

Congestion

MMUAC

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LMP at any bus

ISO's Economic Dispatch Problem

$$\text{Min}_{gen} \sum_{i=1}^{imax} \sum_j Price(i,j) * gen(i,j)$$

Subject to

$$\text{Load Balance } LB: \sum_{i=1}^{nodemax} \sum_j gen(i,j) = \sum_{i=1}^{nodemax} dem(i)$$

Normal Constraints (all transmission lines working)

$$N^U(l,k): \forall l,k \sum_{i=1}^{nodemax} shift((l,k),i) * \left\{ \left[\sum_j gen(i,j) \right] - dem(i) \right\} \leq pmax^n(l,k)$$

$$N^L(l,k): \forall l,k \sum_{i=1}^{nodemax} shift((l,k),i) * \left\{ \left[\sum_j gen(i,j) \right] - dem(i) \right\} \geq pmin^n(l,k)$$

$$LMP_i = \mu + \sum_j dfax_{ij} * \lambda1_j + \sum_j dfax_{ij} * \lambda2_j + \dots$$

$$LMP = SMP + CLMP1 + CLMP2 + \dots$$

Congestion

- **CLMP is not congestion. CLMP indicates a difference in LMP relative to a reference price (SMP) due to constraints.**
- **Congestion is the difference between what load pays for energy and what generation is paid for energy due to transmission constraints, net of virtual bids settlement in LMP market.**
- **Congestion collected from load by a binding transmission constraint is based on the shadow price of the constraint and market flow on that constraint.**
- **Total congestion from binding constraint j=**

$$\lambda_j (\sum_i \sum_j dfax_{ij} * L_i - \sum_i \sum_j dfax_{ij} * G_i) = \lambda_j * (\text{market flow on line } j) = \text{congestion}$$

Congestion

- **Load specific contribution to the congestion collected by a constraint is based on the load's proportional contribution to the market flow (relative to all load) on that constraint.**
- **If two loads, each with a DFAX difference of 0.5 to a constraint, each with 10 MW of load, each will have contributed 50 percent of the load related market flow on the constraint.**
- **Each load will have the contributed 50 percent of the congestion caused by that constraint.**

Two Bus Example

Gen A
Offer: \$25 per MWh
Eco Max: 200 MW



Load: 100 MWh

Limit: 50 MW

Gen B
Offer: \$50 per MWh
Eco Max: 100 MW

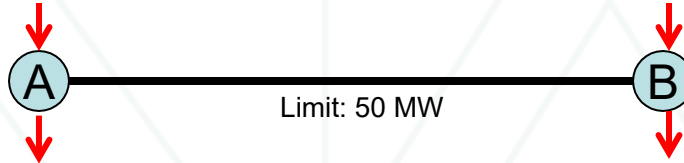


Load: 100 MWh

Two Bus Example

Gen A
Offer: \$25 per MWh
Eco Max: 200 MW

Gen B
Offer: \$50 per MWh
Eco Max: 100 MW



Load: 100 MWh

Load: 100 MWh

Least cost, security constrained dispatch:

- Minimize $\text{GenA} \cdot \text{OfferA} + \text{GenB} \cdot \text{OfferB}$

Subject to

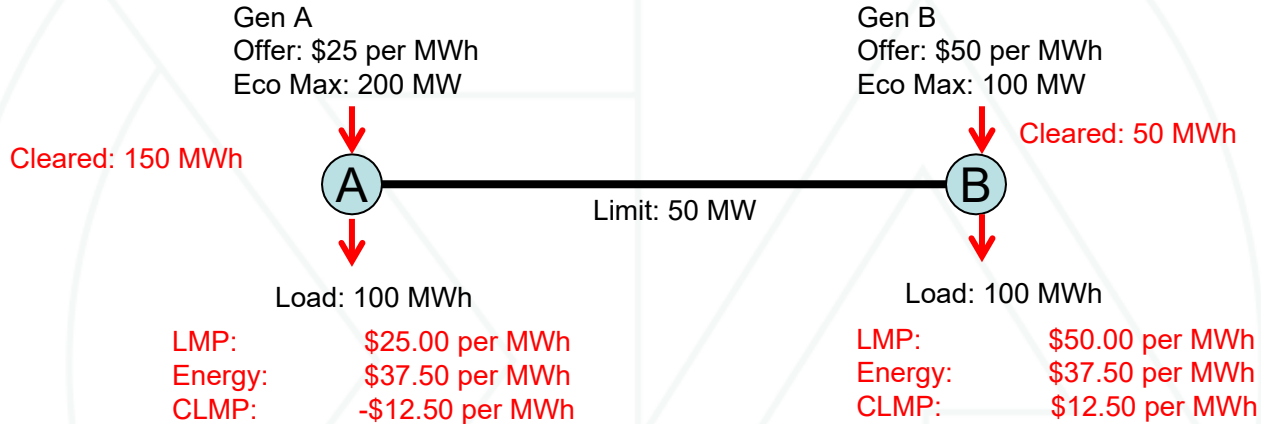
Total Gen = Load ← Shadow price is SMP or energy price

Flow on Line A B \leq Limit (50 MW) ← Shadow price \times dfax is CLMP

GenA output \leq GenA EcoMax

GenB output \leq GenB EcoMax

Two Bus Example (Solution)



Marginal Cost of Reducing the Constraint is:

$$-\$50 + \$25 = -\$25$$

One less MW from the expensive resource at B and one more MW from the less expensive resource at A
 Shadow price of Power balance Constraint: \$-25.0 per MWh, relative (from load reference bus) DFAX of constraint to A = 0.5 and to B = -0.5

$$\text{LMP at Bus B} = \text{SMP} + \text{CLMP at B} = \$37.5 + \$12.5 = \$50$$

$$\text{LMP at Bus A} = \text{SMP} + \text{CLMP at A} = \$37.5 - \$12.5 = \$25$$

- Load Reference Bus is between A and B (fictional point)
- SMP = load weighted average LMP = \$37.50

Two Bus Example (Solution)

Gen A
Offer: \$25 per MWh
Eco Max: 200 MW

Gen B
Offer: \$50 per MWh
Eco Max: 100 MW

Cleared: 150 MWh

Cleared: 50 MWh



Limit: 50 MW

Load: 100 MWh

Load: 100 MWh

LMP: \$25.00 per MWh
Energy: \$37.50 per MWh
CLMP: -\$12.50 per MWh

LMP: \$50.00 per MWh
Energy: \$37.50 per MWh
CLMP: \$12.50 per MWh

CLMP is not congestion

Bus	SMP	CLMP	LMP	Load	Gen	Load CLMP Charges	Generation CLMP Credits	Net CLMP Bill?
A	\$37.50	-\$12.50	\$25.00	100	150	-\$1,250.00	-\$1,875.00	\$625.00
B	\$37.50	\$12.50	\$50.00	100	50	\$1,250.00	\$625.00	\$625.00
						\$0.00	-\$1,250.00	\$1,250.00
Load Weighted CLMP Average Price:						\$0.00		

CLMP charges are not congestion.
CLMP credits are not congestion.

A customer's net CLMP bill is not congestion

Difference in LMPs creates differences in charges to load and credits to generation. This is congestion.

Two Bus Example (Solution)

Bus	SMP	CLMP	LMP	Load	Gen	Load Generation		Net CLMP	
						CLMP Charges	CLMP Credits		
A	\$37.50	-\$12.50	\$25.00	100	150	-\$1,250.00	-\$1,875.00	\$625.00	
B	\$37.50	\$12.50	\$50.00	100	50	\$1,250.00	\$625.00	\$625.00	
						\$0.00	-\$1,250.00	\$1,250.00	Congestion
Load Weighted CLMP Average Price:						\$0.00			

- Moving the reference bus changes the components of LMP (changes SMP and CLMP).
- Moving the reference bus does not change LMP and does not change congestion (the difference between what load paid and generation was paid for energy).
- CLMP and CLMP related charges cannot, therefore, be congestion.
- The customer's net energy bill and net CLMP bill does not indicate the congestion paid by that customer.
- Congestion is the difference between network load payments and network generation revenue caused by constraints.

Bus	SMP	CLMP	LMP	Load	Gen	Load Generation		Net CLMP	
						CLMP Charges	CLMP Credits		
A	\$50.00	-\$25.00	\$25.00	100	150	-\$2,500.00	-\$3,750.00	\$1,250.00	
B	\$50.00	\$0.00	\$50.00	100	50	\$0.00	\$0.00	\$0.00	
						-\$2,500.00	-\$3,750.00	\$1,250.00	Congestion
Load Weighted CLMP Average Price:						-\$12.50			

Two Bus Example (Solution)

- Load customer at B paid the congestion

Bus	SMP	CLMP	LMP	Load	Gen	Load Generation			DFAX Difference	Load Contribution to Market Flow (DFAX Difference)	Proportion of Load Flow Contributions/ Congestion	Congestion Paid
						Charges	Credits	Net Bill?				
A	\$37.50	-\$12.50	\$25.00	100	150	\$2,500.00	\$3,750.00	-\$1,250.00	0	0	0%	\$0.00
B	\$37.50	\$12.50	\$50.00	100	50	\$5,000.00	\$2,500.00	\$2,500.00	-1	-100	100%	\$1,250.00
						\$7,500.00	\$6,250.00	\$1,250.00				
Load Weighted Average Price:						\$37.50	Congestion					

- Generation does not pay congestion.
- Virtual bids are settled.
- Congestion is paid by load:
 - The residual load overpayment after generation is paid and virtuals are settled.

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