Two Settlement Congestion

AFMTF

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Monitoring Analytics

Charges and Credits versus Congestion: Virtual Transactions, Load and Generation

- **Load, Generation, imports, exports, INCs, DECs and UTCs pay or are paid LMP.**
- **The PJM bill reflects charges and credits for buying or selling energy at LMP.**
- **The PJM bill breaks out charges and credits by the components of LMP.**
- **CLMP is a component of LMP caused by transmission constraints.**
- **CLMPs are not congestion.**

Charges and Credits versus Congestion

- Customer has 100 MW of load at bus B and 100 MW of generation at bus A.
- CLMP at bus A is $0 and the CLMP at bus B is $1.
- PJM bill indicates $100 CLMP charges for the load.
- PJM bill indicates $0 CLMP credits for the generation.
- PJM bill total CLMP charges and credits is $100.
- How much congestion did the customer pay?
- Cannot tell from the PJM bill.
- Congestion paid will depend on the network between A and B. That is not provided in the bill.

Charges and Credits versus Congestion: Virtual Transactions, Load and Generation

- **Congestion is the surplus left over after all CLMP related charges and credits are summed over all (system wide) DA and Balancing positions.**
- **A customer's contribution to the congestion surplus is not necessarily reflected in their PJM bill.**
- **CLMP on customer bill will change with changes in the reference bus, congestion does not.**
- **A customer's contribution to congestion surplus can be calculated on a constraint specific basis for both the Day-Ahead and Balancing portions of the Market Day.**

Virtual Bids Are Paid and Credited LMP

- **Virtual bids (INC, DEC and UTC) are credited and charged DA LMP and charged and credited for deviations at RT LMP.**
- **LMP is made up of components, including CLMP.**
- **In the two settlement system:**
  - **Virtual bids have net zero MW at the conclusion of a market day.**
    - Net position is zero MW.
  - **Virtual bids settle out at the conclusion of a market day and receive a net credit or a net charge for each component of LMP.**

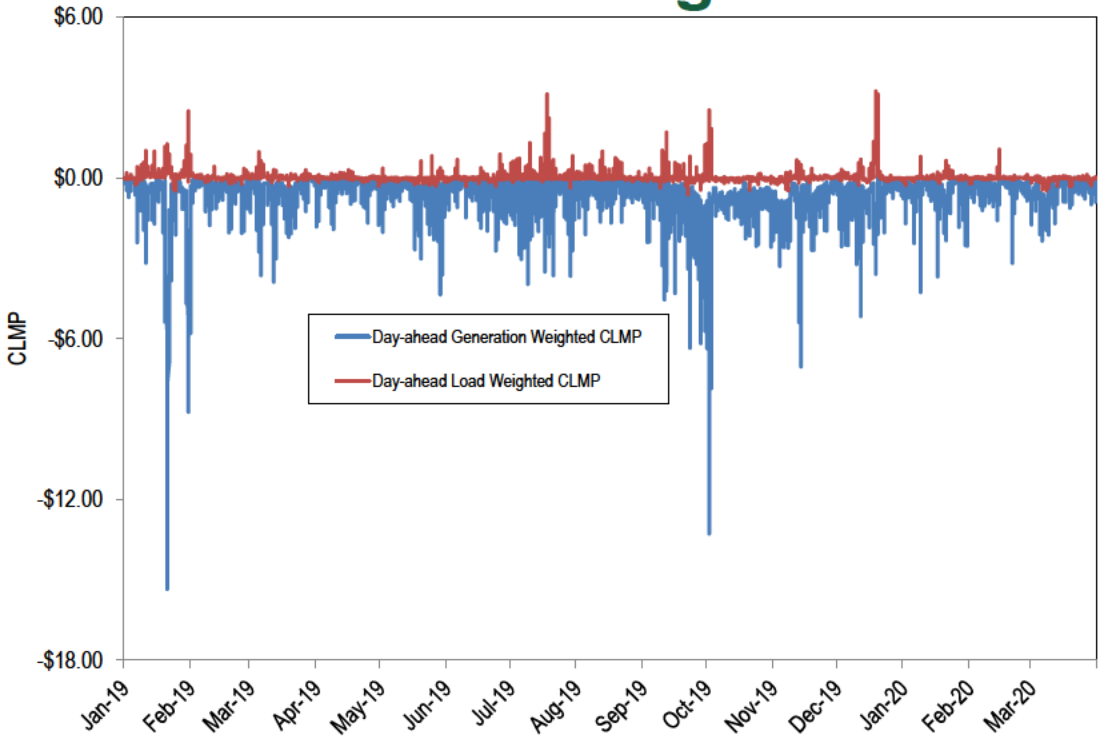
Virtual Bids Are Paid and Credited LMP

	DA MW	DA CLMP	DA Credits (-) / Charges (+)	Balancing MW	RT CLMP	RT Credits (-) / Charges (+)	Net MW	Net Credits/ Charges
INC	1	$2	-$2.00	-1	$1	$1.00	0	-$1.00
DEC	-2	$3	$6.00	2	$1	-$2.00	0	$4.00
UTC Source	1	$2	-$2.00	-1	$1	$1.00	0	-$1.00
UTC Sink	-1	$1	$1.00	1	$1	-$1.00	0	$0.00

Generation Does Not Pay Congestion

- Generation is credited LMP in DA and credited or charged LMP in RT based on deviations from DA.
- LMP is made up of components, including CLMP.
- A negative CLMP at a generation bus indicates that the LMP at the bus is lower than the load weighted average LMP.
- On a weighted basis, LMPs at load buses are higher than LMPs at generation buses. This results in congestion.
- Congestion is a surplus generated by the differences between all charges and all credits caused by transmission constraints.

Day-Ahead Generation Weighted CLMPs and Day-Ahead Load-Weighted CLMPs



Load (Including Exports) Pays Congestion

- Load pays LMP, which are, on average higher than LMP paid to injection sources.
- Load has a net positive MW at the close of the market day in a two settlement system.
- Load pays more for energy than injections are paid for energy due to transmission constraints.
- Congestion is the surplus of CLMP related charges and credits after generation is paid and virtual bids are settled in a two settlement system.
- Load pays this net difference which is congestion.

Load (Including Exports) Pays Congestion.

	DA MW	DA CLMP	DA Credits (-) / Charges (+)	Balancing MW	RT CLMP	RT Credits (-) / Charges (+)	Net MW	Net Credits/ Charges
INC	1	$2	-$2.00	-1	$1	$1.00	0	-$1.00
DEC	-2	$3	$6.00	2	$1	-$2.00	0	$4.00
UTC Source	1	$2	-$2.00	-1	$1	$1.00	0	-$1.00
UTC Sink	-1	$1	$1.00	1	$1	-$1.00	0	$0.00

	DA MW	DA CLMP	DA Credits (-) / Charges (+)	Balancing MW	RT CLMP	RT Credits (-) / Charges (+)	Net MW	Net Credits/ Charges
Generation	2	$2	-$4.00	0	$1	$0.00	2	-$4.00
Load	-1	$3	$3.00	-1	$2	$2.00	-2	$5.00

	Total DA MW		Total DA Credits/Charges	Total Balancing Deviations		RT Credits (-) / Charges (+)	Net MW	Net Credits/ Charges
Total Withddrawals	-4		$10.00	2		-$1.00	-2	$9.00
Total Injections	4		-$8.00	-2		$2.00	2	-$6.00
	0	$0	$2.00	0	$0	$1.00	0	$3.00

Congestion

Two Settlement Congestion: Congestion by Constraint

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The Determination and Distribution of Day-Ahead and Balancing Congestion

- **Congestion is generated by constraint.**
- **The contribution to congestion by load is determined by constraint.**
- **Load's payment of congestion by constraint is based on the shadow price of the constraint and the dfax of the constraint to downstream (high price side) load.**
- **Load downstream of a constraint is determined by positive CLMP effect of constraint on a load bus.**
- **Whether a load is downstream of a constraint is determined after moving the reference bus to the bus with the lowest negative CLMP caused by that constraint.**

Day-Ahead Congestion

- Collect CLMP by constraint by bus by hour.
- Collect load by bus by hour.
- Collect generation by bus by hour.
- Collect day ahead transactions by bus by hour (WHLIN, WHLOUT, IMPORT, EXPORT, UTCs, INTERNAL)
- Calculate day ahead congestion by constraint for each hour (sum of CLMP x MW).
- Move the reference bus to the location of the most negative CLMP caused by the studied constraint and update resulting CLMPs caused by the constraint studied.
- By constraint, calculate downstream (+CLMP) congestion charges to load by bus by hour.
- By constraint, calculate the proportion of downstream (+CLMP) congestion charges collected at each downstream bus by hour by physical load.
- Congestion collected from a downstream load bus is each constraint's total congestion times the proportion of downstream (+CLMP) congestion charges collected at that bus by hour.

DA System Example

Bus	Gen MW	Load MW	CLMP	Load Charges	Generation Credits	Congestion (Net Charges)
A	1		-$50.00	$0.00	-$50.00	
B1	1	0.5	$50.00	$25.00	$50.00	
B2	0	1.5	$50.00	$75.00	$0.00	
Total	2	2		$100.00	$0.00	$100.00

1 MW Transfer Limit

Bus	Gen MW	Load MW	CLMP	Load Charges	Generation Credits	Congestion (Net Charges)	Proportion of CLMP Charges to Load	Constraint Specific Congestion Paid by Bus
A	1		0	$0	$0			
B1	1	0.5	$100	$50	$100		25%	$25
B2	0	1.5	$100	$150	$0		75%	$75
Total	2	2		$200	$100	$100	100%	$100

Balancing Congestion

- Collect real time CLMP by studied constraint by bus/aggregate by 5 min interval.
- Collect day-ahead and real-time load by aggregate by hour.
- Collect day ahead generation by bus by hour and real-time generation by bus by 5 min interval.
- Collect day-ahead and real-time transactions by bus by 5 min interval.
- Collect deviations by bus by 5 min interval or by aggregate by 5 min interval.
- Calculate balancing congestion by constraint for each 5 min interval (based on deviations and constraint real-time CLMP).
- Move the reference bus to the location of the most negative CLMP caused by the studied constraint and update resulting CLMPs caused by the constraint studied.
- By constraint, calculate downstream real-time (+CLMP) congestion charges to load by aggregate by 5 min interval (not balancing).
- By constraint, calculate downstream real-time (+CLMP) congestion charges to load by bus by 5 min interval (not balancing) using aggregate to bus factors.

Balancing Congestion Continued

- **By constraint, calculate the proportion of real-time (not balancing) downstream (+CLMP) congestion charges collected at each downstream bus by 5 min interval.**
- **Balancing congestion collected from a downstream load bus is each constraint's total balancing congestion times the proportion of downstream real-time (+CLMP) congestion charges that would have been collected at that bus by 5 min interval.**

RT System Example

Real-time positions, CLMP and real-time inferred congestion

Bus	Gen MW	Load MW	CLMP	Load Charges	Generation Credits	Congestion (Net Charges)	Proportion of CLMP Charges to Load
A	1.5		$0.00	$0.00	$0.00		
B1	0.5	0.25	$100.00	$25.00	$50.00		12.50%
B2	0	1.75	$100.00	$175.00	$0.00		87.50%
Total	2	2		$200.00	$50.00	$150.00	100.00%

1.5 MW Transfer Limit

Balancing positions, CLMP, Balancing Congestion

Bus	Gen Deviations	Load deviations	CLMP	Load Charges	Generation Credits	Balancing Congestion (Net Charges)
A	0.5		$0.00	$0.00	$0.00	
B1	-0.5	-0.25	$100.00	-$25.00	-$50.00	
B2	0	0.25	$100.00	$25.00	$0.00	
Total	0	0		$0.00	-$50.00	$50.00

Balancing Congestion Paid by Bus

Proportion of Real-Time Congestion and Bus Specific Balancing Congestion Paid

Bus	Gen Deviations	Load deviations	CLMP	Load Charges	Generation Credits	Balancing Congestion (Net Charges)	Proportion of RT Solution CLMP Charges to Load	Constraint Specific Congestion Paid by Bus
A	0.5		$0.00	$0.00	$0.00			
B1	-0.5	-0.25	$100.00	-$25.00	-$50.00		12.50%	$6.25
B2	0	0.25	$100.00	$25.00	$0.00		87.50%	$43.75
Total	0	0		$0.00	-$50.00	$50.00	100.00%	$50.00

Total Congestion = DA + Balancing

Bus	Actual Gen (RT)	Actual Load (RT)	Load Charges	Generation Credits	Total Actual Congestion	DA Constraint Specific Congestion Paid by Bus	Balancing Constraint Specific Congestion Paid by Bus	Constraint Specific Congestion Paid by Bus
A	1.5	0	$0.00	$0.00				
B1	0.5	0.25	$25.00	$50.00		$25	$6.25	$31.25
B2	0	1.75	$175.00	$0.00		$75	$43.75	$118.75
Total	2	2	$200.00	$50.00	$150.00	$100	$50.00	$150.00

Network Congestion Determination Methodology: Moving the Reference Bus, 12 Bus Model

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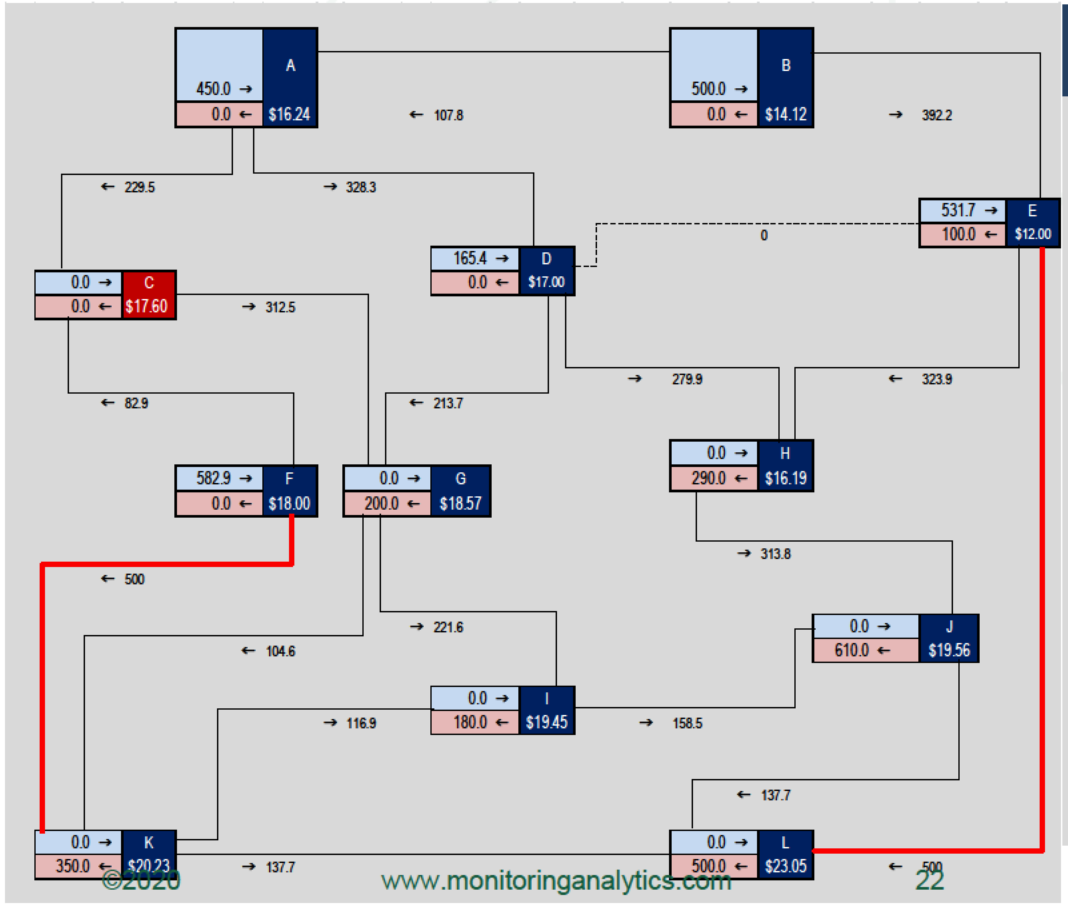
The Determination and Distribution of Day-Ahead Congestion: 12 Bus Model

- Congestion is generated by constraint.
- The contribution to congestion by load is determined by constraint.
- Load contribution to congestion collected by constraint is based on the shadow price of the constraint and the dfax of the constraint to downstream (high price side) load.
- Load downstream of a constraint is determined by positive CLMP effect of constraint on a load bus.
- Whether a load is downstream of a constraint is determined after moving the reference bus to the bus with the lowest negative CLMP caused by that constraint.

DA System Example



Energy Market Offers and Bids

ID	Node	Gen Offer ($/MWh)	Gen (MWh)	Load (MWh)
1	A	10.00	450.0	
2	B	12.00	500.0	
3	C	25.00	250.0	
4	D	17.00	350.0	
5	E	12.00	650.0	
6	F	10.00	450.0	
7	G	0.00	0.0	200.0
8	H	0.00	0.0	290.0
9	I	0.00	0.0	180.0
10	J	0.00	0.0	140.0
11	K	0.00	0.0	350.0
12	L	0.00	0.0	500.0
13	J	0.00	0.0	470.0
14	F	18.00	400.0	
15	E	0.00		100.0
16	C	0.00		
17	D	0.00		
18	E	0.00		
19	F	0.00		
20	G	0.00		

Energy Market Clearing

	LMP	Gen	Load
	16.24	450.0	0.0
	14.12	500.0	0.0
	17.60	0.0	0.0
M	17.00	165.4	0.0
M	12.00	531.7	0.0
	18.00	450.0	0.0
	18.57	0.0	200.0
	16.19	0.0	290.0
	19.45	0.0	180.0
	19.56	0.0	140.0
	20.23	0.0	350.0
	23.05	0.0	500.0
	19.56	0.0	470.0
M	18.00	132.9	0.0
	12.00	0.0	100.0
	17.60	0.0	0.0
	17.00	0.0	0.0
	12.00	0.0	0.0
	18.00	0.0	0.0
	18.57	0.0	0.0
Total		2230.0	2230.0

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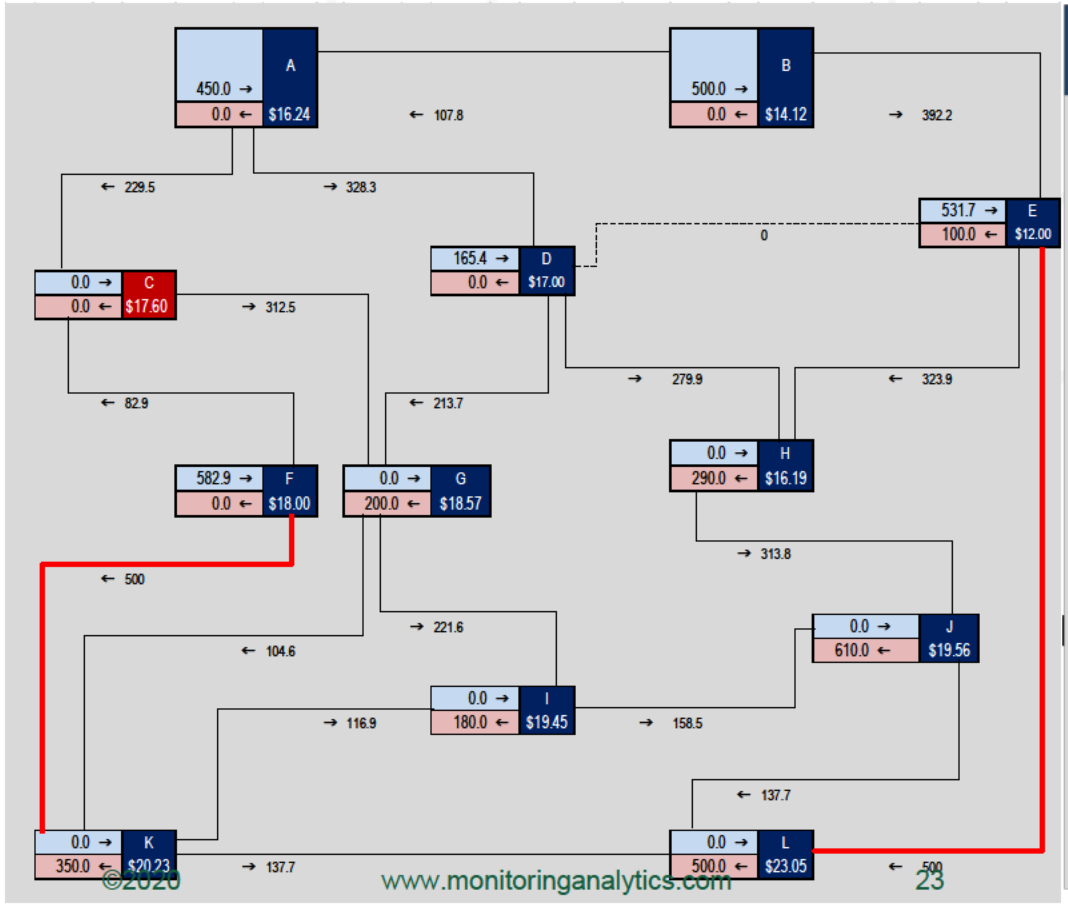
DA System Example

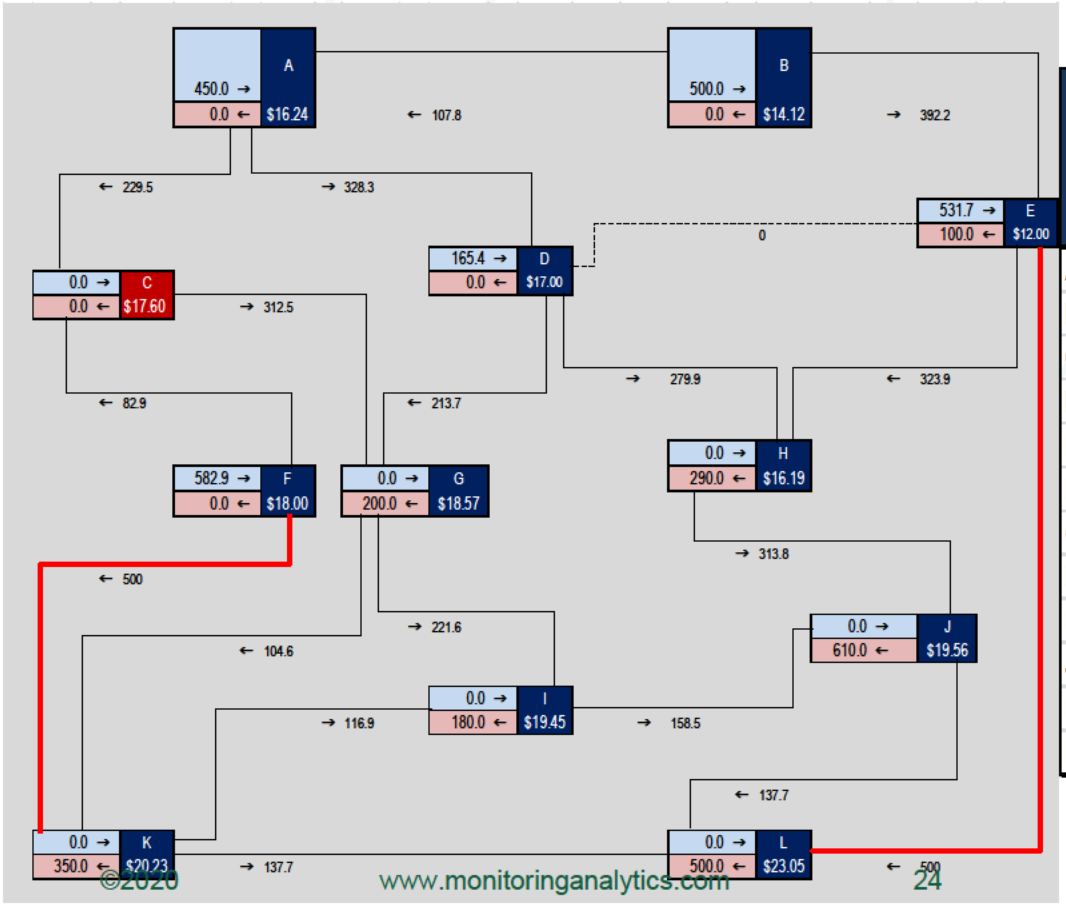


Congestion Calculations

Line	Flow (MW)	Limit (MW)	Shadow Price ($/MWh)	Total Congestion $
AB	-107.83	300.00	$ -	$ -
AC	229.55	350.00	$ -	$ -
AD	328.28	400.00	$ -	$ -
BE	392.17	500.00	$ -	$ -
CF	-82.91	500.00	$ -	$ -
CG	312.46	500.00	$ -	$ -
DE	0.00	500.00	$ -	$ -
DG	213.72	500.00	$ -	$ -
DH	279.94	500.00	$ -	$ -
EH	323.88	500.00	$ -	$ -
EL	500.00	500.00	$ (17.36)	$ (8,678.54)
FK	500.00	500.00	$ (1.83)	$ (914.78)
GI	221.55	500.00	$ -	$ -
GK	104.63	500.00	$ -	$ -
HJ	313.82	500.00	$ -	$ -
IJ	158.48	500.00	$ -	$ -
IK	-116.93	500.00	$ -	$ -
JL	-137.70	500.00	$ -	$ -
KL	137.70	500.00	$ -	$ -
			Total	$ (9,593.32)
			Generation Credits	$ 34,053.48
			Load Payments	$ 43,646.80
			Net Congestion	$ 9,593.32

DA System Example

Bus E is closest to the source side of the constraint EL.



	EL CLMP	FK CLMP	SMP	LMP
A	$ (1.58)	$ 0.21	$ 17.60	16.24
B	$ (3.80)	$ 0.31	$ 17.60	14.12
C	$ -	$ -	$ 17.60	17.60
D	$ (0.93)	$ 0.33	$ 17.60	17.00
E	$ (6.01)	$ 0.41	$ 17.60	12.00
F	$ 0.98	$ (0.59)	$ 17.60	18.00
G	$ 0.59	$ 0.37	$ 17.60	18.57
H	$ (1.82)	$ 0.40	$ 17.60	16.19
I	$ 1.35	$ 0.50	$ 17.60	19.45
J	$ 1.49	$ 0.47	$ 17.60	19.56
K	$ 1.96	$ 0.66	$ 17.60	20.23
L	$ 4.93	$ 0.51	$ 17.60	23.05

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DA System Example: EL

$17.60 + -$6.01= $11.59

	EL CLMP	FK CLMP	SMP	LMP	Move Reference Bus: SMP + CLMP of EL Only LMP	Move Reference Bus: EL SMP	Move Reference Bus: EL CLMP	Move Reference Bus: LMP*
A	$ (1.58)	$ 0.21	$ 17.60	16.24	$ 16.02	$ 11.59	$ 4.43	$ 16.02
B	$ (3.80)	$ 0.31	$ 17.60	14.12	$ 13.80	$ 11.59	$ 2.21	$ 13.80
C	$ -	$ -	$ 17.60	17.60	$ 17.60	$ 11.59	$ 6.01	$ 17.60
D	$ (0.93)	$ 0.33	$ 17.60	17.00	$ 16.67	$ 11.59	$ 5.08	$ 16.67
E	$ (6.01)	$ 0.41	$ 17.60	12.00	$ 11.59	$ 11.59	$ -	$ 11.59
F	$ 0.98	$ (0.59)	$ 17.60	18.00	$ 18.58	$ 11.59	$ 6.99	$ 18.58
G	$ 0.59	$ 0.37	$ 17.60	18.57	$ 18.19	$ 11.59	$ 6.60	$ 18.19
H	$ (1.82)	$ 0.40	$ 17.60	16.19	$ 15.78	$ 11.59	$ 4.19	$ 15.78
I	$ 1.35	$ 0.50	$ 17.60	19.45	$ 18.95	$ 11.59	$ 7.36	$ 18.95
J	$ 1.49	$ 0.47	$ 17.60	19.56	$ 19.09	$ 11.59	$ 7.50	$ 19.09
K	$ 1.96	$ 0.66	$ 17.60	20.23	$ 19.56	$ 11.59	$ 7.97	$ 19.56
L	$ 4.93	$ 0.51	$ 17.60	23.05	$ 22.53	$ 11.59	$ 10.94	$ 22.53

Any bus with a positive CLMP after reference bus move is downstream of EL.

Move the reference bus to the low (source) side of the constraint EL

LMP*= SMP + CLMP of EL

LMP* is the total LMP based on effect of EL. Difference between LMP* and new SMP is the CLMP of EL

DA System Example

	Move Reference Bus			
	SMP + CLMP of EL Only LMP	EL SMP	EL CLMP	LMP*
A	$ 16.02	$ 11.59	$ 4.43	$ 16.02
B	$ 13.80	$ 11.59	$ 2.21	$ 13.80
C	$ 17.60	$ 11.59	$ 6.01	$ 17.60
D	$ 16.67	$ 11.59	$ 5.08	$ 16.67
E	$ 11.59	$ 11.59	$ -	$ 11.59
F	$ 18.58	$ 11.59	$ 6.99	$ 18.58
G	$ 18.19	$ 11.59	$ 6.60	$ 18.19
H	$ 15.78	$ 11.59	$ 4.19	$ 15.78
I	$ 18.95	$ 11.59	$ 7.36	$ 18.95
J	$ 19.09	$ 11.59	$ 7.50	$ 19.09
K	$ 19.56	$ 11.59	$ 7.97	$ 19.56
L	$ 22.53	$ 11.59	$ 10.94	$ 22.53

		Total Congestion			
Bus	EL + CLMP	$ 8,678.54 Load	Charges	Proportion	Congestion Source
A	4.43	0.0	$0.00	0.0%	$0.00
B	2.21	0.0	$0.00	0.0%	$0.00
C	6.01	0.0	$0.00	0.0%	$0.00
D	5.08	0.0	$0.00	0.0%	$0.00
E	0	100.0	$0.00	0.0%	$0.00
F	6.99	0.0	$0.00	0.0%	$0.00
G	6.6	200.0	$1,320.00	10.0%	$869.87
H	4.19	290.0	$1,215.10	9.2%	$800.74
I	7.36	180.0	$1,324.80	10.1%	$873.03
J	7.5	140.0	$1,050.00	8.0%	$691.94
K	7.97	350.0	$2,789.50	21.2%	$1,838.26
L	10.94	500.0	$5,470.00	41.5%	$3,604.69
			$13,169.40		$8,678.54

The Determination and Source of Balancing Congestion

- **The determination of balancing congestion is based on the same principle as the allocation of day-ahead congestion.**
- **The system real-time optimization follows the same logic as the day ahead optimization and provides the binding constraint, shadow prices and CLMP.**

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