Power System Economics and Market Modeling

M8: Developing an LMP Analysis for a Multi-Area Case

PowerWorld Corporation

2001 South First Street
Champaign, Illinois 61820
+1 (217) 384.6330

support@powerworld.com
http://www.powerworld.com

LMP Analysis: Outline

- Sample California study: process overview
  - One possible “step by step” approach for developing LMP Analysis on a utility-scale multi-area case
  - Use of Super Area to model ISO control
  - Analysis of unenforceable constraints
- More on unenforceable constraints and other OPF challenges

Sample California Study

Process Overview

- Case Development
  - Select area(s) of interest for study
  - Establish the set of OPF controls: OPF, unit commitment, and AGC settings
  - Establish the set of OPF constraints: Limit Monitoring settings
- Load cost curves for thermal generators
- Solve unconstrained OPF for area lambdas
- Set hydro dispatch to historical levels and hydro cost curves to unconstrained area lambdas
- Solve transmission-constrained OPF
- Review results, analyze unenforceable constraints, and iterate process as necessary

Case Development Suggestions

- Full OPF analysis on a large case may be time consuming
- For extremely congested cases, there may be no solution that satisfies all constraints
- For meaningful results, it is recommended that the scope of analysis be limited to a region of interest such as a few control areas or a single RTO territory

Case Development Suggestions

- Align the part of the system to be optimized with the generator controls to remove the constraints
- Do not monitor elements in the part of the system not on OPF control
- Only place the part of the system to be studied on OPF control

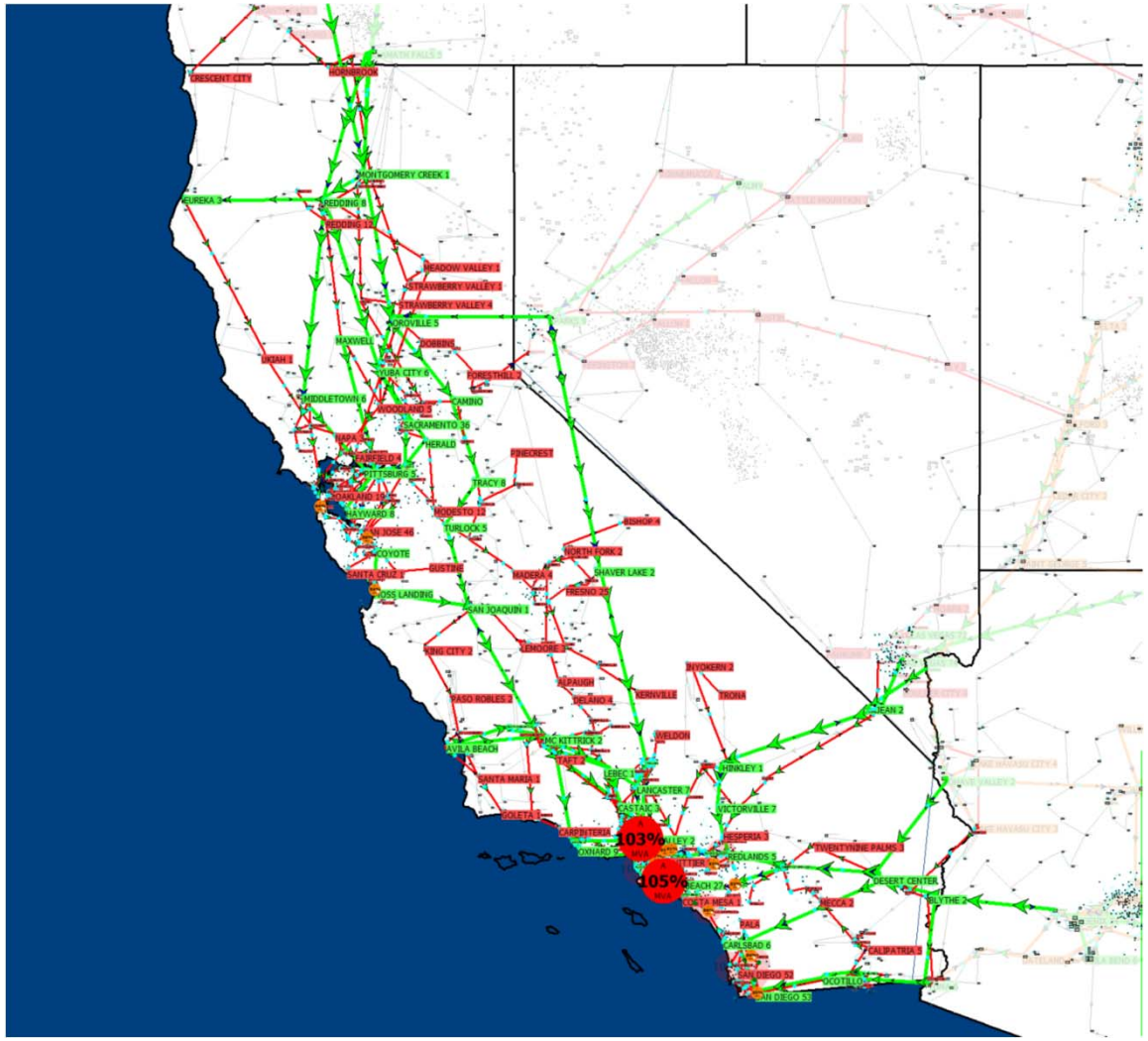
Western Case

- Load the *ACTIVSg10k_OPF.raw* case
- Settings described on following slides may be loaded from *M08_Multi-Area LMP\aux1000Master.aux*
- Suppose we wish to model an LMP market for California
  - 5 separate control areas
  - 1098 total generating units, 852 committed generating units
  - 7 branch thermal violations in base case

ACTIVSg10kCA.pwd

Starting Case with Overloads on High-Voltage Grid

Note use of Emphasis, Dynamic Formatting, and dynamically-sized pie charts on one-line diagram

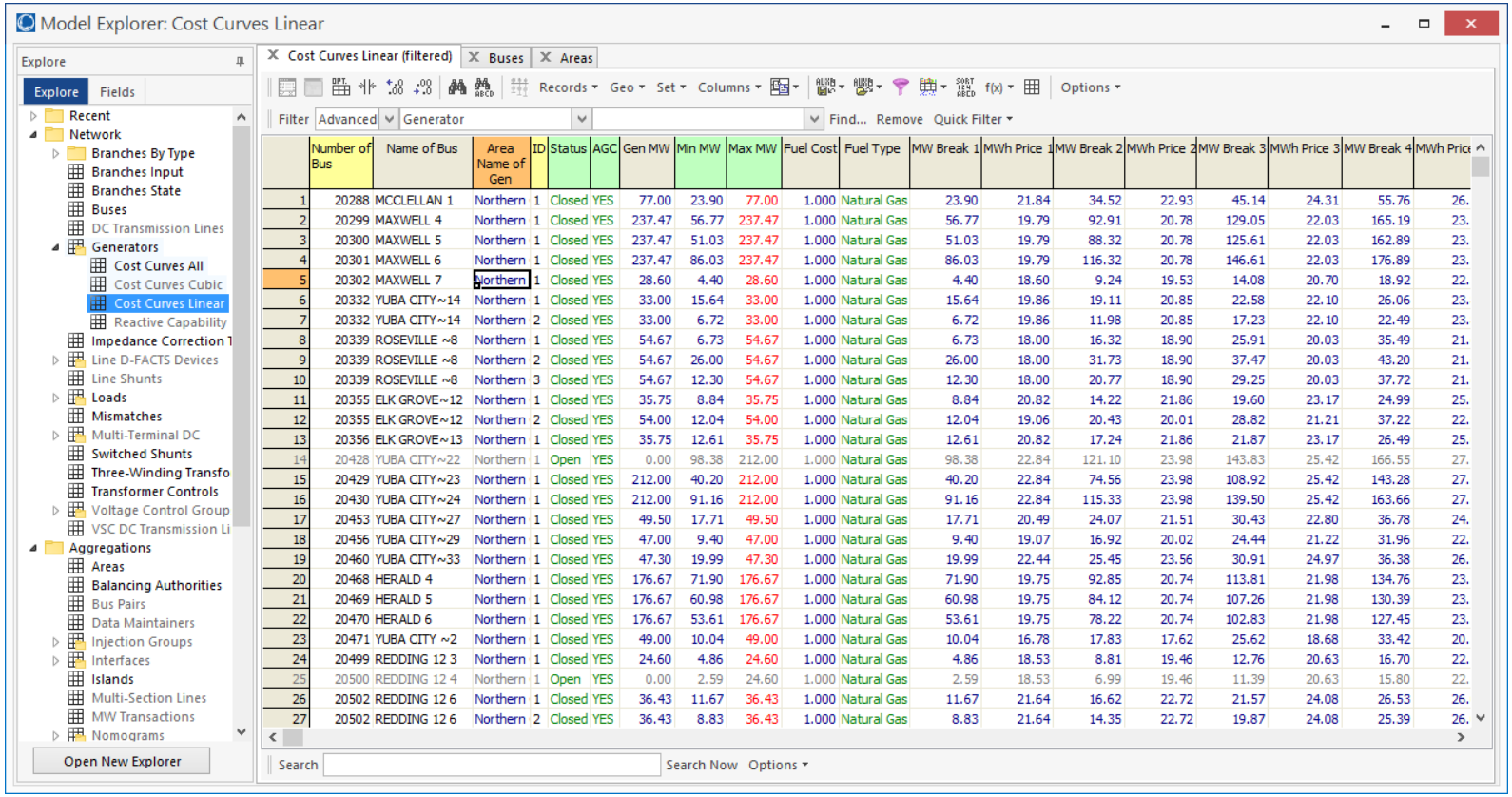


Case Development

- Solve the power flow first!
- Area/Zone Filters: show areas 3-7 only
- Area AGC
  - Set areas 3-7 on OPF control
  - Set area 9 to Off AGC
  - Set all other areas to Part. Fact AGC
  - Set all Area Unspecified MW Interchange equal to actual interchange (Interchange -> Actual MW Export)
- Generator AGC: set to YES for all generators in areas 3-7 except hydro, wind, and solar (load cost curves for types)
- Limit Monitoring Settings
  - Report limits for areas 3-7 only, 100 kV and above
  - Do not monitor radial lines

Cost Curves

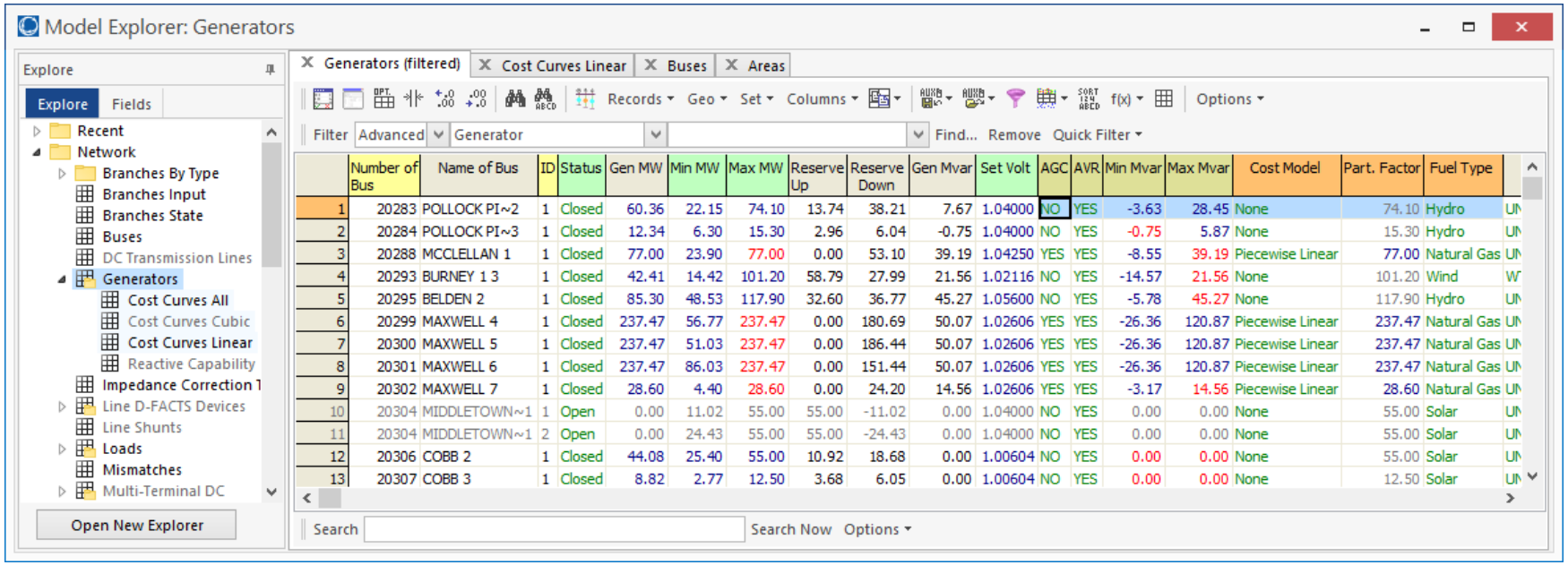
- Load cost curves and fuel types: *aux1060GeneratorCostModels.aux*



	Number of Bus	Name of Bus	Area Name of Gen	ID	Status	AGC	Gen MW	Min MW	Max MW	Fuel Cost	Fuel Type	MW Break 1	MWh Price 1	MW Break 2	MWh Price 2	MW Break 3	MWh Price 3	MW Break 4	MWh Price
1	20288	MCCLELLAN 1	Northern	1	Closed	YES	77.00	23.90	77.00	1.000	Natural Gas	23.90	21.84	34.52	22.93	45.14	24.31	55.76	26.
2	20299	MAXWELL 4	Northern	1	Closed	YES	237.47	56.77	237.47	1.000	Natural Gas	56.77	19.79	92.91	20.78	129.05	22.03	165.19	23.
3	20300	MAXWELL 5	Northern	1	Closed	YES	237.47	51.03	237.47	1.000	Natural Gas	51.03	19.79	88.32	20.78	125.61	22.03	162.89	23.
4	20301	MAXWELL 6	Northern	1	Closed	YES	237.47	86.03	237.47	1.000	Natural Gas	86.03	19.79	116.32	20.78	146.61	22.03	176.89	23.
5	20302	MAXWELL 7	Northern	1	Closed	YES	28.60	4.40	28.60	1.000	Natural Gas	4.40	18.60	9.24	19.53	14.08	20.70	18.92	22.
6	20332	YUBA CITY~14	Northern	1	Closed	YES	33.00	15.64	33.00	1.000	Natural Gas	15.64	19.86	19.11	20.85	22.58	22.10	26.06	23.
7	20332	YUBA CITY~14	Northern	2	Closed	YES	33.00	6.72	33.00	1.000	Natural Gas	6.72	19.86	11.98	20.85	17.23	22.10	22.49	23.
8	20339	ROSEVILLE ~8	Northern	1	Closed	YES	54.67	6.73	54.67	1.000	Natural Gas	6.73	18.00	16.32	18.90	25.91	20.03	35.49	21.
9	20339	ROSEVILLE ~8	Northern	2	Closed	YES	54.67	26.00	54.67	1.000	Natural Gas	26.00	18.00	31.73	18.90	37.47	20.03	43.20	21.
10	20339	ROSEVILLE ~8	Northern	3	Closed	YES	54.67	12.30	54.67	1.000	Natural Gas	12.30	18.00	20.77	18.90	29.25	20.03	37.72	21.
11	20355	ELK GROVE~12	Northern	1	Closed	YES	35.75	8.84	35.75	1.000	Natural Gas	8.84	20.82	14.22	21.86	19.60	23.17	24.99	25.
12	20355	ELK GROVE~12	Northern	2	Closed	YES	54.00	12.04	54.00	1.000	Natural Gas	12.04	19.06	20.43	20.01	28.82	21.21	37.22	22.
13	20356	ELK GROVE~13	Northern	1	Closed	YES	35.75	12.61	35.75	1.000	Natural Gas	12.61	20.82	17.24	21.86	21.87	23.17	26.49	25.
14	20428	YUBA CITY~22	Northern	1	Open	YES	0.00	98.38	212.00	1.000	Natural Gas	98.38	22.84	121.10	23.98	143.83	25.42	166.55	27.
15	20429	YUBA CITY~23	Northern	1	Closed	YES	212.00	40.20	212.00	1.000	Natural Gas	40.20	22.84	74.56	23.98	108.92	25.42	143.28	27.
16	20430	YUBA CITY~24	Northern	1	Closed	YES	212.00	91.16	212.00	1.000	Natural Gas	91.16	22.84	115.33	23.98	139.50	25.42	163.66	27.
17	20453	YUBA CITY~27	Northern	1	Closed	YES	49.50	17.71	49.50	1.000	Natural Gas	17.71	20.49	24.07	21.51	30.43	22.80	36.78	24.
18	20456	YUBA CITY~29	Northern	1	Closed	YES	47.00	9.40	47.00	1.000	Natural Gas	9.40	19.07	16.92	20.02	24.44	21.22	31.96	22.
19	20460	YUBA CITY~33	Northern	1	Closed	YES	47.30	19.99	47.30	1.000	Natural Gas	19.99	22.44	25.45	23.56	30.91	24.97	36.38	26.
20	20468	HERALD 4	Northern	1	Closed	YES	176.67	71.90	176.67	1.000	Natural Gas	71.90	19.75	92.85	20.74	113.81	21.98	134.76	23.
21	20469	HERALD 5	Northern	1	Closed	YES	176.67	60.98	176.67	1.000	Natural Gas	60.98	19.75	84.12	20.74	107.26	21.98	130.39	23.
22	20470	HERALD 6	Northern	1	Closed	YES	176.67	53.61	176.67	1.000	Natural Gas	53.61	19.75	78.22	20.74	102.83	21.98	127.45	23.
23	20471	YUBA CITY ~2	Northern	1	Closed	YES	49.00	10.04	49.00	1.000	Natural Gas	10.04	16.78	17.83	17.62	25.62	18.68	33.42	20.
24	20499	REDDING 12 3	Northern	1	Closed	YES	24.60	4.86	24.60	1.000	Natural Gas	4.86	18.53	8.81	19.46	12.76	20.63	16.70	22.
25	20500	REDDING 12 4	Northern	1	Open	YES	0.00	2.59	24.60	1.000	Natural Gas	2.59	18.53	6.99	19.46	11.39	20.63	15.80	22.
26	20502	REDDING 12 6	Northern	1	Closed	YES	36.43	11.67	36.43	1.000	Natural Gas	11.67	21.64	16.62	22.72	21.57	24.08	26.53	26.
27	20502	REDDING 12 6	Northern	2	Closed	YES	36.43	8.83	36.43	1.000	Natural Gas	8.83	21.64	14.35	22.72	19.87	24.08	25.39	26.

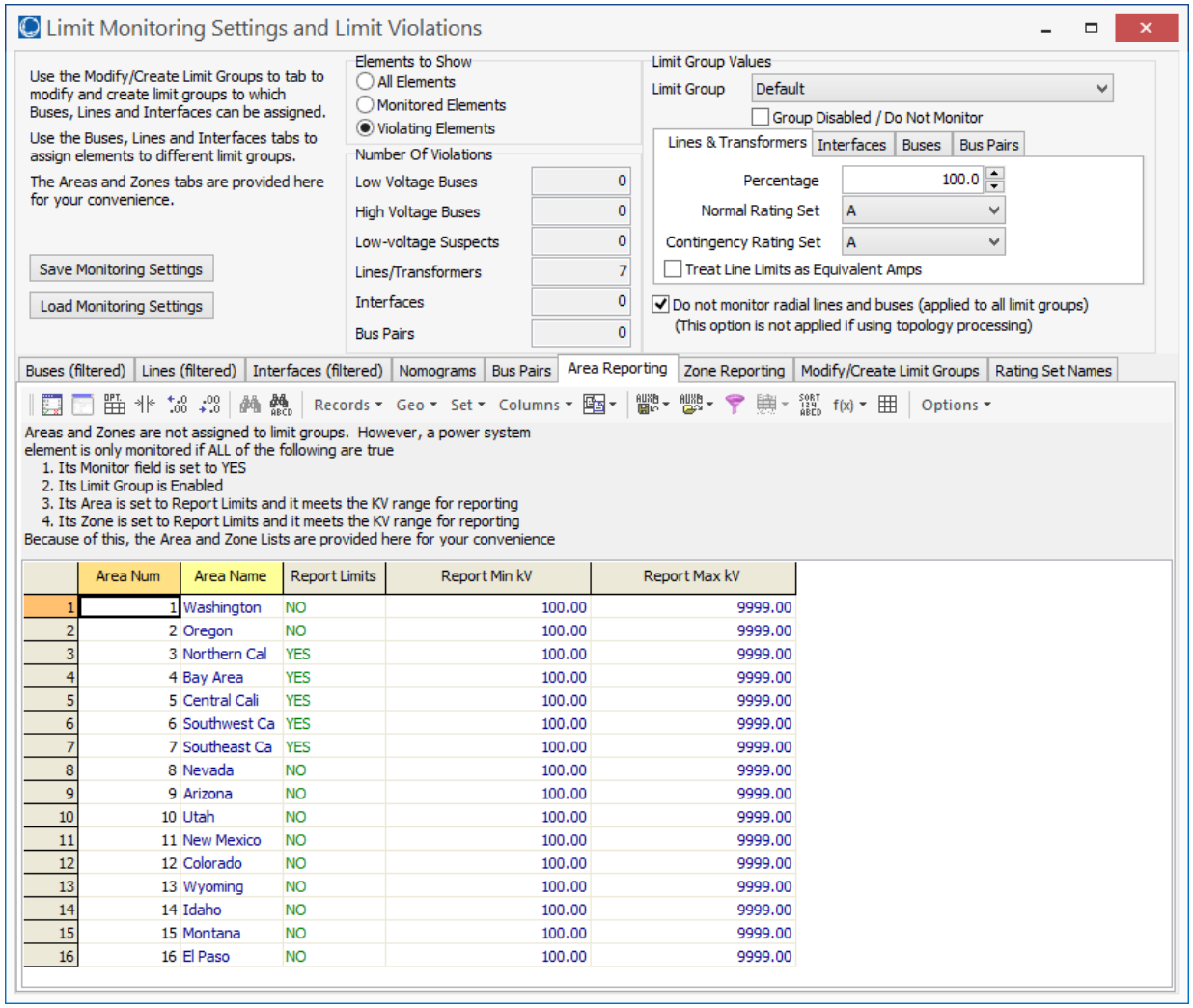
Generator AGC

- Set AGC = NO for generators with fuel types of Hydro, Wind, or Solar
- Advanced filters for each may be loaded from *aux1010FiltersExpressions.aux*



	Number of Bus	Name of Bus	ID	Status	Gen MW	Min MW	Max MW	Reserve Up	Reserve Down	Gen Mvar	Set Volt	AGC	AVR	Min Mvar	Max Mvar	Cost Model	Part. Factor	Fuel Type
1	20283	POLLOCK PI~2	1	Closed	60.36	22.15	74.10	13.74	38.21	7.67	1.04000	NO	YES	-3.63	28.45	None	74.10	Hydro
2	20284	POLLOCK PI~3	1	Closed	12.34	6.30	15.30	2.96	6.04	-0.75	1.04000	NO	YES	-0.75	5.87	None	15.30	Hydro
3	20288	MCCLELLAN 1	1	Closed	77.00	23.90	77.00	0.00	53.10	39.19	1.04250	YES	YES	-8.55	39.19	Piecewise Linear	77.00	Natural Gas
4	20293	BURNEY 1 3	1	Closed	42.41	14.42	101.20	58.79	27.99	21.56	1.02116	NO	YES	-14.57	21.56	None	101.20	Wind
5	20295	BELDEN 2	1	Closed	85.30	48.53	117.90	32.60	36.77	45.27	1.05600	NO	YES	-5.78	45.27	None	117.90	Hydro
6	20299	MAXWELL 4	1	Closed	237.47	56.77	237.47	0.00	180.69	50.07	1.02606	YES	YES	-26.36	120.87	Piecewise Linear	237.47	Natural Gas
7	20300	MAXWELL 5	1	Closed	237.47	51.03	237.47	0.00	186.44	50.07	1.02606	YES	YES	-26.36	120.87	Piecewise Linear	237.47	Natural Gas
8	20301	MAXWELL 6	1	Closed	237.47	86.03	237.47	0.00	151.44	50.07	1.02606	YES	YES	-26.36	120.87	Piecewise Linear	237.47	Natural Gas
9	20302	MAXWELL 7	1	Closed	28.60	4.40	28.60	0.00	24.20	14.56	1.02606	YES	YES	-3.17	14.56	Piecewise Linear	28.60	Natural Gas
10	20304	MIDDLETOWN~1	1	Open	0.00	11.02	55.00	55.00	-11.02	0.00	1.04000	NO	YES	0.00	0.00	None	55.00	Solar
11	20304	MIDDLETOWN~1	2	Open	0.00	24.43	55.00	55.00	-24.43	0.00	1.04000	NO	YES	0.00	0.00	None	55.00	Solar
12	20306	COBB 2	1	Closed	44.08	25.40	55.00	10.92	18.68	0.00	1.00604	NO	YES	0.00	0.00	None	55.00	Solar
13	20307	COBB 3	1	Closed	8.82	2.77	12.50	3.68	6.05	0.00	1.00604	NO	YES	0.00	0.00	None	12.50	Solar

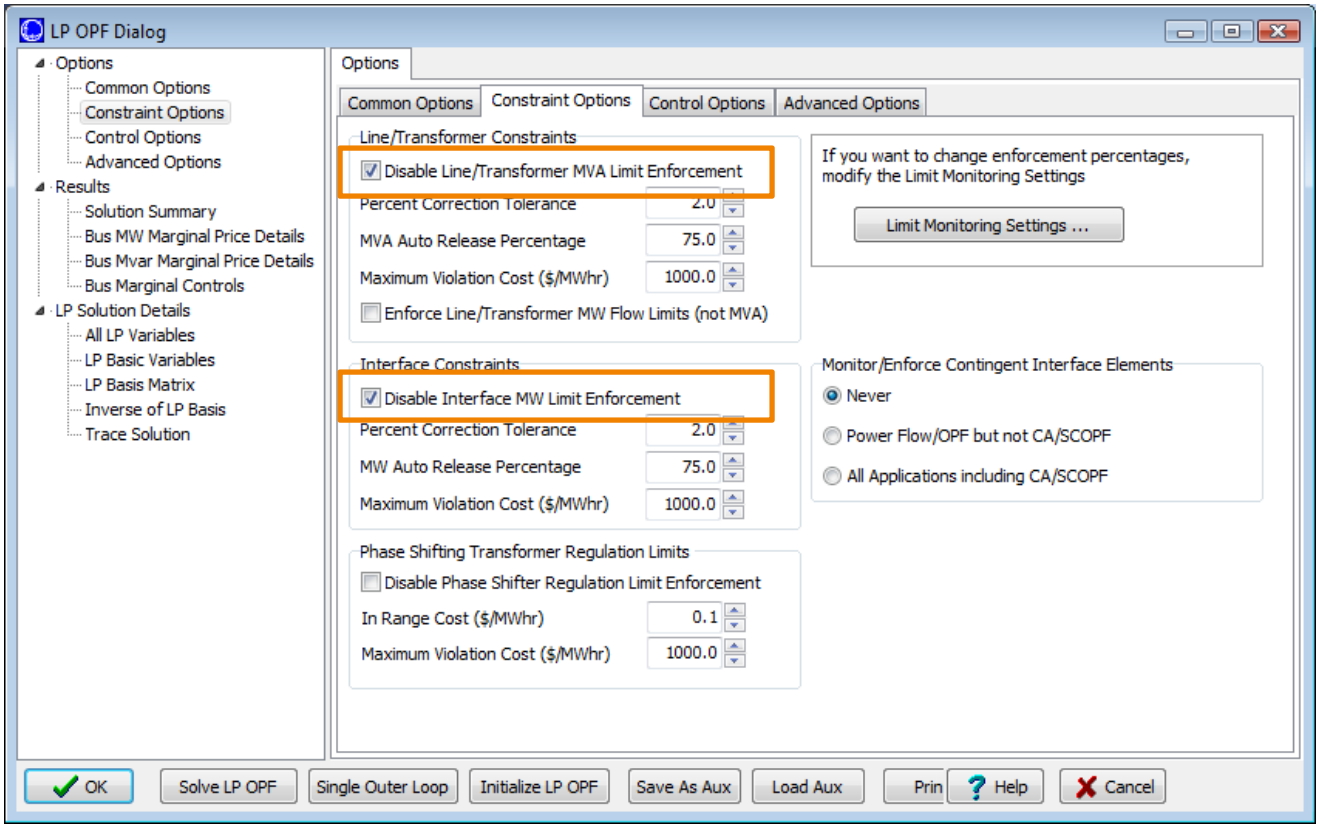
Limit Monitoring



	Area Num	Area Name	Report Limits	Report Min kV	Report Max kV
1	1	Washington	NO	100.00	9999.00
2	2	Oregon	NO	100.00	9999.00
3	3	Northern Cal	YES	100.00	9999.00
4	4	Bay Area	YES	100.00	9999.00
5	5	Central Cali	YES	100.00	9999.00
6	6	Southwest Ca	YES	100.00	9999.00
7	7	Southeast Ca	YES	100.00	9999.00
8	8	Nevada	NO	100.00	9999.00
9	9	Arizona	NO	100.00	9999.00
10	10	Utah	NO	100.00	9999.00
11	11	New Mexico	NO	100.00	9999.00
12	12	Colorado	NO	100.00	9999.00
13	13	Wyoming	NO	100.00	9999.00
14	14	Idaho	NO	100.00	9999.00
15	15	Montana	NO	100.00	9999.00
16	16	El Paso	NO	100.00	9999.00

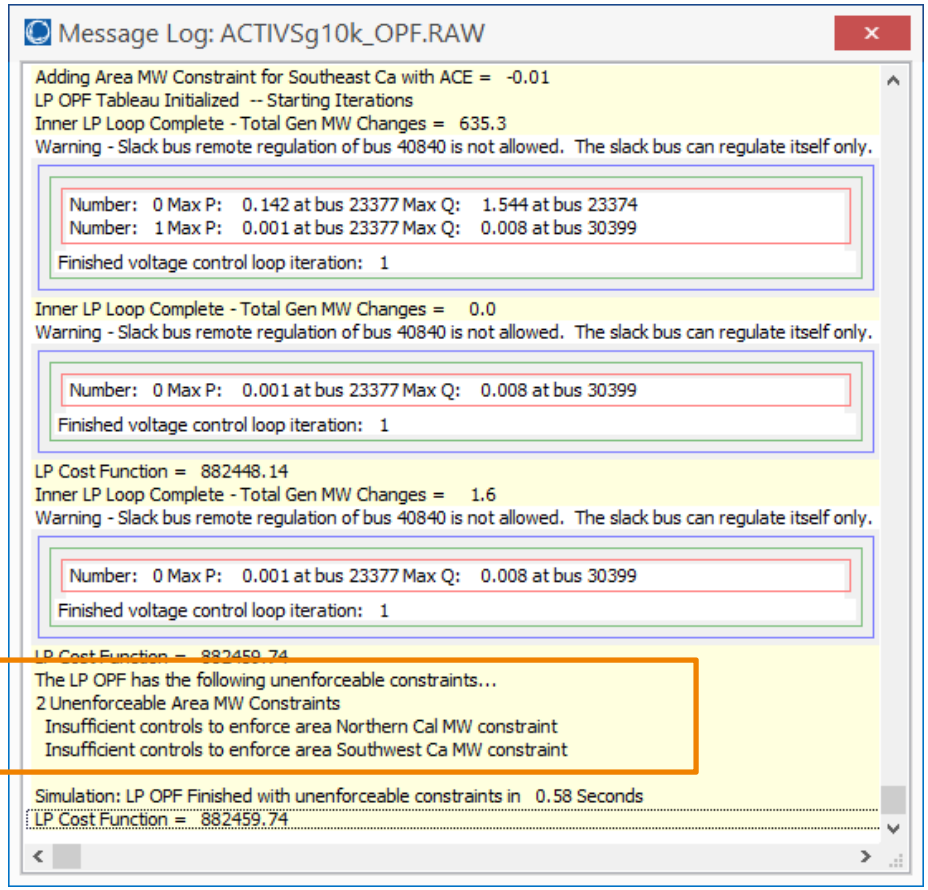
Solve Unconstrained OPF

- Disable all controls except Generator MW
- Do not enforce branch or interface constraints



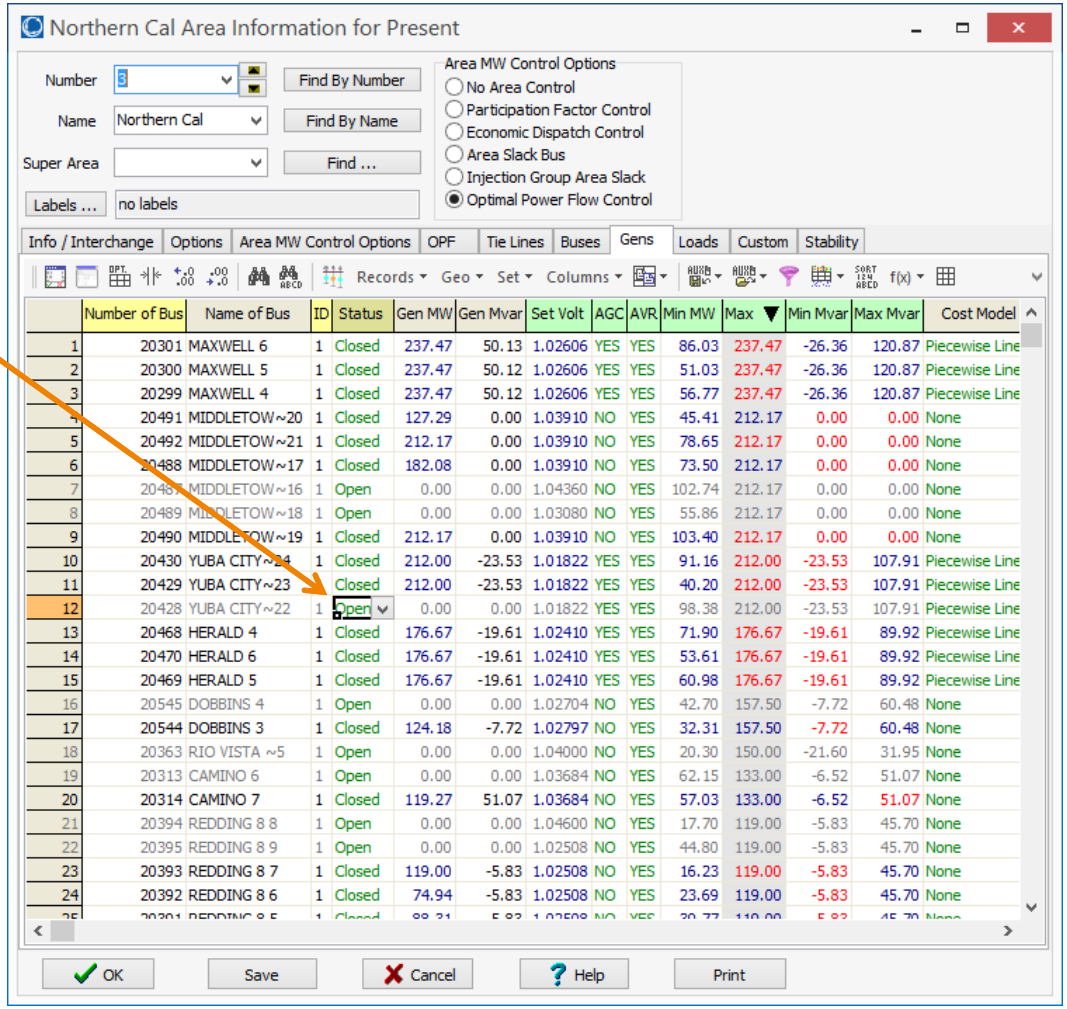
Unenforceable Area Constraints

- This can occur if all AGCable generators in an area are at min and max limits.
- Even if ACE is met prior to solution, changes in losses can create need for make-up power
- Simulator applies hard-coded $5000/MWh penalty factor to unenforceable area constraints



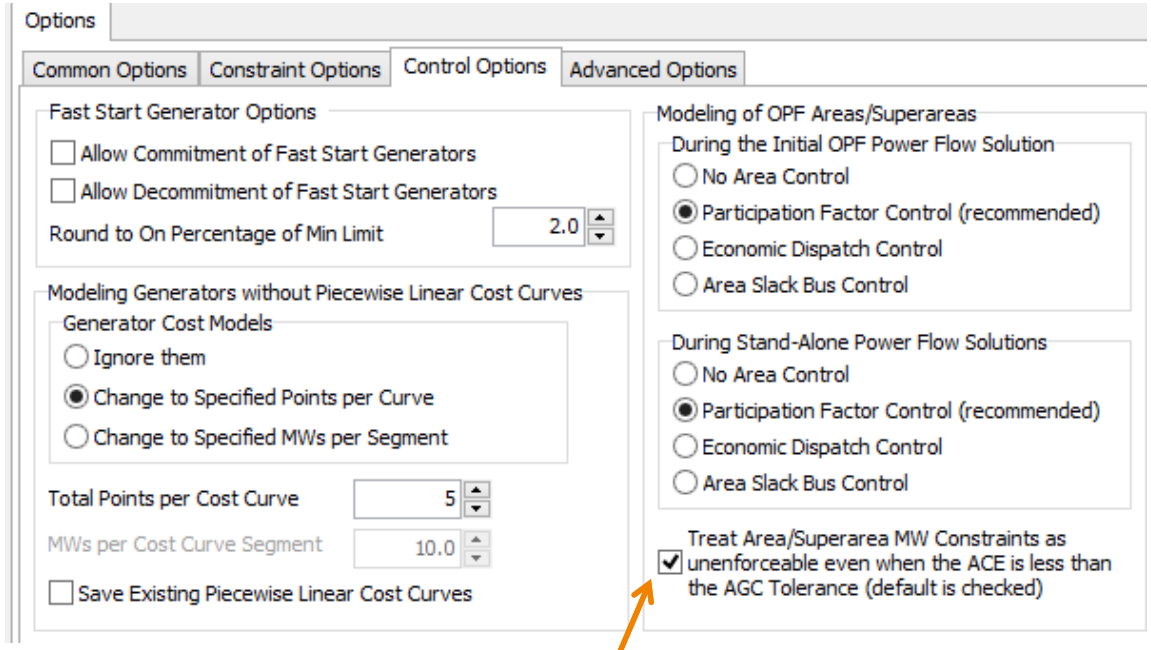
Unenforceable Area Constraints

- Area 3 AGCable generators are at Max MW
- Close largest AGCable unit
- Repeat for area 6
- Could also adjust Area MW Transactions (e.g. increase imports to these areas)
- Resolve power flow and then OPF



Unenforceable Area Constraints

- Also an option to relax Area/SuperArea constraints up to AGC Tolerance (**OPF Options and Results… → Options → Control Options**)
- Treats ACE constraints as inequality constraints
- This could prevent some unenforceable area constraints, but additional reserves are still usually desirable



Uncheck to relax ACE constraints

Unenforceable Area Constraints: Tips

- Examine Generator records or Area field “Gen MW AGC Range Up”
- To resolve
  - Commit more generation
  - Make more generation AGCable, or designate some units as OPF Fast Start
  - Increase imports, or make Area part of a Super Area
  - Decrease load, or make load dispatchable
  - Uncheck “Treat Area/Superarea MW Constraints as unenforceable even when the ACE is less than the AGC Tolerance”

Unconstrained OPF

- Note that there is a single marginal MW price within each area
- Areas' power balance are the only binding constraints
- Single marginal control for each area

LP Solution Details

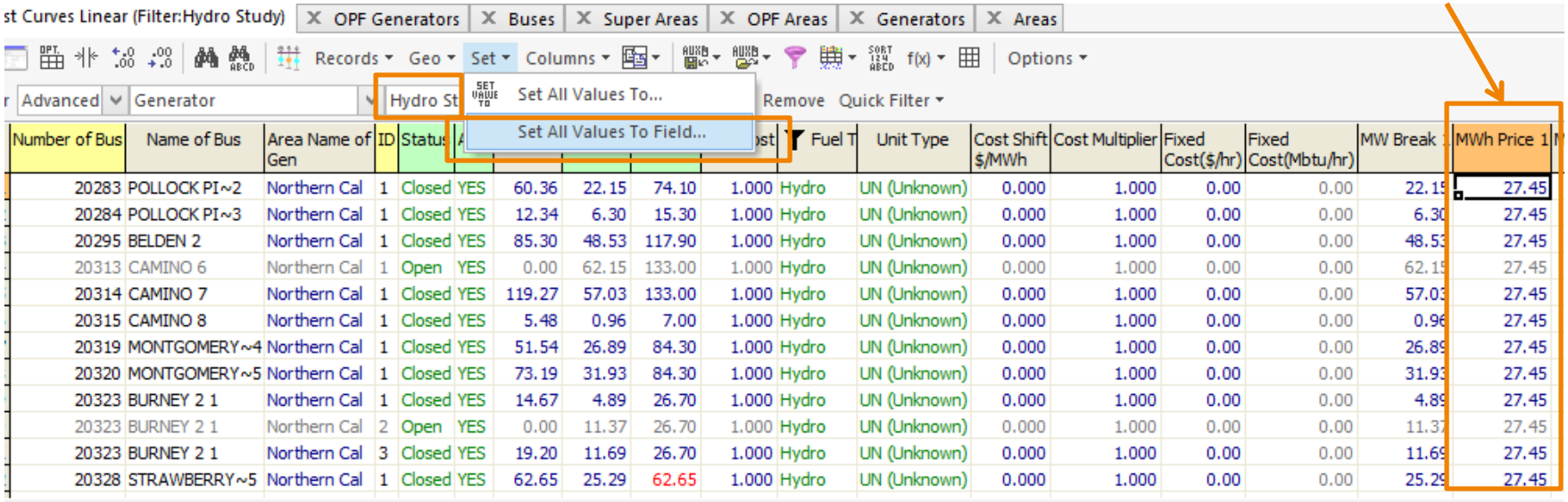
All LP Variables | LP Basic Variables | LP Basis Matrix | Inverse of LP Basis | Trace Solution

Records | Set | Columns | Options

	Constraint ID	Contingency ID	RHS b value	Lambda	Slack Pos	Gen 20430 #1 MW Control	Gen 21646 #1 MW Control	Gen 23309 #2 MW Control	Gen 26174 #1 MW Control	Gen 28831 #1 MW Control
1	Area 3 MW Constraint	Base Case	0.000	27.450	434	1.000				
2	Area 4 MW Constraint	Base Case	0.001	28.680	435		1.000			
3	Area 5 MW Constraint	Base Case	0.001	26.680	436			1.000		
4	Area 6 MW Constraint	Base Case	-0.004	27.720	437				1.000	
5	Area 7 MW Constraint	Base Case	-0.001	32.410	438					1.000

Set Cost Curves for Hydro Units

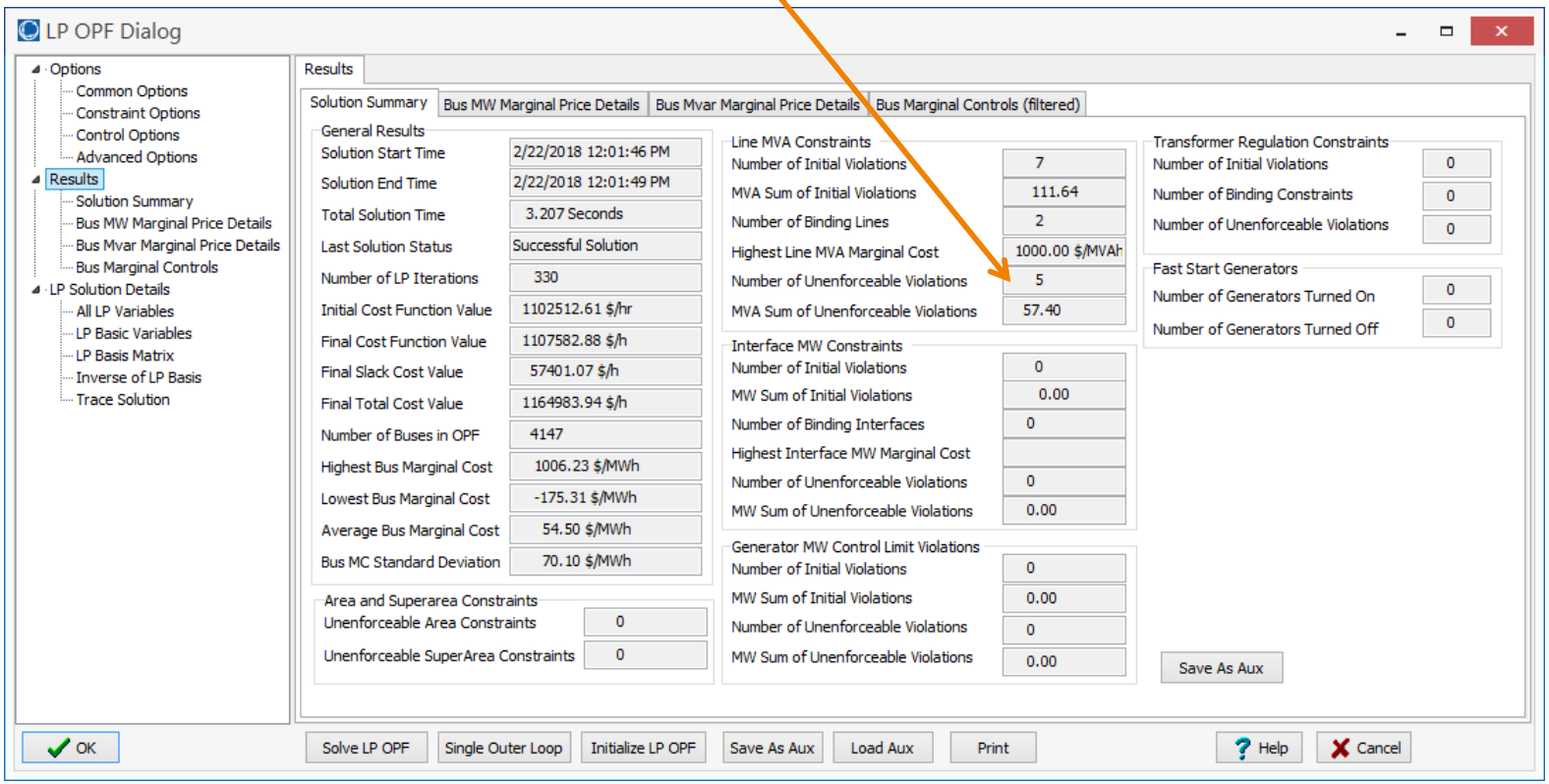
- For each Hydro Unit (filter *Hydro Study*), set
  - AGC = YES
  - Cost Model = Piecewise Linear
  - Breakpoint (MW Break 1) = Minimum MW
  - offer price (MWh Price 1) = MW Marginal Cost of its bus



Number of Bus	Name of Bus	Area Name of Gen	ID	Status	A					Fuel T	Unit Type	Cost Shift $/MWh	Cost Multiplier	Fixed Cost($/hr)	Fixed Cost(Mbtu/hr)	MW Break	MWh Price 1
20283	POLLOCK PI~2	Northern Cal	1	Closed	YES	60.36	22.15	74.10	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	22.15	27.45
20284	POLLOCK PI~3	Northern Cal	1	Closed	YES	12.34	6.30	15.30	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	6.30	27.45
20295	BELDEN 2	Northern Cal	1	Closed	YES	85.30	48.53	117.90	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	48.53	27.45
20313	CAMINO 6	Northern Cal	1	Open	YES	0.00	62.15	133.00	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	62.15	27.45
20314	CAMINO 7	Northern Cal	1	Closed	YES	119.27	57.03	133.00	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	57.03	27.45
20315	CAMINO 8	Northern Cal	1	Closed	YES	5.48	0.96	7.00	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	0.96	27.45
20319	MONTGOMERY~4	Northern Cal	1	Closed	YES	51.54	26.89	84.30	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	26.89	27.45
20320	MONTGOMERY~5	Northern Cal	1	Closed	YES	73.19	31.93	84.30	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	31.93	27.45
20323	BURNEY 2 1	Northern Cal	1	Closed	YES	14.67	4.89	26.70	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	4.89	27.45
20323	BURNEY 2 1	Northern Cal	2	Open	YES	0.00	11.37	26.70	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	11.37	27.45
20323	BURNEY 2 1	Northern Cal	3	Closed	YES	19.20	11.69	26.70	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	11.69	27.45
20328	STRAWBERRY~5	Northern Cal	1	Closed	YES	62.65	25.29	62.65	1.000	Hydro	UN (Unknown)	0.000	1.000	0.00	0.00	25.29	27.45

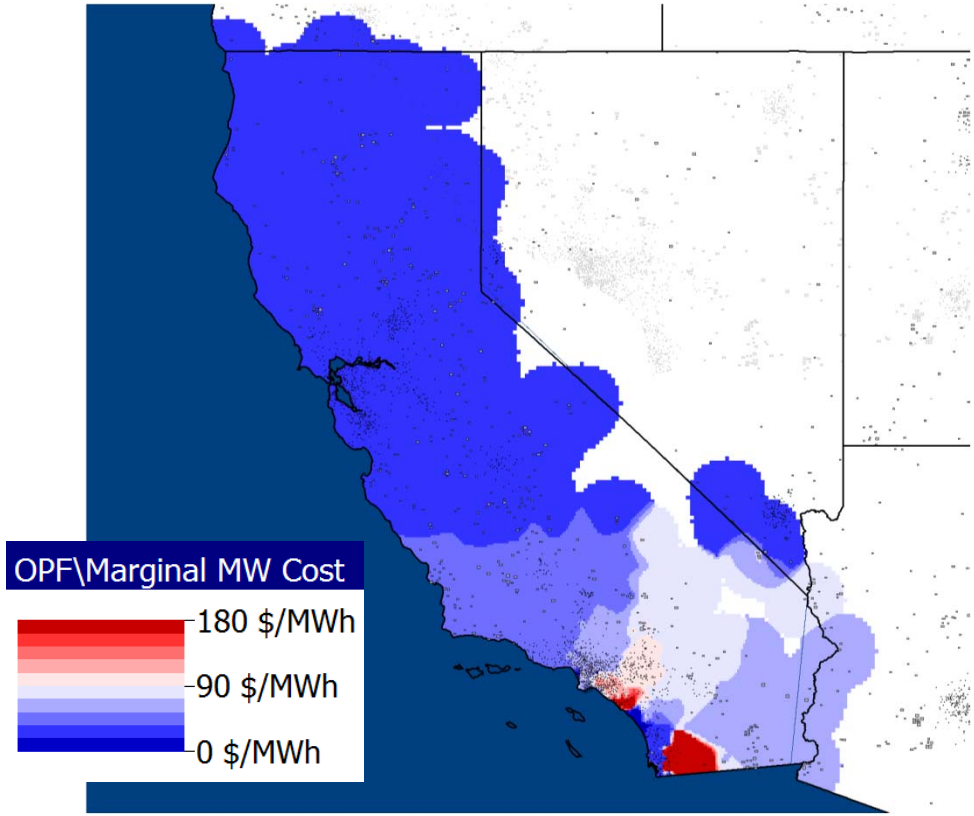
Solve Constrained OPF

- Enable constraint enforcement (on *Constraint Options*)
- Solve OPF, note several unenforceable constraints

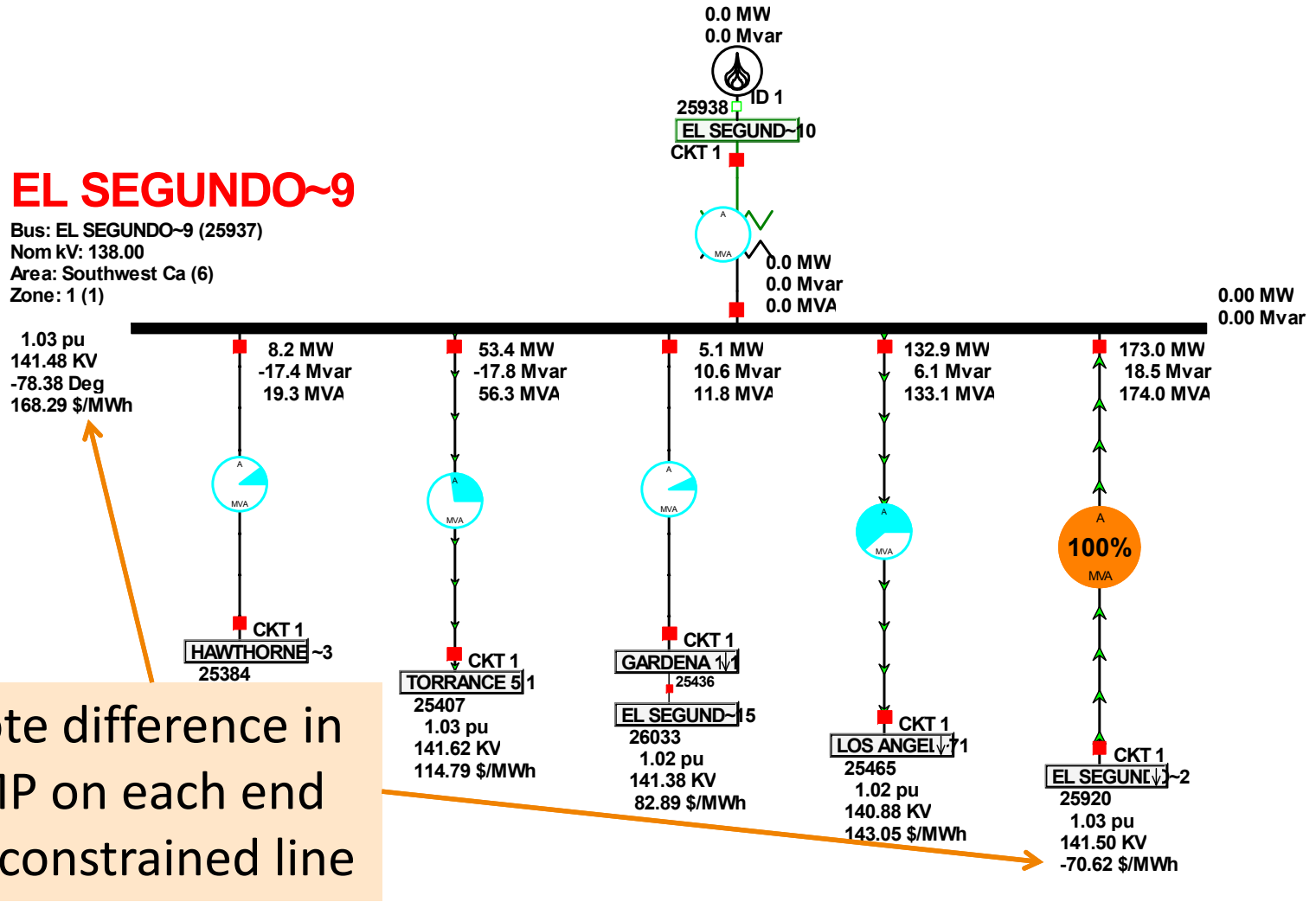


LMP Contour

- Note high LMPs in constraint pockets and seams along area boundaries



Effect of Line Constraints



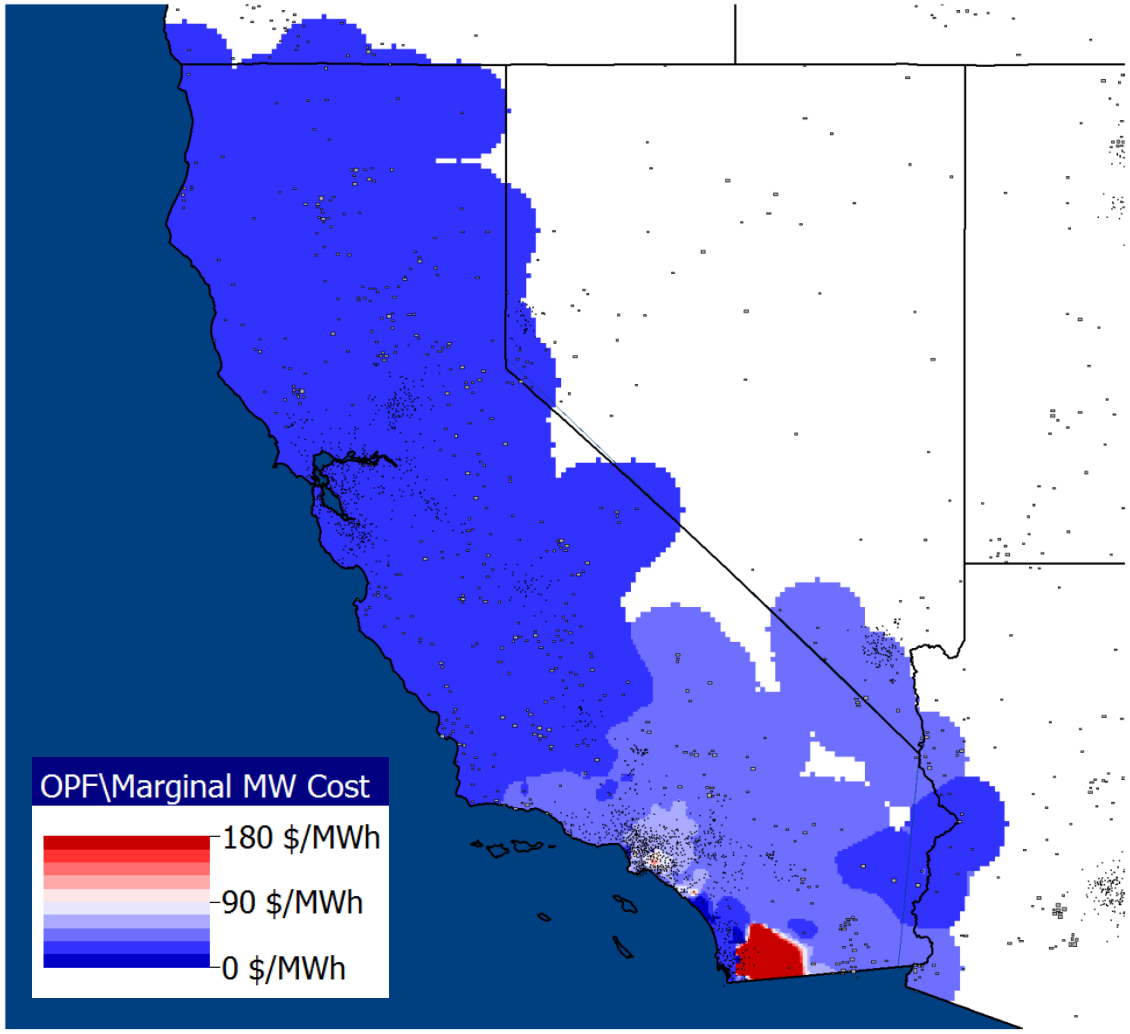
Note difference in LMP on each end of constrained line

Options for Further Analysis

- Increase available units (and reserve margin) in areas with limited supply
  - Many generators at their max output
  - 6% committed, dispatchable reserves
- Place 5 California Areas on Super Area Control
  - Single power balance constraint for entire super area
  - Allows areas with limited capacity increase imports from other areas in the ISO/super area

California Super Area

- Hydro Price = $30, system-wide
- Note easing of some constraints and high-price pockets
- 4 unenforceable constraints remain



Options for Further Analysis

- Check sensitivities on unenforceable constraints
  - Optionally ignore or raise limits, change unit commitment, or include demand response (curtailable load)
  - Some unenforceable constraints may be unavoidable due to load pockets
- Incorporate contingencies with Contingent Interfaces (flowgates)
- Change cost curves (e.g. model a 10% increase in fuel cost)

Unenforceable Constraints

- Examine LP Basis Matrix
- Check TLR sensitivities on overloaded lines to understand relationship between flows and generator and load values
  - Look for generators with high sensitivities that could be committed or de-committed to relieve constraints
  - Look for loads with high sensitivities that could be curtailed

LP Basis Matrix

- Most marginal controller sensitivities have very low absolute value
  - Suggests presence of load pockets
  - Opposite signs for different constraints (relieving one makes another worse)
- We could also examine sensitivities for controls that are at breakpoints, limits, or not committed

LP Solution Details

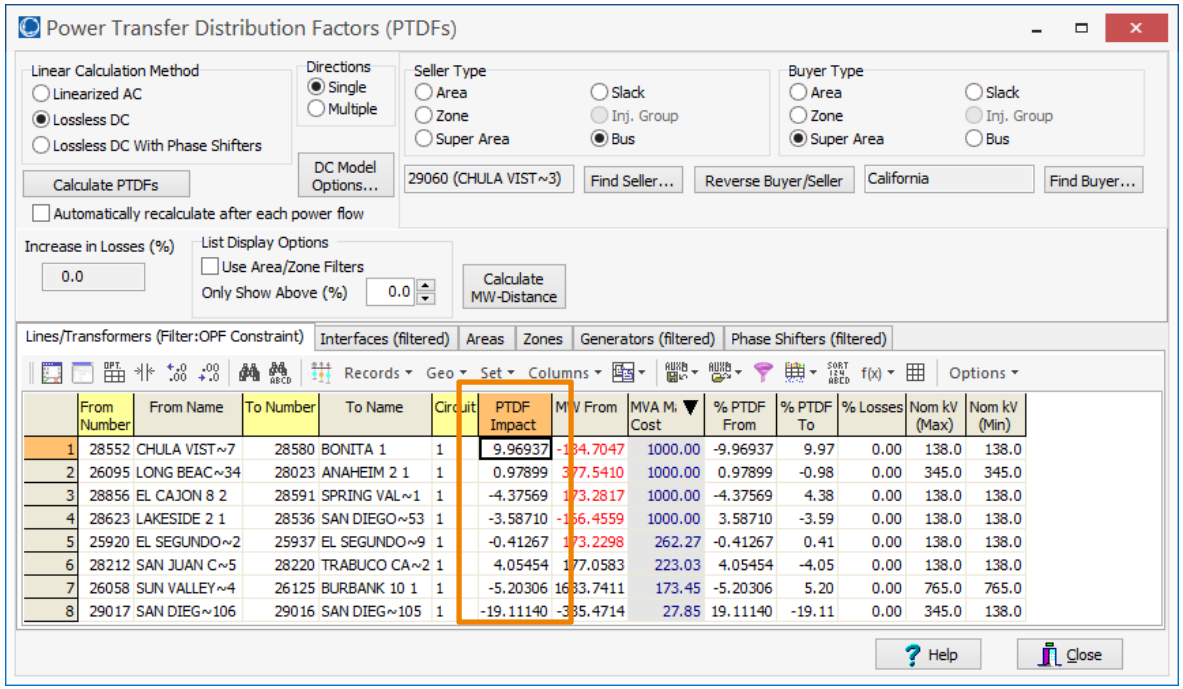
All LP Variables | LP Basic Variables | LP Basis Matrix | Inverse of LP Basis | Trace Solution

Records | Set | Columns | Options

	Constraint ID	Contingency ID	RHS b value	Lambda	Slack Pos	Gen 29004 #1 MW Control	Gen 25923 #1 MW Control	Gen 26197 #1 MW Control	Slack-Line 26095 TO 28023 CKT 1	Gen 29060 #1 MW Control	Slack-Line 28623 TO 28536 CKT 1	Slack-Line 28856 TO 28591 CKT 1	Slack-Line 28552 TO 28580 CKT 1	Gen 26098 #1 MW Control
1	Line from 28856 to 28591 ckt. 1	Base Case	-0.116	1000.000	629	0.002	0.000	0.000		-0.043		1.000		0.000
2	Line from 28552 to 28580 ckt. 1	Base Case	-0.068	1000.000	630	-0.007	-0.002	-0.002		0.088			1.000	-0.002
3	Line from 26095 to 28023 ckt. 1	Base Case	-0.146	1000.000	626	0.001	-0.002	-0.006	1.000	0.001				0.025
4	Line from 28623 to 28536 ckt. 1	Base Case	-0.094	1000.000	628	0.011	0.003	0.003		-0.035	1.000			0.003
5	Line from 25920 to 25937 ckt. 1	Base Case	0.000	262.428	624	-0.001	0.103	0.003		-0.001				0.004
6	Line from 28212 to 28220 ckt. 1	Base Case	-0.000	223.315	627	0.024	-0.025	-0.024		0.016				-0.026
7	Line from 26058 to 26125 ckt. 1	Base Case	-0.000	173.538	625	-0.011	-0.066	0.081		-0.008				-0.045
8	SuperArea California MW Constraint	Base Case	0.000	34.476	623	1.000	1.000	1.000		1.000				1.000
9	Transformer from 29017 to 29016 ckt. 1	Base Case	-0.000	27.842	631	-0.010	-0.002	-0.002		-0.174				-0.002

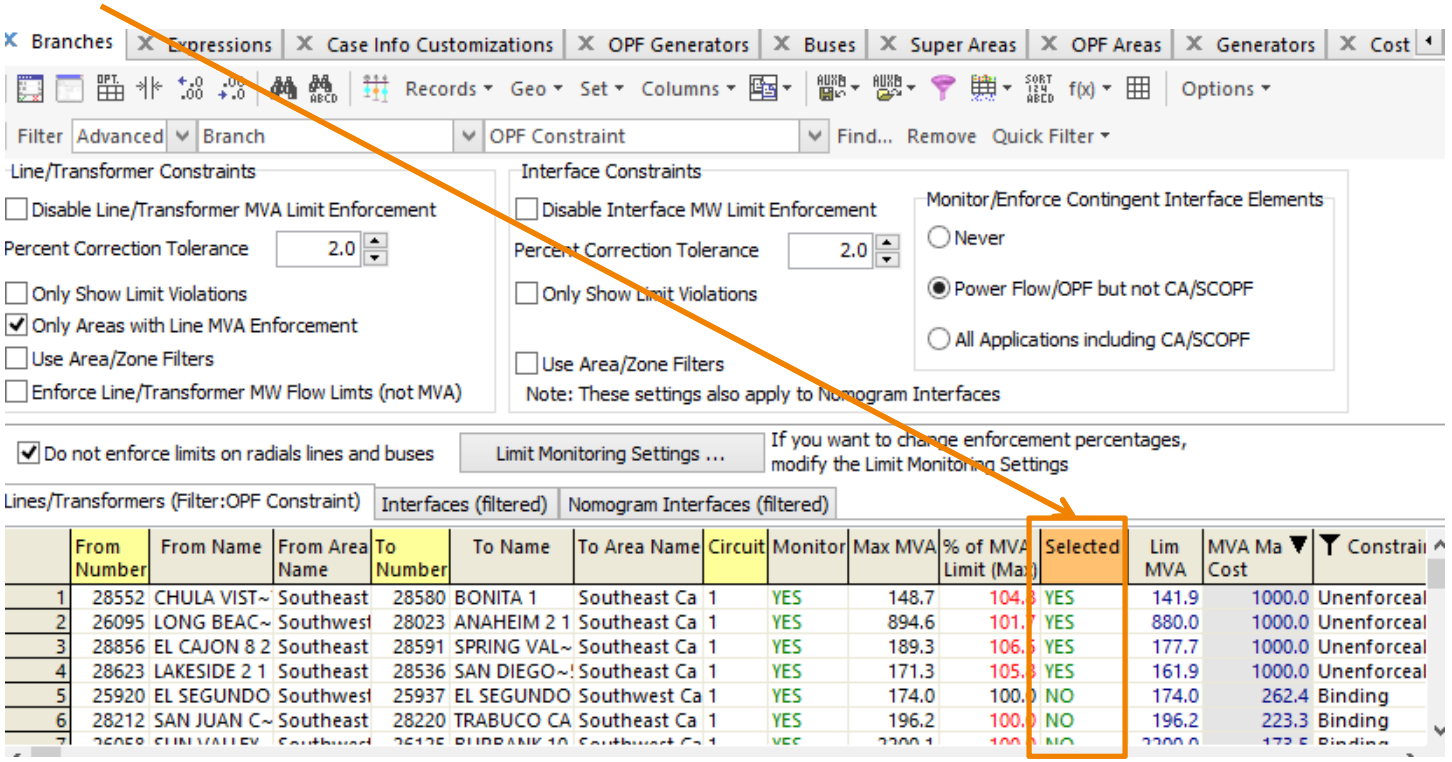
PTDF Example

- Load *SensitivityCalcs.aux*
  - *PTDF Impact* expression adjusts sign of PTDF to correspond to direction of flow
  - *PTDF Impact* < 0 means transfer reduces flow
- Calculate PTDF for transfer from Bus 29060 to California Super Area
- Note that increasing generation at 29060 would relieve some constraints but exacerbate others



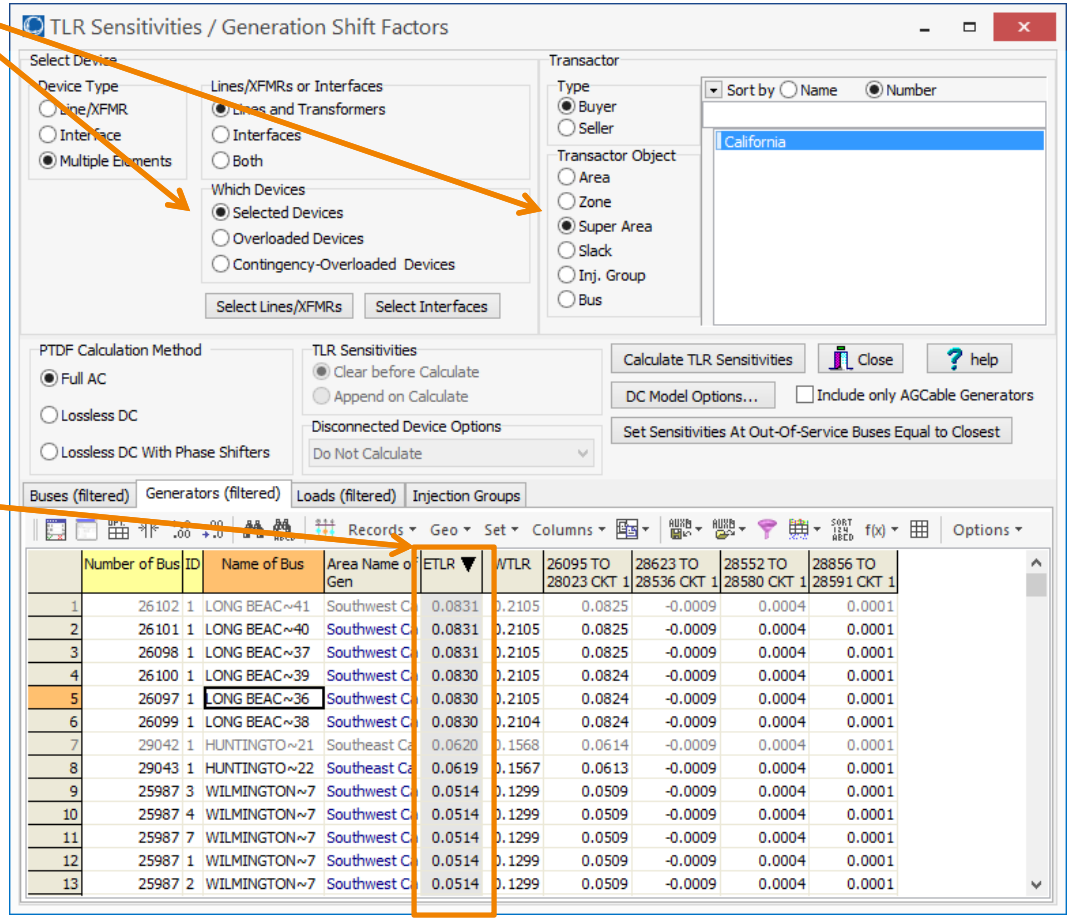
Multiple Element TLR

- *SensitivityCalcs.aux* also contains expressions and data grids to aid this analysis
- "Select" lines that are unenforceable constraints



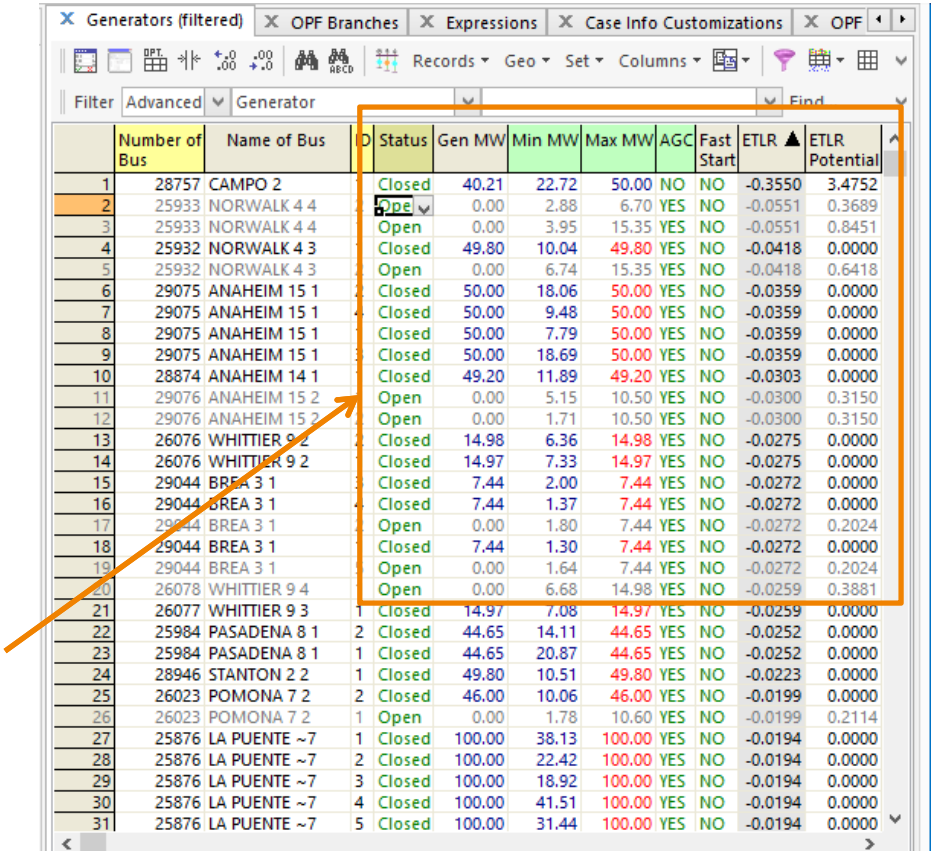
Multiple Element TLR

- TLR on *Selected Devices* with Super Area as buyer
- Negative values on de-committed generators indicate units that may relieve congestion if committed
- Positive values on committed generators (especially those at Min MW) indicate that de-committing may help



Multiple Element TLR

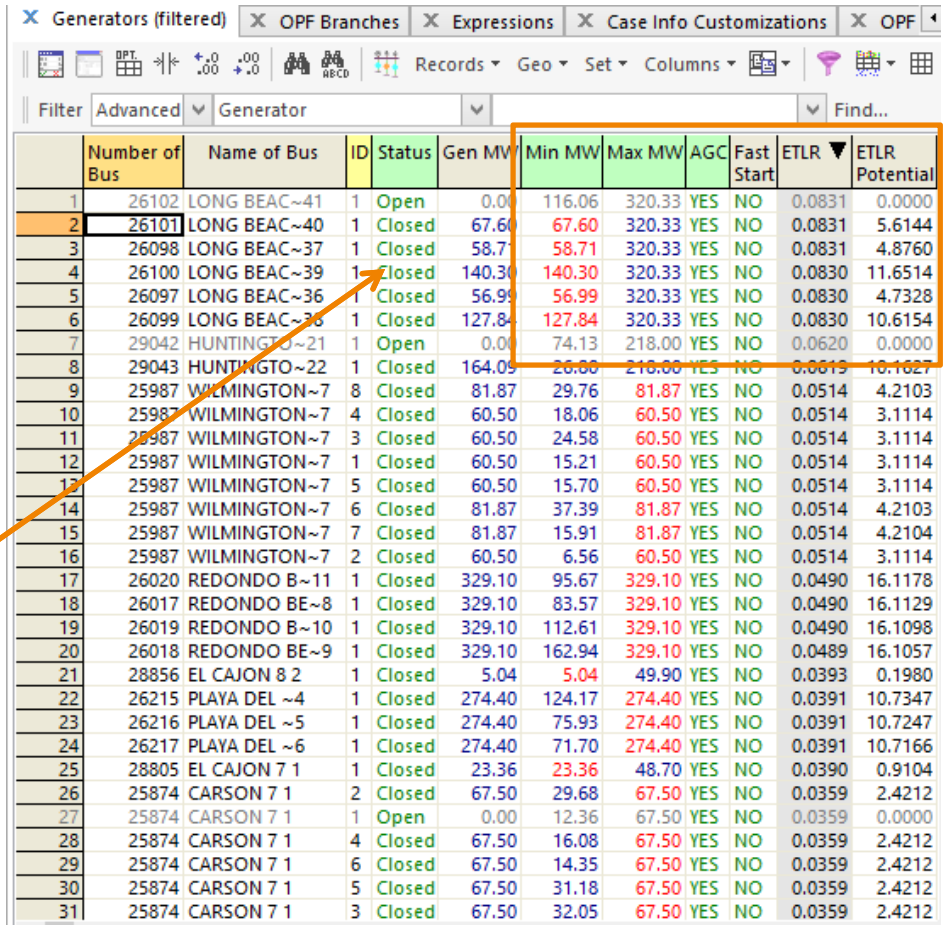
- Generators display, sorted by ascending ETLR
- Note how committed, AGCable units with most negative ETLR are generally maxed out
- Try committing more units with negative ETLR or those with highest product of ETLR and Max MW (custom expression “ETLR Potential”)
- e.g. Commit 8 units in the top 20 units that are not already committed
- Resolving power flow and OPF yields a reduction of about 7 MVA of unenforceable violations



	Number of Bus	Name of Bus	ID	Status	Gen MW	Min MW	Max MW	AGC	Fast Start	ETLR	ETLR Potential
1	28757	CAMPO 2		Closed	40.21	22.72	50.00	NO	NO	-0.3550	3.4752
2	25933	NORWALK 4 4		Open	0.00	2.88	6.70	YES	NO	-0.0551	0.3689
3	25933	NORWALK 4 4		Open	0.00	3.95	15.35	YES	NO	-0.0551	0.8451
4	25932	NORWALK 4 3		Closed	49.80	10.04	49.80	YES	NO	-0.0418	0.0000
5	25932	NORWALK 4 3		Open	0.00	6.74	15.35	YES	NO	-0.0418	0.6418
6	29075	ANAHEIM 15 1		Closed	50.00	18.06	50.00	YES	NO	-0.0359	0.0000
7	29075	ANAHEIM 15 1		Closed	50.00	9.48	50.00	YES	NO	-0.0359	0.0000
8	29075	ANAHEIM 15 1		Closed	50.00	7.79	50.00	YES	NO	-0.0359	0.0000
9	29075	ANAHEIM 15 1		Closed	50.00	18.69	50.00	YES	NO	-0.0359	0.0000
10	28874	ANAHEIM 14 1		Closed	49.20	11.89	49.20	YES	NO	-0.0303	0.0000
11	29076	ANAHEIM 15 2		Open	0.00	5.15	10.50	YES	NO	-0.0300	0.3150
12	29076	ANAHEIM 15 2		Open	0.00	1.71	10.50	YES	NO	-0.0300	0.3150
13	26076	WHITTIER 9 2		Closed	14.98	6.36	14.98	YES	NO	-0.0275	0.0000
14	26076	WHITTIER 9 2		Closed	14.97	7.33	14.97	YES	NO	-0.0275	0.0000
15	29044	BREA 3 1		Closed	7.44	2.00	7.44	YES	NO	-0.0272	0.0000
16	29044	BREA 3 1		Closed	7.44	1.37	7.44	YES	NO	-0.0272	0.0000
17	29044	BREA 3 1		Open	0.00	1.80	7.44	YES	NO	-0.0272	0.2024
18	29044	BREA 3 1		Closed	7.44	1.30	7.44	YES	NO	-0.0272	0.0000
19	29044	BREA 3 1		Open	0.00	1.64	7.44	YES	NO	-0.0272	0.2024
20	26078	WHITTIER 9 4		Open	0.00	6.68	14.98	YES	NO	-0.0259	0.3881
21	26077	WHITTIER 9 3	1	Closed	14.97	7.08	14.97	YES	NO	-0.0259	0.0000
22	25984	PASADENA 8 1	2	Closed	44.65	14.11	44.65	YES	NO	-0.0252	0.0000
23	25984	PASADENA 8 1	1	Closed	44.65	20.87	44.65	YES	NO	-0.0252	0.0000
24	28946	STANTON 2 2	1	Closed	49.80	10.51	49.80	YES	NO	-0.0223	0.0000
25	26023	POMONA 7 2	2	Closed	46.00	10.06	46.00	YES	NO	-0.0199	0.0000
26	26023	POMONA 7 2	1	Open	0.00	1.78	10.60	YES	NO	-0.0199	0.2114
27	25876	LA PUENTE ~7	1	Closed	100.00	38.13	100.00	YES	NO	-0.0194	0.0000
28	25876	LA PUENTE ~7	2	Closed	100.00	22.42	100.00	YES	NO	-0.0194	0.0000
29	25876	LA PUENTE ~7	3	Closed	100.00	18.92	100.00	YES	NO	-0.0194	0.0000
30	25876	LA PUENTE ~7	4	Closed	100.00	41.51	100.00	YES	NO	-0.0194	0.0000
31	25876	LA PUENTE ~7	5	Closed	100.00	31.44	100.00	YES	NO	-0.0194	0.0000

Multiple Element TLR

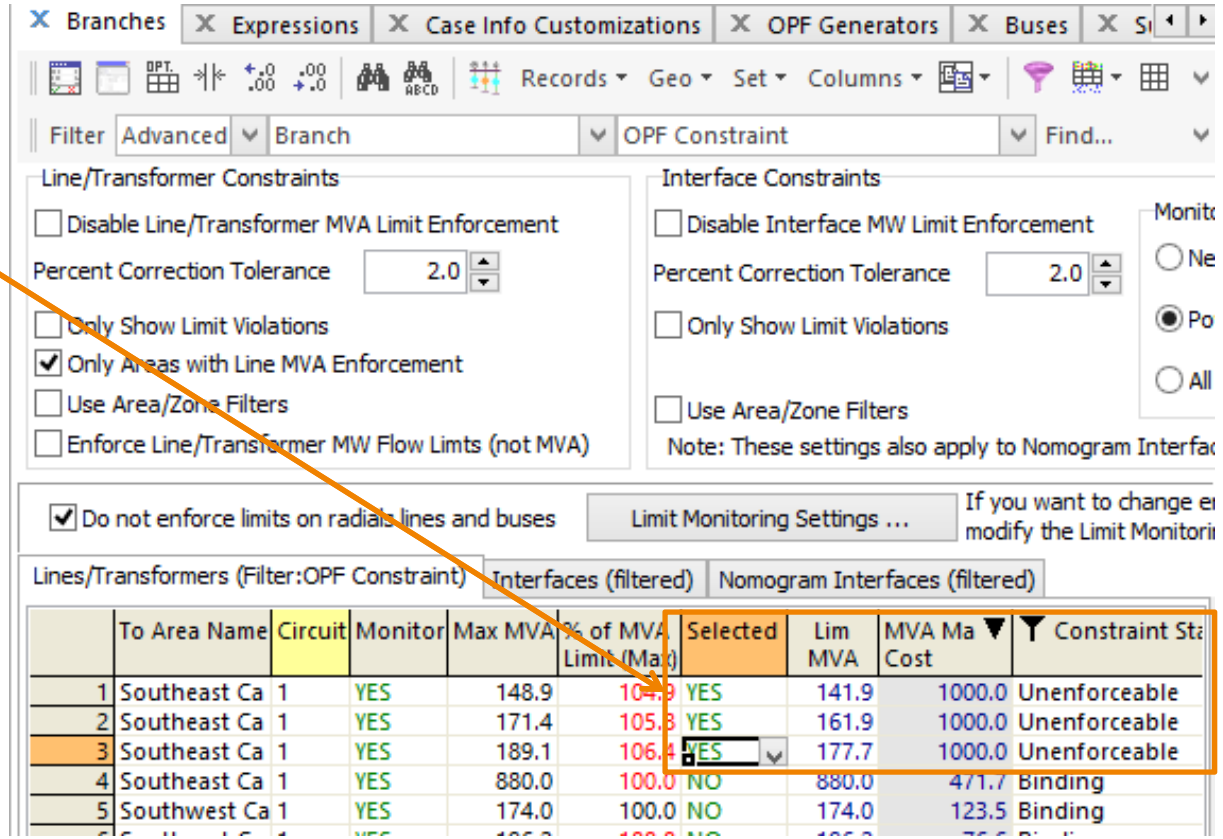
- Generators display, sorted by descending ETLR
- Note how committed units with most positive ETLR are generally at minimum limit
- Try de-committing units with positive ETLR or those with highest product of ETLR and Max MW (custom expression "ETLR Potential")
- e.g. De-commit highest output LONG BEACH unit
- Solve power flow, then Re-solve OPF



	Number of Bus	Name of Bus	ID	Status	Gen MW	Min MW	Max MW	AGC	Fast Start	ETLR	ETLR Potential
1	26102	LONG BEAC~41	1	Open	0.00	116.06	320.33	YES	NO	0.0831	0.0000
2	26101	LONG BEAC~40	1	Closed	67.60	67.60	320.33	YES	NO	0.0831	5.6144
3	26098	LONG BEAC~37	1	Closed	58.71	58.71	320.33	YES	NO	0.0831	4.8760
4	26100	LONG BEAC~39	1	Closed	140.30	140.30	320.33	YES	NO	0.0830	11.6514
5	26097	LONG BEAC~36	1	Closed	56.99	56.99	320.33	YES	NO	0.0830	4.7328
6	26099	LONG BEAC~38	1	Closed	127.84	127.84	320.33	YES	NO	0.0830	10.6154
7	29042	HUNTINGTO~21	1	Open	0.00	74.13	218.00	YES	NO	0.0620	0.0000
8	29043	HUNTINGTO~22	1	Closed	164.09	26.00	218.00	YES	NO	0.0619	10.1627
9	25987	WILMINGTON~7	8	Closed	81.87	29.76	81.87	YES	NO	0.0514	4.2103
10	25987	WILMINGTON~7	4	Closed	60.50	18.06	60.50	YES	NO	0.0514	3.1114
11	25987	WILMINGTON~7	3	Closed	60.50	24.58	60.50	YES	NO	0.0514	3.1114
12	25987	WILMINGTON~7	1	Closed	60.50	15.21	60.50	YES	NO	0.0514	3.1114
13	25987	WILMINGTON~7	5	Closed	60.50	15.70	60.50	YES	NO	0.0514	3.1114
14	25987	WILMINGTON~7	6	Closed	81.87	37.39	81.87	YES	NO	0.0514	4.2103
15	25987	WILMINGTON~7	7	Closed	81.87	15.91	81.87	YES	NO	0.0514	4.2104
16	25987	WILMINGTON~7	2	Closed	60.50	6.56	60.50	YES	NO	0.0514	3.1114
17	26020	REDONDO B~11	1	Closed	329.10	95.67	329.10	YES	NO	0.0490	16.1178
18	26017	REDONDO BE~8	1	Closed	329.10	83.57	329.10	YES	NO	0.0490	16.1129
19	26019	REDONDO B~10	1	Closed	329.10	112.61	329.10	YES	NO	0.0490	16.1098
20	26018	REDONDO BE~9	1	Closed	329.10	162.94	329.10	YES	NO	0.0489	16.1057
21	28856	EL CAJON 8 2	1	Closed	5.04	5.04	49.90	YES	NO	0.0393	0.1980
22	26215	PLAYA DEL ~4	1	Closed	274.40	124.17	274.40	YES	NO	0.0391	10.7347
23	26216	PLAYA DEL ~5	1	Closed	274.40	75.93	274.40	YES	NO	0.0391	10.7247
24	26217	PLAYA DEL ~6	1	Closed	274.40	71.70	274.40	YES	NO	0.0391	10.7166
25	28805	EL CAJON 7 1	1	Closed	23.36	23.36	48.70	YES	NO	0.0390	0.9104
26	25874	CARSON 7 1	2	Closed	67.50	29.68	67.50	YES	NO	0.0359	2.4212
27	25874	CARSON 7 1	1	Open	0.00	12.36	67.50	YES	NO	0.0359	0.0000
28	25874	CARSON 7 1	4	Closed	67.50	16.08	67.50	YES	NO	0.0359	2.4212
29	25874	CARSON 7 1	6	Closed	67.50	14.35	67.50	YES	NO	0.0359	2.4212
30	25874	CARSON 7 1	5	Closed	67.50	31.18	67.50	YES	NO	0.0359	2.4212
31	25874	CARSON 7 1	3	Closed	67.50	32.05	67.50	YES	NO	0.0359	2.4212

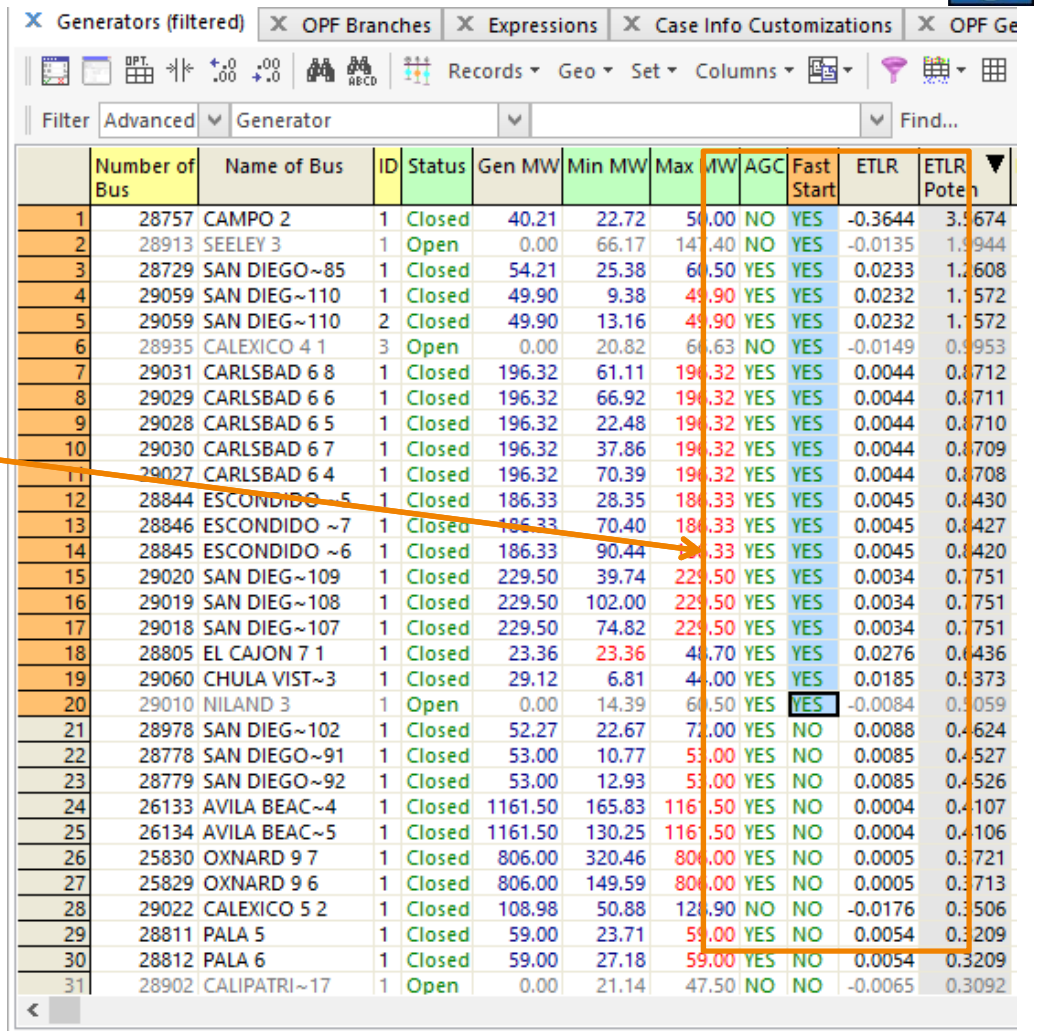
Multiple Element TLR

- 3 Unenforceable Constraints remain
- Unselect all lines and select just these 3
- Re-calculate multi-element TLR



Multiple Element TLR

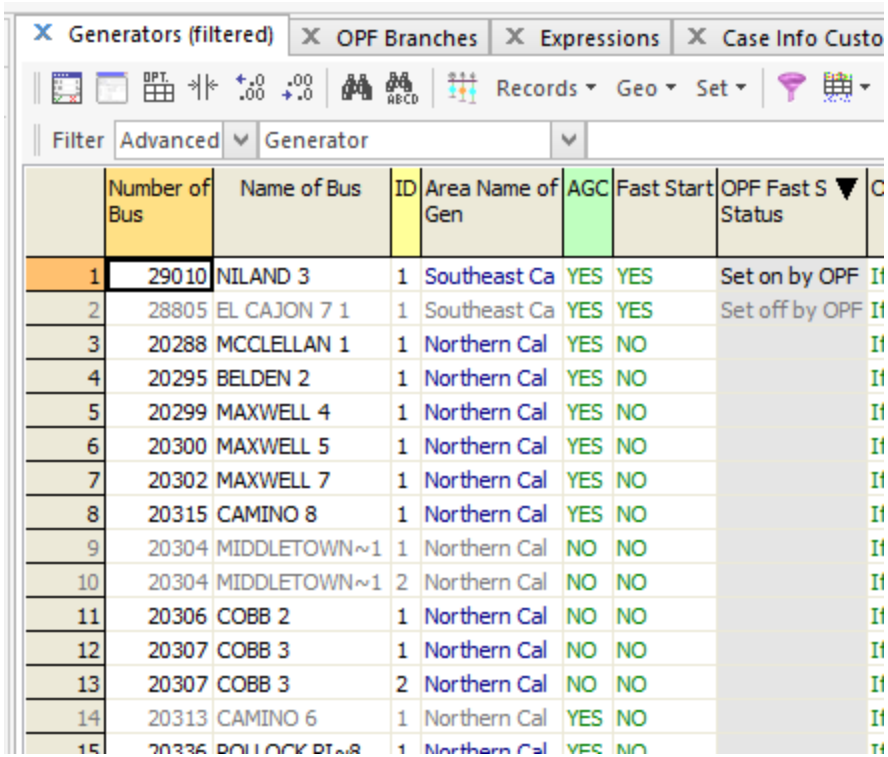
- Return to Generators display
- Sort by descending "ETLR Potential" (custom expression)
- Designating all units with ETLR Potential > 0.5 as "Fast Start"
- Allow Commitment and Decommitment of Fast Start Generators on *LP OPF Dialog*
- Re-solve OPF



	Number of Bus	Name of Bus	ID	Status	Gen MW	Min MW	Max MW	AGC	Fast Start	ETLR	ETLR Pote
1	28757	CAMPO 2	1	Closed	40.21	22.72	50.00	NO	YES	-0.3644	3.5674
2	28913	SEELEY 3	1	Open	0.00	66.17	147.40	NO	YES	-0.0135	1.9944
3	28729	SAN DIEGO~85	1	Closed	54.21	25.38	60.50	YES	YES	0.0233	1.2608
4	29059	SAN DIEG~110	1	Closed	49.90	9.38	49.90	YES	YES	0.0232	1.1572
5	29059	SAN DIEG~110	2	Closed	49.90	13.16	49.90	YES	YES	0.0232	1.1572
6	28935	CALEXICO 4 1	3	Open	0.00	20.82	66.63	NO	YES	-0.0149	0.9953
7	29031	CARLSBAD 6 8	1	Closed	196.32	61.11	196.32	YES	YES	0.0044	0.6712
8	29029	CARLSBAD 6 6	1	Closed	196.32	66.92	196.32	YES	YES	0.0044	0.6711
9	29028	CARLSBAD 6 5	1	Closed	196.32	22.48	196.32	YES	YES	0.0044	0.6710
10	29030	CARLSBAD 6 7	1	Closed	196.32	37.86	196.32	YES	YES	0.0044	0.6709
11	29027	CARLSBAD 6 4	1	Closed	196.32	70.39	196.32	YES	YES	0.0044	0.6708
12	28844	ESCONDIDO ~5	1	Closed	186.33	28.35	186.33	YES	YES	0.0045	0.6430
13	28846	ESCONDIDO ~7	1	Closed	186.33	70.40	186.33	YES	YES	0.0045	0.6427
14	28845	ESCONDIDO ~6	1	Closed	186.33	90.44	186.33	YES	YES	0.0045	0.6420
15	29020	SAN DIEG~109	1	Closed	229.50	39.74	229.50	YES	YES	0.0034	0.7751
16	29019	SAN DIEG~108	1	Closed	229.50	102.00	229.50	YES	YES	0.0034	0.7751
17	29018	SAN DIEG~107	1	Closed	229.50	74.82	229.50	YES	YES	0.0034	0.7751
18	28805	EL CAJON 7 1	1	Closed	23.36	23.36	46.70	YES	YES	0.0276	0.6436
19	29060	CHULA VIST~3	1	Closed	29.12	6.81	44.00	YES	YES	0.0185	0.5373
20	29010	NILAND 3	1	Open	0.00	14.39	60.50	YES	YES	-0.0084	0.3059
21	28978	SAN DIEG~102	1	Closed	52.27	22.67	72.00	YES	NO	0.0088	0.4624
22	28778	SAN DIEGO~91	1	Closed	53.00	10.77	53.00	YES	NO	0.0085	0.4527
23	28779	SAN DIEGO~92	1	Closed	53.00	12.93	53.00	YES	NO	0.0085	0.4526
24	26133	AVILA BEAC~4	1	Closed	1161.50	165.83	1161.50	YES	NO	0.0004	0.4107
25	26134	AVILA BEAC~5	1	Closed	1161.50	130.25	1161.50	YES	NO	0.0004	0.4106
26	25830	OXNARD 9 7	1	Closed	806.00	320.46	806.00	YES	NO	0.0005	0.3721
27	25829	OXNARD 9 6	1	Closed	806.00	149.59	806.00	YES	NO	0.0005	0.3713
28	29022	CALEXICO 5 2	1	Closed	108.98	50.88	128.90	NO	NO	-0.0176	0.3506
29	28811	PALA 5	1	Closed	59.00	23.71	59.00	YES	NO	0.0054	0.3209
30	28812	PALA 6	1	Closed	59.00	27.18	59.00	YES	NO	0.0054	0.3209
31	28902	CALIPATRI~17	1	Open	0.00	21.14	47.50	NO	NO	-0.0065	0.3092

OPF Fast Start Status

- 1 unit turned on, 1 unit turned off by OPF
- Sum of MVA overloads is reduced, but 3 unenforceable constraints remain



Generators (filtered) | OPF Branches | Expressions | Case Info Custo

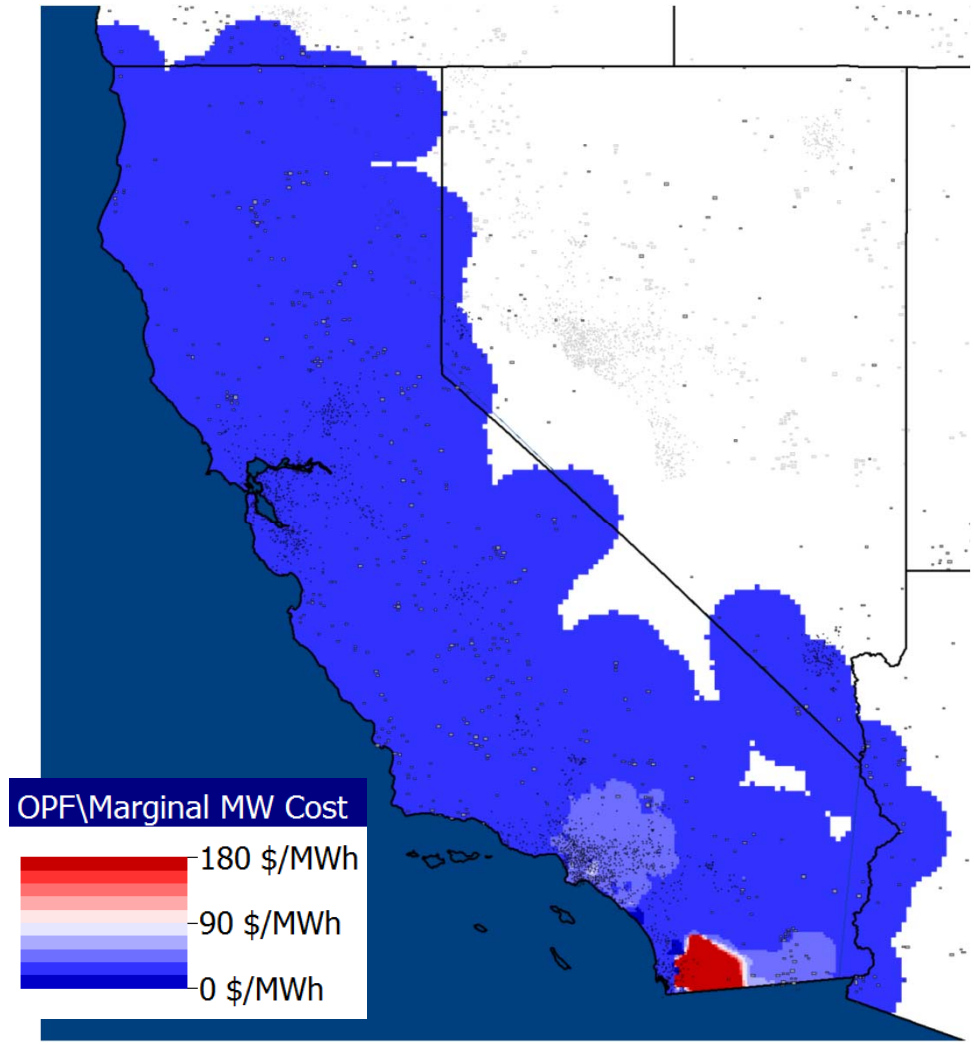
Records | Geo | Set

Filter: Advanced | Generator

	Number of Bus	Name of Bus	ID	Area Name of Gen	AGC	Fast Start	OPF Fast S Status	C
1	29010	NILAND 3	1	Southeast Ca	YES	YES	Set on by OPF	It
2	28805	EL CAJON 7 1	1	Southeast Ca	YES	YES	Set off by OPF	It
3	20288	MCCLELLAN 1	1	Northern Cal	YES	NO		It
4	20295	BELDEN 2	1	Northern Cal	YES	NO		It
5	20299	MAXWELL 4	1	Northern Cal	YES	NO		It
6	20300	MAXWELL 5	1	Northern Cal	YES	NO		It
7	20302	MAXWELL 7	1	Northern Cal	YES	NO		It
8	20315	CAMINO 8	1	Northern Cal	YES	NO		It
9	20304	MIDDLETOWN~1	1	Northern Cal	NO	NO		It
10	20304	MIDDLETOWN~1	2	Northern Cal	NO	NO		It
11	20306	COBB 2	1	Northern Cal	NO	NO		It
12	20307	COBB 3	1	Northern Cal	NO	NO		It
13	20307	COBB 3	2	Northern Cal	NO	NO		It
14	20313	CAMINO 6	1	Northern Cal	YES	NO		It
15	20336	POLLOCK PI~8	1	Northern Cal	YES	NO		It

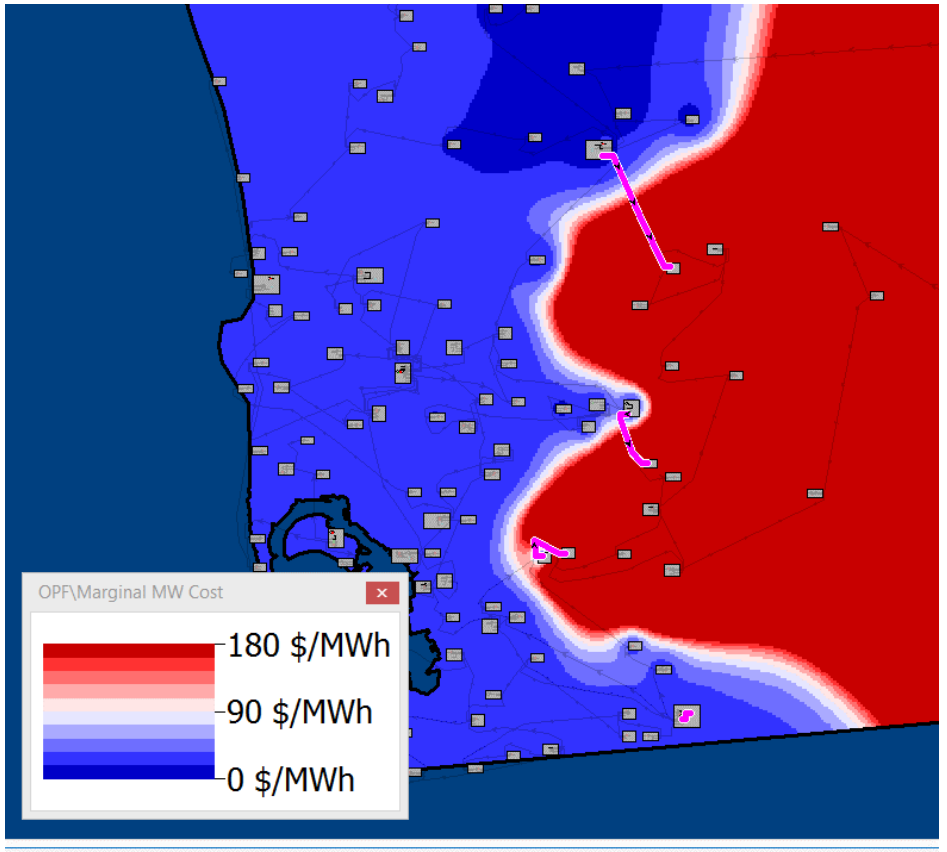
Updated Color Contour

- Pricing is fairly uniform system-wide except for pocket near San Diego



San Diego Area with Dynamic Formatting

- Overloaded lines across the pricing boundary
- Turn off all layers except “Borders”, “ContourStencil”, and “Default Layer”
- For Dynamic Formatting set “Overloaded Lines”, check the *Force Visibility* checkbox



ETLR Bus Sensitivities

- Highest negative ETLR for remaining unenforceable constraints occur at load buses
- Wind generator (not AGCable)

Buses (filtered) | OPF Branches | Expressions | Case Info Customizations | OPF Generators | Super Areas

Records | Geo | Set | Columns | f(x)

Filter: Advanced | Bus | Find... | Remove | Quick Filter

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	ETL	Load MW	Load Mvar	Gen MW	Gen Mvar	S S
1	28621	LAKESIDE 1 1	Southeast Ca	138.00	0.99214	136.915	-83.17	-0.97	39.76	22.81			
2	28622	LAKESIDE 1 2	Southeast Ca	138.00	0.99250	136.965	-83.14	-0.97					
3	28623	LAKESIDE 2 1	Southeast Ca	138.00	0.99475	137.275	-82.85	-0.97	37.15	17.52			
4	28632	EL CAJON 5 2	Southeast Ca	138.00	0.99353	137.107	-83.39	-0.97	58.56	10.56			
5	28591	SPRING VAL~1	Southeast Ca	138.00	1.01345	139.856	-83.07	-0.96	52.53	5.35			
6	28590	LA MESA 3 1	Southeast Ca	138.00	0.99670	137.545	-83.84	-0.96	28.60	8.76			
7	28630	EL CAJON 4 2	Southeast Ca	138.00	1.00882	139.217	-83.40	-0.96	38.34	9.88			
8	28629	EL CAJON 4 1	Southeast Ca	138.00	1.00903	139.246	-83.38	-0.96					
9	28628	EL CAJON 3 1	Southeast Ca	138.00	0.99990	137.986	-83.90	-0.96	54.35	5.88			
10	28575	LA MESA 2 2	Southeast Ca	138.00	1.00342	138.471	-83.67	-0.95	57.17	16.95			
11	28573	LA MESA 1 1	Southeast Ca	138.00	1.00388	138.535	-83.57	-0.95	34.26	14.16			
12	28552	CHULA VIST~7	Southeast Ca	138.00	1.00704	138.972	-83.21	-0.95	49.80	17.35			
13	28600	CHULA VIS~12	Southeast Ca	138.00	1.00164	138.227	-83.53	-0.93	36.87	12.16			
14	28602	CHULA VIS~14	Southeast Ca	138.00	1.00164	138.227	-83.53	-0.93					
15	28601	CHULA VIS~13	Southeast Ca	138.00	1.00188	138.260	-83.51	-0.93					
16	28642	JAMUL 1	Southeast Ca	138.00	0.99624	137.481	-83.29	-0.86	17.31	6.12			
17	28643	JAMUL 2	Southeast Ca	138.00	0.99634	137.495	-83.28	-0.86					
18	28644	ALPINE 1 1	Southeast Ca	138.00	0.98973	136.583	-82.62	-0.76	35.31	8.84			
19	28633	EL CAJON 6 1	Southeast Ca	138.00	0.98849	136.411	-81.90	-0.70	64.75	8.39			
20	28634	EL CAJON 6 2	Southeast Ca	138.00	0.98871	136.442	-81.87	-0.69					
21	28756	CAMPO 1	Southeast Ca	138.00	1.00735	139.014	-75.37	-0.37	14.02	2.22			
22	28757	CAMPO 2	Southeast Ca	18.00	1.01768	18.318	-73.28	-0.36			40.21	10.65	
23	28905	OCOTILLO 3	Southeast Ca	138.00	1.02274	141.138	-70.45	-0.08					
24	28707	HEBER 1 2	Southeast Ca	138.00	1.01946	140.686	-68.70	-0.04	13.20	5.28			
25	28706	HEBER 1 1	Southeast Ca	138.00	1.01956	140.699	-68.69	-0.04					

Demand Response

- Loads may have benefit functions, allowing them to respond to price signals in the OPF
- Load the aux file *CALoadBenefitModel.aux:* includes benefit functions for 19 loads in this pocket

Benefit Curves Linear (filtered) | OPF Branches | Expressions | Case Info Customizations | OPF Generators | Buses | Super Areas | OPF Areas | Generators | Cost Cur

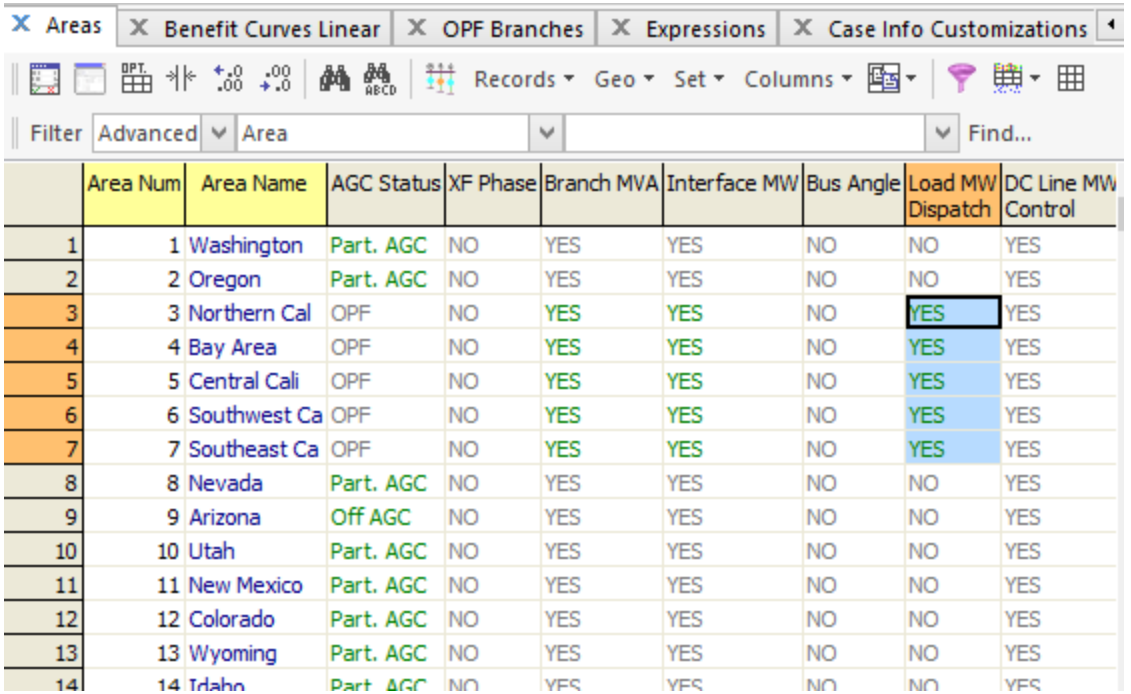
Records | Geo | Set | Columns | f(x) | Options

Filter: Advanced | Load | Find... | Remove | Quick Filter

	Number of Bus	Name of Bus	ID	Status	MW	Min MW	Max MW	Benefit Model	ETLR	MW Break 1	MWh Price 1	MW Break 2	MWh Price 2	MW Break 3	MWh Price 3	MW Break 4	MWh Price 4
1	28628	EL CAJON 3 1	1	Closed YES	38.34	0.00	38.34	Piecewise Linear	-0.96	7.67	1000.00	15.34	800.00	23.00	200.00	30.67	50.00
2	28628	EL CAJON 3 1	2	Closed YES	16.01	0.00	16.01	Piecewise Linear	-0.96	3.20	1000.00	6.40	800.00	9.61	200.00	12.81	50.00
3	28591	SPRING VAL~1	1	Closed YES	52.53	0.00	52.53	Piecewise Linear	-0.96	10.51	1000.00	21.01	800.00	31.52	200.00	42.02	50.00
4	28590	LA MESA 3 1	1	Closed YES	28.60	0.00	28.60	Piecewise Linear	-0.96	5.72	1000.00	11.44	800.00	17.16	200.00	22.88	50.00
5	28575	LA MESA 2 2	1	Closed YES	34.26	0.00	34.26	Piecewise Linear	-0.95	6.85	1000.00	13.70	800.00	20.56	200.00	27.41	50.00
6	28633	EL CAJON 6 1	1	Closed YES	58.56	0.00	58.56	Piecewise Linear	-0.70	11.71	1000.00	23.42	800.00	35.14	200.00	46.85	50.00
7	28632	EL CAJON 5 2	1	Closed YES	58.56	0.00	58.56	Piecewise Linear	-0.97	11.71	1000.00	23.42	800.00	35.14	200.00	46.85	50.00
8	28630	EL CAJON 4 2	1	Closed YES	38.34	0.00	38.34	Piecewise Linear	-0.96	7.67	1000.00	15.34	800.00	23.00	200.00	30.67	50.00
9	28623	LAKESIDE 2 1	1	Closed YES	37.15	0.00	37.15	Piecewise Linear	-0.97	7.43	1000.00	14.86	800.00	22.29	200.00	29.72	50.00
10	28575	LA MESA 2 2	2	Closed YES	22.91	0.00	22.91	Piecewise Linear	-0.95	4.58	1000.00	9.16	800.00	13.75	200.00	18.33	50.00
11	28644	ALPINE 1 1	1	Closed YES	35.31	0.00	35.31	Piecewise Linear	-0.76	7.06	1000.00	14.12	800.00	21.19	200.00	28.25	50.00
12	28573	LA MESA 1 1	1	Closed YES	34.26	0.00	34.26	Piecewise Linear	-0.95	6.85	1000.00	13.70	800.00	20.56	200.00	27.41	50.00
13	28600	CHULA VIS~12	1	Closed YES	36.87	0.00	36.87	Piecewise Linear	-0.93	7.37	1000.00	14.75	800.00	22.12	200.00	29.50	50.00
14	28621	LAKESIDE 1 1	1	Closed YES	37.15	0.00	37.15	Piecewise Linear	-0.97	7.43	1000.00	14.86	800.00	22.29	200.00	29.72	50.00
15	28642	JAMUL 1	2	Closed YES	1.79	0.00	1.79	Piecewise Linear	-0.86	0.36	1000.00	0.72	800.00	1.07	200.00	1.43	50.00
16	28642	JAMUL 1	1	Closed YES	15.52	0.00	15.52	Piecewise Linear	-0.86	3.10	1000.00	6.21	800.00	9.31	200.00	12.42	50.00
17	28633	EL CAJON 6 1	2	Closed YES	6.19	0.00	6.19	Piecewise Linear	-0.70	1.24	1000.00	2.48	800.00	3.71	200.00	4.95	50.00
18	28621	LAKESIDE 1 1	2	Closed YES	2.61	0.00	2.61	Piecewise Linear	-0.97	0.52	1000.00	1.04	800.00	1.57	200.00	2.09	50.00
19	28552	CHULA VIST~7	1	Closed YES	49.80	0.00	49.80	Piecewise Linear	-0.95	9.96	1000.00	19.92	800.00	29.88	200.00	39.84	50.00
20	20025	UKIAH 2 1	1	Closed NO	30.33	0.00	30.33	Piecewise Linear	0.00								
21	20023	UKIAH 1 2	1	Closed NO	31.74	0.00	31.74	Piecewise Linear	0.00								

Demand Response

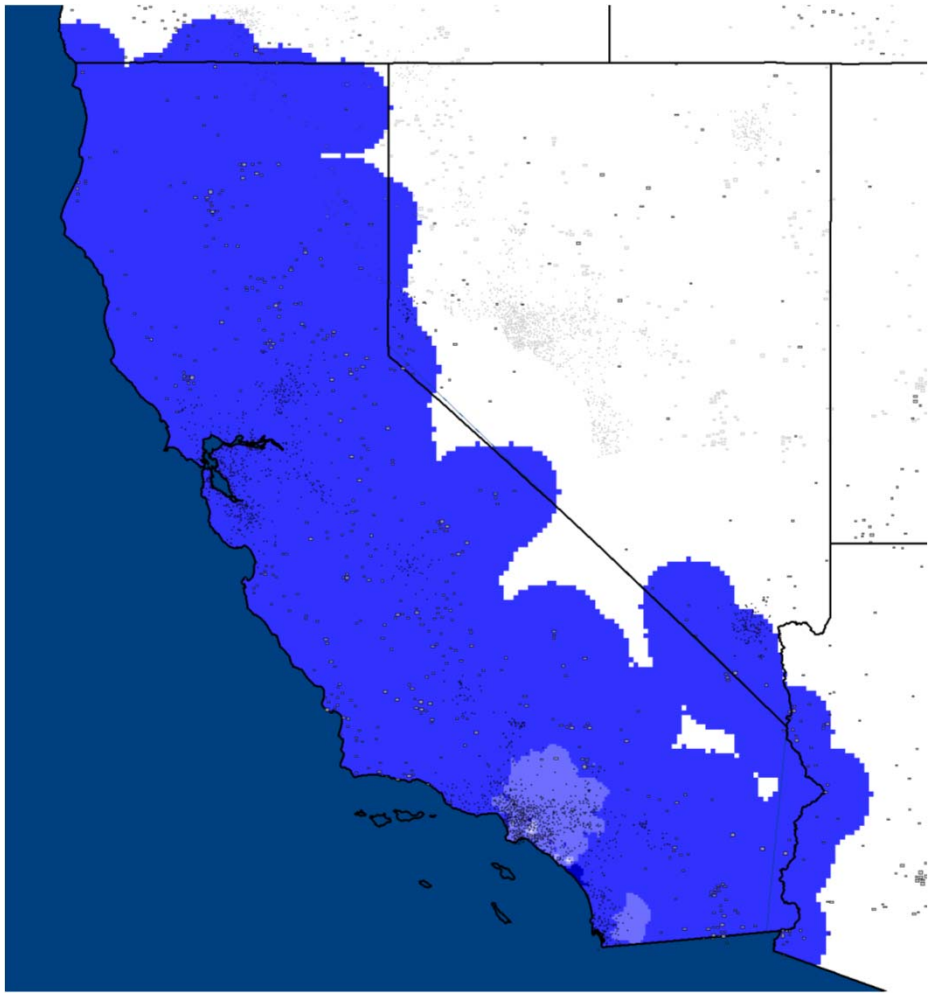
- Enable OPF load controls
  - Globally in *OPF Options and Results*
  - By Area for Areas 3-7 in OPF Areas Case Info Display
- Re-solve OPF



	Area Num	Area Name	AGC Status	XF Phase	Branch MVA	Interface MW	Bus Angle	Load MW Dispatch	DC Line MW Control
1	1	Washington	Part. AGC	NO	YES	YES	NO	NO	YES
2	2	Oregon	Part. AGC	NO	YES	YES	NO	NO	YES
3	3	Northern Cal	OPF	NO	YES	YES	NO	YES	YES
4	4	Bay Area	OPF	NO	YES	YES	NO	YES	YES
5	5	Central Cali	OPF	NO	YES	YES	NO	YES	YES
6	6	Southwest Ca	OPF	NO	YES	YES	NO	YES	YES
7	7	Southeast Ca	OPF	NO	YES	YES	NO	YES	YES
8	8	Nevada	Part. AGC	NO	YES	YES	NO	NO	YES
9	9	Arizona	Off AGC	NO	YES	YES	NO	NO	YES
10	10	Utah	Part. AGC	NO	YES	YES	NO	NO	YES
11	11	New Mexico	Part. AGC	NO	YES	YES	NO	NO	YES
12	12	Colorado	Part. AGC	NO	YES	YES	NO	NO	YES
13	13	Wyoming	Part. AGC	NO	YES	YES	NO	NO	YES
14	14	Idaho	Part. AGC	NO	YES	YES	NO	NO	YES

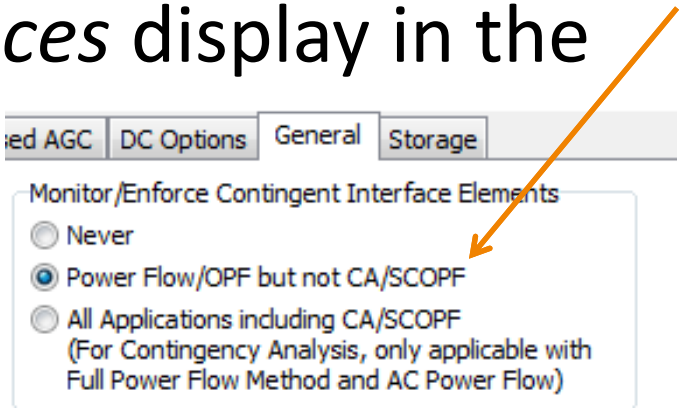
Demand Response

- Updated contour shows more uniform pricing
- Constraints into remaining pockets are binding rather than unenforceable
- Total reduction in load is about 30 MW



Incorporate Contingencies with Flowgates

- Load *CAContingentInterfaces.aux*
- Each flowgate interface includes a monitored element and a contingent element
- Make sure Contingent Interface Elements are Enforced in OPF (*Simulator Options -> General* tab or *OPF -> Interfaces Display*)
- Close *OPF Branches/Interfaces* display in the *Model Explorer*
- Re-solve OPF



More on OPF Challenges

OPF Formulation and Solution

- More on Unenforceable Constraints
  - Radial Elements
  - Mvar loops in AC power flow
  - Unusual modeling parameters
- Insufficient Reserves: not enough controls to satisfy area ACE constraint
- Too Much Power Transfer

Analysis of Unenforceable Constraints

- Example: Load *Eastern2.pwb* (has cost info)
- Choose **Add Ons** ribbon tab → **Primal LP**
  - We end up with 46 unenforceable constraints
- Of these many seem to be caused by radial
  - Change Limit Monitoring Settings to **Ignore Radial Lines and Buses**
    - Radial Bus is connected to the system by only one transmission line
    - Radial Line is a line connected to a radial bus.
  - Choosing this reduces the unenforceable list to 30 constraints.

Unenforceable Constraints

- If you look at the MW and MVar flows on these lines you'll find that many have VERY large MVar flows
  - Add Columns for **Max MW** and **Max MVar** on **Add Ons** ribbon tab → **OPF Case Info** → **OPF Lines and Transformers**
- If you look through the case, you'll find many very strange LTC tap ratio settings
- Also some are due to phase-shifters being in series with an overloaded branch

Reset LTC Taps

- Set all transformers on LTC control to a tap ratio of 1.00 (perform manually, or load *Eastern2ChangeTransformers.aux)*
- Re-solve power flow, then OPF
- May also examine Circulating Mvar Flows
  - **Tools** -> **Connections** -> **Find Circulating MW or Mvar Flows**
  - Check relative tap ratios in Flow Cycles with high Loss Mvar Reduction

Unenforceable Constraints

- This results in a reduced list of 20 unenforceable constraints

Lines/Transformers | Interfaces | Nomogram Interfaces

	From Number	From Name	From Area Name	To Number	To Name	To Area Name	Circuit	Monitor	Max MVA	% of MVA Li ▼ (Max)	Lim MVA	MVA Marg. C ▼	Constraint Status
1	440	EPIKE	PENELEC	445	EPIKE	PENELEC	1	YES	61.6	236.9	26.0	9999.0	Unenforceable
2	6361	GOULDST	BGE	6372	WP PH.S1	BGE	1	YES	65.9	160.8	41.0	9999.0	Unenforceable
3	430	TRADECIT	PENELEC	432	PUNXSUTA	PENELEC	1	YES	45.8	158.1	29.0	9999.0	Unenforceable
4	423	SHAWVILL	PENELEC	428	SHAWVILL	PENELEC	1	YES	119.1	154.6	77.0	9999.0	Unenforceable
5	434	SHAWVILL	PENELEC	436	SHAWVILL	PENELEC	1	YES	118.7	154.1	77.0	9999.0	Unenforceable
6	6362	WESTPORT	BGE	6372	WP PH.S1	BGE	1	YES	66.1	146.9	45.0	9999.0	Unenforceable
7	4257	PLYMOUTH	PECO	4262	PLYMOUTH	PECO	1	YES	71.9	126.1	57.0	9999.0	Unenforceable
8	4257	PLYMOUTH	PECO	4261	PLYMOUTH	PECO	1	YES	71.6	121.4	59.0	9999.0	Unenforceable
9	384	NMESHOPP	PENELEC	406	MEHOOPAN	PENELEC	1	YES	82.0	115.5	71.0	9999.0	Unenforceable
10	6288	NEWGT872	BGE	6361	GOULDST	BGE	1	YES	47.1	114.9	41.0	9999.0	Unenforceable
11	4214	NWALES	PECO	4217	N WALES4	PECO	1	YES	92.7	113.0	82.0	9999.0	Unenforceable
12	3080	SAKRON	PP&L	3230	SAKRON	PP&L	5	YES	99.5	109.3	91.0	9999.0	Unenforceable
13	3080	SAKRON	PP&L	3230	SAKRON	PP&L	3	YES	197.4	108.5	182.0	9999.0	Unenforceable
14	3080	SAKRON	PP&L	3230	SAKRON	PP&L	4	YES	194.4	107.4	181.0	9999.0	Unenforceable
15	3390	KEY CM 1	PP&L	3408	SIEGFRIE	PP&L	1	YES	45.6	106.1	43.0	9999.0	Unenforceable
16	3391	KEY CM 2	PP&L	3399	NAZARETH	PP&L	1	YES	47.6	103.4	46.0	9999.0	Unenforceable
17	3390	KEY CM 1	PP&L	3399	NAZARETH	PP&L	1	YES	47.5	103.3	46.0	9999.0	Unenforceable
18	8863	MILLROAD	DP&L	8872	SUNSETLA	DP&L	1	YES	141.0	103.0	137.0	9999.0	Unenforceable
19	434	SHAWVILL	PENELEC	435	SHAWVILL	PENELEC	1	YES	129.1	100.9	128.0	9999.0	Unenforceable
20	419	SHAWVILL	PENELEC	428	SHAWVILL	PENELEC	1	YES	128.5	100.4	128.0	9999.0	Unenforceable
21	1562	BIRDBORO	METED	1593	PINE LNE	METED	1	YES	34.0	100.0	34.0	3434.1	Binding
22	228	TYRONEN	PENELEC	425	PHILIPSB	PENELEC	1	YES	125.0	100.0	125.0	513.0	Binding

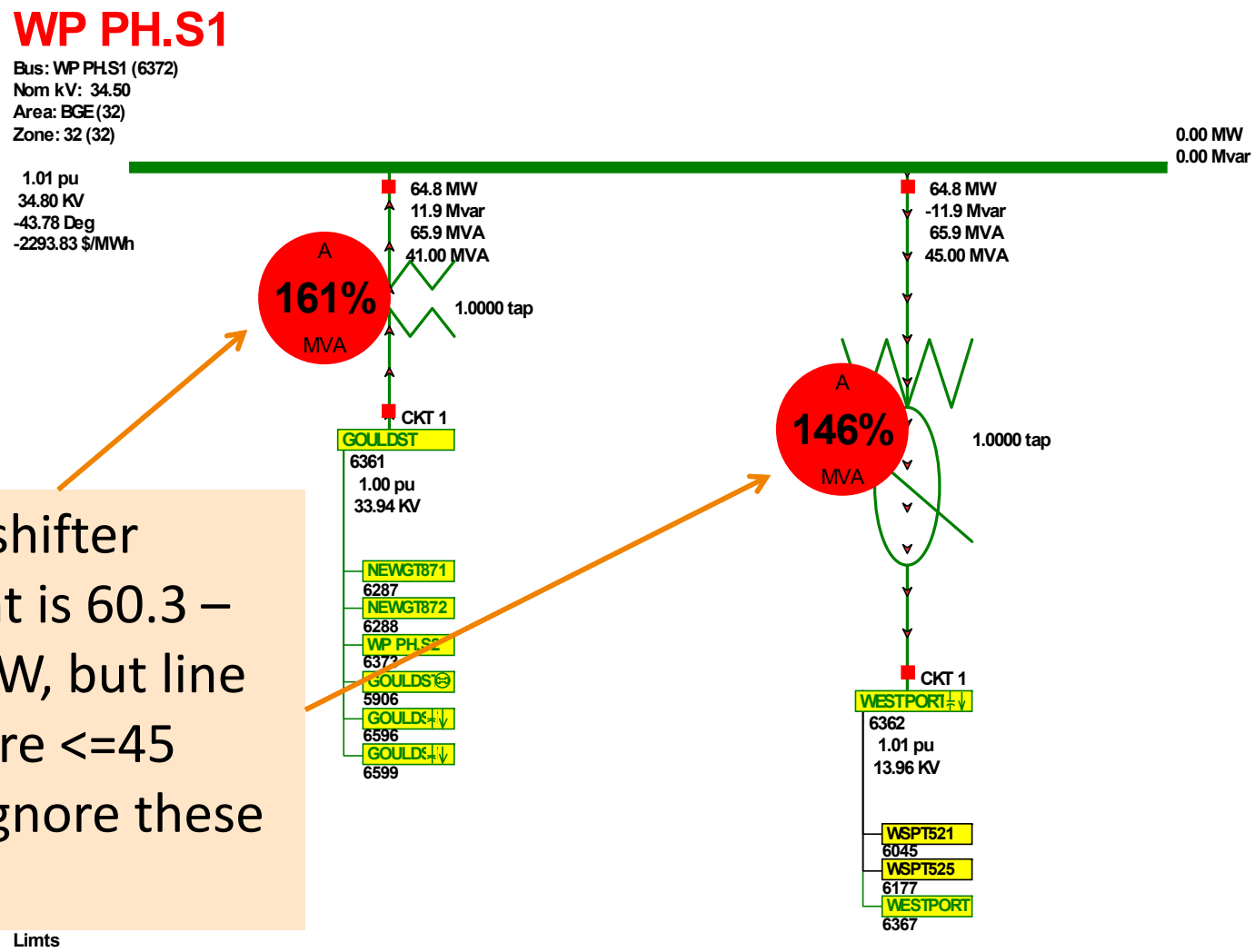
Phase-Shifting Transformers

- Phase Shifters have three control options
  - None – leave at a fixed angle
  - Power Flow – Allow the power flow solution to dispatch according to the MW setpoints of the controller
  - OPF – Allow the OPF's linear program to "dispatch" the transformer for a more global optimization
- OPF phase-shifter control is often necessary if load is varied with the time-step simulation, unless appropriate phase-shifter control settings are known for each load level

Use Caution with Phase-Shifter OPF Control

- Phase-shifter setpoints are often important for stability
- The setpoints may vary with load or seasonal generation pattern
- Options to consider:
  - ignore MVA/Amp limit enforcement where obvious conflicts occur between limit and phase-shifter setpoints (e.g. overloaded line in series with phase-shifter)
  - allow only a few phase shifters to operate on OPF control where it is known that stability margins are sufficient
  - choose to Enforce MW Regulation Limits in OPF (branch field for phase-shifters)
  - tighten the angle limits of phase shifters to limit range of OPF dispatch

Conflict between Phase-Shifter Setpoint and Line Limits

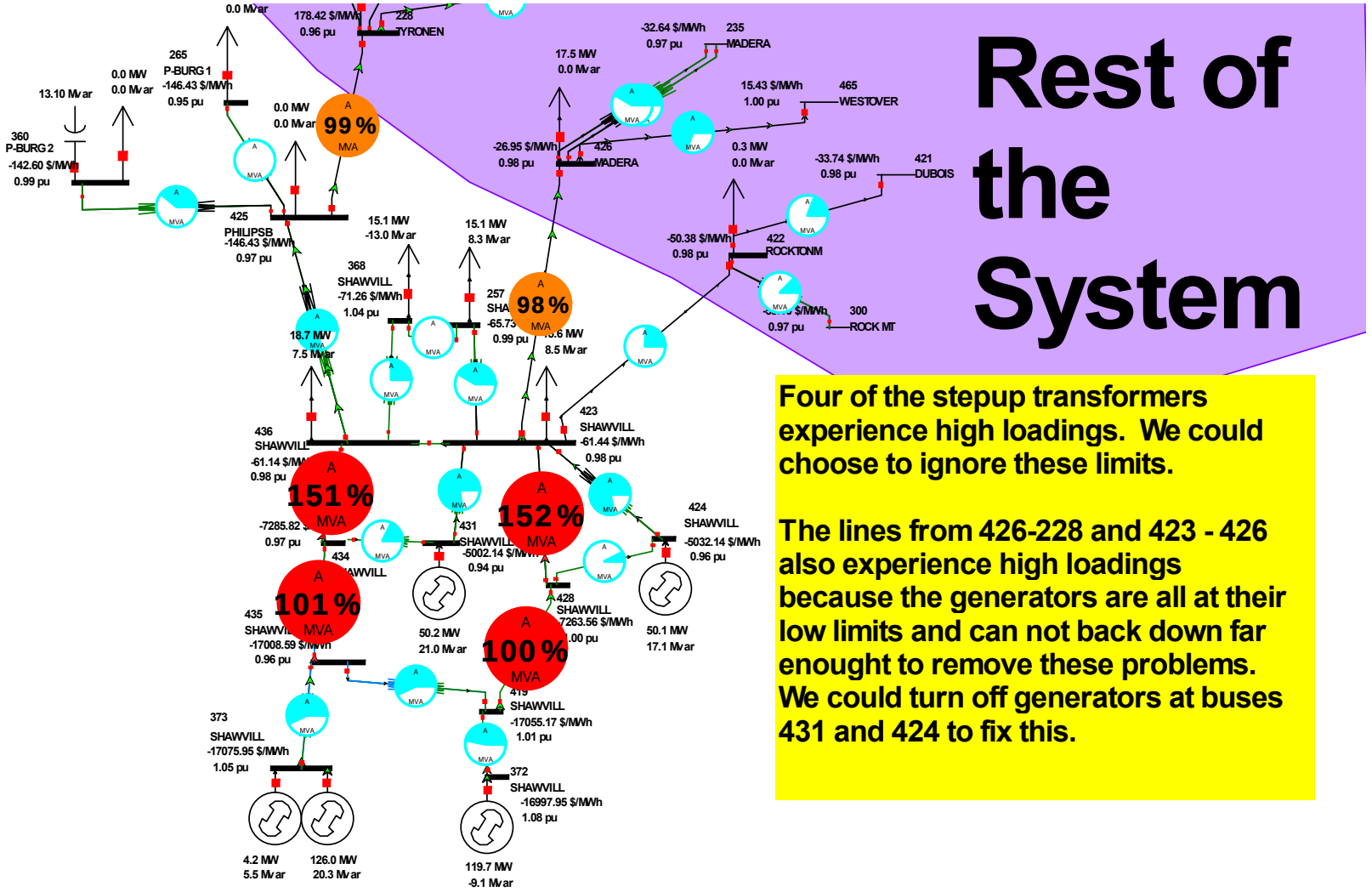


Phase-shifter setpoint is 60.3 – 72.9 MW, but line limits are <=45 MVA; ignore these lines

A Closer Look

- Look more closely at the majority of the remaining unenforceable constraints
  - Continues to show a large number of under radial elements which should probably just be ignored
- A handful of elements require greater study
  - Draw a oneline diagram to represent this part of the system
  - You will start to see what the problem is
- Changes described in following slides may be automatically loaded with *Eastern2Monitor Changes.aux*

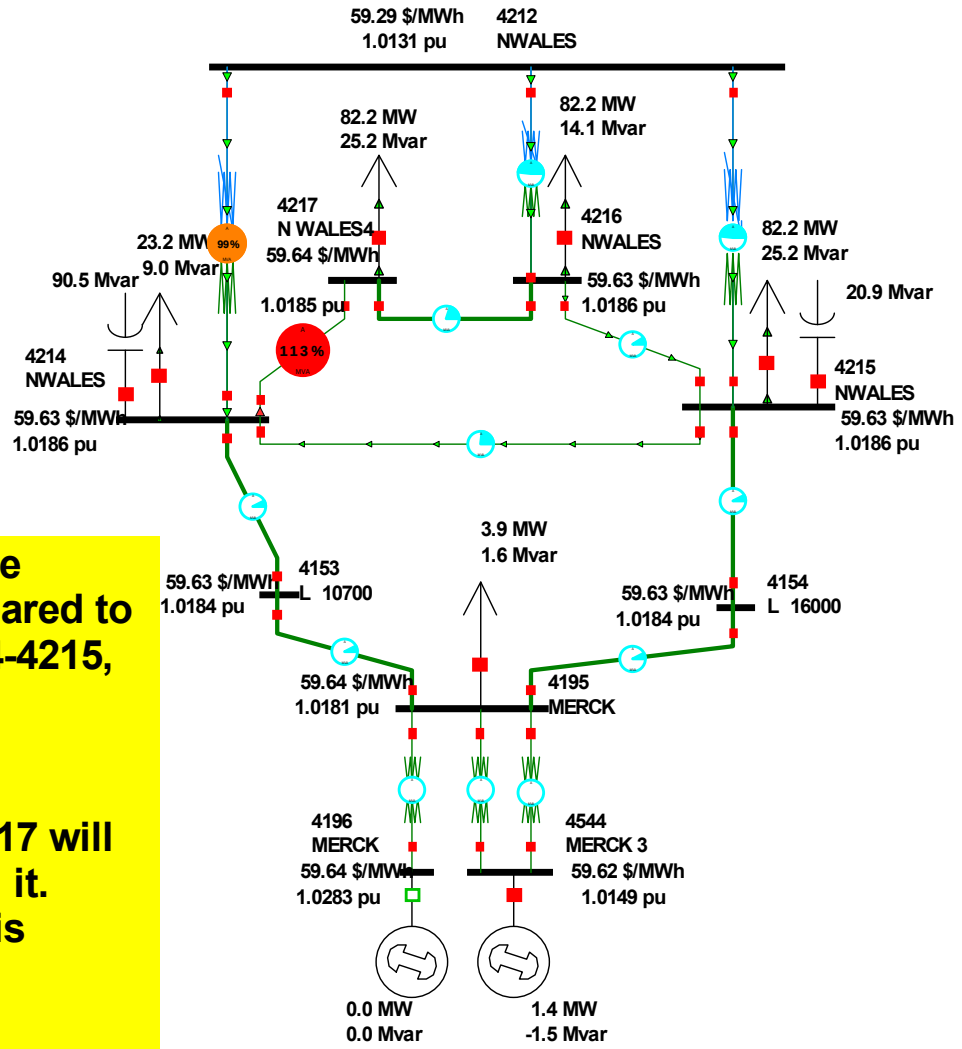
Example: Internal Shawville



Four of the stepup transformers experience high loadings. We could choose to ignore these limits.

The lines from 426-228 and 423 - 426 also experience high loadings because the generators are all at their low limits and can not back down far enought to remove these problems. We could turn off generators at buses 431 and 424 to fix this.

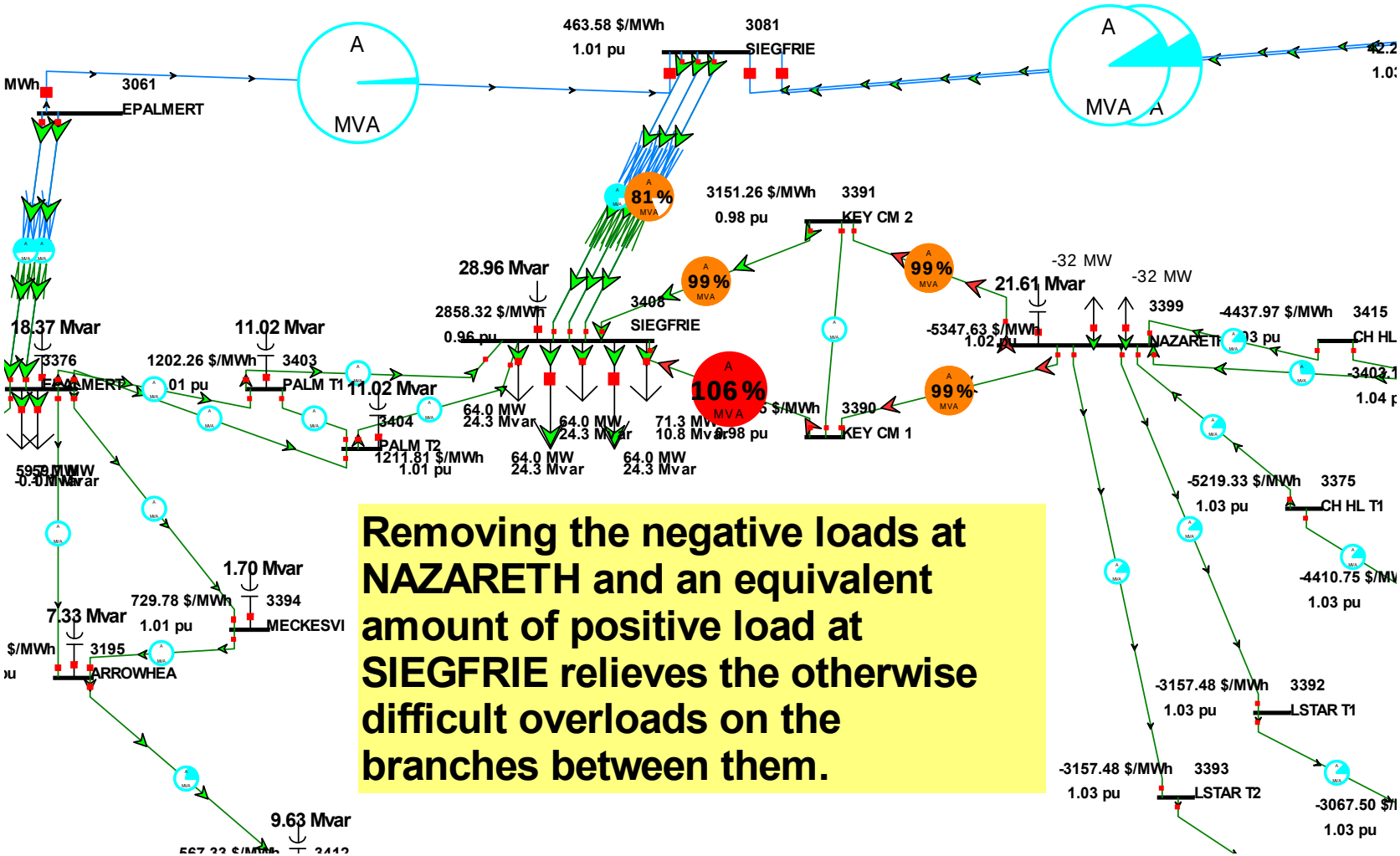
Example: Internal Merck



4217-4216 line has a large impedance of 0.15 compared to the lines 4214-4217, 4214-4215, 4216-4215 which have impedances of 0.0002

This means that 4216-4217 will NEVER have any flow on it. Thus the line 4214-4217 is essentially radial.

Siegfried – Nazareth Limits



After these changes we remove all unenforceable Constraints

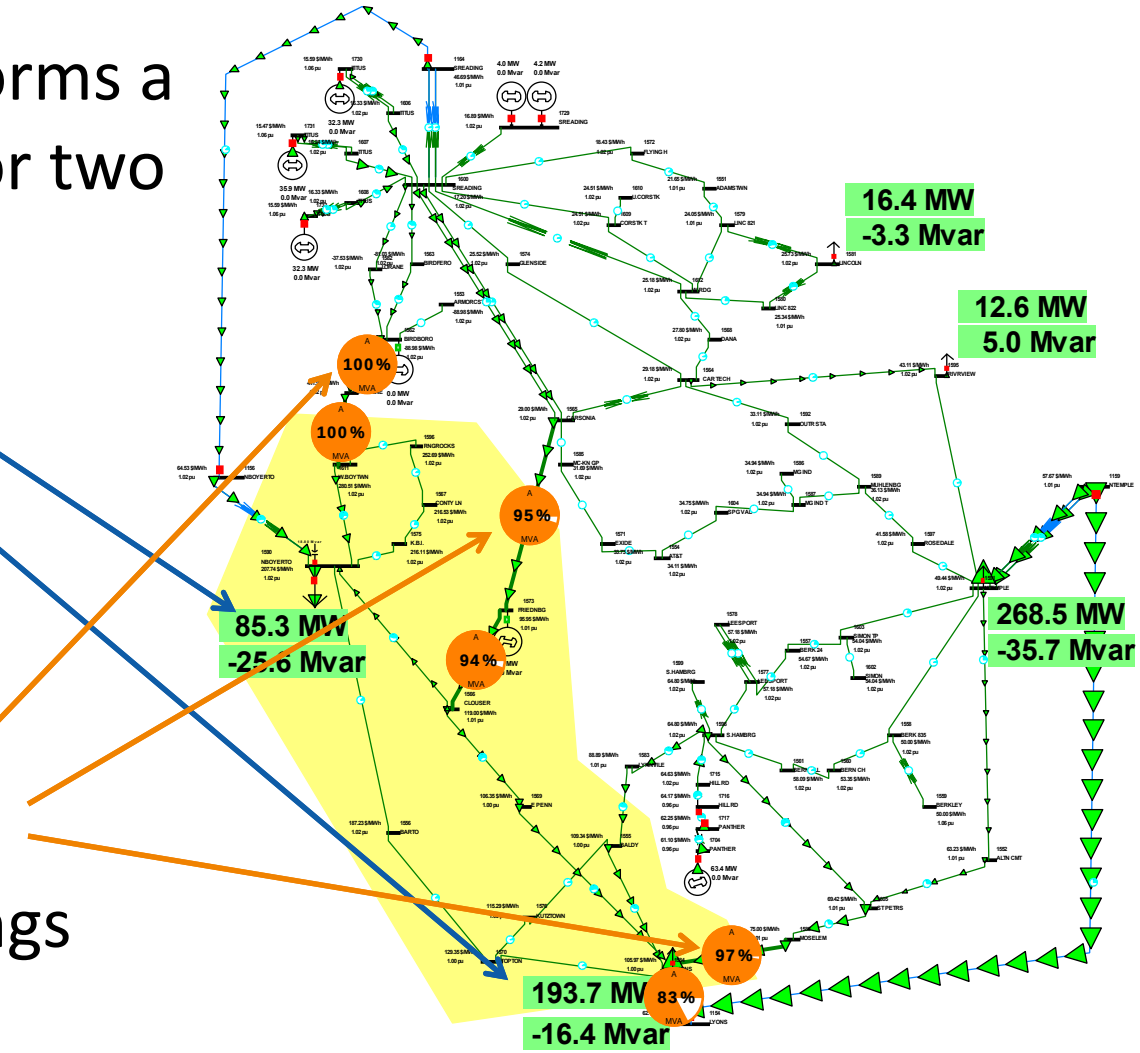
- Still some very high cost constraints remain
- BIRDBORO – PINE LANE = $753/MVAhr

Lines/Transformers | Interfaces

	From Number	From Name	From Area Name	To Number	To Name	To Area Name	Circuit	Monitor	Max MVA	% of MVA Limit (Max)	Lim MVA	MVA Ma ▼ Cost	Constraint Status
1	1562	BIRDBORO	METED	1593	PINE LNE	METED	1	YES	34.0	99.9	34.0	752.5	Binding
2	3390	KEY CM 1	PP&L	3408	SIEGFRIE	PP&L	1	YES	43.0	100.0	43.0	256.0	Binding
3	4954	ATHENIA	PSE&G	5020	SADDLEBR	PSE&G	1	YES	340.8	93.1	366.0	157.7	Binding
4	228	TYRONEN	PENELEC	425	PHILIPSB	PENELEC	1	YES	125.0	100.0	125.0	120.6	Binding
5	1152	HUNTERST	METED	1221	HUNTERST	METED	2	YES	250.9	100.0	251.0	117.4	Binding
6	4111	EDDYSTON	PECO	4172	LLANERCH	PECO	1	YES	215.0	100.0	215.0	79.2	Binding
7	6288	NEWGT872	BGE	6361	GOULDST	BGE	1	YES	41.0	100.0	41.0	26.1	Binding
8	4957	BAYONNE	PSE&G	5044	COGEN TE	PSE&G	1	YES	219.1	100.0	219.0	22.1	Binding
9	8857	DUPONTED	DP&L	8871	SILVERSI	DP&L	1	YES	79.0	100.0	79.0	15.4	Binding
10	2	BRANCHBU	PJM500	7	ELROY	PJM500	1	YES	772.8	25.2	3066.0		

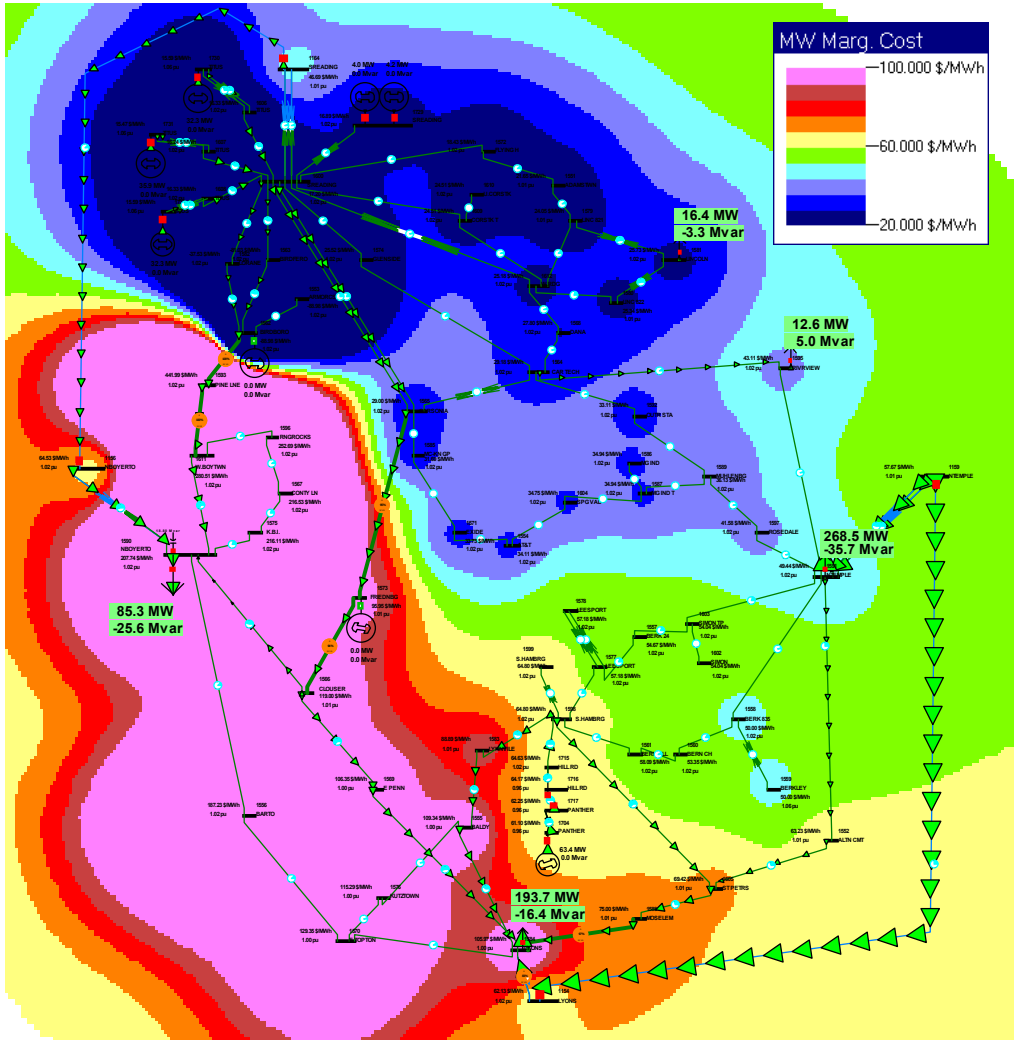
Birdboro – Pine Lane

- Yellow Region forms a "load pocket" for two large loads
  - 85.3 MW
  - 193.7 MW
- The 69 kV lines feeding this region have high loadings



Contour of Prices around Birdboro – Pine Lane

- Load Pocket
- These prices could be reasonable.



Unenforceable Constraints Summary

- Look for radial systems and “load pockets”
- Look for generators or phase-shifters which can relieve problems
  - Give the OPF more controls to FIX the problems
- Look for constraints which don’t make sense
  - Radial lines serving load
  - Radial transformers/lines leaving generators
- Use your judgment to setup a reasonable case
- Realize that some unenforceable constraints are inevitable at first