

Power System Economics and Market Modeling



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



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

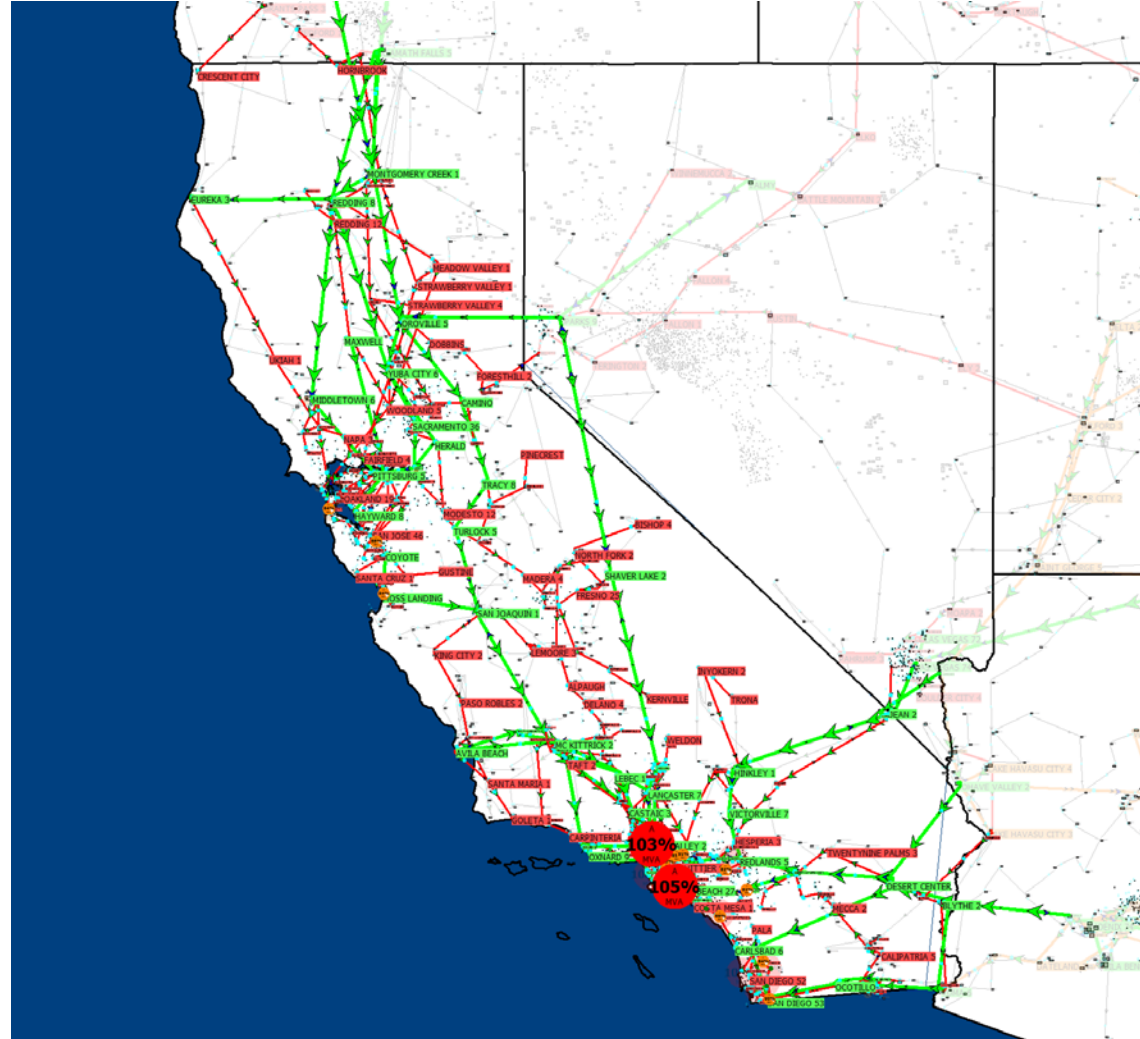


- Load the *ACTIVSg10k_OPF.raw* case
- Settings described on following slides may be loaded from *M08_Multi-Area LMP\aux1000Master.aux*
- Suppose we wish to model an LMP market for California
 - 5 separate control areas
 - 1098 total generating units, 852 committed generating units
 - 7 branch thermal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

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*

Model Explorer: Cost Curves Linear

Explore

Recent

Network

Branches By Type

Branches Input

Branches State

Buses

DC Transmission Lines

Generators

Cost Curves All

Cost Curves Cubic

Cost Curves Linear

Reactive Capability

Impedance Correction

Line D-FACTS Devices

Line Shunts

Loads

Mismatches

Multi-Terminal DC

Switched Shunts

Three-Winding Transfo

Transformer Controls

Voltage Control Group

VSC DC Transmission Li

Aggregations

Areas

Balancing Authorities

Bus Pairs

Data Maintainers

Injection Groups

Interfaces

Islands

Multi-Section Lines

MW Transactions

Nomograms

Open New Explorer

Cost Curves Linear (filtered)

Records

Geo

Set

Columns

Find...

Remove

Quick Filter

Options

	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	MW/h Price 1	MW Break 2	MW/h Price 2	MW Break 3	MW/h Price 3	MW Break 4	MW/h Price 4
1	20288	MCLELLAN 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	26.00
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	23.00
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	23.00
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	23.00
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	22.00
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	23.00
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	23.00
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	21.00
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	21.00
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	21.00
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	25.00
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	22.00
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	25.00
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	27.00
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	27.00
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	27.00
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	24.00
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	22.00
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	26.00
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	23.00
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	23.00
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	23.00
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	20.00
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	22.00
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	22.00
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	26.00
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	26.00

Search

Search Now

Options

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*

Model Explorer: Generators

Explore Fields

Recent Network

- Branches By Type
- Branches Input
- Branches State
- Buses
- DC Transmission Lines
- Generators
- Cost Curves All
- Cost Curves Cubic
- Cost Curves Linear
- Reactive Capability
- Impedance Correction 1
- Line D-FACTS Devices
- Line Shunts
- Loads
- Mismatches
- Multi-Terminal DC

Open New Explorer

Generators (filtered) Cost Curves Linear Buses Areas

Filter Advanced Generator Find... Remove Quick Filter

	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	UN
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	UN
3	20288	MCLELLAN 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	UN
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	W
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	UN
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	UN
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	UN
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	UN
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	UN
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	UN
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	UN
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	UN
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	UN

Search Search Now Options

Limit Monitoring



Report limits
for areas 3-7
only, 100 kV
and above

Limit Monitoring Settings and Limit Violations

Use the Modify/Create Limit Groups to tab to modify and create limit groups to which Buses, Lines and Interfaces can be assigned. Use the Buses, Lines and Interfaces tabs to assign elements to different limit groups. The Areas and Zones tabs are provided here for your convenience.

Save Monitoring Settings
Load Monitoring Settings

Elements to Show
☐ All Elements
☐ Monitored Elements
☒ Violating Elements

Number Of Violations
Low Voltage Buses: 0
High Voltage Buses: 0
Low-voltage Suspects: 0
Lines/Transformers: 7
Interfaces: 0
Bus Pairs: 0

Limit Group Values
Limit Group: Default
☐ Group Disabled / Do Not Monitor

Lines & Transformers | Interfaces | Buses | Bus Pairs
Percentage: 100.0
Normal Rating Set: A
Contingency Rating Set: A
☐ Treat Line Limits as Equivalent Amps
☒ Do not monitor radial lines and buses (applied to all limit groups) (This option is not applied if using topology processing)

Buses (filtered) | Lines (filtered) | Interfaces (filtered) | Nomograms | Bus Pairs | Area Reporting | Zone Reporting | Modify/Create Limit Groups | Rating Set Names

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

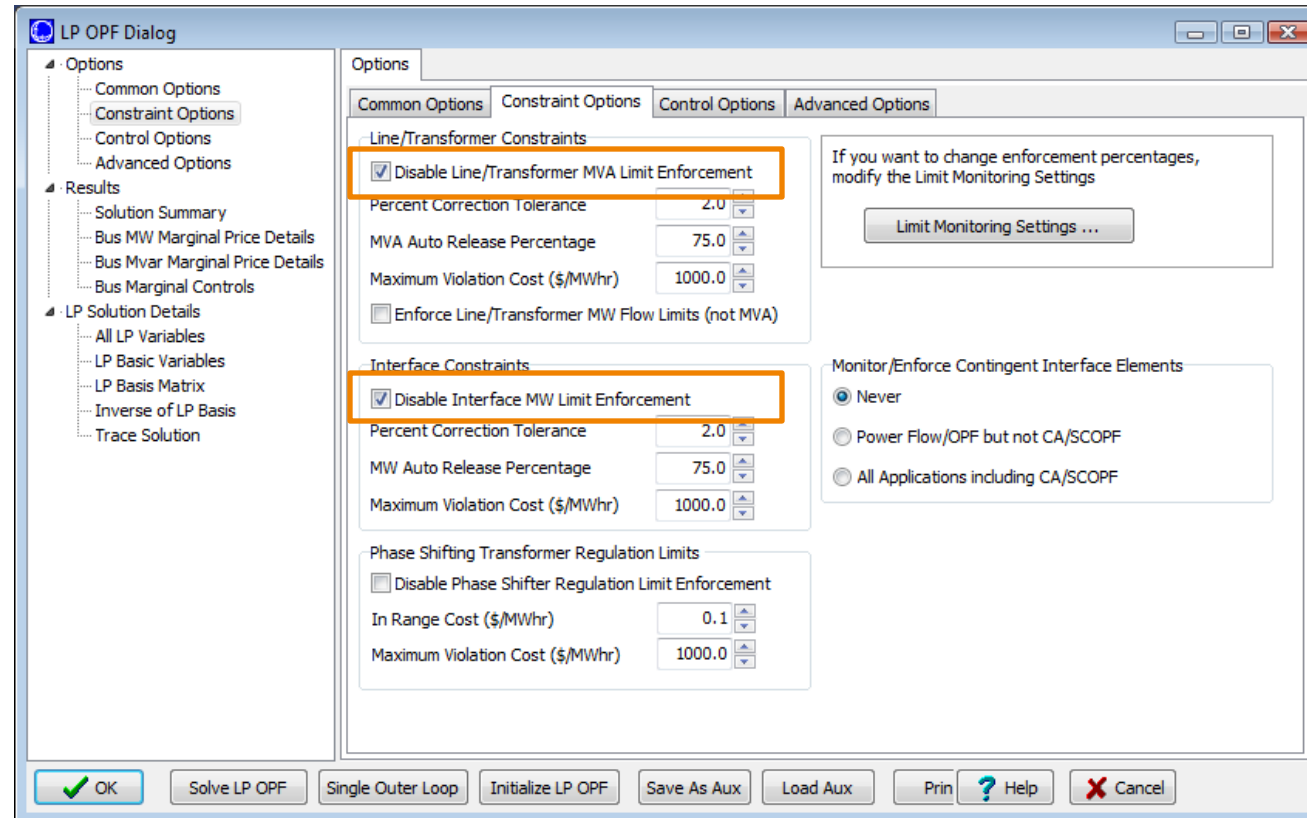
Areas and Zones are not assigned to limit groups. However, a power system element is only monitored if ALL of the following are true:
1. Its Monitor field is set to YES
2. Its Limit Group is Enabled
3. Its Area is set to Report Limits and it meets the KV range for reporting
4. Its Zone is set to Report Limits and it meets the KV range for reporting
Because of this, the Area and Zone Lists are provided here for your convenience

	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 Cal	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



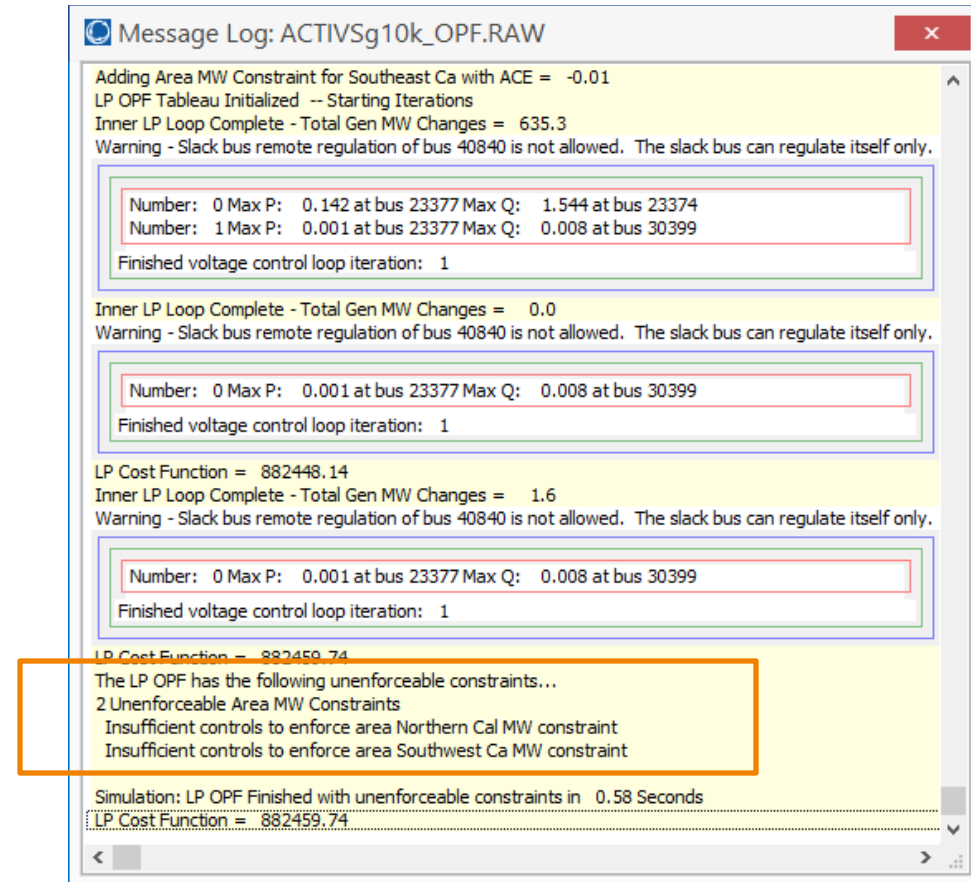
- Disable all controls except Generator MW
- Do not enforce branch or interface constraints



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

Northern Cal Area Information for Present

Number: 8 Find By Number
Name: Northern Cal Find By Name
Super Area: Find ...
Labels: no labels

Area MW Control Options:
☐ No Area Control
☐ Participation Factor Control
☐ Economic Dispatch Control
☐ Area Slack Bus
☐ Injection Group Area Slack
☒ Optimal Power Flow Control

Info / Interchange Options Area MW Control Options OPF Tie Lines Buses Gens Loads Custom Stability

	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Set Volt	AGC	AVR	Min MW	Max	Min Mvar	Max Mvar	Cost Model
1	20301	MAXWELL 6	1	Closed	237.47	50.13	1.02606	YES	YES	86.03	237.47	-26.36	120.87	Piecewise Line
2	20300	MAXWELL 5	1	Closed	237.47	50.12	1.02606	YES	YES	51.03	237.47	-26.36	120.87	Piecewise Line
3	20299	MAXWELL 4	1	Closed	237.47	50.12	1.02606	YES	YES	56.77	237.47	-26.36	120.87	Piecewise Line
4	20491	MIDDLETOW~20	1	Closed	127.29	0.00	1.03910	NO	YES	45.41	212.17	0.00	0.00	None
5	20492	MIDDLETOW~21	1	Closed	212.17	0.00	1.03910	NO	YES	78.65	212.17	0.00	0.00	None
6	20488	MIDDLETOW~17	1	Closed	182.08	0.00	1.03910	NO	YES	73.50	212.17	0.00	0.00	None
7	20487	MIDDLETOW~16	1	Open	0.00	0.00	1.04360	NO	YES	102.74	212.17	0.00	0.00	None
8	20489	MIDDLETOW~18	1	Open	0.00	0.00	1.03080	NO	YES	55.86	212.17	0.00	0.00	None
9	20490	MIDDLETOW~19	1	Closed	212.17	0.00	1.03910	NO	YES	103.40	212.17	0.00	0.00	None
10	20430	YUBA CITY~24	1	Closed	212.00	-23.53	1.01822	YES	YES	91.16	212.00	-23.53	107.91	Piecewise Line
11	20429	YUBA CITY~23	1	Closed	212.00	-23.53	1.01822	YES	YES	40.20	212.00	-23.53	107.91	Piecewise Line
12	20428	YUBA CITY~22	1	Open	0.00	0.00	1.01822	YES	YES	98.38	212.00	-23.53	107.91	Piecewise Line
13	20468	HERALD 4	1	Closed	176.67	-19.61	1.02410	YES	YES	71.90	176.67	-19.61	89.92	Piecewise Line
14	20470	HERALD 6	1	Closed	176.67	-19.61	1.02410	YES	YES	53.61	176.67	-19.61	89.92	Piecewise Line
15	20469	HERALD 5	1	Closed	176.67	-19.61	1.02410	YES	YES	60.98	176.67	-19.61	89.92	Piecewise Line
16	20545	DOBBINS 4	1	Open	0.00	0.00	1.02704	NO	YES	42.70	157.50	-7.72	60.48	None
17	20544	DOBBINS 3	1	Closed	124.18	-7.72	1.02797	NO	YES	32.31	157.50	-7.72	60.48	None
18	20363	RIO VISTA ~5	1	Open	0.00	0.00	1.04000	NO	YES	20.30	150.00	-21.60	31.95	None
19	20313	CAMINO 6	1	Open	0.00	0.00	1.03684	NO	YES	62.15	133.00	-6.52	51.07	None
20	20314	CAMINO 7	1	Closed	119.27	51.07	1.03684	NO	YES	57.03	133.00	-6.52	51.07	None
21	20394	REDDING 8 8	1	Open	0.00	0.00	1.04600	NO	YES	17.70	119.00	-5.83	45.70	None
22	20395	REDDING 8 9	1	Open	0.00	0.00	1.02508	NO	YES	44.80	119.00	-5.83	45.70	None
23	20393	REDDING 8 7	1	Closed	119.00	-5.83	1.02508	NO	YES	16.23	119.00	-5.83	45.70	None
24	20392	REDDING 8 6	1	Closed	74.94	-5.83	1.02508	NO	YES	23.69	119.00	-5.83	45.70	None
25	20391	REDDING 8 5	1	Closed	88.31	-5.83	1.02508	NO	YES	20.77	119.00	-5.83	45.70	None

OK Save Cancel Help Print

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

Options

Common Options | Constraint Options | Control Options | Advanced Options

Fast Start Generator Options

☐ Allow Commitment of Fast Start Generators

☐ Allow Decommitment of Fast Start Generators

Round to On Percentage of Min Limit: 2.0

Modeling Generators without Piecewise Linear Cost Curves

Generator Cost Models

☐ Ignore them

☒ Change to Specified Points per Curve

☐ Change to Specified MWs per Segment

Total Points per Cost Curve: 5

MWs per Cost Curve Segment: 10.0

☐ Save Existing Piecewise Linear Cost Curves

Modeling of OPF Areas/Superareas

During the Initial OPF Power Flow Solution

☐ No Area Control

☒ Participation Factor Control (recommended)

☐ Economic Dispatch Control

☐ Area Slack Bus Control

During Stand-Alone Power Flow Solutions

☐ No Area Control

☒ Participation Factor Control (recommended)

☐ Economic Dispatch Control

☐ Area Slack Bus Control

Treat Area/Superarea MW Constraints as unenforceable even when the ACE is less than the AGC Tolerance (default is checked) ☒

Uncheck to relax ACE constraints

Unenforceable Area Constraints: Tips

- Examine Generator records or Area fields “Gen MW AGC Range Up” and “Gen MW AGC Range Down”
- 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										
OPT. < .0 .00 > .00 .00 > ABCD Records Set Columns f(x) 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

st Curves Linear (Filter:Hydro Study) X OPF Generators X Buses X Super Areas X OPF Areas X Generators X Areas

Records Geo Set Columns Options

Advanced Generator Hydro St Set All Values To... Remove Quick Filter

Number of Bus	Name of Bus	Area Name of Gen	ID	Status	Cost	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

The screenshot shows the 'LP OPF Dialog' window with the 'Results' tab selected. The 'Results' tab contains several sub-sections with data tables. An orange arrow points from the text 'note several unenforceable constraints' to the 'Number of Unenforceable Violations' field in the 'Line MVA Constraints' section.

General Results	
Solution Start Time	2/22/2018 12:01:46 PM
Solution End Time	2/22/2018 12:01:49 PM
Total Solution Time	3.207 Seconds
Last Solution Status	Successful Solution
Number of LP Iterations	330
Initial Cost Function Value	1102512.61 \$/hr
Final Cost Function Value	1107582.88 \$/h
Final Slack Cost Value	57401.07 \$/h
Final Total Cost Value	1164983.94 \$/h
Number of Buses in OPF	4147
Highest Bus Marginal Cost	1006.23 \$/MWh
Lowest Bus Marginal Cost	-175.31 \$/MWh
Average Bus Marginal Cost	54.50 \$/MWh
Bus MC Standard Deviation	70.10 \$/MWh

Line MVA Constraints	
Number of Initial Violations	7
MVA Sum of Initial Violations	111.64
Number of Binding Lines	2
Highest Line MVA Marginal Cost	1000.00 \$/MVAh
Number of Unenforceable Violations	5
MVA Sum of Unenforceable Violations	57.40

Transformer Regulation Constraints	
Number of Initial Violations	0
Number of Binding Constraints	0
Number of Unenforceable Violations	0

Fast Start Generators	
Number of Generators Turned On	0
Number of Generators Turned Off	0

Interface MW Constraints	
Number of Initial Violations	0
MW Sum of Initial Violations	0.00
Number of Binding Interfaces	0
Highest Interface MW Marginal Cost	
Number of Unenforceable Violations	0
MW Sum of Unenforceable Violations	0.00

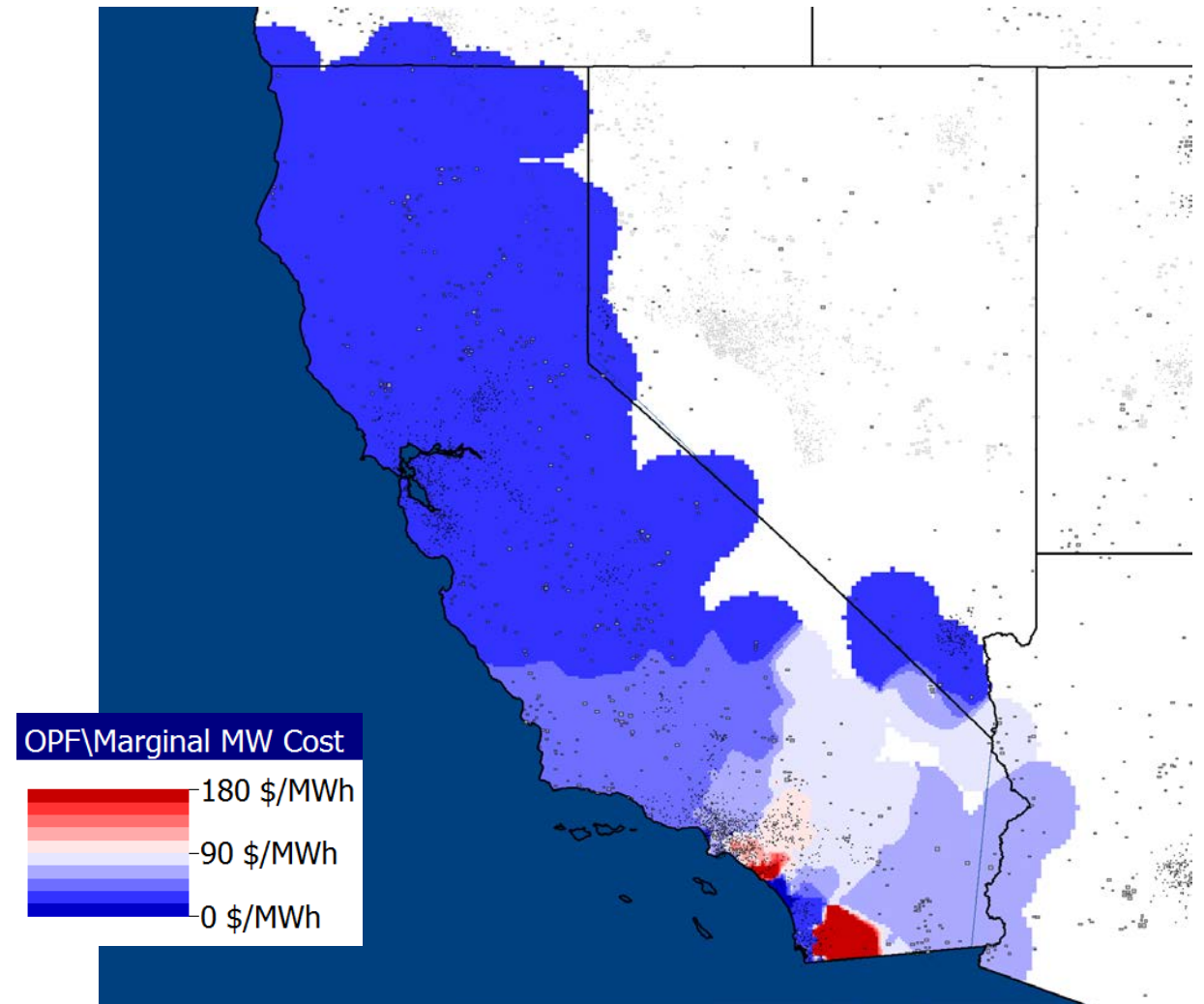
Generator MW Control Limit Violations	
Number of Initial Violations	0
MW Sum of Initial Violations	0.00
Number of Unenforceable Violations	0
MW Sum of Unenforceable Violations	0.00

Area and Superarea Constraints	
Unenforceable Area Constraints	0
Unenforceable SuperArea Constraints	0

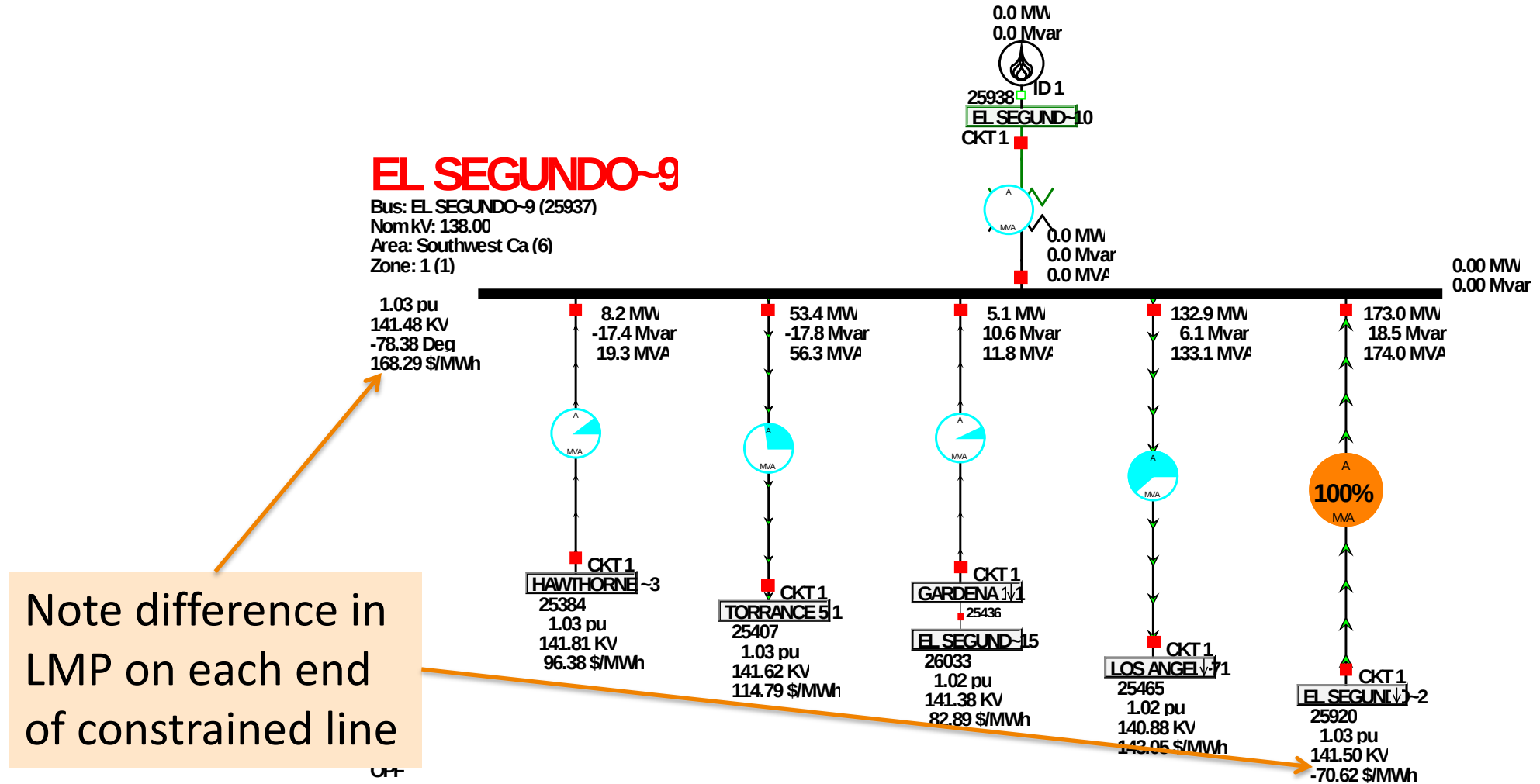
Buttons at the bottom: OK, Solve LP OPF, Single Outer Loop, Initialize LP OPF, Save As Aux, Load Aux, Print, Help, Cancel.

LMP Contour

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



Effect of Line Constraints



Options for Further Analysis

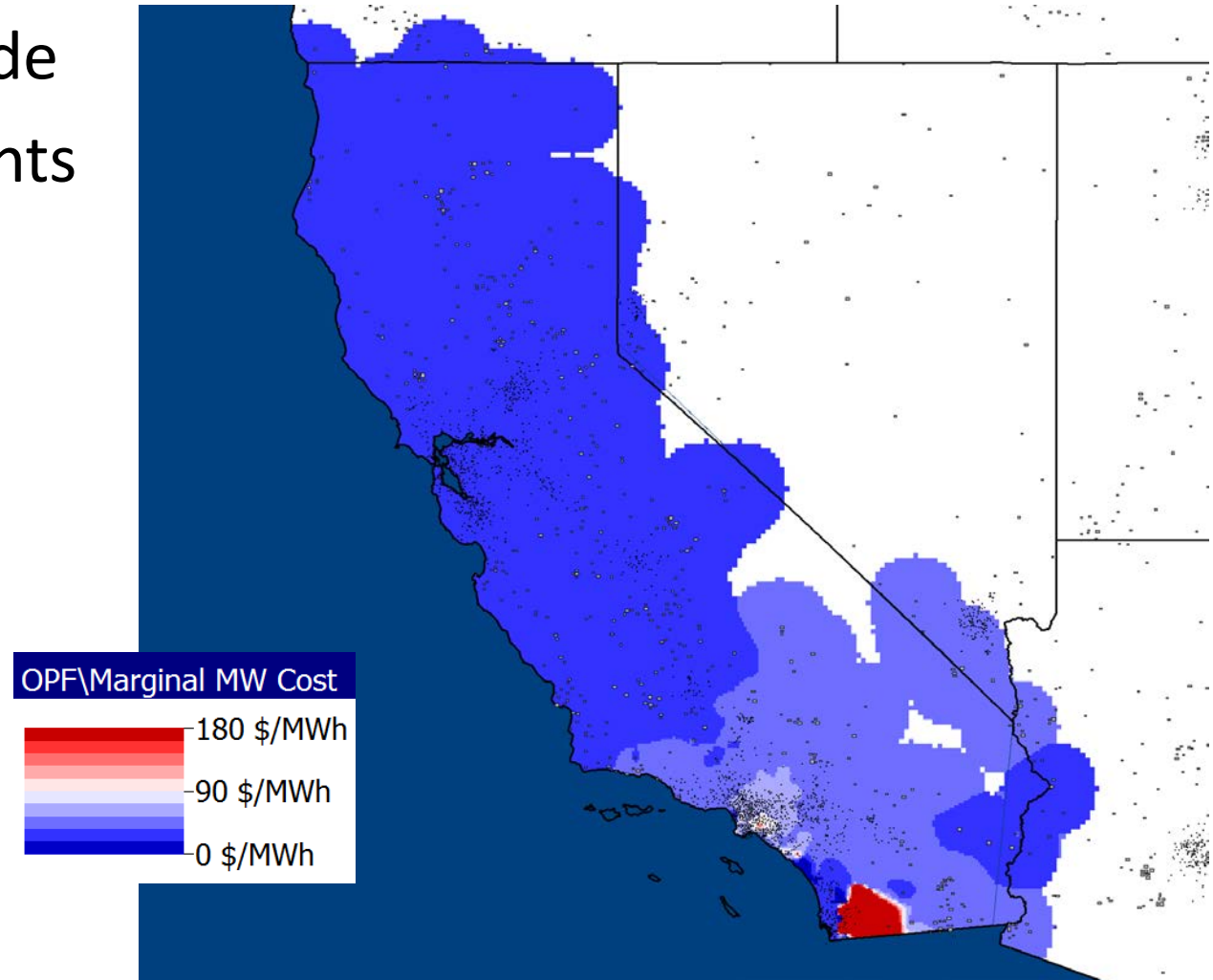


- Increase available units (and reserve margin) in areas with limited supply
 - Many generators at their max output
 - 6% committed, dispatchable reserves
- Place 5 California Areas on Super Area Control
 - Single power balance constraint for entire super area
 - Allows areas with limited capacity increase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

Power Transfer Distribution Factors (PTDFs)

Linear Calculation Method: ☐ Linearized AC, ☒ Lossless DC, ☐ Lossless DC With Phase Shifters

Directions: ☒ Single, ☐ Multiple

DC Model Options...

Calculate PTDFs

☐ Automatically recalculate after each power flow

Increase in Losses (%): 0.0

List Display Options: ☐ Use Area/Zone Filters, Only Show Above (%): 0.0

Calculate MW-Distance

Seller Type: ☐ Area, ☐ Zone, ☐ Super Area, ☐ Slack, ☐ Inj. Group, ☒ Bus

Buyer Type: ☐ Area, ☐ Zone, ☒ Super Area, ☐ Slack, ☐ Inj. Group, ☐ Bus

29060 (CHULA VIST~3) Find Seller... Reverse Buyer/Seller California Find Buyer...

Lines/Transformers (Filter: OPF Constraint) Interfaces (filtered) Areas Zones Generators (filtered) Phase Shifters (filtered)

	From Number	From Name	To Number	To Name	Circuit	PTDF Impact	MW From	MVA M. Cost	% PTDF From	% PTDF To	% Losses	Nom kV (Max)	Nom kV (Min)
1	28552	CHULA VIST~7	28580	BONITA 1	1	9.96937	34.7047	1000.00	-9.96937	9.97	0.00	138.0	138.0
2	26095	LONG BEAC~34	28023	ANAHEIM 2 1	1	0.97899	77.5410	1000.00	0.97899	-0.98	0.00	345.0	345.0
3	28856	EL CAJON 8 2	28591	SPRING VAL~1	1	-4.37569	73.2817	1000.00	-4.37569	4.38	0.00	138.0	138.0
4	28623	LAKESIDE 2 1	28536	SAN DIEGO~53	1	-3.58710	66.4559	1000.00	3.58710	-3.59	0.00	138.0	138.0
5	25920	EL SEGUNDO~2	25937	EL SEGUNDO~9	1	-0.41267	73.2298	262.27	-0.41267	0.41	0.00	138.0	138.0
6	28212	SAN JUAN C~5	28220	TRABUCO CA~2	1	4.05454	77.0583	223.03	4.05454	-4.05	0.00	138.0	138.0
7	26058	SUN VALLEY~4	26125	BURBANK 10 1	1	-5.20306	33.7411	173.45	-5.20306	5.20	0.00	765.0	765.0
8	29017	SAN DIEG~106	29016	SAN DIEG~105	1	-19.11140	35.4714	27.85	19.11140	-19.11	0.00	345.0	138.0

Help Close

Multiple Element Shift Factors



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

Filter: Advanced Branch OPF Constraint Find... Remove Quick Filter

Line/Transformer Constraints

☐ Disable Line/Transformer MVA Limit Enforcement

Percent Correction Tolerance: 2.0

☐ Only Show Limit Violations

☒ Only Areas with Line MVA Enforcement

☐ Use Area/Zone Filters

☐ Enforce Line/Transformer MW Flow Limits (not MVA)

Interface Constraints

☐ Disable Interface MW Limit Enforcement

Percent Correction Tolerance: 2.0

☐ Only Show Limit Violations

☐ Use Area/Zone Filters

Note: These settings also apply to Nomogram Interfaces

Monitor/Enforce Contingent Interface Elements

☐ Never

☒ Power Flow/OPF but not CA/SCOPF

☐ All Applications including CA/SCOPF

☒ Do not enforce limits on radials lines and buses

Limit Monitoring Settings ...

If you want to change enforcement percentages, modify the Limit Monitoring Settings

Lines/Transformers (Filter: OPF Constraint) Interfaces (filtered) Nomogram Interfaces (filtered)

	From Number	From Name	From Area Name	To Number	To Name	To Area Name	Circuit	Monitor	Max MVA	% of MVA Limit (Mag)	Selected	Lim MVA	MVA Ma Cost	Constrain
1	28552	CHULA VIST~	Southeast	28580	BONITA 1	Southeast Ca	1	YES	148.7	104.8	YES	141.9	1000.0	Unenforceal
2	26095	LONG BEAC~	Southwest	28023	ANAHEIM 2 1	Southeast Ca	1	YES	894.6	101.7	YES	880.0	1000.0	Unenforceal
3	28856	EL CAJON 8 2	Southeast	28591	SPRING VAL~	Southeast Ca	1	YES	189.3	106.6	YES	177.7	1000.0	Unenforceal
4	28623	LAKESIDE 2 1	Southeast	28536	SAN DIEGO~	Southeast Ca	1	YES	171.3	105.8	YES	161.9	1000.0	Unenforceal
5	25920	EL SEGUNDO	Southwest	25937	EL SEGUNDO	Southwest Ca	1	YES	174.0	100.0	NO	174.0	262.4	Binding
6	28212	SAN JUAN C~	Southeast	28220	TRABUCO CA	Southeast Ca	1	YES	196.2	100.0	NO	196.2	223.3	Binding
7	26059	SUN VALLEY	Southwest	26135	BURBANK 10	Southwest Ca	1	YES	2200.1	100.0	NO	2200.0	173.5	Binding

Multiple Element Shift Factors

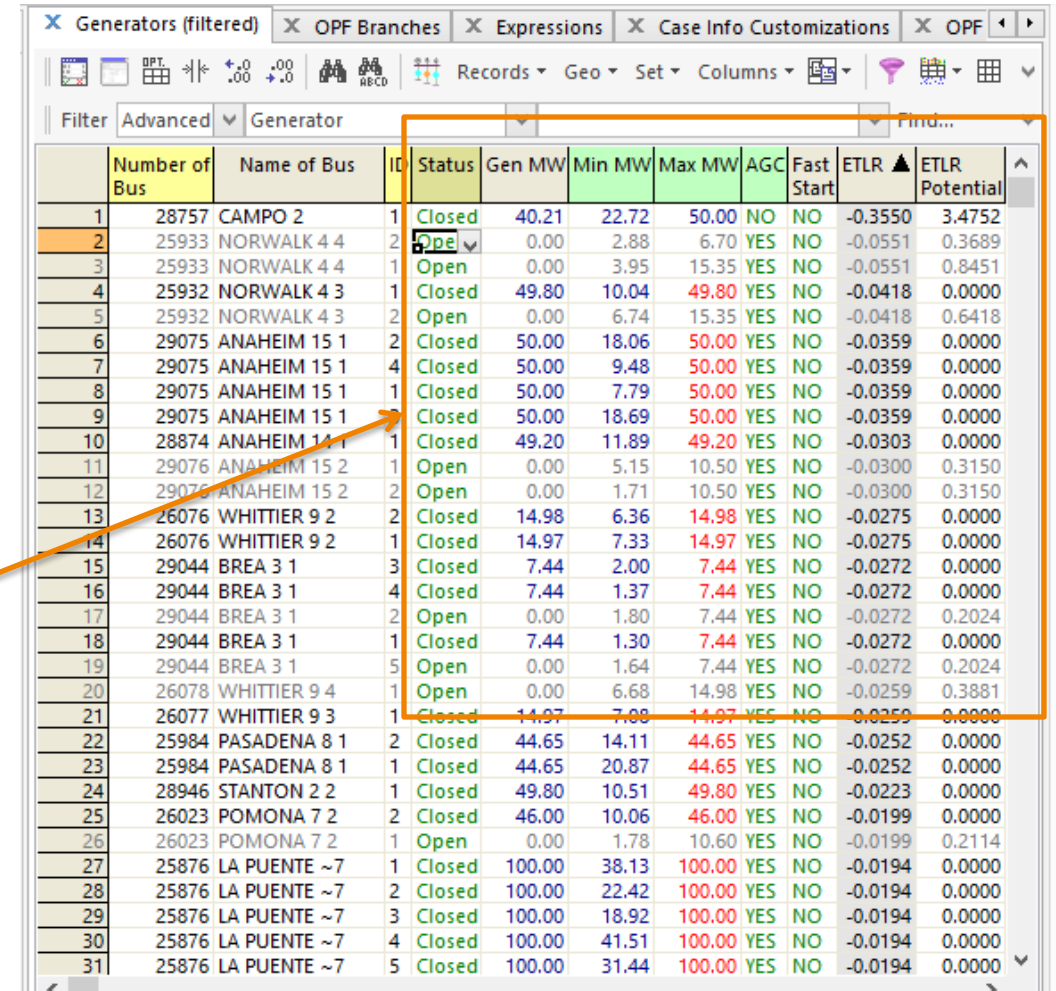


- Shift Factors on *Selected Devices* with Super Area as buyer
- Negative values on de-committed generators indicate units that may relieve congestion if committed
- Positive values on committed generators (especially those at Min MW) indicate that de-committing may help

	Number of Bus	ID	Name of Bus	Area Name of Gen	ETLR	WTLR	26095 TO 28023 CKT 1	28623 TO 28536 CKT 1	28552 TO 28580 CKT 1	28856 TO 28591 CKT 1
1	26102	1	LONG BEAC~41	Southwest C	0.0831	0.2105	0.0825	-0.0009	0.0004	0.0001
2	26101	1	LONG BEAC~40	Southwest C	0.0831	0.2105	0.0825	-0.0009	0.0004	0.0001
3	26098	1	LONG BEAC~37	Southwest C	0.0831	0.2105	0.0825	-0.0009	0.0004	0.0001
4	26100	1	LONG BEAC~39	Southwest C	0.0830	0.2105	0.0824	-0.0009	0.0004	0.0001
5	26097	1	LONG BEAC~36	Southwest C	0.0830	0.2105	0.0824	-0.0009	0.0004	0.0001
6	26099	1	LONG BEAC~38	Southwest C	0.0830	0.2104	0.0824	-0.0009	0.0004	0.0001
7	29042	1	HUNTINGTO~21	Southeast C	0.0620	0.1568	0.0614	-0.0009	0.0004	0.0001
8	29043	1	HUNTINGTO~22	Southeast C	0.0619	0.1567	0.0613	-0.0009	0.0004	0.0001
9	25987	3	WILMINGTON~7	Southwest C	0.0514	0.1299	0.0509	-0.0009	0.0004	0.0001
10	25987	4	WILMINGTON~7	Southwest C	0.0514	0.1299	0.0509	-0.0009	0.0004	0.0001
11	25987	7	WILMINGTON~7	Southwest C	0.0514	0.1299	0.0509	-0.0009	0.0004	0.0001
12	25987	1	WILMINGTON~7	Southwest C	0.0514	0.1299	0.0509	-0.0009	0.0004	0.0001
13	25987	2	WILMINGTON~7	Southwest C	0.0514	0.1299	0.0509	-0.0009	0.0004	0.0001

Multiple Element Shift Factors

- Generators display, sorted by ascending ETLR (Effective Transmission Loading Relief)
- 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	1	Closed	40.21	22.72	50.00	NO	NO	-0.3550	3.4752
2	25933	NORWALK 4 4	2	Open	0.00	2.88	6.70	YES	NO	-0.0551	0.3689
3	25933	NORWALK 4 4	1	Open	0.00	3.95	15.35	YES	NO	-0.0551	0.8451
4	25932	NORWALK 4 3	1	Closed	49.80	10.04	49.80	YES	NO	-0.0418	0.0000
5	25932	NORWALK 4 3	2	Open	0.00	6.74	15.35	YES	NO	-0.0418	0.6418
6	29075	ANAHEIM 15 1	2	Closed	50.00	18.06	50.00	YES	NO	-0.0359	0.0000
7	29075	ANAHEIM 15 1	4	Closed	50.00	9.48	50.00	YES	NO	-0.0359	0.0000
8	29075	ANAHEIM 15 1	1	Closed	50.00	7.79	50.00	YES	NO	-0.0359	0.0000
9	29075	ANAHEIM 15 1	1	Closed	50.00	18.69	50.00	YES	NO	-0.0359	0.0000
10	28874	ANAHEIM 14 1	1	Closed	49.20	11.89	49.20	YES	NO	-0.0303	0.0000
11	29076	ANAHEIM 15 2	1	Open	0.00	5.15	10.50	YES	NO	-0.0300	0.3150
12	29076	ANAHEIM 15 2	2	Open	0.00	1.71	10.50	YES	NO	-0.0300	0.3150
13	26076	WHITTIER 9 2	2	Closed	14.98	6.36	14.98	YES	NO	-0.0275	0.0000
14	26076	WHITTIER 9 2	1	Closed	14.97	7.33	14.97	YES	NO	-0.0275	0.0000
15	29044	BREA 3 1	3	Closed	7.44	2.00	7.44	YES	NO	-0.0272	0.0000
16	29044	BREA 3 1	4	Closed	7.44	1.37	7.44	YES	NO	-0.0272	0.0000
17	29044	BREA 3 1	2	Open	0.00	1.80	7.44	YES	NO	-0.0272	0.2024
18	29044	BREA 3 1	1	Closed	7.44	1.30	7.44	YES	NO	-0.0272	0.0000
19	29044	BREA 3 1	5	Open	0.00	1.64	7.44	YES	NO	-0.0272	0.2024
20	26078	WHITTIER 9 4	1	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 Shift Factors



- 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

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

Filter Advanced Generator Find...

	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	26042	HUNTINGTO~21	1	Open	0.00	74.13	218.00	YES	NO	0.0620	0.0000
8	29043	HUNTINGTO~22	1	Closed	164.09	28.00	218.00	YES	NO	0.0619	10.1827
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 Shift Factors



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

Branches Expressions Case Info Customizations OPF Generators Buses SI

Filter Advanced Branch OPF Constraint Find...

Line/Transformer Constraints

☐ Disable Line/Transformer MVA Limit Enforcement

Percent Correction Tolerance 2.0

☐ Only Show Limit Violations

☒ Only Areas with Line MVA Enforcement

☐ Use Area/Zone Filters

☐ Enforce Line/Transformer MW Flow Limits (not MVA)

Interface Constraints

☐ Disable Interface MW Limit Enforcement

Percent Correction Tolerance 2.0

☐ Only Show Limit Violations

☐ Use Area/Zone Filters

Note: These settings also apply to Nomogram Interface

☒ Do not enforce limits on radials lines and buses Limit Monitoring Settings ... If you want to change or modify the Limit Monitoring

Lines/Transformers (Filter:OPF Constraint) Interfaces (filtered) Nomogram Interfaces (filtered)

	To Area Name	Circuit	Monitor	Max MVA	% of MVA Limit (Max)	Selected	Lim MVA	MVA Max Cost	Constraint Sta
1	Southeast Ca	1	YES	148.9	104.9	YES	141.9	1000.0	Unenforceable
2	Southeast Ca	1	YES	171.4	105.3	YES	161.9	1000.0	Unenforceable
3	Southeast Ca	1	YES	189.1	106.4	YES	177.7	1000.0	Unenforceable
4	Southeast Ca	1	YES	880.0	100.0	NO	880.0	471.7	Binding
5	Southwest Ca	1	YES	174.0	100.0	NO	174.0	123.5	Binding

Multiple Element Shift Factors



- 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

Generators (filtered) | OPF Branches | Expressions | Case Info Customizations | OPF Ge

Filter: Advanced | Generator | Find...

	Number of Bus	Name of Bus	ID	Status	Gen MW	Min MW	Max MW	AGC	Fast Start	ETLR	ETLR Poten
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	60.63	NO	YES	-0.0149	0.9953
7	29031	CARLSBAD 6 8	1	Closed	196.32	61.11	196.32	YES	YES	0.0044	0.8712
8	29029	CARLSBAD 6 6	1	Closed	196.32	66.92	196.32	YES	YES	0.0044	0.8711
9	29028	CARLSBAD 6 5	1	Closed	196.32	22.48	196.32	YES	YES	0.0044	0.8710
10	29030	CARLSBAD 6 7	1	Closed	196.32	37.86	196.32	YES	YES	0.0044	0.8709
11	29027	CARLSBAD 6 4	1	Closed	196.32	70.39	196.32	YES	YES	0.0044	0.8708
12	28844	ESCONDIDO ~5	1	Closed	186.33	28.35	186.33	YES	YES	0.0045	0.8430
13	28846	ESCONDIDO ~7	1	Closed	186.33	70.40	186.33	YES	YES	0.0045	0.8427
14	28845	ESCONDIDO ~6	1	Closed	186.33	90.44	186.33	YES	YES	0.0045	0.8420
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	40.70	YES	YES	0.0276	0.6436
19	29060	CHULA VIST~3	1	Closed	29.12	6.81	40.00	YES	YES	0.0185	0.5373
20	29010	NILAND 3	1	Open	0.00	14.39	60.50	YES	YES	-0.0084	0.5059
21	28978	SAN DIEG~102	1	Closed	52.27	22.67	72.00	YES	NO	0.0088	0.4824
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



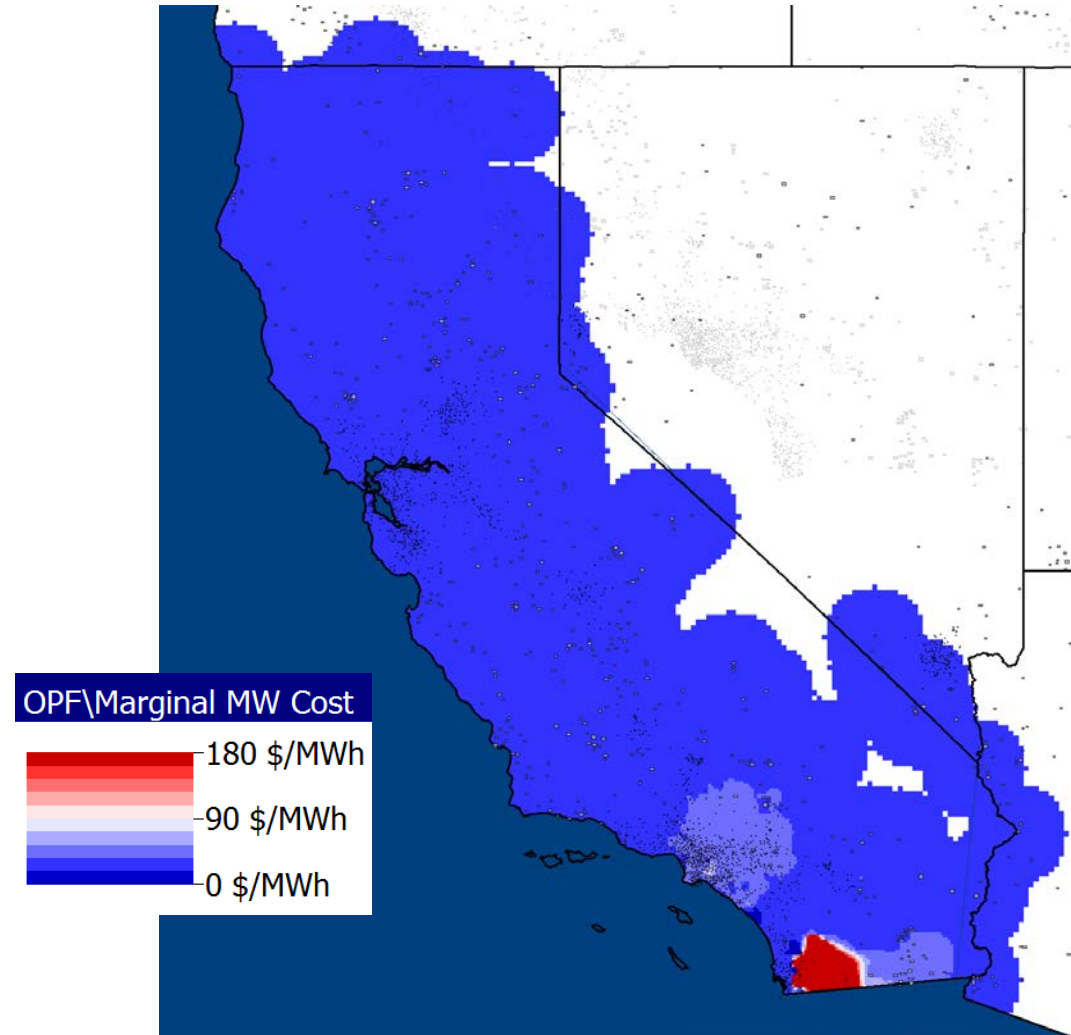
- 1 unit turned on, 1 unit turned off by OPF
- Sum of MVA overloads is reduced, but 3 unenforceable constraints remain

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	
1	29010	NILAND 3	1	Southeast Ca	YES	YES	Set on by OPF	If
2	28805	EL CAJON 7 1	1	Southeast Ca	YES	YES	Set off by OPF	If
3	20288	MCCLELLAN 1	1	Northern Cal	YES	NO		If
4	20295	BELDEN 2	1	Northern Cal	YES	NO		If
5	20299	MAXWELL 4	1	Northern Cal	YES	NO		If
6	20300	MAXWELL 5	1	Northern Cal	YES	NO		If
7	20302	MAXWELL 7	1	Northern Cal	YES	NO		If
8	20315	CAMINO 8	1	Northern Cal	YES	NO		If
9	20304	MIDDLETOWN~1	1	Northern Cal	NO	NO		If
10	20304	MIDDLETOWN~1	2	Northern Cal	NO	NO		If
11	20306	COBB 2	1	Northern Cal	NO	NO		If
12	20307	COBB 3	1	Northern Cal	NO	NO		If
13	20307	COBB 3	2	Northern Cal	NO	NO		If
14	20313	CAMINO 6	1	Northern Cal	YES	NO		If
15	20335	BOLLOCK PT~8	1	Northern Cal	YES	NO		If

Updated Color Contour



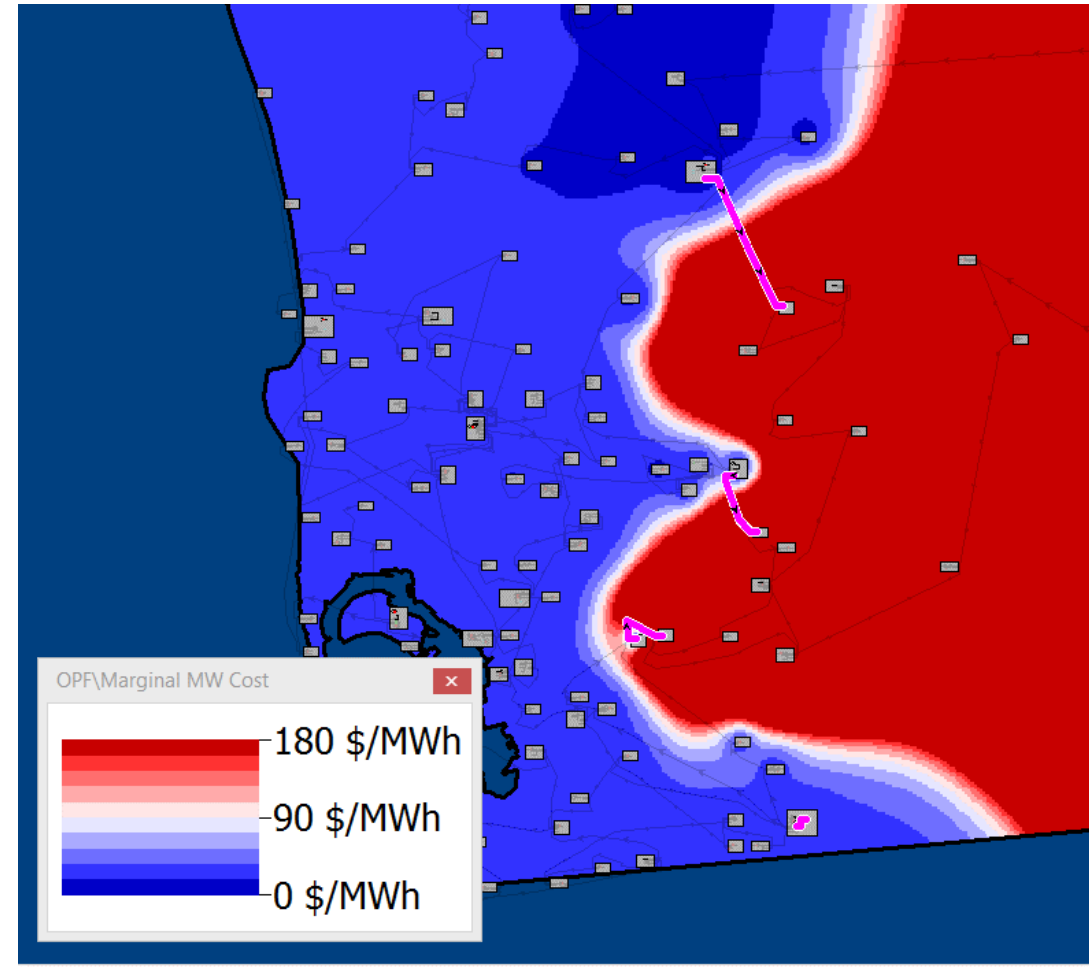
- Pricing is fairly uniform system-wide except for pocket near San Diego



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)

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	ETLR ▲	Load MW	Load Mvar	Gen MW	Gen Mvar	S
1	28621	LAKE SIDE 1 1	Southeast Ca	138.00	0.99214	136.915	-83.17	-0.97	39.76	22.81			
2	28622	LAKE SIDE 1 2	Southeast Ca	138.00	0.99250	136.965	-83.14	-0.97					
3	28623	LAKE SIDE 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 VIST~12	Southeast Ca	138.00	1.00164	138.227	-83.53	-0.93	36.87	12.16			
14	28602	CHULA VIST~14	Southeast Ca	138.00	1.00164	138.227	-83.53	-0.93					
15	28601	CHULA VIST~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	14.82	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)																
Records Geo Set Columns 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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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



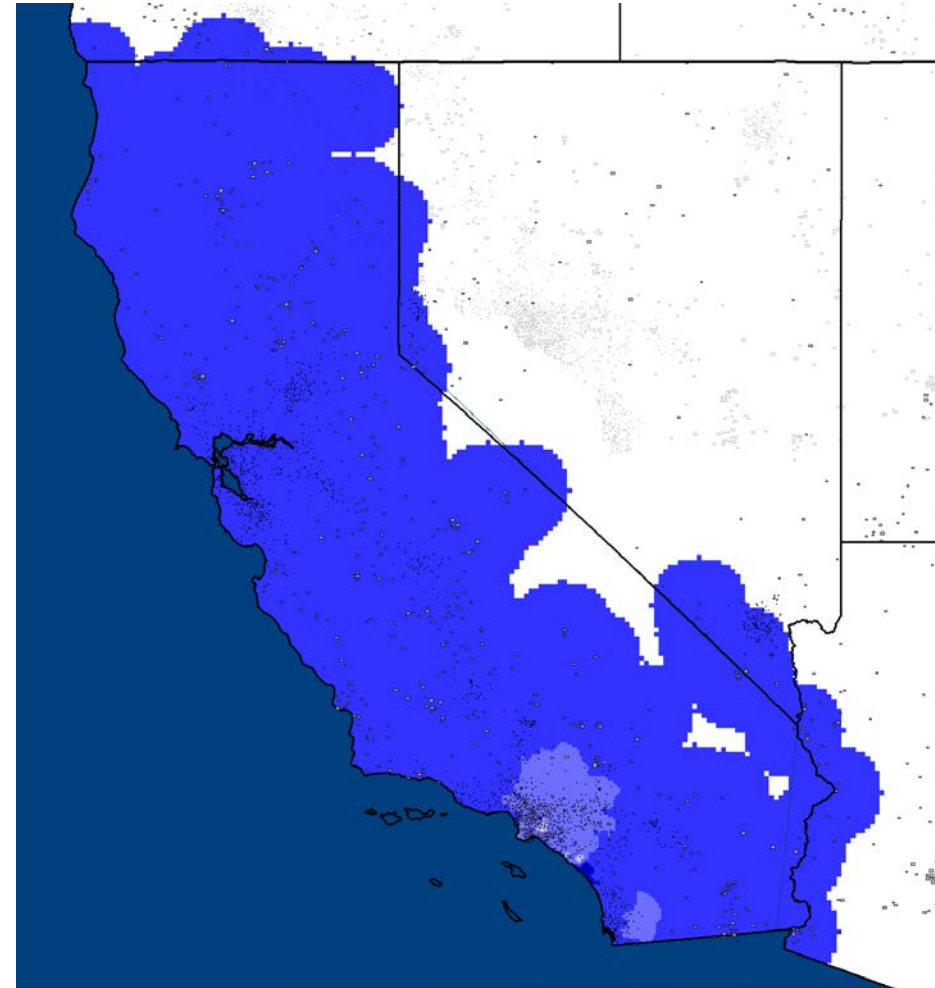
- Enable OPF load controls
 - Globally in *OPF Options and Results*
 - By Area for Areas 3-7 in OPF Areas Case Info Display
- Re-solve OPF

Areas									
Benefit Curves Linear									
OPF Branches									
Expressions									
Case Info Customizations									
Records									
Geo									
Set									
Columns									
Find...									
Filter									
Advanced									
Area									
Find...									
	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



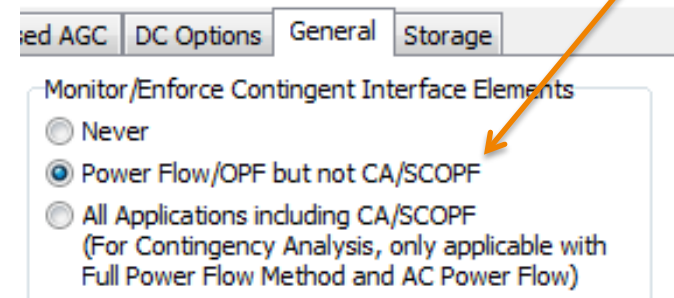
- Updated contour shows more uniform pricing
- Constraints into remaining pockets are binding rather than unenforceable
- Total reduction in load is about 30 MW



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



Contingencies with Flowgates



- A new set of constraints become unenforceable and a pocket of high prices re-appears in the LA area
- Re-calculate multi-element shift factors, now choosing *Overloaded Devices* and *Both* Lines/XFMRs and Interfaces
- Designate the generators with the most negative ETLRs (El Segundo and Torrance) as Fast Start and re-solve the OPF



Other Examples of OPF Challenges

OPF Unenforceable Constraints



- Radial Elements
- Mvar loops in AC power flow
- Unusual modeling parameters

Analysis of Unenforceable Constraints



- Example: Load *M08_LMP Multi-Area\UnenforceableConstraints.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 29 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 *UC_ChangeTransformers.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	Xfrmr	Tap Ratio	Monitor	Max MW	Max Mvar	Max MVA	% of MVA Limit (Max)	Lim MVA	MVA Marg. (▼)	Constraint Status
1	6288	BUS 6288	AREA 8	6361	BUS 6361	AREA 8	1	YES	1.000	YES	47.010	3.078	47.1	114.9	41.0	9999.0	Unenforceable
2	430	BUS 430	AREA 2	432	BUS 432	AREA 2	1	NO	1.000	YES	45.339	6.793	45.8	158.1	29.0	9999.0	Unenforceable
3	3390	BUS 3390	AREA 5	3408	BUS 3408	AREA 5	1	NO	1.000	YES	45.361	4.811	45.6	106.1	43.0	9999.0	Unenforceable
4	384	BUS 384	AREA 2	406	BUS 406	AREA 2	1	NO	1.000	YES	79.750	19.132	82.0	115.5	71.0	9999.0	Unenforceable
5	3080	BUS 3080	AREA 5	3230	BUS 3230	AREA 5	5	YES	0.925	YES	92.197	37.370	99.5	109.3	91.0	9999.0	Unenforceable
6	434	BUS 434	AREA 2	436	BUS 436	AREA 2	1	YES	1.000	YES	115.594	26.680	118.6	154.1	77.0	9999.0	Unenforceable
7	4257	BUS 4257	AREA 6	4262	BUS 4262	AREA 6	1	YES	1.000	YES	70.775	12.554	71.9	126.1	57.0	9999.0	Unenforceable
8	419	BUS 419	AREA 2	428	BUS 428	AREA 2	1	YES	1.000	YES	125.474	27.835	128.5	100.4	128.0	9999.0	Unenforceable
9	440	BUS 440	AREA 2	445	BUS 445	AREA 2	1	YES	0.937	YES	56.785	23.873	61.6	236.9	26.0	9999.0	Unenforceable
10	423	BUS 423	AREA 2	428	BUS 428	AREA 2	1	YES	1.000	YES	116.069	26.660	119.1	154.7	77.0	9999.0	Unenforceable
11	3390	BUS 3390	AREA 5	3399	BUS 3399	AREA 5	1	NO	1.000	YES	46.740	8.660	47.5	103.3	46.0	9999.0	Unenforceable
12	3080	BUS 3080	AREA 5	3230	BUS 3230	AREA 5	3	YES	0.925	YES	183.292	73.285	197.4	108.5	182.0	9999.0	Unenforceable
13	4214	BUS 4214	AREA 6	4217	BUS 4217	AREA 6	1	NO	1.000	YES	82.444	42.467	92.7	113.1	82.0	9999.0	Unenforceable
14	6362	BUS 6362	AREA 8	6372	BUS 6372	AREA 8	1	YES	1.000	YES	64.828	13.749	66.1	146.9	45.0	9999.0	Unenforceable
15	6361	BUS 6361	AREA 8	6372	BUS 6372	AREA 8	1	YES	1.000	YES	65.118	11.900	65.9	160.8	41.0	9999.0	Unenforceable
16	434	BUS 434	AREA 2	435	BUS 435	AREA 2	1	YES	1.000	YES	124.426	34.432	129.1	100.9	128.0	9999.0	Unenforceable
17	8863	BUS 8863	AREA 11	8872	BUS 8872	AREA 11	1	NO	1.000	YES	1.739	141.043	141.0	103.0	137.0	9999.0	Unenforceable
18	3391	BUS 3391	AREA 5	3399	BUS 3399	AREA 5	1	NO	1.000	YES	46.734	8.928	47.6	103.4	46.0	9999.0	Unenforceable
19	3080	BUS 3080	AREA 5	3230	BUS 3230	AREA 5	4	YES	0.925	YES	180.526	72.047	194.4	107.4	181.0	9999.0	Unenforceable
20	4257	BUS 4257	AREA 6	4261	BUS 4261	AREA 6	1	YES	1.000	YES	70.510	12.519	71.6	121.4	59.0	9999.0	Unenforceable
21	1562	BUS 1562	AREA 3	1593	BUS 1593	AREA 3	1	NO	1.000	YES	29.557	17.502	34.0	100.0	34.0	3341.9	Binding
22	228	BUS 228	AREA 2	425	BUS 425	AREA 2	1	NO	1.000	YES	124.693	24.267	125.0	100.0	125.0	447.9	Binding
23	4111	BUS 4111	AREA 6	4172	BUS 4172	AREA 6	1	NO	1.000	YES	212.329	33.783	215.0	100.0	215.0	161.4	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

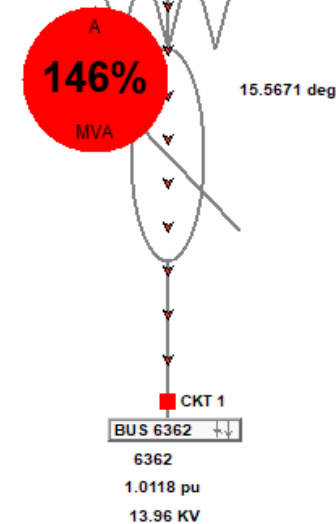
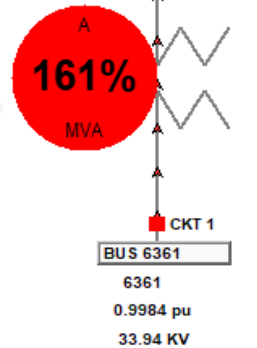


BUS 6372

Bus: BUS 6372 (6372)
Nom kV: 34.50
Area: AREA 8 (8)
Zone: ZONE 8 (8)

1.0087 pu
34.80 KV
-43.78 Deg
-2293.88 \$/MWh

0.00 MW
0.00 Mvar



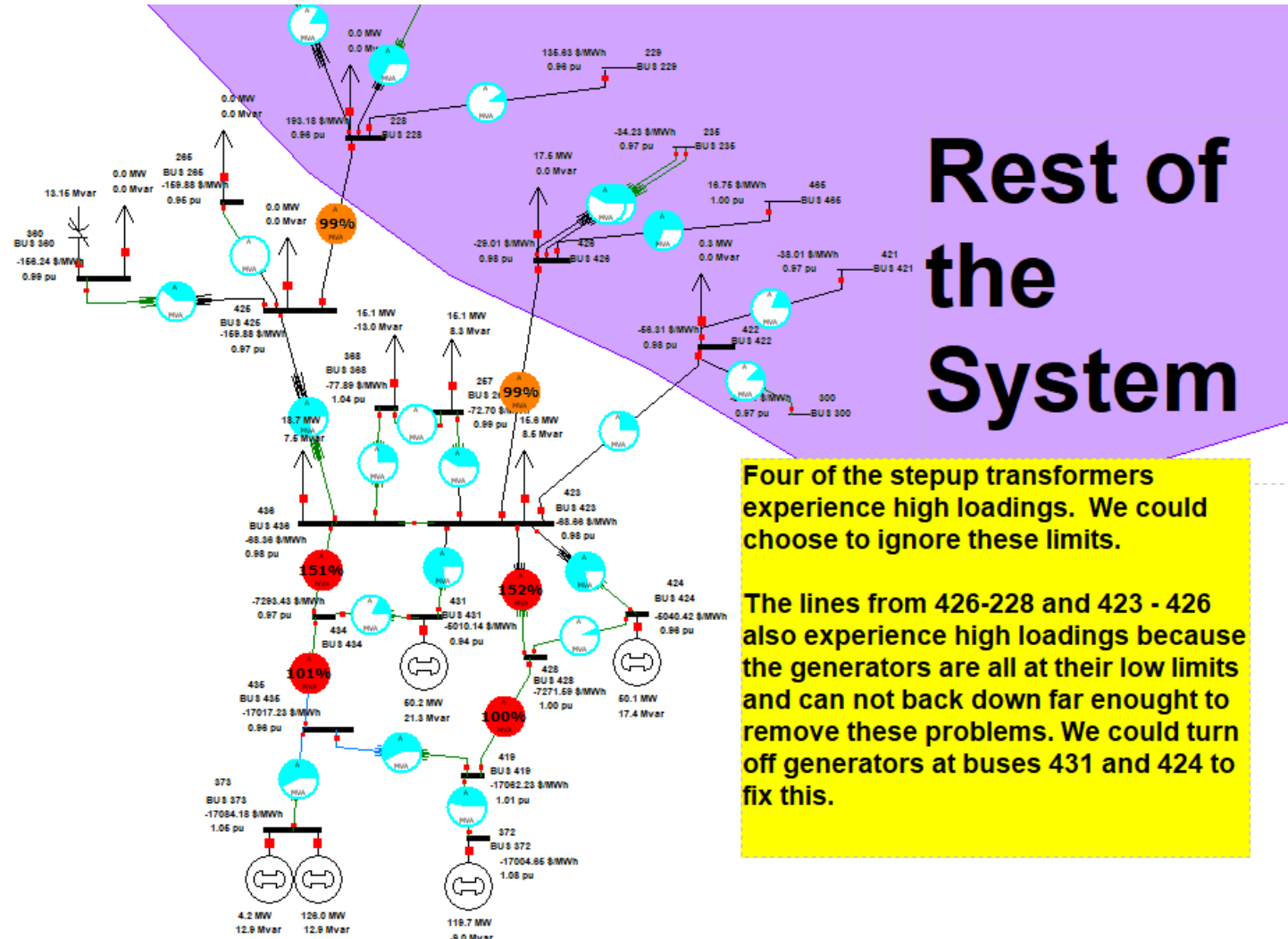
Phase-shifter setpoint is 60.3 – 72.9 MW, but line limits are ≤ 45 MVA; ignore these lines

A Closer Look

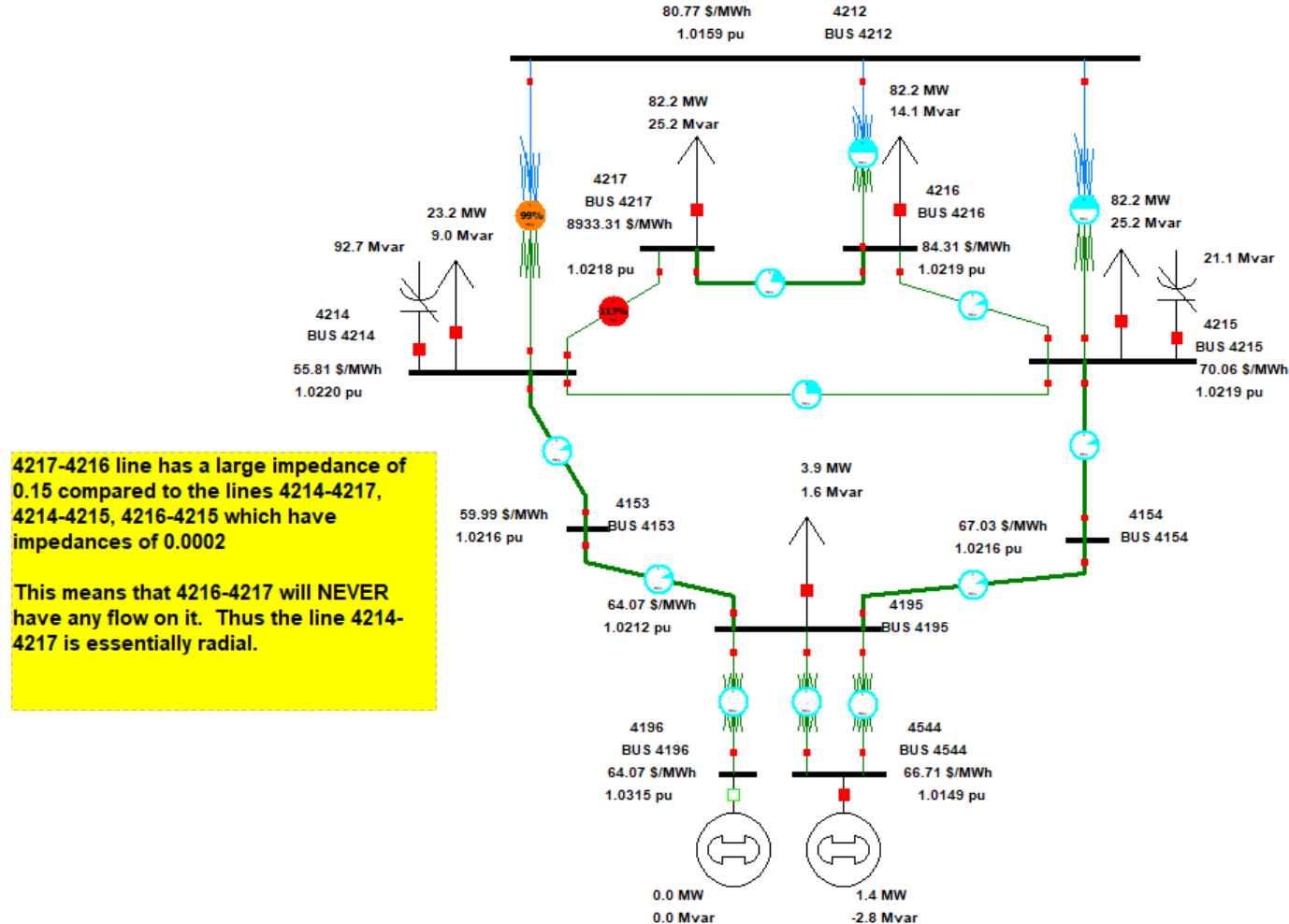


- Look more closely at the majority of the remaining unenforceable constraints
 - Continues to show a large number of under radial elements which should probably just be ignored
- A handful of elements require greater study
 - Draw a oneline diagram to represent this part of the system
 - You will start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

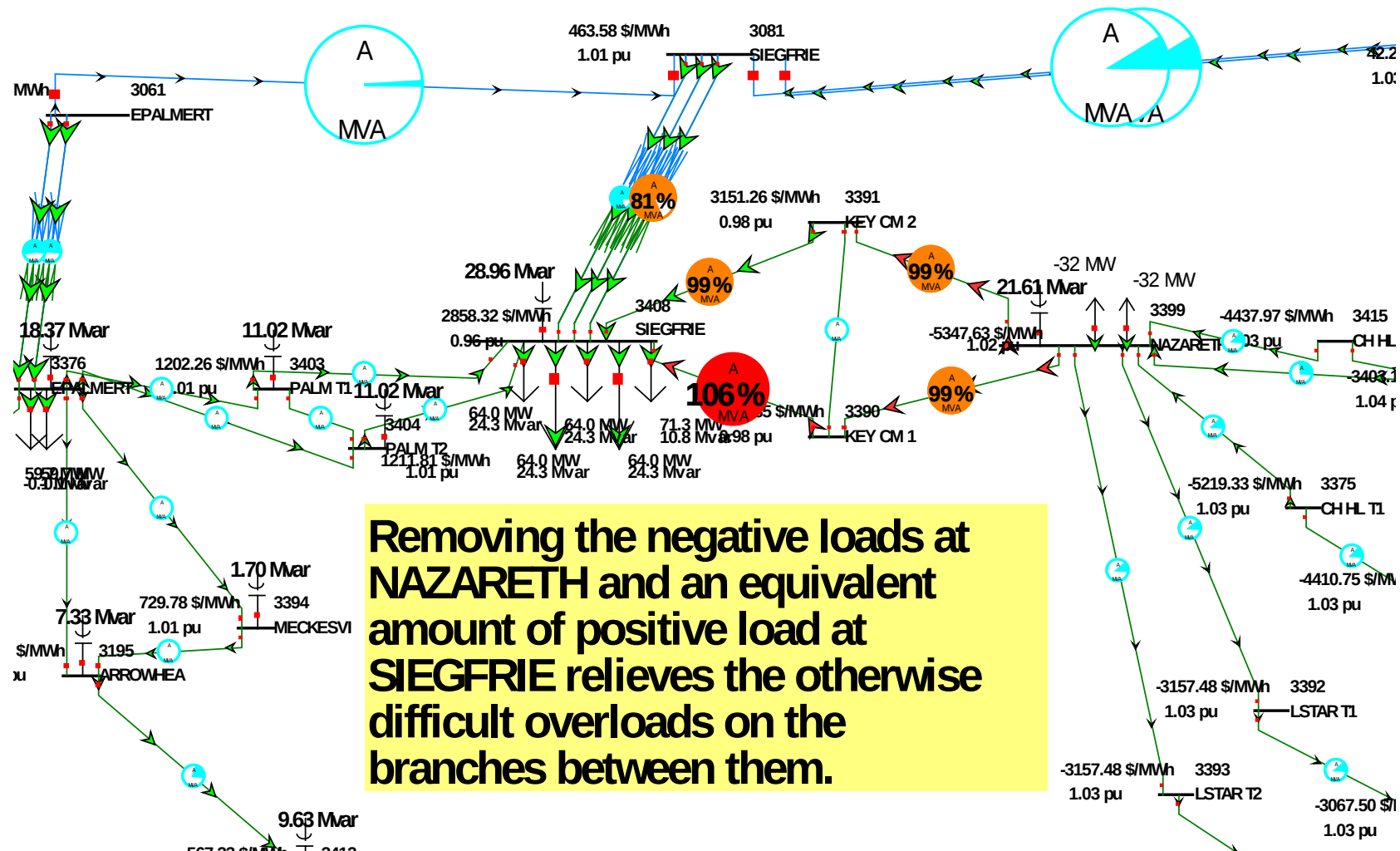
Example: GSU Loading



Example: High Impedance Bus Tie



Negative Loads



After these changes we remove all unenforceable Constraints



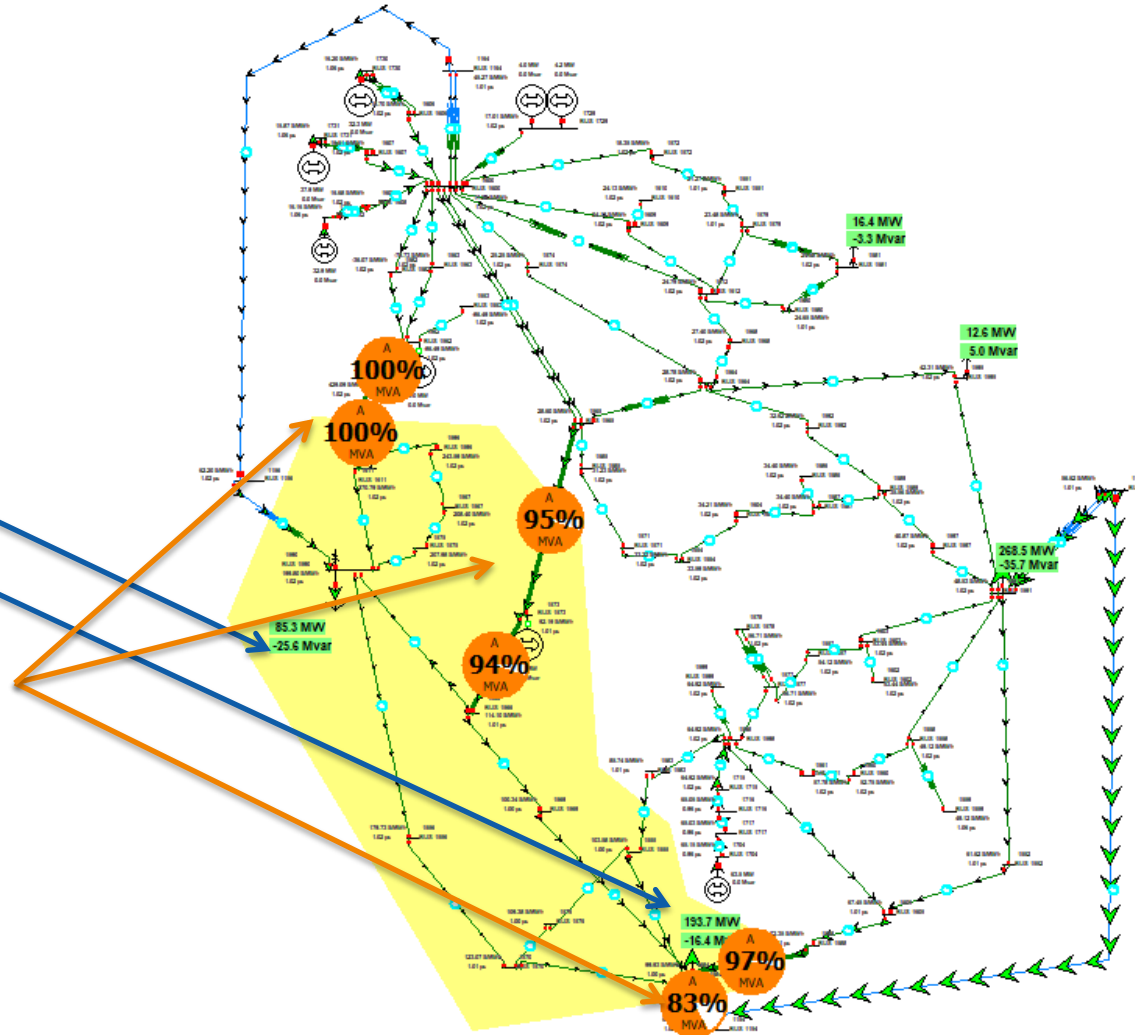
- Still some very high cost constraints remain
- 1562 – 1593 = \$752.3/MVAhr

Lines/Transformers		Interfaces															
	From Number	From Name	From Area Name	To Number	To Name	To Area Name	Circuit	Xfrmr	Tap Ratio	Monitor	Max MW	Max Mvar	Max MVA	% of MVA Limit (Max)	Lim MVA	MVA Marg. (▼)	Constraint Status
1	1562	BUS 1562	AREA 3	1593	BUS 1593	AREA 3	1	NO	1.000	YES	29.577	17.406	34.0	99.9	34.0	752.3	Binding
2	3390	BUS 3390	AREA 5	3408	BUS 3408	AREA 5	1	NO	1.000	YES	42.803	4.253	43.0	100.0	43.0	256.0	Binding
3	4954	BUS 4954	AREA 7	5020	BUS 5020	AREA 7	1	NO	1.000	YES	338.302	44.331	341.2	93.2	366.0	157.8	Binding
4	228	BUS 228	AREA 2	425	BUS 425	AREA 2	1	NO	1.000	YES	124.683	24.347	125.0	100.0	125.0	120.0	Binding
5	1152	BUS 1152	AREA 3	1221	BUS 1221	AREA 3	2	YES	1.000	YES	250.259	17.883	250.9	100.0	251.0	117.4	Binding
6	4111	BUS 4111	AREA 6	4172	BUS 4172	AREA 6	1	NO	1.000	YES	212.369	33.362	215.0	100.0	215.0	79.2	Binding
7	4957	BUS 4957	AREA 7	5044	BUS 5044	AREA 7	1	YES	0.985	YES	211.176	65.545	219.1	100.0	219.0	22.1	Binding
8	8857	BUS 8857	AREA 11	8871	BUS 8871	AREA 11	1	NO	1.000	YES	78.515	8.762	79.0	100.0	79.0	15.4	Binding
9	6287	BUS 6287	AREA 8	6361	BUS 6361	AREA 8	1	YES	1.000	YES	40.983	2.339	41.0	100.0	41.0	10.8	Binding
10	2	BUS 2	AREA 1	7	BUS 7	AREA 1	1	NO	1.000	YES	682.093	364.012	773.1	25.2	3066.0		
11	4	BUS 4	AREA 1	13	BUS 13	AREA 1	1	NO	1.000	YES	1293.858	300.094	1328.2	43.3	3066.0		
12	3	BUS 3	AREA 1	7026	BUS 7026	AREA 9	1	YES	0.998	YES	900.361	57.833	901.4	70.0	1287.0		
13	4	BUS 4	AREA 1	26	BUS 26	AREA 1	1	NO	1.000	YES	1463.892	189.755	1467.7	47.9	3066.0		
14	4	BUS 4	AREA 1	5963	BUS 5963	AREA 8	1	YES	0.991	YES	656.470	109.981	665.6	67.9	980.0		
15	2	BUS 2	AREA 1	6	BUS 6	AREA 1	1	NO	1.000	YES	893.312	13.906	893.4	29.1	3066.0		

Load Pocket

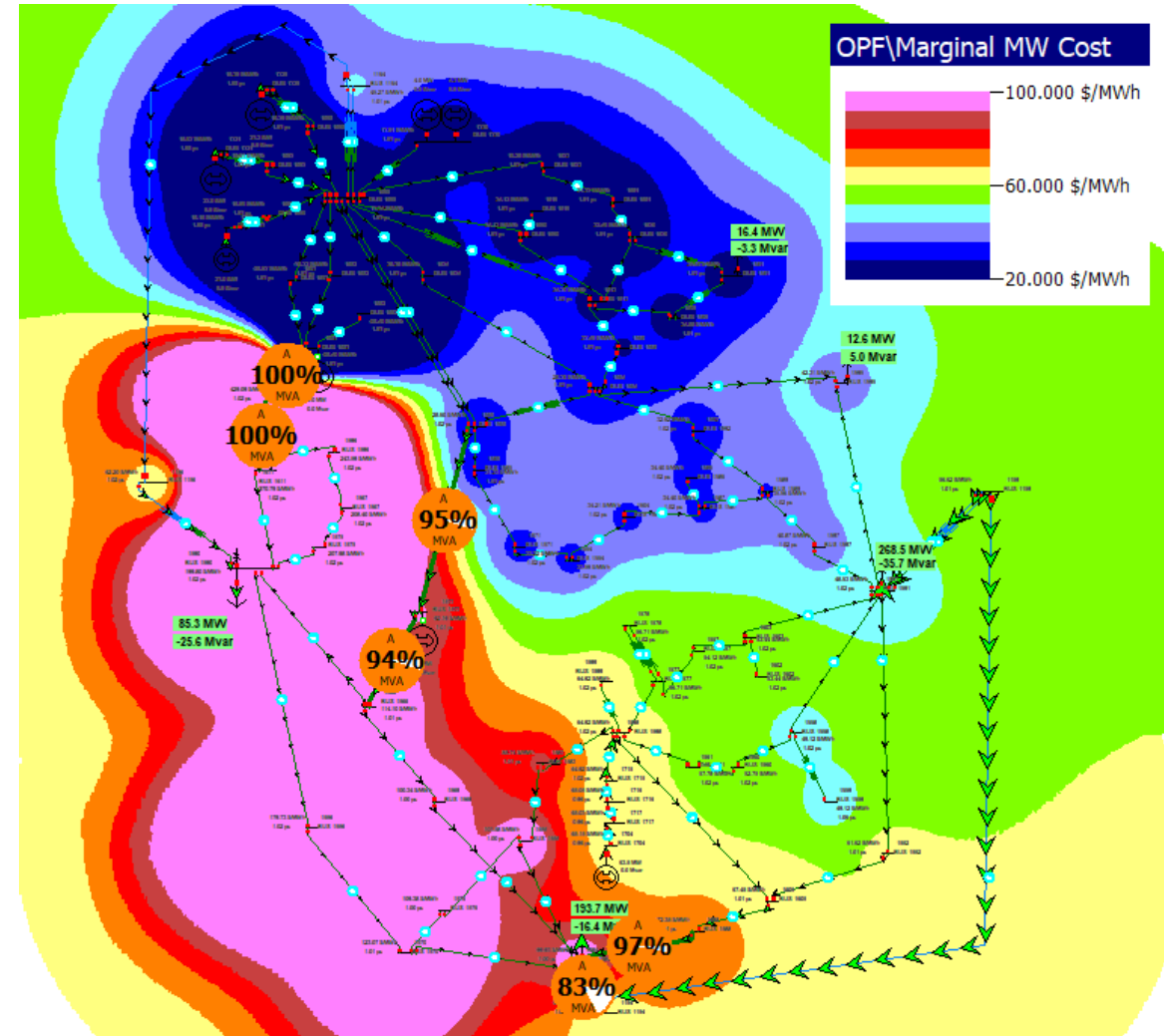


- Yellow Region forms a “load pocket” for two large loads
 - 85.3 MW
 - 193.7 MW
- The 69 kV lines feeding this region have high loadings



Price Contour at the 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