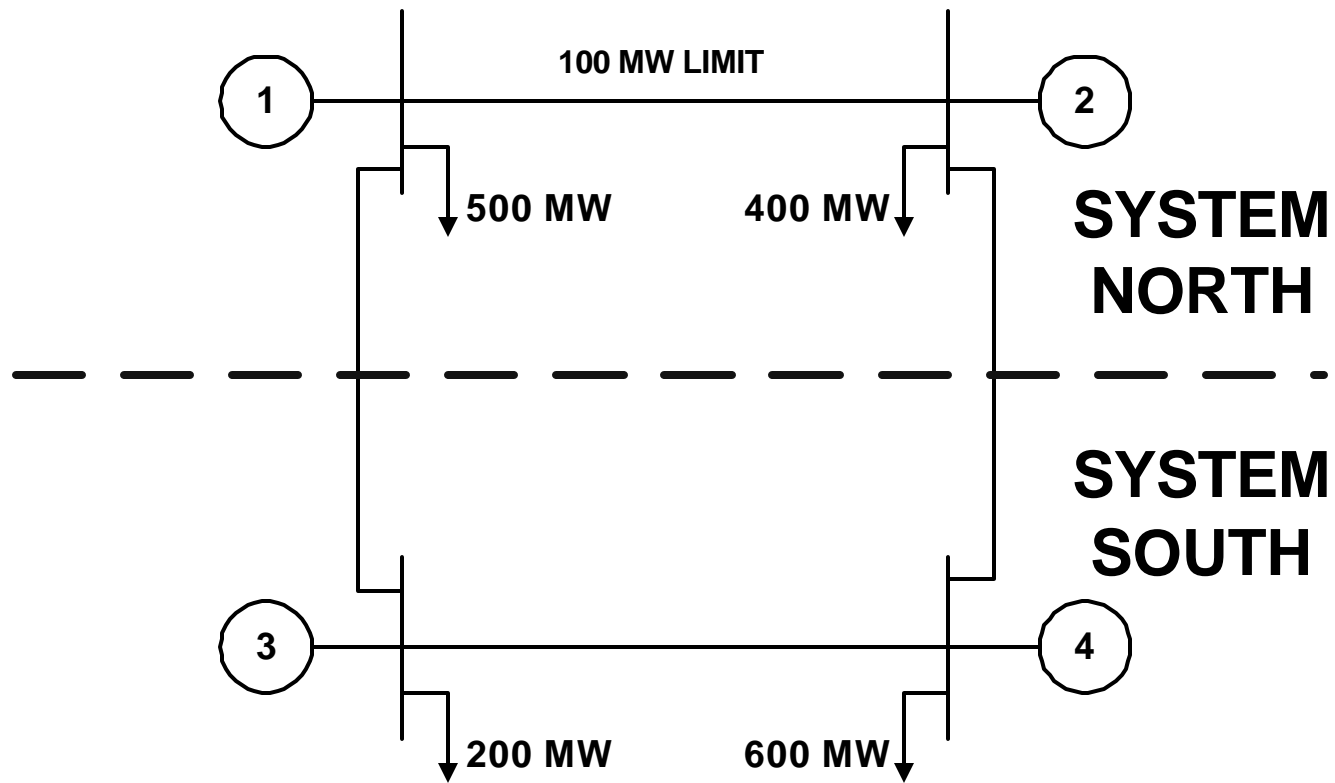
**If both A and B were operated as one market with one LMP calculation – there would be no such difference**



# Problems with Seams

- Trading across the seam is difficult due to price differences that are only due to regional OPF solutions

# Combined System

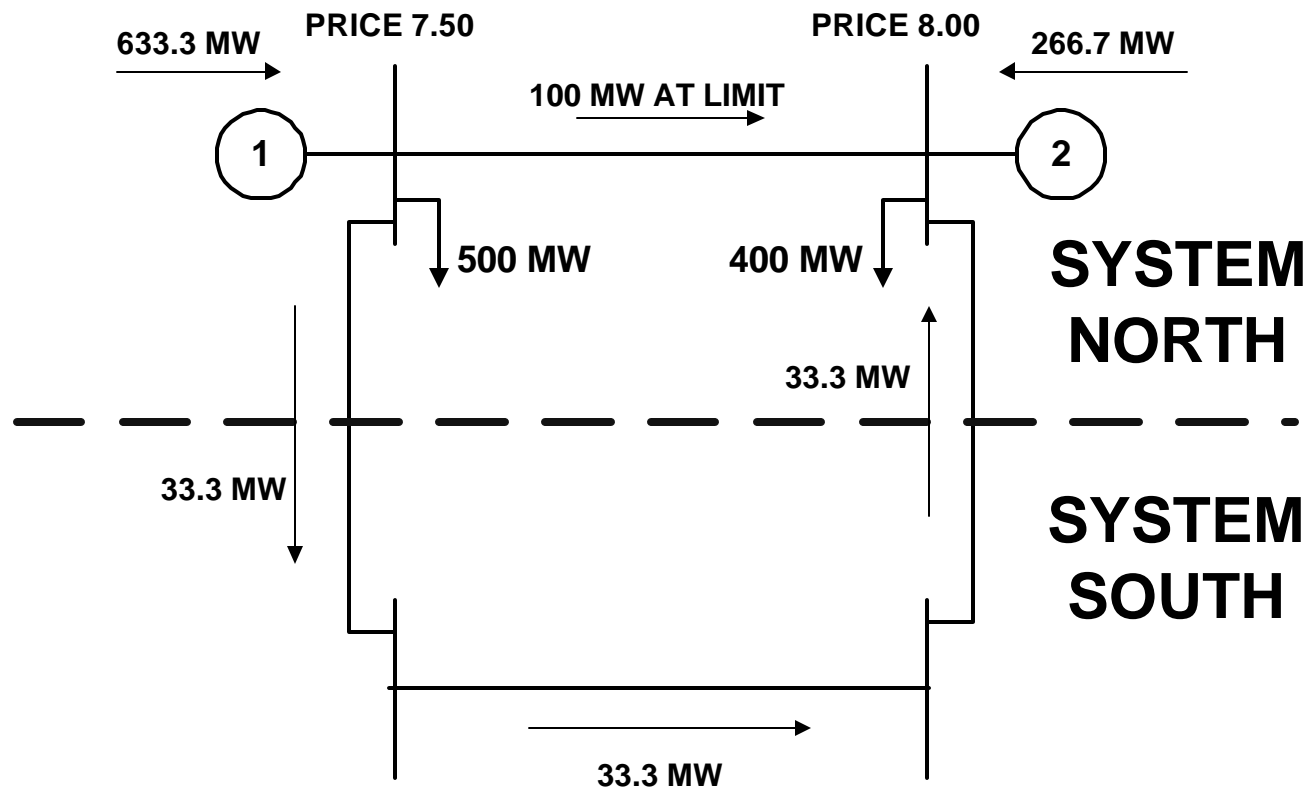




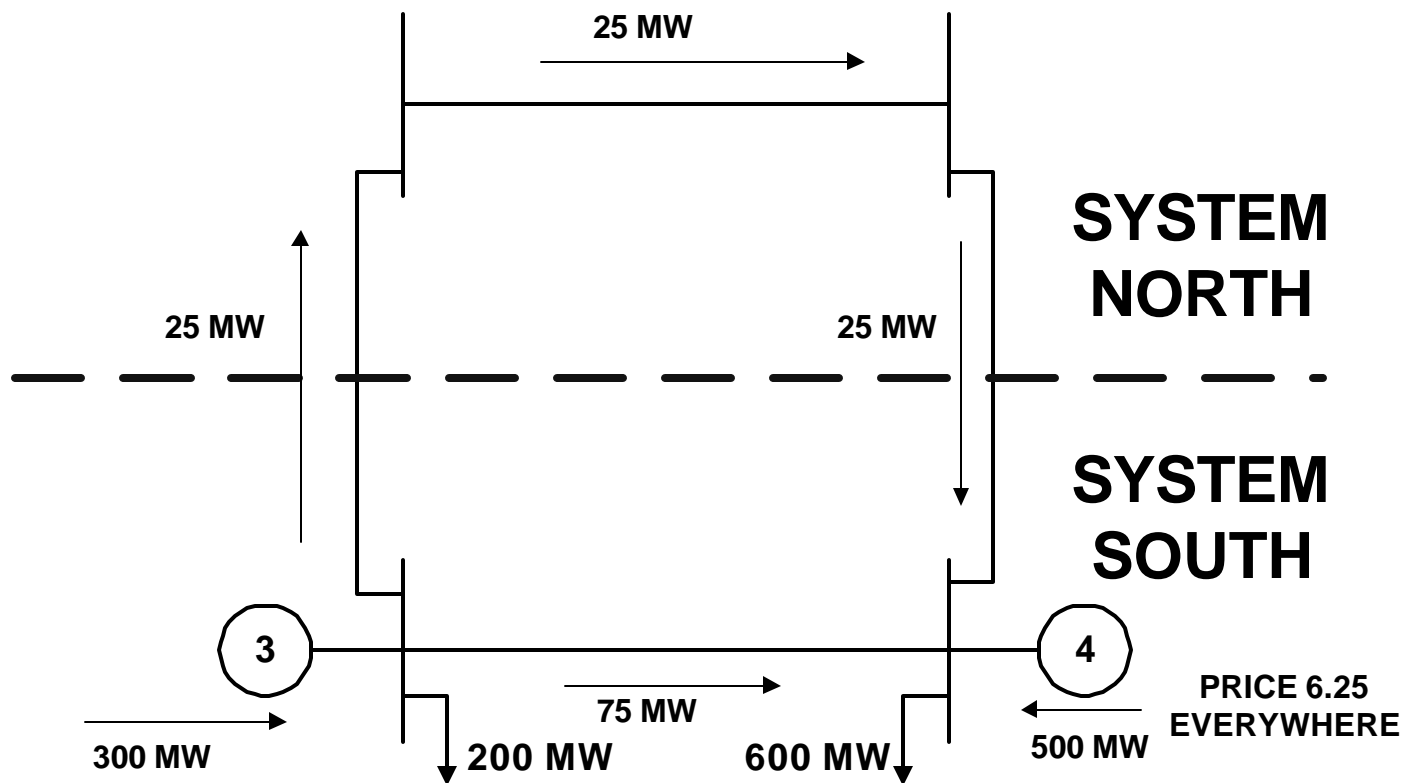
# Pricing Data for Combined System

BUS	PRICE (\$/MWh)	MW
1	5.00	400
1	7.50	400
2	6.50	200
2	8.00	200
3	6.00	300
3	8.50	100
4	4.50	400
4	6.25	200

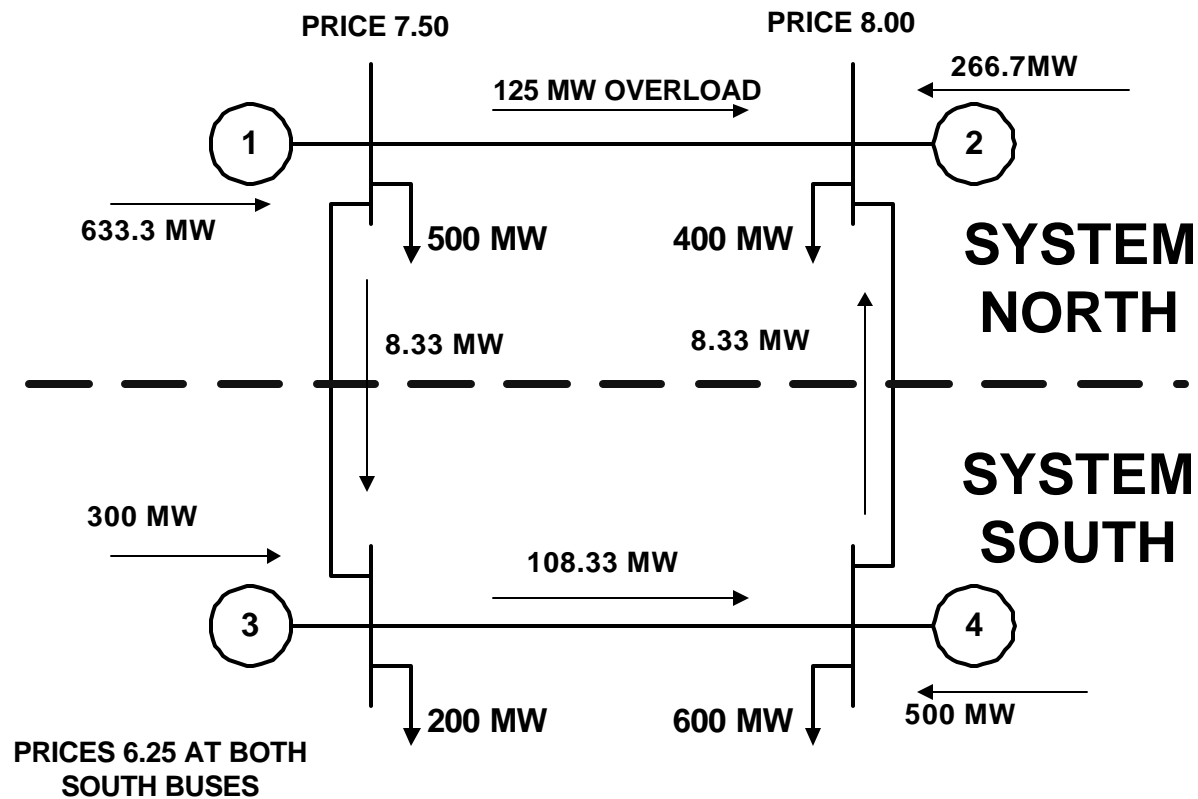
# NORTH System alone



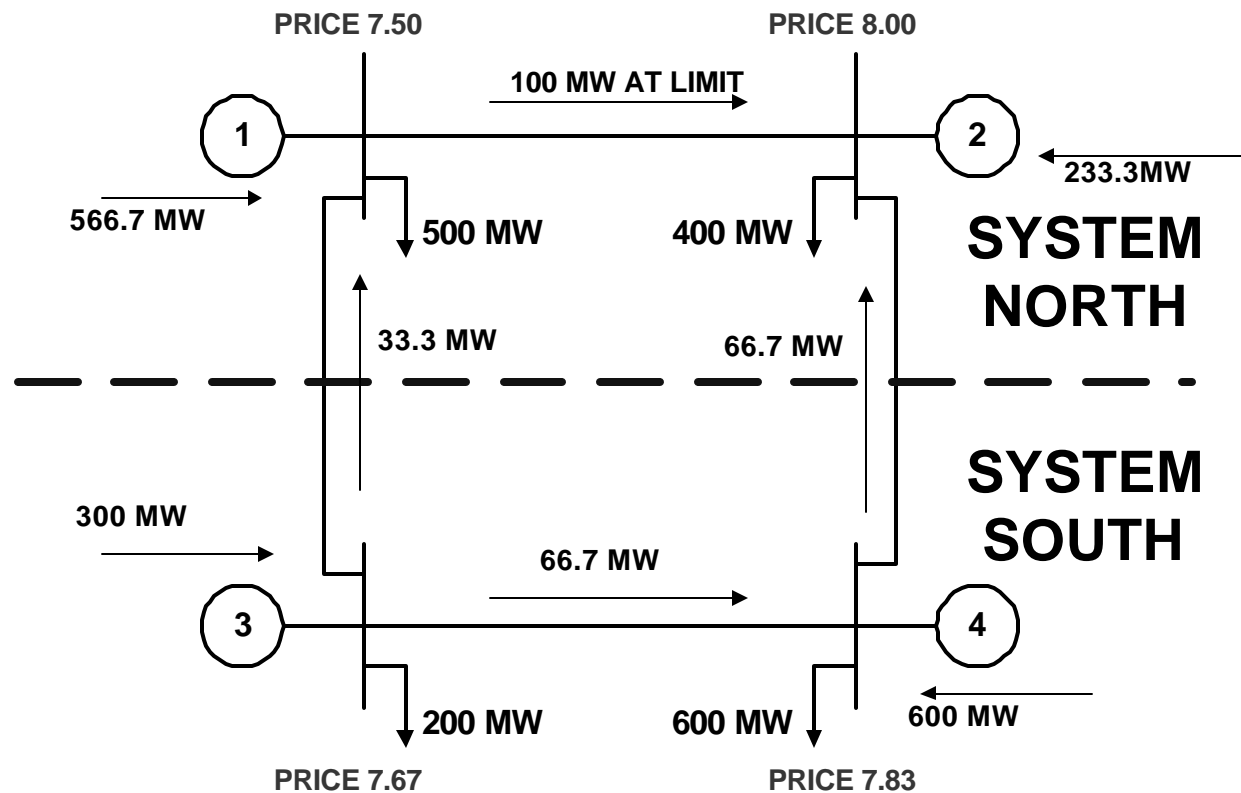
# SOUTH System alone



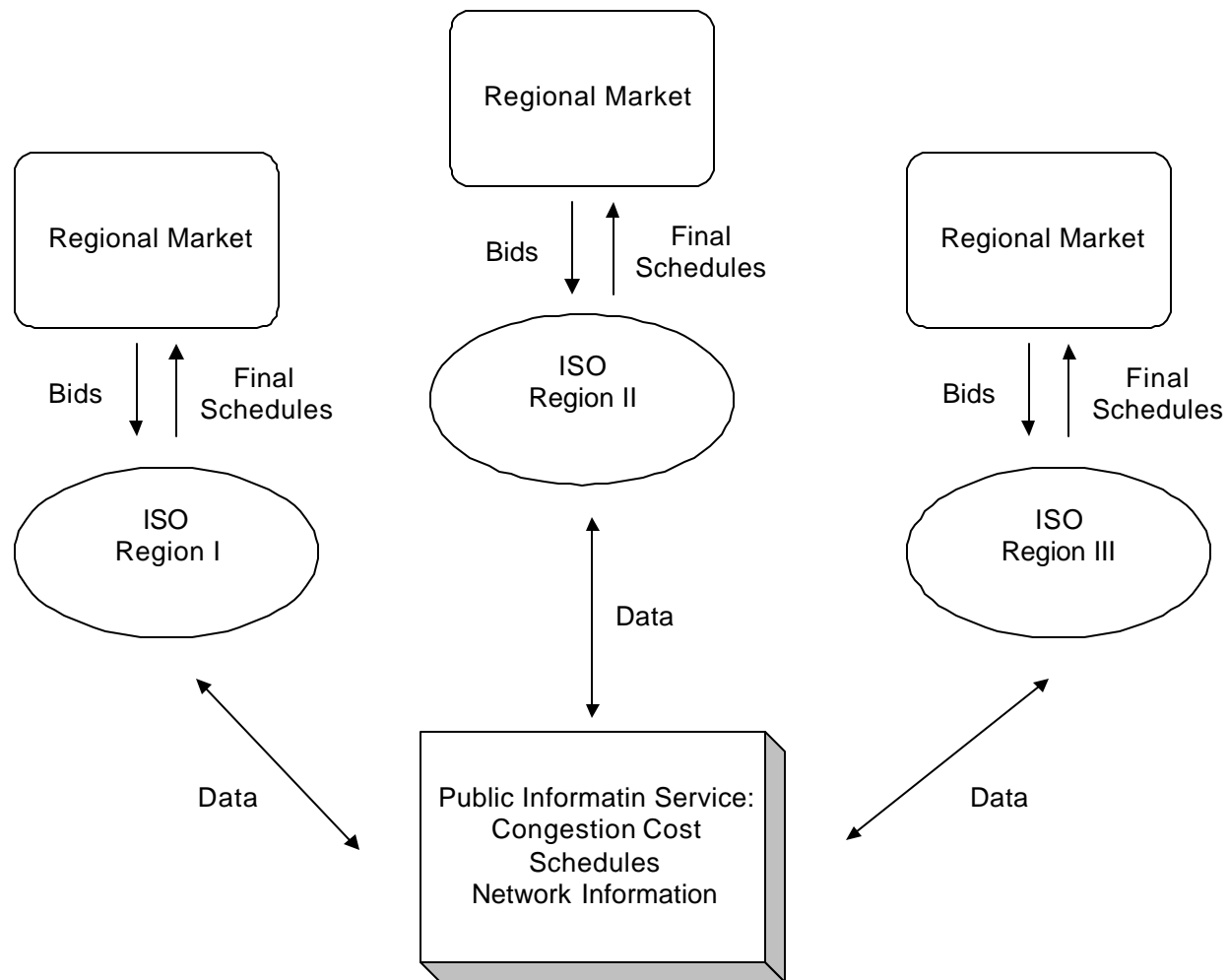
# Superposition of all flows



# Optimal Solution for Combined System



# Solution to the “Seams” Problem

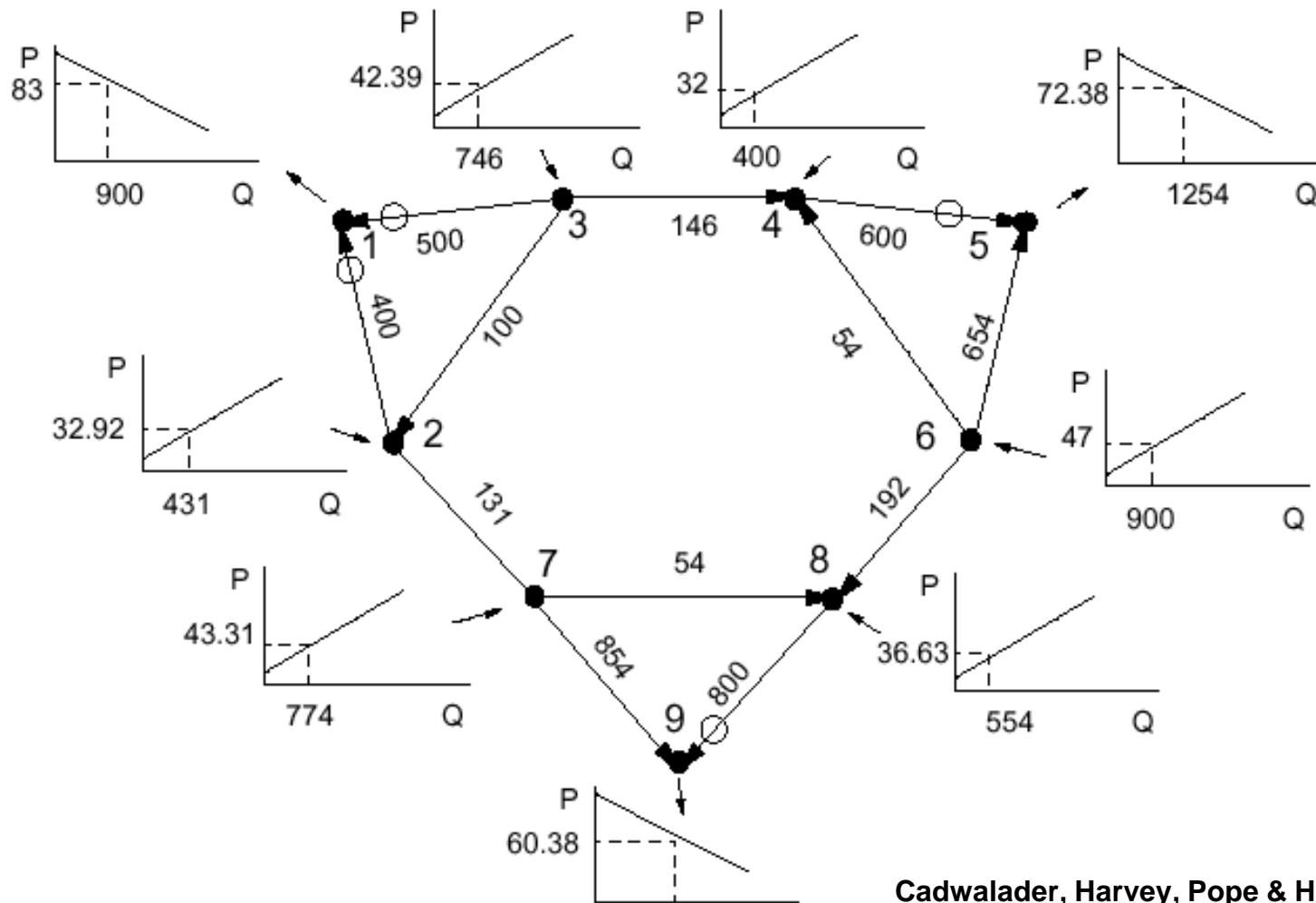




# Information Exchanged

- All regions have the same network model covering all regions
- After the solution of each region's OPF:
  - exchange power injections, LMP's for each bus
  - exchange binding transmission constraint lambdas
- Each region now recalculates with a penalty term for its effect on other region's constraints
- Usually converges in three iteration for linear case

# Constrained Market Solution



Cadwalader, Harvey, Pope & Hogan  
Harvard University 1999

# Iterative Solution to the Constrained Market

Region Bus No.		Start Iteration	1 <sup>st</sup> Iteration	2 <sup>nd</sup> Iteration	3 <sup>rd</sup> Iteration	Final Iteration
1	Price (\$/MW)	50	82.30	82.95	83.00	83.00
	Load (MW)	2000	923	900	900	900
2	Price (\$/MW)	50	33.62	32.63	32.90	32.90
	Load (MW)	-1000	-454	-421	-430	-430
3	Price (\$/MW)	50	42.24	42.75	42.38	42.38
	Load (MW)	-1000	-741	-758	-746	-746
4	Price (\$/MW)	50	31.43	31.95	32.00	32.00
	Load (MW)	-1000	-381	-398	-400	-400
5	Price (\$/MW)	50	71.32	72.43	72.38	72.38
	Load (MW)	2000	1289	1252	1254	1254
6	Price (\$/MW)	50	47.93	46.97	47.00	47.00
	Load (MW)	-1000	-931	-899	-900	-900
7	Price (\$/MW)	50	44.03	43.27	43.29	43.30
	Load (MW)	-1000	-801	-776	-776	-777
8	Price (\$/MW)	50	36.91	36.64	36.64	36.65
	Load (MW)	-1000	-564	-555	-555	-555
9	Price (\$/MW)	50	60.23	60.43	60.40	60.40
	Load (MW)	2000	1659	1652	1653	1654



# Congestion Constraints

Branch No.	1	2	3	4	5	6	7	8	9	10	11	12
From Bus	1	1	2	2	3	4	4	5	6	7	7	8
To Bus	2	3	3	7	4	5	6	6	8	8	9	9
Lambda	-69.98	-20.79	0.00	0.00	0.00	65.73	0.00	0.00	0.00	0.00	0.00	40.78



# Research Challenge for Seams Problem

- Do all of the OPF matching using an AC network model, an AC OPF and AC security analysis
- This presents a great problem wrt convergence and stability of solutions
- Added complexity: solve the seams problem within a SCUC