WWSIS III: Western Frequency Response and Transient Stability Study

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Today's Agenda

New Slide

8:30am Welcome & Introductions
8:45am Study Scenarios
- Light spring
- Heavy summer
9:45am Break
10:00am Frequency Response
11:00am Transient Stability
- COI Stability
Noon Working Lunch
1:00pm Transient Stability
- Transmission Expansion
- Load Impact & Distributed Generation
- Local Stability Issues
3:00pm Break
3:15pm Transient Stability continued
- Extreme Renewable Scenario
- CSP Sensitivity
- Headroom Depletion
4:00pm Summary & Next Steps
5:00pm Adjourn

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TRC Call: Do not Cite - Not for Further Distribution

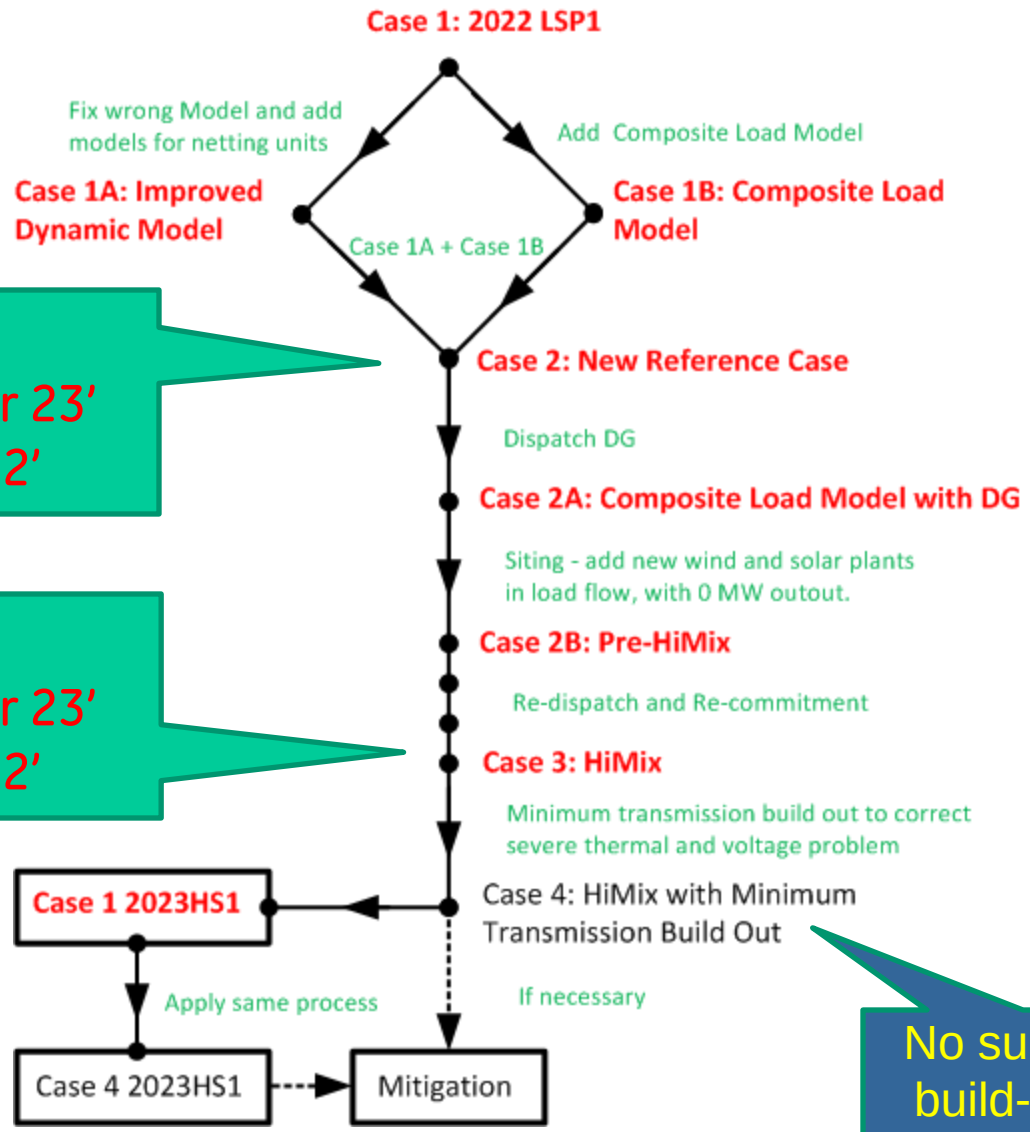
Study Objective/Overview (from Kick-off)

- Illustrate the frequency response and transient stability of the US WECC to large disturbances, including generation outages and critical tie-line disturbances, under a variety of system conditions.
- Explore the potential impact of substantially increased levels of wind and solar generation on frequency response and transient stability
- Test various operational and control options to improve system frequency response and transient stability
- Examine and test metrics of system conditions intended to provide operational assistance in positioning the system for adequate frequency and transient stability performance.
  - Consider how possible additional dynamic constraints on system performance might be included in economic simulations

Task 1 - Study Databases & Establish Initial Conditions

- Case Cases/Initial Conditions:
  - WECC TEPPC LSP '22 – light spring load condition:
  - WECC HS '23 – heavy summer load
- Baseline reconciliation:
  - WECC '22 Cases and WWSIS II Plexos "TEPPC" base conditions
  - Wind & Solar Plants – including additions
  - Other Generation – particular attention to Δs
- Build-out High Mix Scenarios for Renewable Penetration
  - Understand Δ Plexos TEPPC -> HiMix
  - Use to guide Δ WECC LSP'22 -> WECC HiMix LSP'22
- Siting:
  - By BA, based on WWSIS scenario
  - Local/intra-BA changes minimal (we are focused on bulk WECC system issues, not local constraints)
- Incremental Commitment and Dispatch (for added wind & solar)
  - Critical to credible and comparable cases
- Incremental (but minimal) transmission reinforcements

Evaluation of Study Cases



Base cases:
HS – Heavy Summer 23'
LSP – Light Spring 22'

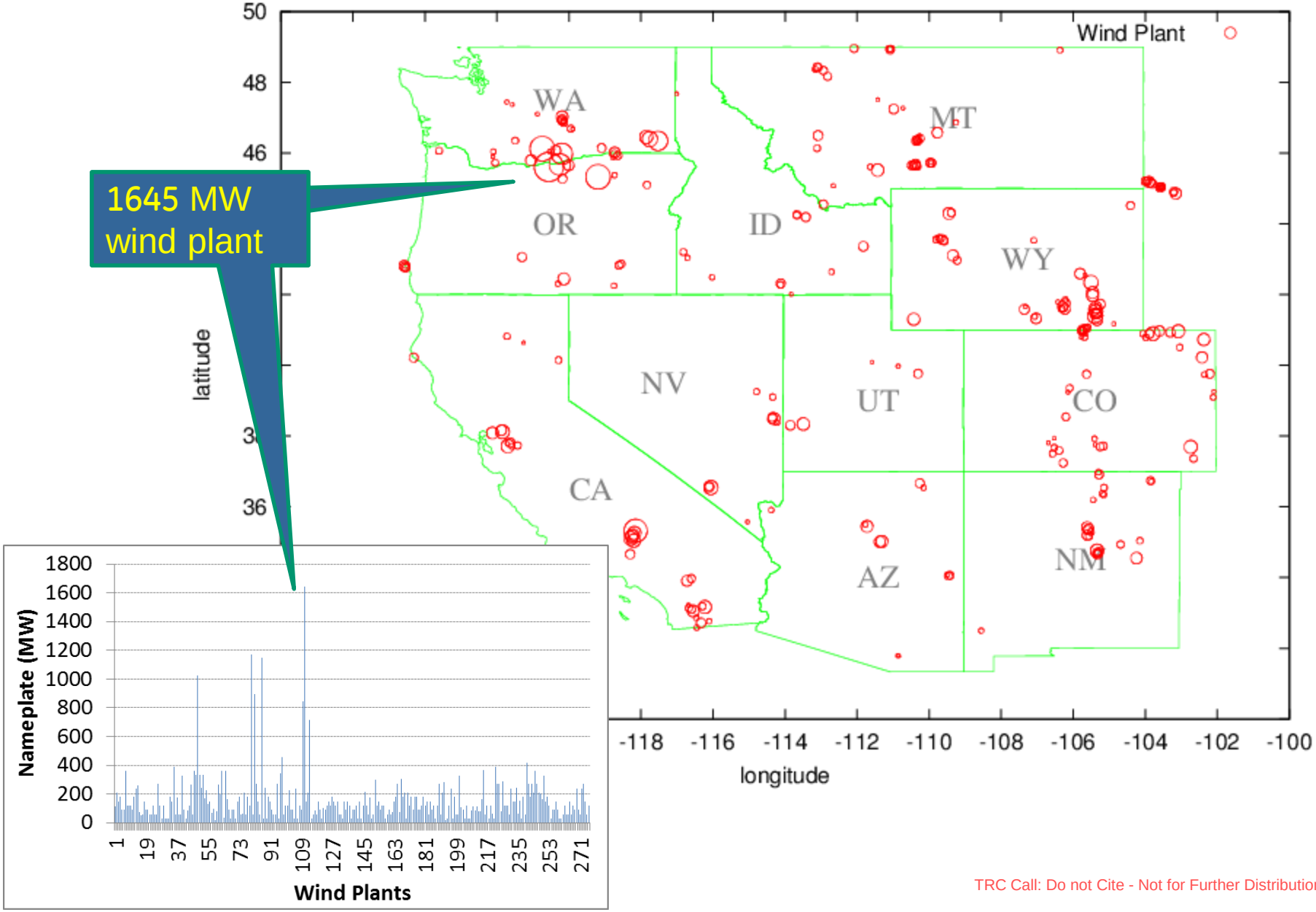
HiMix cases:
HS – Heavy Summer 23'
LSP – Light Spring 22'

No substantial build-out was required

1. Four Master Load flows

Renewables

Wind Plants from WWSIS2



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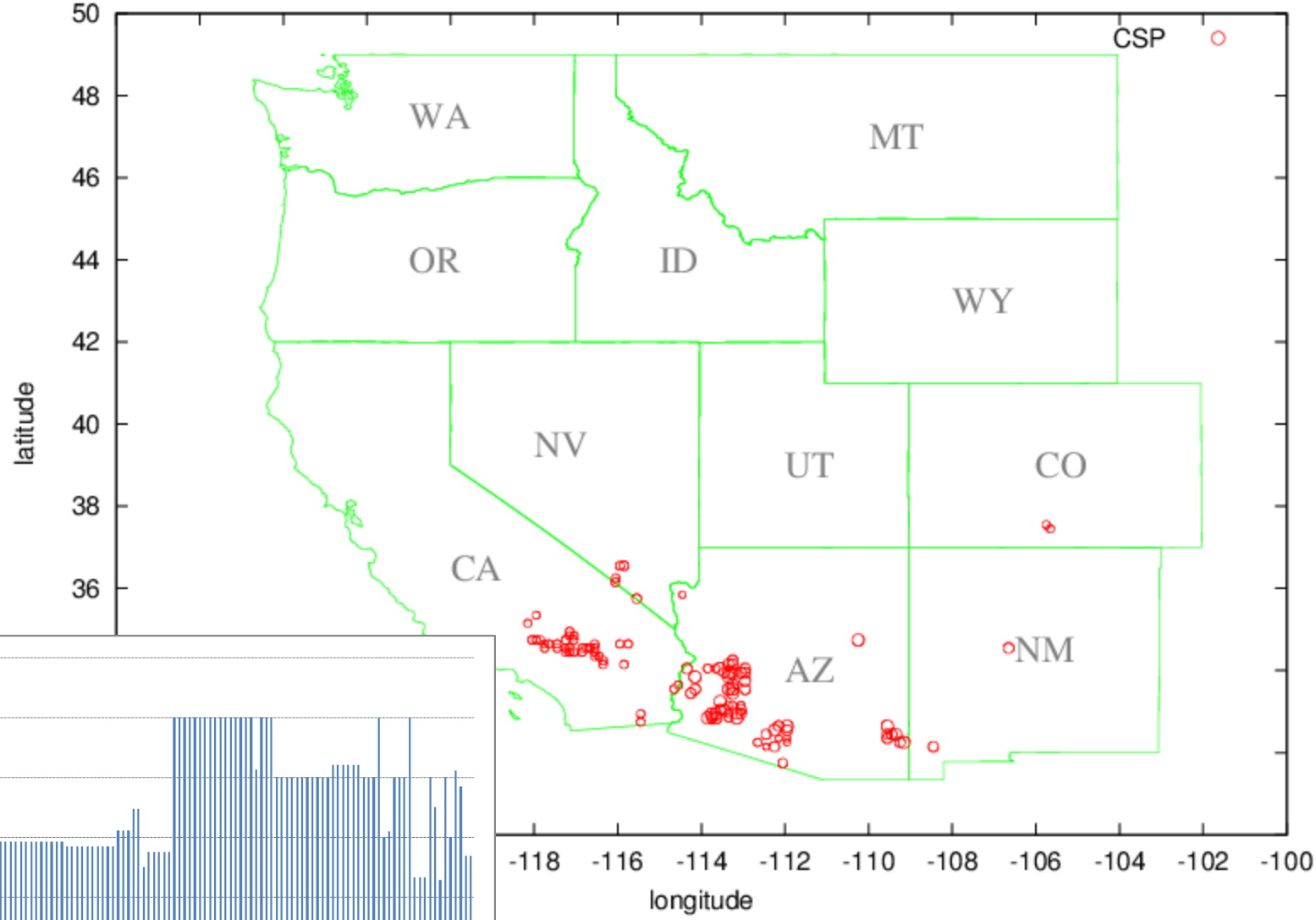
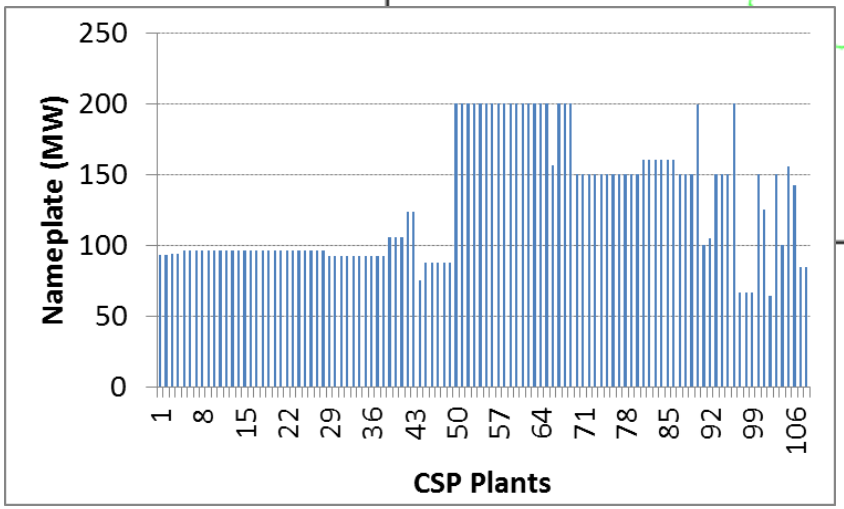
CSP Plants from WWSIS2





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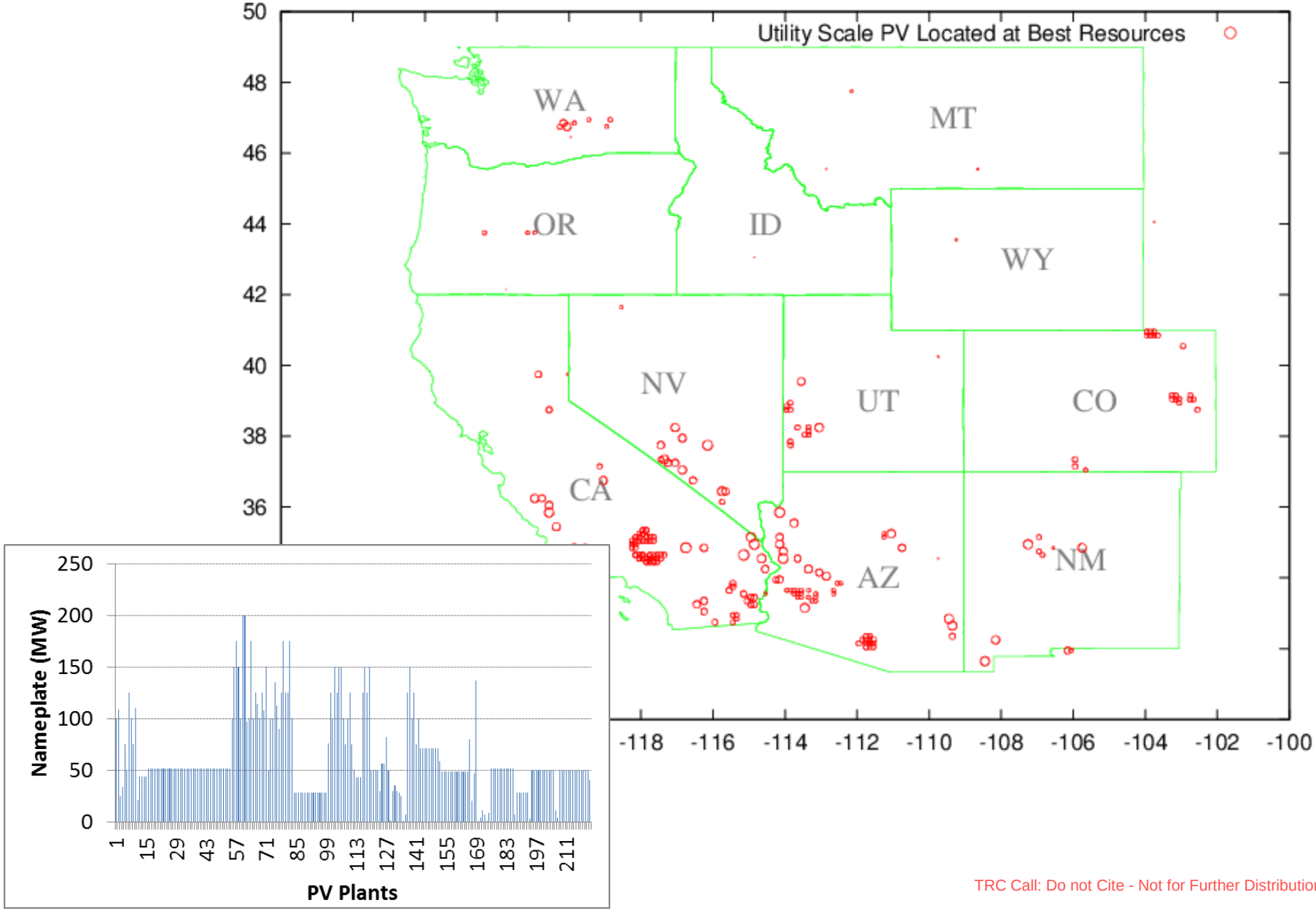
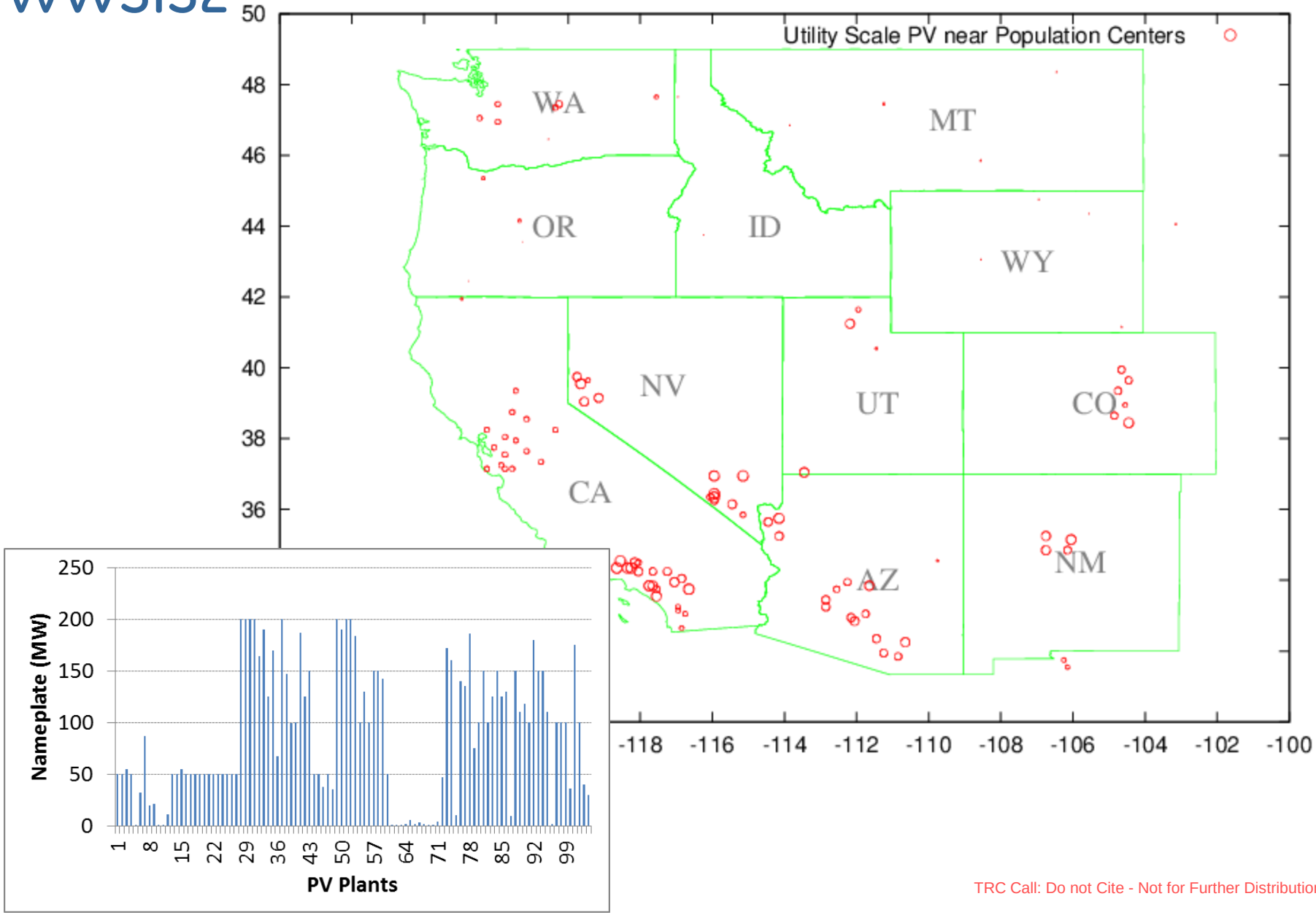
Utility Scale PV located at the Best Resources from WWSIS2

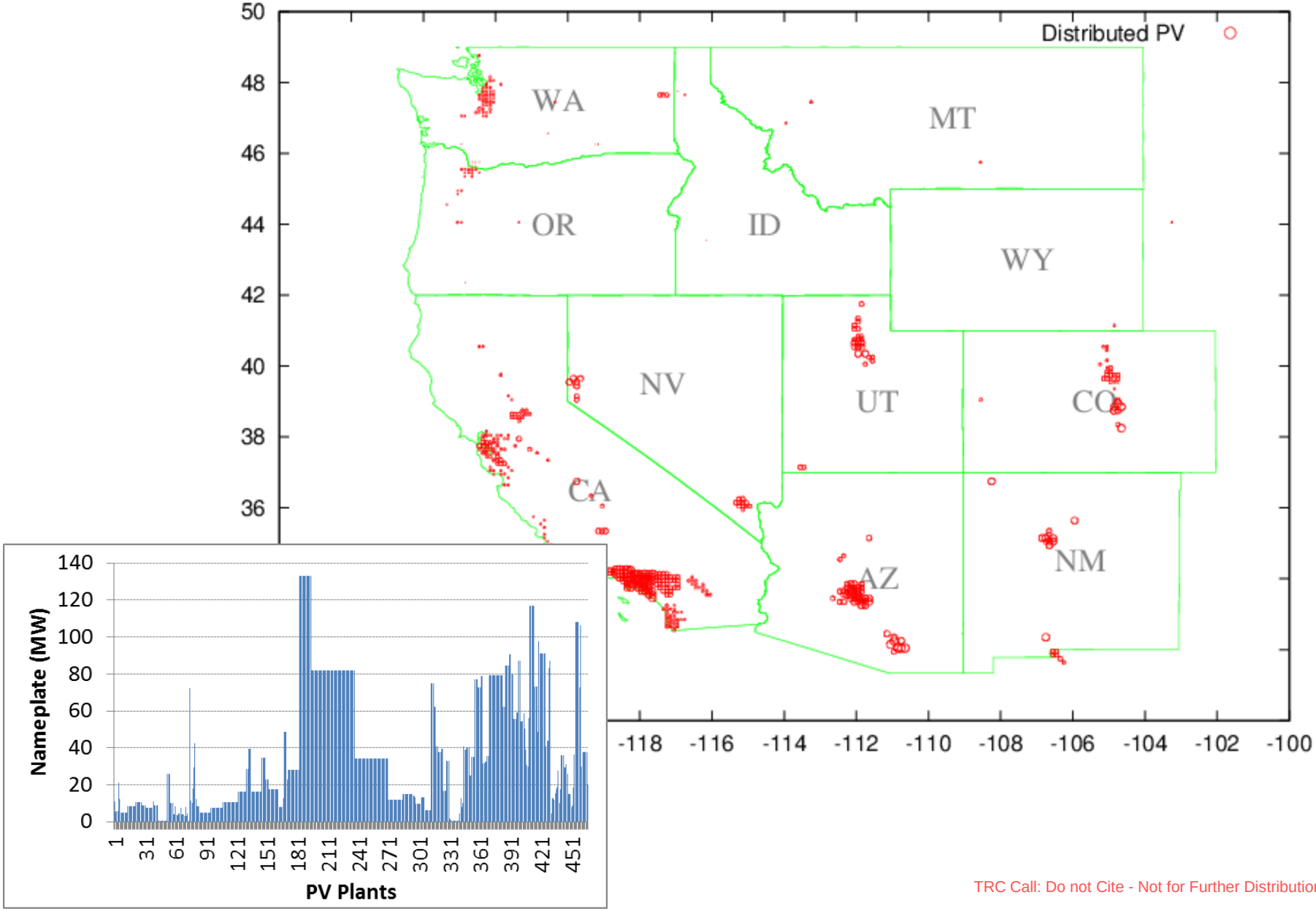


Utility Scale PV near Population Centers from WWSIS2

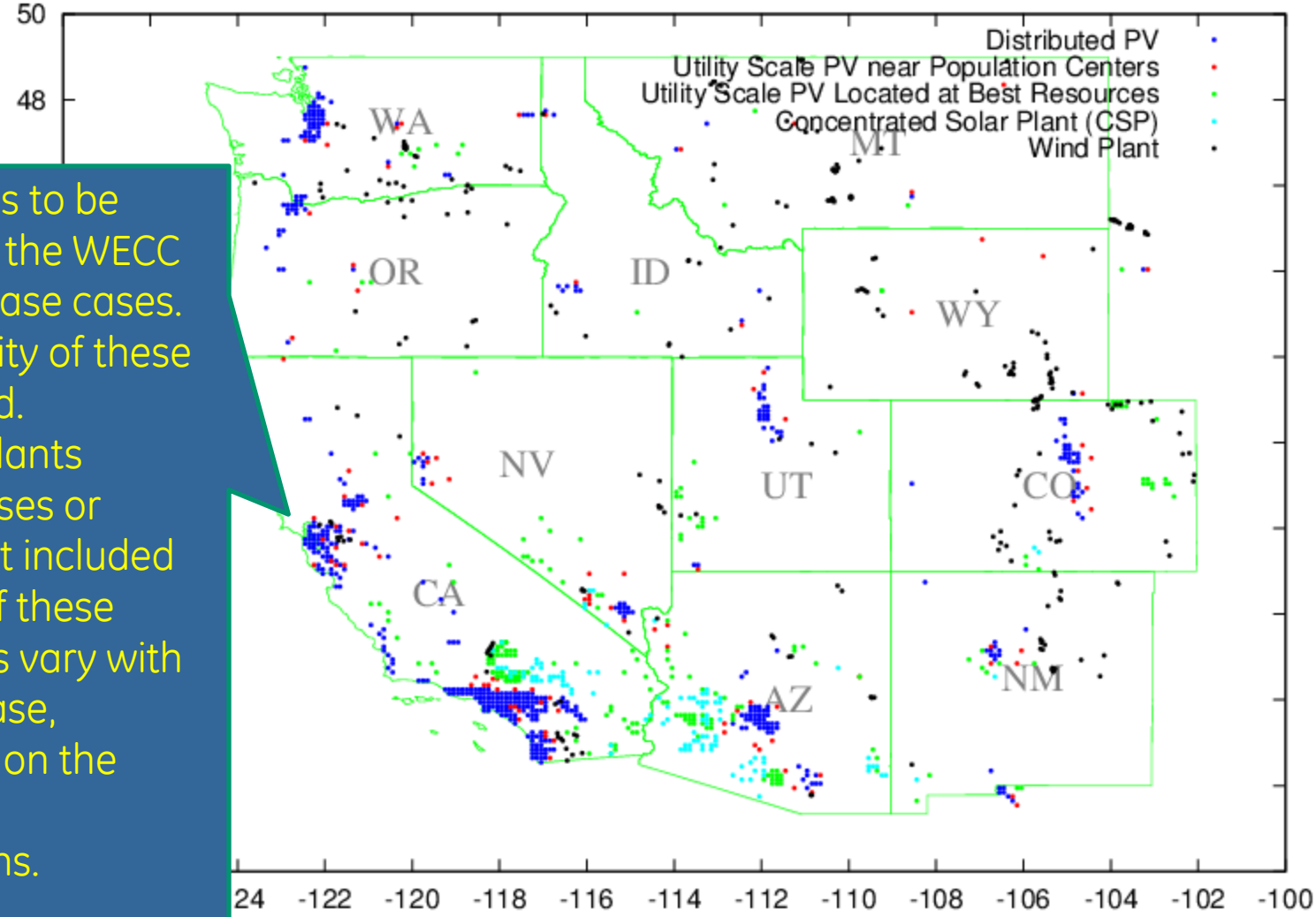


TRC Call: Do not Cite - Not for Further Distribution

Distributed PV from WWSIS2



All Renewables from WWSIS2

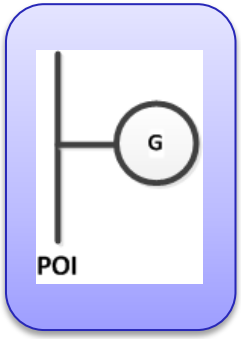


- Renewables to be added into the WECC load flow base cases.
- Vast majority of these were added.
- WWSIS II plants without buses or isolated not included
- Dispatch of these renewables vary with different case, depending on the renewable penetrations.

Renewable Modeling in Power Flow

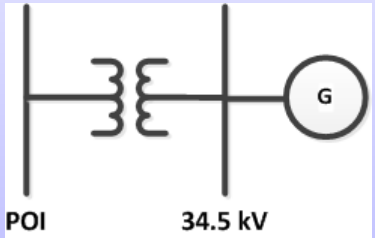
Modified Slide

Renewables in WWSIS-2 study

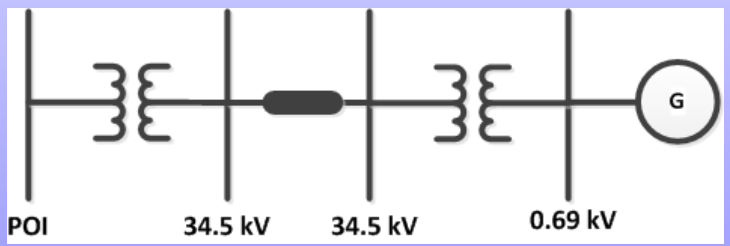


In load flow, newly added renewable were modeled as a single plant, with appropriate system build outs.

Renewables in PSLF



CSP



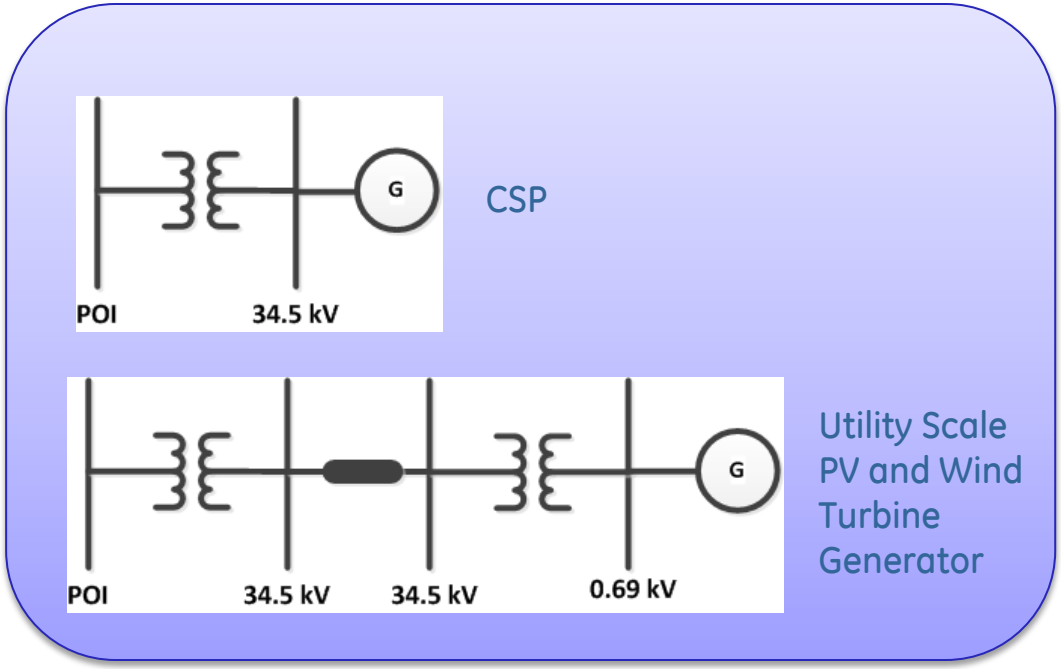
Utility Scale PV and Wind Turbine Generator

Note: Distributed PV embedded with the load are modeled separately and discussed later.

Renewable Modeling in Dynamics

- CSP – synchronous machine, standard WECC model without governor response
- Utilities scale PV – with voltage regulation and LVRT (gewtg and ewtgfc)
- Wind turbine model – type 3 with voltage regulation and LVRT (gewtg, wtg, wndtge)

Renewables in PSLF



Four Master Load flows

- 22'LSP Base Case
- 22'LSP HiMix Case
- 23'HS Base Case
- 23'HS HiMix Case

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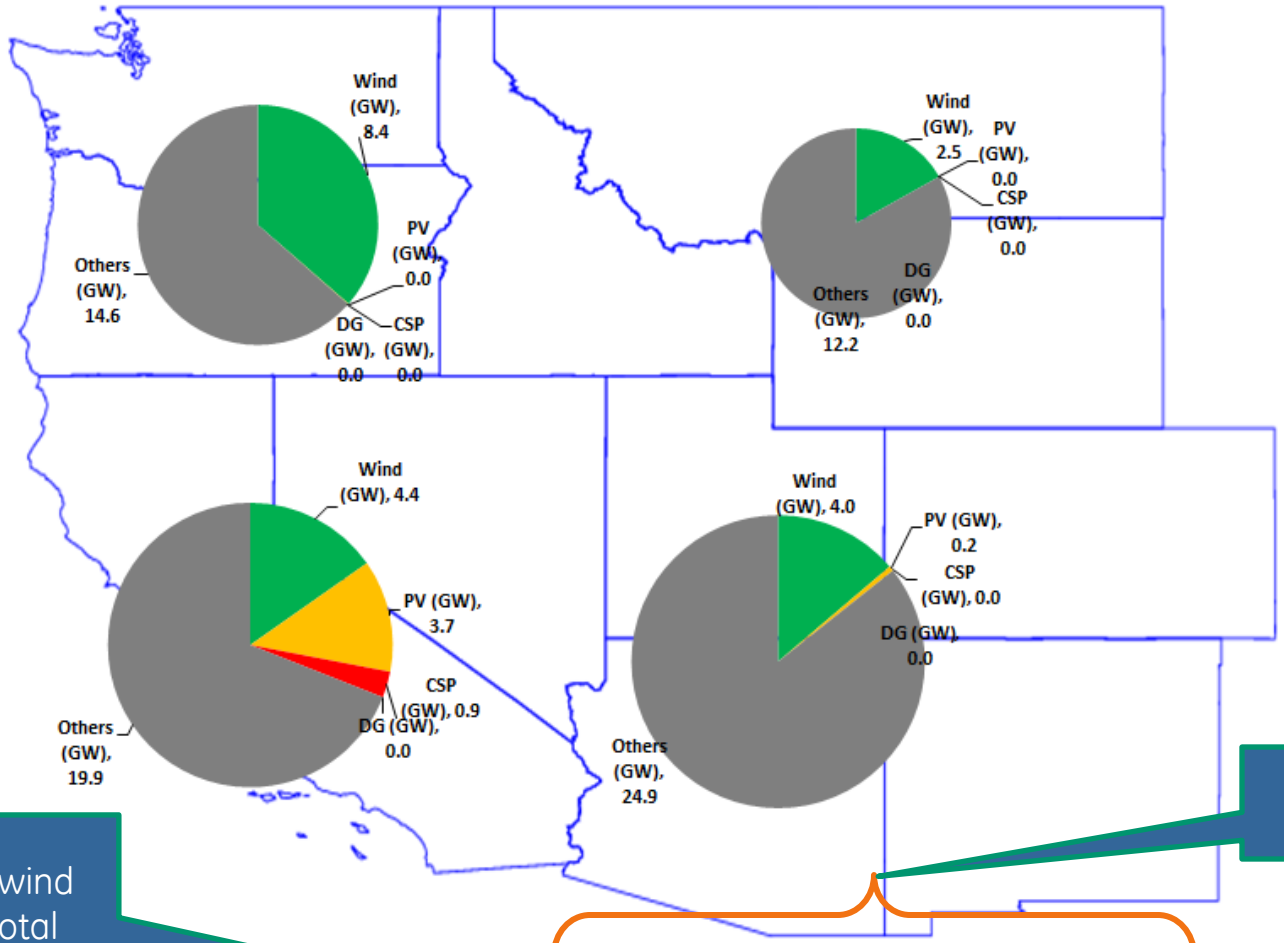
Preliminary Results: Not for Further Distribution or Citation

2022LSP Base Case – Renewable Conditions



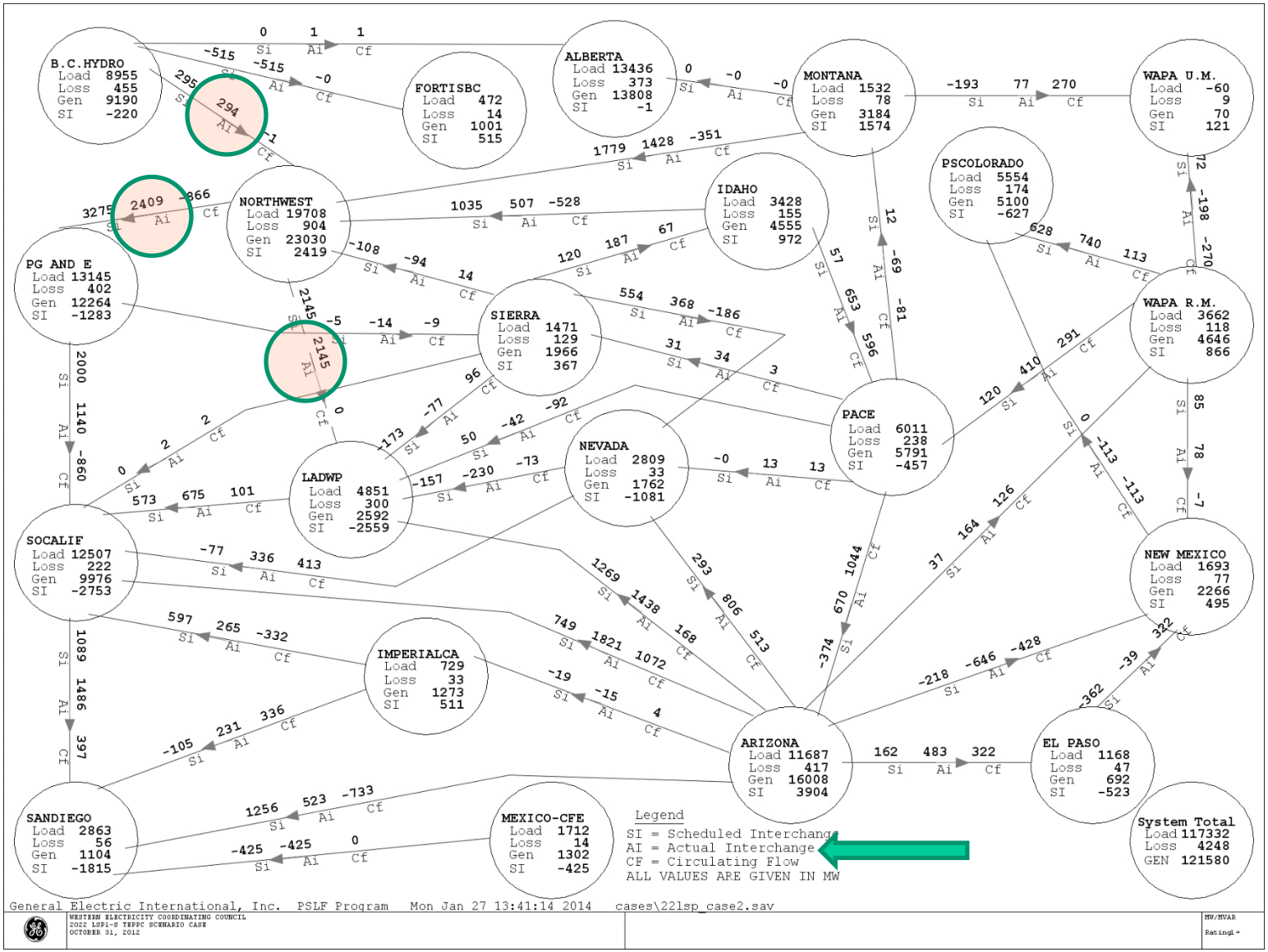
US only

~ 25 GW of wind and solar total

	WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Wind (GW)	20.9	4.4	4.0	2.5	8.4
PV (GW)	3.9	3.7	0.2	0.0	0.0
CSP (GW)	0.9	0.9	0.0	0.0	0.0
DG (GW)	0.0	0.0	0.0	0.0	0.0
Others (GW)	94.7	19.9	24.9	12.2	14.6
total (GW)	120.3	28.9	29.1	14.7	22.9

Preliminary Results: Not for Further Distribution or Citation

2022LSP Base Case – PSLF Bubble Diagram



imagination at work

Preliminary Results: Not for Further Distribution or Citation

Performance Metrics: Area/Regional Monitoring

- New dynamic model (epcmod) to regional performance

Headroom is the difference between Pmax and Pgen on Governor Responsive units

Chan ID	Description
fr	Frequency (Hz) calculated from MVA weighted speed of synch machines
pg	Pgen of units with governors (GW)
mc	Capacity of units with governors (GW)
hr	Headroom on units with governors (GW)
nu	Number of units with governors
pm	Mechanical power of unit with governors (GW)
mv	MVA rating of unit with governors (GVA)
px	Pgen of units w/o governors (GW)
mx	Mechanical power of units w/o governors (GW)
nx	# units w/o governors
qg	Qgen of all synchronous generators (GVAr)
pl	P load (GW)
ql	Q load (GVAr)
pw	Pgen – Wind (GW)
qw	Qgen – Wind (GVAR)
pv	Pgen – Solar PV
qv	Qgen – Solar PV
ps	Pgen - Pumped storage hydro (GW)
dg	Pgen- DG (solar PV)

2022LSP Base Case – Initial Condition Metrics

		WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Pgen of synchronous generators with GR (GW)	pg	43.5	6.4	10.4	2.9	12.4
Capacity of synchronous generators with GR (GW)	mc	64.2	11.7	15.0	4.1	17.3
Headroom on synchronous generators with GR (GW)	**hr**	**20.7**	**5.3**	**4.6**	**1.3**	**4.9**
Number of synchronous generators with GR (GW)	**nu**	**800**	**169**	**128**	**90**	**202**
Mechanical power of synchronous generators with GR (GW)	pm	43.6	6.4	10.4	2.9	12.5
MVA rating of synchronous generators with GR (GW)	mv	65.5	12.4	16.5	4.4	16.1
Pgen of synchronous generators w/o GR (GW)	px	52.1	14.4	14.6	9.3	2.1
Mechanical synchronous generators w/o GR (GW)	mx	52.3	14.5	14.6	9.4	2.1
Number of synchronous generators w/o GR (GW)	nx	754	295	72	127	62
Pgen of all synchronous generators (GW)	pq	95.6	20.8	24.9	12.2	14.6
Qgen of all synchronous generators (GVAr)	qg	5.1	-0.7	2.2	0.8	0.8
P load (GW)	pl	111.2	33.1	25.7	11.2	19.0
Q load (GVAr)	ql	31.7	8.0	7.3	3.4	4.2
Pgen – Wind (GW)	**pw**	**20.9**	**4.4**	**4.0**	**2.5**	**8.4**
Qgen – Wind (GVAR)	qw	-1.0	-0.4	0.4	-0.2	-0.7
Pgen – Solar PV	**pv**	**3.9**	**3.7**	**0.2**	**0.0**	**0.0**
Qgen – Solar PV	qv	-0.2	-0.2	0.0	0.0	0.0
Pgen - CSP (GW)	**pc**	**0.9**	**0.9**	**0.0**	**0.0**	**0.0**
Pgen - DG (solar PV)	**dg**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Kt	Kt	0.46	0.34	0.44	0.26	0.62

Kt definition important!

Kt: the ratio of power generation capability of units with GR to the MW capability of all GR units plus MW dispatch of non-GR units.

2022LSP Base Case – Initial Condition Metrics

	Name	ID	freq	Pgen_gov	mwcap	headroom	num_gov	mnech_gov	mva_gov	pgen_nogov	mva_nogen	num_nogov	pgs_tot	qgq_tot	pload	qload	pg_wind	qg_wind	pg_pv	qg_pvv	pg_csp	pg_dg	num_hrm
1	WECC	WE	60.0	43.5	64.2	20.7	800	43.6	65.5	52.1	52.3	754	95.6	5.1	111.2	31.7	20.9	-1.0	3.9	-0.2	0.9	0.0	800
2	CALIFORNIA	CA	60.0	6.4	11.7	5.3	169	6.4	12.4	14.4	14.5	295	20.8	-0.7	33.1	8.0	4.4	-0.4	3.7	-0.2	0.9	0.0	169
3	DSW	DS	60.0	10.4	15.0	4.6	128	10.4	16.5	14.6	14.6	72	24.9	2.2	25.7	7.3	4.0	0.4	0.2	0.0	0.0	0.0	128
4	NORTHEAST	NE	60.0	2.9	4.1	1.3	90	2.9	4.4	9.3	9.4	127	12.2	0.8	11.2	3.4	2.5	-0.2	0.0	0.0	0.0	0.0	90
54	ALBERTA	AL	60.0	2.0	3.3	1.4	67	2.0	3.5	10.1	10.1	80	12.1	1.8	13.4	6.1	1.7	-0.1	0.0	0.0	0.0	0.0	67
14	ARIZONA	AZ	60.0	4.1	6.4	2.2	56	4.1	6.5	10.6	10.6	41	14.7	1.2	10.4	3.3	0.3	0.0	0.1	0.0	0.0	0.0	56
50	B.C.HYDRO	BC	60.0	8.4	11.1	2.8	118	8.4	10.9	0.8	0.8	107	9.1	0.0	8.7	2.3	0.0	0.0	0.0	0.0	0.0	0.0	118
11	EL PASO	EL	60.0	0.2	0.3	0.1	3	0.2	0.4	0.4	0.4	7	0.6	0.1	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	3
60	IDAHO	ID	60.0	1.4	1.9	0.5	29	1.4	1.8	2.7	2.7	36	4.1	0.2	3.2	0.6	0.4	-0.1	0.0	0.0	0.0	0.0	29
21	IMPERIALCA	IV	60.0	0.2	0.3	0.1	2	0.2	0.3	1.0	1.0	35	1.2	0.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	2
26	LADWP	LA	60.0	1.5	1.8	0.3	9	1.5	1.9	1.0	1.0	2	2.5	0.2	4.6	0.9	0.2	-0.1	0.0	0.0	0.0	0.0	9
20	MEXICO-CFE	MX	60.0	0.4	0.7	0.3	7	0.4	0.8	0.3	0.3	2	0.7	0.0	1.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	7
62	MONTANA	MT	60.0	0.3	0.6	0.3	28	0.3	0.6	2.5	2.5	17	2.8	0.4	1.5	0.5	0.4	-0.1	0.0	0.0	0.0	0.0	28
18	NEVADA	NV	60.0	1.0	1.4	0.4	7	1.0	1.8	0.5	0.5	3	1.5	0.1	2.5	0.6	0.0	0.0	0.1	0.0	0.0	0.0	7
10	NEW MEXICO	NM	60.0	0.8	1.4	0.5	6	0.8	1.6	0.3	0.3	2	1.1	0.2	1.7	0.4	1.1	0.0	0.0	0.0	0.0	0.0	6
40	NORTHWEST	NW	60.0	12.4	17.3	4.9	202	12.5	16.1	2.1	2.1	62	14.6	0.8	19.0	4.2	8.4	-0.7	0.0	0.0	0.0	0.0	202
65	PACE	PC	60.0	0.8	1.2	0.4	27	0.8	1.4	2.8	2.8	24	3.7	0.3	5.1	1.9	1.4	0.0	0.0	0.0	0.0	0.0	27
30	PG AND E	PG	60.0	3.4	6.7	3.2	124	3.5	7.0	7.3	7.3	193	10.8	-0.7	12.6	3.6	0.8	0.0	1.9	0.0	0.0	0.0	124
70	PSCOLORADO	CO	60.0	1.5	1.7	0.2	9	1.5	2.1	1.6	1.6	4	3.1	0.5	5.2	1.3	1.8	0.1	0.0	0.0	0.0	0.0	9
22	SANDIEGO	SD	60.0	0.1	0.2	0.1	1	0.1	0.2	0.2	0.2	16	0.3	0.0	2.7	0.6	0.3	0.0	0.5	0.1	0.0	0.0	1
64	SIERRA	SP	60.0	0.4	0.5	0.1	6	0.4	0.6	1.3	1.3	50	1.7	0.0	1.4	0.3	0.3	-0.1	0.0	0.0	0.0	0.0	6
24	SOCALIF	SC	60.0	1.2	2.8	1.6	33	1.2	2.9	4.9	5.0	49	6.1	-0.2	12.5	2.7	3.2	-0.3	1.3	-0.3	0.9	0.0	33
52	FORTISBC	FB	60.0	0.6	0.8	0.2	18	0.6	0.8	0.4	0.4	8	1.0	0.2	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	18
73	WAPA R.M.	WR	60.0	2.7	3.8	1.1	47	2.7	4.2	1.2	1.2	15	3.8	0.1	3.5	1.2	0.7	0.2	0.0	0.0	0.0	0.0	47
63	WAPA U.M.	WU	60.0	0.1	0.1	0.0	1	0.1	0.1	0.0	0.0	1	0.1	0.0	-0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1

To be counted as a Governor Response (GR) unit, a unit must have:

- Governor model
- Baseload flag is off
- Headroom not zero

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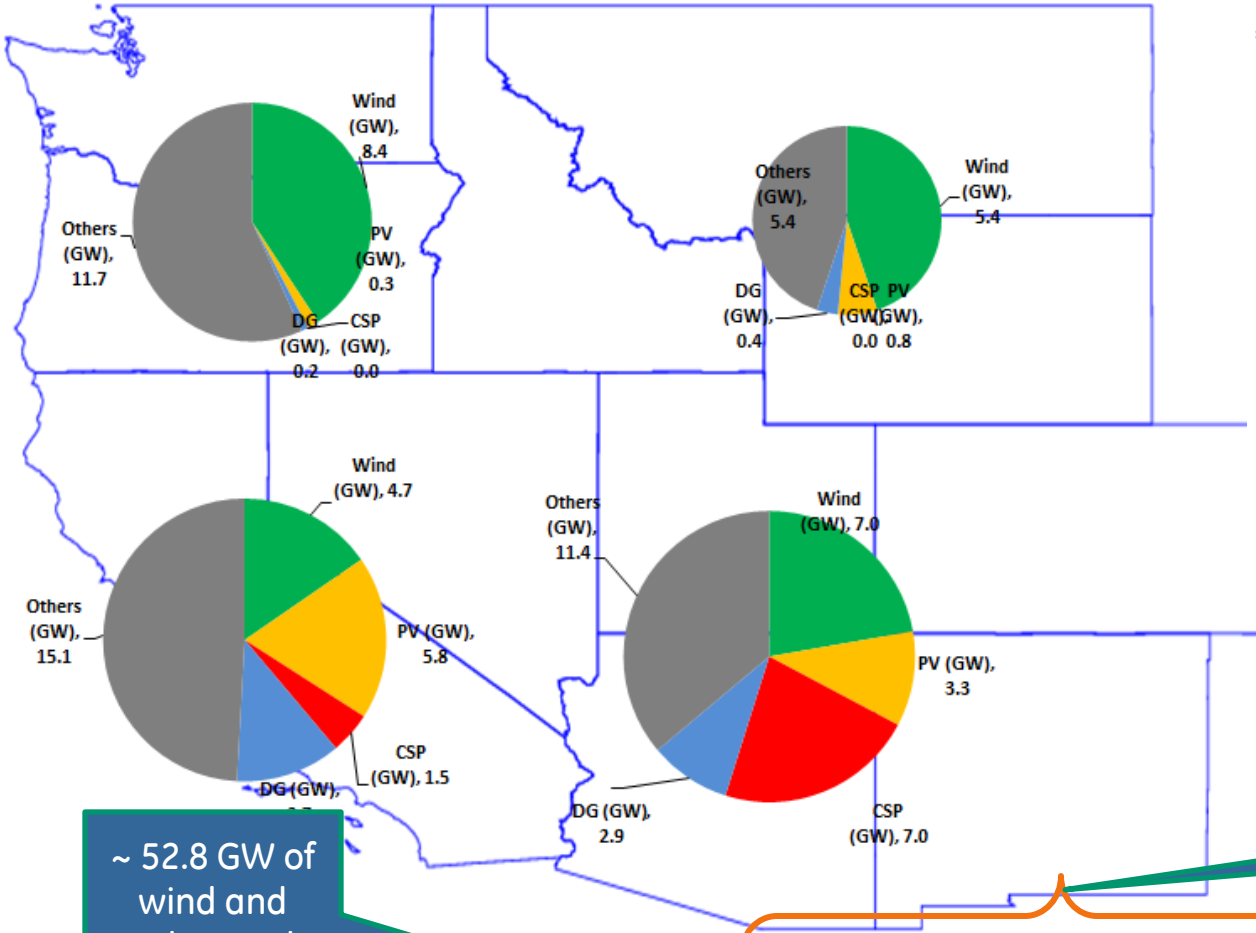
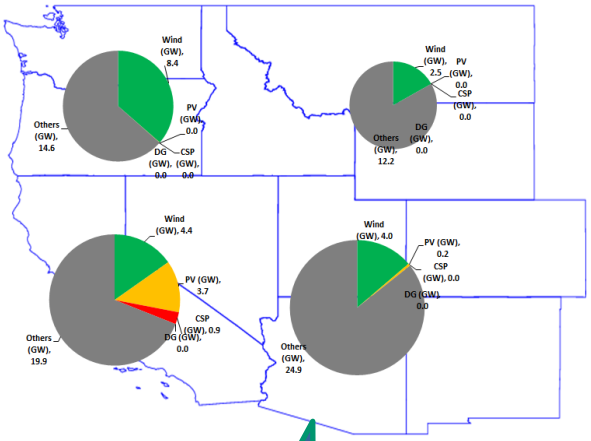
22'LSP Base Case to 22'LSP HiMix Case

2022 LSP HiMix Case – Renewable Conditions





~ 25 GW of wind and solar total in Base Case

US only

~ 52.8 GW of wind and solar total

	WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Wind (GW)	27.2	4.7	7.0	5.4	8.4
PV (GW)	10.2	5.8	3.3	0.8	0.3
CSP (GW)	8.4	1.5	7.0	0.0	0.0
DG (GW)	7.0	3.7	2.9	0.4	0.2
Others (GW)	65.7	15.1	11.4	5.4	11.7
total (GW)	118.6	30.8	31.6	12.0	20.5

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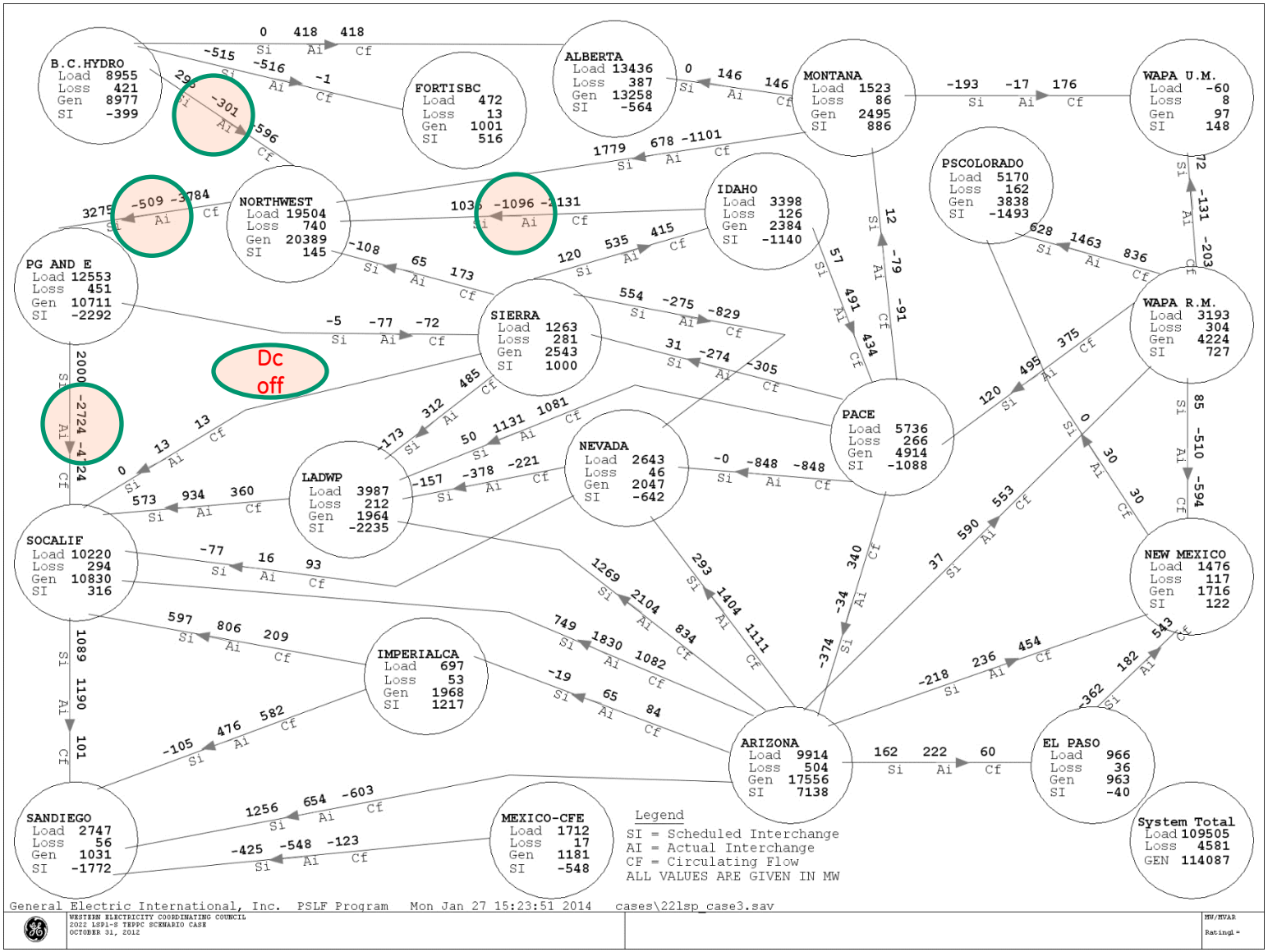
Preliminary Results: Not for Further Distribution or Citation

2022 LSP HiMix Case – PSLF Bubble Diagram



imagination at work

Mining Plexos Case – Renewable Summary

Renewables summary for sample 31775

Fraction of PV that is distributed generation (DG)

Means "utility scale" PV

TEPCC (WWSIS II) @ 31775

Area #	CSP	WWSIS PV	WWSIS_wind
54			
14	515	1017	3261
50			
11	0	0	2
60		0	127
21	0	143	364
26	849	1123	0
20			
62	0	0	147
18	16	16	0
10	167	302	31
40	0	0	3960
65	0	0	1065
30	0	0	14
70	186	497	299
22	0	0	0
64	0	38	74
24	1098	2722	3421
52			
73	0	521	655
63		0	0
-1	34		
Total	2865	6379	13418

HiMix @ 31775

Area #	CSP	WWSIS PV	DG ratio	DG	PV	WWSIS_wind
54						
14	6375	3532	0.42	1471	2061	560
50						
11	143	428	0.47	202	227	2
60		0			0	150
21	124	309	0.10	32	277	337
26	493	1267	0.68	864	403	0
20						
62	0	5	0.44	2	3	1593
18	113	542	0.31	166	376	0
10	162	550	0.40	217	333	27
40	0	538	0.38	204	334	4551
65	0	326	0.73	239	87	2772
30	0	1274	0.46	584	690	30
70	178	962	0.37	355	608	594
22	0	205	0.57	116	89	0
64	0	936	0.22	208	728	661
24	1378	5238	0.44	2287	2951	2746
52						
73	0	792	0.46	364	428	3346
63		0	0.00	0	0	27
-1	644					
Total	9610	16905		7312	9592	17395

Difference

Area #	CSP	WWSIS PV	DG	PV	Wind
54					
14	5860	2515	1471	1044	-2701
50					
11	143	428	202	227	0
60	0	0	0	0	23
21	124	166	32	134	-26
26	-356	144	864	-720	0
20					
62	0	5	2	3	1446
18	97	526	166	360	0
10	-5	248	217	31	-4
40	0	538	204	334	591
65	0	326	239	87	1707
30	0	1274	584	690	16
70	-8	465	355	110	295
22	0	205	116	89	0
64	0	898	208	690	587
24	280	2516	2287	229	-676
52					
73	0	271	364	-93	2691
63	0	0	0	0	27
-1	609				
Total	6746	10526	7312	3214	3977

Remember these are from the Plexos case, NOT the WECC LSP base case

2022LSP Add Renewables – Capacity (nameplate rating)

2022LSP Base

Capacity of existing renewables from base case not changed. so Yellow is the MAX of green and blue

2022LSP HiMix

	2022 LSP				WWSIS2-HiMix				2022 LSP HiMix			
Area #	CSP	DG	PV	Wind	CSP	DG	PV	Wind	CSP	DG	PV	Wind
54	0	0	0	2707	0	0	0	0	0		0	2707
14	0	0	971	175	7654	3655	5120	1440	6879		4923	1435
50	0	0	0	108	0	0	0	0	0		0	108
11	0	62	0	0	142	305	343	50	142		343	50
60	0	0	0	643	0	0	0	569	0		0	643
21	0	0	0	0	188	71	611	917	188		611	917
26	0	0	0	576	1043	1961	913	0	1043		913	576
20	0	0	0	0	0	15	0	294	0		0	0
62	0	0	0	707	0	21	27	3988	0		11	3975
18	0	0	64	0	229	285	642	0	229		556	0
10	0	0	100	1726	156	758	1160	3084	156		1260	3108
40	0	0	59	8680	0	500	817	11642	0		869	11655
65	0	0	0	2384	0	1126	409	4082	0		390	4111
30	0	0	3232	2399	0	1474	1740	1799	0		3232	2399
70	0	0	79	2134	169	547	937	1720	169		1016	2134
22	0	64	516	712	0	357	275	0	0		516	712
64	0	0	0	432	0	432	1511	821	0		1504	777
24	1436	0	2139	4497	2813	4741	6118	3149	2814		5913	4497
52	0	0	0	0	0	0	0	0	0		0	0
73	0	0	4	739	0	594	696	8149	0		690	8136
63	0	0	0	0	0	0	1	60	0		0	60
Total	1436	127	7164	28616	12393	16842	21322	41762	11618		22747	47999

This is WECC LSP base case

This is from the Plexos Hi-Mix cases

This is where we drove the LSP'22 Hi-Mix cases

2022LSP Add Renewables – Total Dispatch

(MW instantaneous production)

2022LSP Base Case

Dispatch of existing renewables from base case not changed. so Yellow is the MAX of green and blue

Target for 2022LSP HiMix Case

	2022LSP Base Case				WWSIS2-HiMix				2022LSP HiMix Case			
Area #	**CSP**	**DG**	**PV**	**Wind**	**CSP**	**DG**	**PV**	**Wind**	**CSP**	**DG**	**PV**	**Wind**
54	0	0	0	1665	0	0	0	0	0	0	0	1665
14	0	0	667	126	6375	1471	2061	560	6375	1471	2061	560
50	0	0	0	6	0	0	0	0	0	0	0	6
11	0	62	0	0	143	202	227	2	143	202	227	2
60	0	0	0	485	0	0	0	150	0	0	0	485
21	0	0	0	0	124	32	277	337	124	32	277	337
26	0	0	0	190	493	864	403	0	493	864	403	190
20	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	390	0	2	3	1593	0	2	3	1593
18	0	0	60	0	113	166	376	0	113	166	376	0
10	0	0	70	1078	162	217	333	27	162	217	333	1078
40	0	0	34	8341	0	204	334	4551	0	204	334	8341
65	0	0	0	1408	0	239	87	2772	0	239	87	2772
30	0	0	1928	733	0	584	690	30	0	584	1928	733
70	0	0	24	1822	178	355	608	594	178	355	608	1822
22	0	64	464	272	0	116	89	0	0	116	464	272
64	0	0	0	280	0	208	728	661	0	208	728	661
24	1451	0	1538	2937	1378	2287	2951	2746	1451	2287	2951	2937
52	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	3	736	0	364	428	3346	0	364	428	3346
63	0	0	0	0	0	0	0	27	0	0	0	27
Total	1451	127	4787	20469	8966	7311	9595	17396	9039	7311	11208	26827

This is WECC LSP base case

This is from the Plexos Hi-Mix cases

This is where we drove the LSP'22 Hi-Mix cases

2022LSP Add Renewables – Dispatch Delta

Delta Renewable Generation Only

CSP	DG	PV	Wind
0	0	0	0
6375	1471	1394	434
0	0	0	0
143	140	227	2
0	0	0	0
124	32	277	337
493	864	403	0
0	0	0	0
0	2	3	1203
113	166	316	0
162	217	263	0
0	204	300	0
0	239	87	1364
0	584	0	0
178	355	584	0
0	52	0	0
0	208	728	381
0	2287	1413	0
0	0	0	0
0	364	425	2610
0	0	0	27
7588	7184	6420	6358

Delta Renewable Capacity Only

CSP	DG	PV	Wind
0		0	0
6879		3952	1260
0		0	0
142		343	50
0		0	0
188		611	917
1043		913	0
0		0	0
0		11	3268
229		492	0
156		1160	1383
0		810	2975
0		390	1728
0		0	0
169		937	0
0		0	0
0		1504	345
1378		3774	0
0		0	0
0		686	7398
0		0	60
10182		15583	19383

Target Capacity Factor of Added Renewable

CSP	DG	PV	Wind
0%		0%	0%
93%		35%	34%
0%		0%	0%
101%		66%	4%
0%		0%	0%
66%		45%	37%
47%		44%	0%
0%		0%	0%
0%		27%	37%
49%		64%	0%
104%		23%	0%
0%		37%	0%
0%		22%	79%
0%		0%	0%
105%		62%	0%
0%		0%	0%
0%		48%	110%
0%		37%	0%
0%		0%	0%
0%		62%	35%
0%		0%	45%
75%		41%	33%

Trying to ADD ~20 GW more wind and solar (DG not included) to the LSP'22 case

Area 64 wind dispatch only to 100%.

Dispatch of existing renewables from Base Case not changed. Largely meet the targets respecting capacity.

TRC Call: Do not Cite - Not for Further Distribution

2022LSP HiMix Case – Initial Condition Metrics

		WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Pgen of synchronous generators with GR (GW)	pg	34.4	5.4	5.4	2.7	9.5
Capacity of synchronous generators with GR (GW)	mc	56.3	10.7	8.7	3.8	17.2
Headroom on synchronous generators with GR (GW)	**hr**	**21.9**	**5.3**	**3.3**	**1.1**	**7.7**
Number of synchronous generators with GR (GW)	**nu**	**768**	**167**	**103**	**88**	**200**
Mechanical power of synchronous generators with GR (GW)	pm	34.4	5.4	5.5	2.7	9.5
MVA rating of synchronous generators with GR (GW)	mv	56.7	11.4	9.5	4.1	16.0
Pgen of synchronous generators w/o GR (GW)	px	39.8	11.2	12.9	2.7	2.1
Mechanical synchronous generators w/o GR (GW)	mx	40.3	11.3	13.3	2.7	2.1
Number of synchronous generators w/o GR (GW)	nx	740	284	93	106	62
Pgen of all synchronous generators (GW)	pq	74.2	16.6	18.4	5.4	11.7
Qgen of all synchronous generators (GVAr)	qg	3.6	-0.2	2.7	0.6	-1.2
P load (GW)	pl	109.5	32.0	25.0	11.3	19.1
Q load (GVAr)	ql	29.7	7.6	5.8	3.2	4.3
Pgen – Wind (GW)	**pw**	**27.2**	**4.7**	**7.0**	**5.4**	**8.4**
Qgen – Wind (GVAR)	qw	-2.0	-0.1	0.3	-0.6	-1.3
Pgen – Solar PV	**pv**	**10.2**	**5.8**	**3.3**	**0.8**	**0.3**
Qgen – Solar PV	qv	-1.3	-0.3	-0.9	0.1	-0.2
Pgen - CSP (GW)	**pc**	**8.4**	**1.5**	**7.0**	**0.0**	**0.0**
Pgen - DG (solar PV)	**dg**	**7.0**	**3.7**	**2.9**	**0.4**	**0.2**
Kt	Kt	0.42	0.33	0.27	0.30	0.61

Kt was 0.46 in the base case.

Kt was 0.26 in the base case: committed GR units come out of limits

DG was not included in the Kt calculation.

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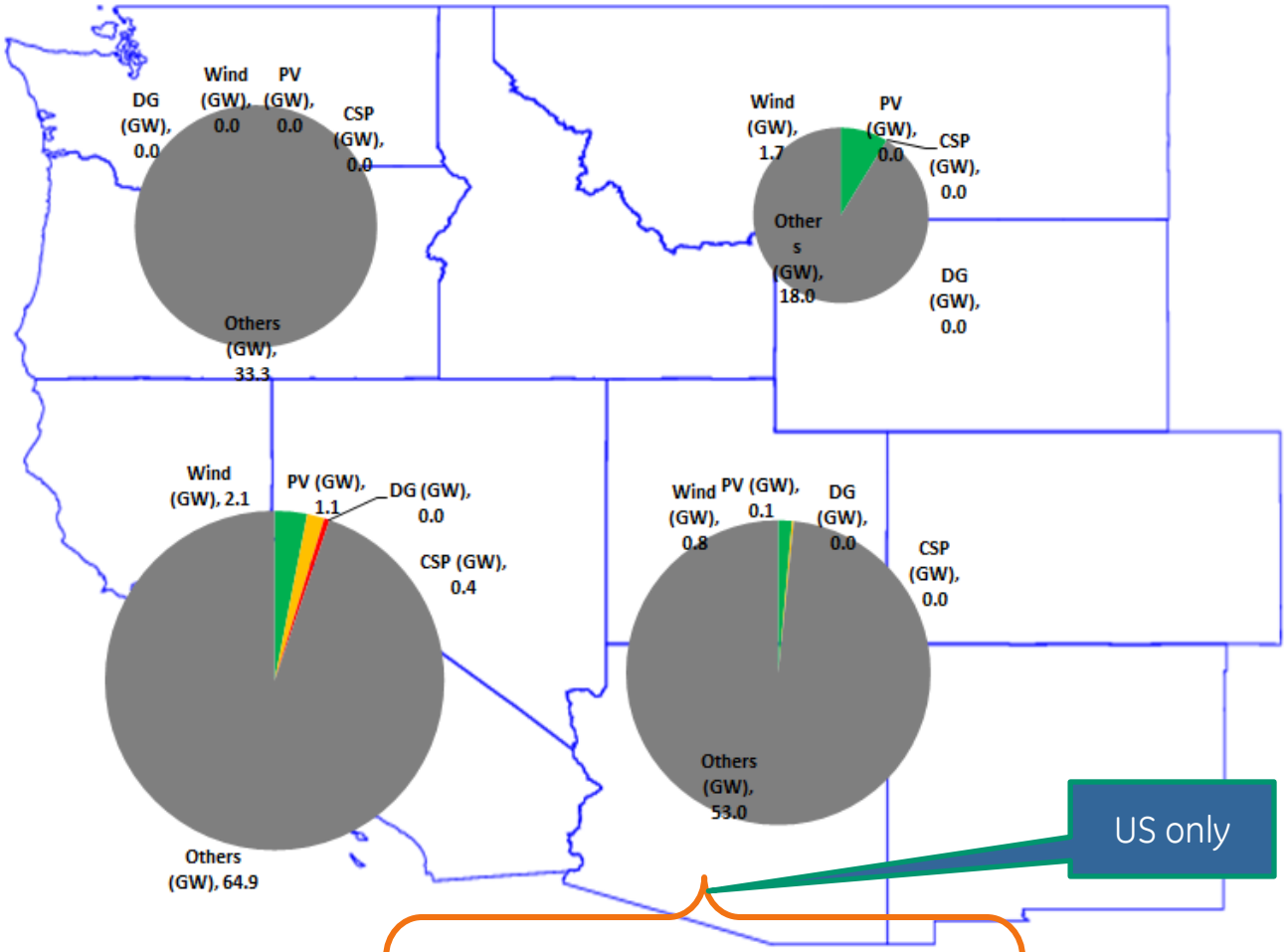
2022LSP HiMix Case – Initial Condition Metrics

	Name	ID	freq	Pgen_gov	mwcap	headroom	num_gov	mnech_gov	mva_gov	pgen_nogov	mva_nogen	num_nogov	pgs_tot	qgq_tot	pload	qload	pg_wind	qg_wind	pg_pv	qg_pvv	pg_csp	pg_dg	num_hrm
1	WECC	WE	60.0	34.4	56.3	21.9	768	34.4	56.7	39.8	40.3	740	74.2	3.6	109.5	29.7	27.2	-2.0	10.2	-1.3	8.4	7.0	768
2	CALIFORNIA	CA	60.0	5.4	10.7	5.3	167	5.4	11.4	11.2	11.3	284	16.6	-0.2	32.0	7.6	4.7	-0.1	5.8	-0.3	1.5	3.7	167
3	DSW	DS	60.0	5.4	8.7	3.3	103	5.5	9.5	12.9	13.3	93	18.4	2.7	25.0	5.8	7.0	0.3	3.3	-0.9	7.0	2.9	103
4	NORTHEAST	NE	60.0	2.7	3.8	1.1	88	2.7	4.1	2.7	2.7	106	5.4	0.6	11.3	3.2	5.4	-0.6	0.8	0.1	0.0	0.4	88
54	ALBERTA	AL	60.0	2.0	3.3	1.4	67	2.0	3.5	9.6	9.6	78	11.6	1.7	13.4	6.1	1.7	-0.3	0.0	0.0	0.0	0.0	67
14	ARIZONA	AZ	60.0	3.3	5.4	2.1	51	3.3	5.3	11.2	11.5	70	14.5	1.9	10.1	2.9	0.8	-0.1	1.4	-0.5	6.4	1.4	51
50	B.C.HYDRO	BC	60.0	8.4	11.1	2.8	118	8.4	10.9	0.5	0.5	106	8.9	-0.3	8.6	2.3	0.0	0.0	0.0	0.0	0.0	0.0	118
11	EL PASO	EL	60.0	0.2	0.3	0.1	3	0.2	0.4	0.4	0.5	6	0.7	0.0	1.1	0.2	0.0	0.0	0.2	-0.1	0.1	0.2	3
60	IDAHO	ID	60.0	1.4	1.9	0.5	29	1.4	1.8	0.5	0.5	31	1.9	0.2	3.2	0.6	0.4	-0.1	0.0	0.0	0.0	0.0	29
21	IMPERIALCA	IV	60.0	0.2	0.3	0.1	2	0.2	0.3	1.1	1.1	36	1.3	0.0	0.6	0.2	0.3	0.0	0.3	0.0	0.1	0.0	2
26	LADWP	LA	60.0	0.5	0.8	0.3	8	0.5	0.9	0.6	0.6	12	1.1	0.1	4.2	0.5	0.2	-0.1	0.4	-0.1	0.5	0.8	8
20	MEXICO-CFE	MX	60.0	0.3	0.5	0.2	6	0.3	0.5	0.3	0.3	2	0.6	0.1	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	6
62	MONTANA	MT	60.0	0.3	0.6	0.3	28	0.3	0.6	0.4	0.4	13	0.7	0.0	1.3	0.5	1.6	-0.4	0.0	0.0	0.0	0.0	28
18	NEVADA	NV	60.0	0.8	1.0	0.3	6	0.8	1.5	0.6	0.6	5	1.4	0.3	2.4	0.4	0.0	0.0	0.4	-0.1	0.1	0.2	6
10	NEW MEXICO	NM	60.0	0.0	0.0	0.0	3	0.0	0.0	0.2	0.2	1	0.2	0.0	1.5	-0.2	1.1	0.1	0.3	-0.2	0.2	0.2	3
40	NORTHWEST	NW	60.0	9.5	17.2	7.7	200	9.5	16.0	2.1	2.1	62	11.7	-1.2	19.1	4.3	8.4	-1.3	0.3	-0.2	0.0	0.2	200
65	PACE	PC	60.0	0.7	0.9	0.2	25	0.7	1.1	1.0	1.0	14	1.6	0.1	5.4	1.8	2.8	-0.3	0.1	0.0	0.0	0.2	25
30	PG AND E	PG	60.0	3.4	6.6	3.2	123	3.4	7.0	5.2	5.2	167	8.6	-0.5	12.0	3.7	0.8	0.0	1.9	0.0	0.0	0.6	123
70	PSCOLORADO	CO	60.0	0.9	1.0	0.1	4	0.9	1.2	0.5	0.5	3	1.4	0.4	5.3	1.3	1.8	0.3	0.6	-0.1	0.2	0.3	4
22	SANDIEGO	SD	60.0	0.1	0.2	0.1	1	0.1	0.2	0.1	0.1	12	0.2	0.0	2.7	0.6	0.3	0.0	0.5	0.1	0.0	0.1	1
64	SIERRA	SP	60.0	0.4	0.5	0.1	6	0.4	0.6	0.8	0.8	48	1.2	0.3	1.4	0.3	0.6	0.1	0.7	0.2	0.0	0.2	6
24	SOCALIF	SC	60.0	1.2	2.8	1.6	33	1.2	2.9	4.3	4.4	57	5.5	0.2	12.5	2.6	3.2	0.0	2.7	-0.2	0.9	2.2	33
52	FORTISBC	FB	60.0	0.6	0.8	0.2	18	0.6	0.8	0.4	0.4	8	1.0	0.2	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	18
73	WAPA R.M.	WR	60.0	0.2	0.9	0.7	36	0.2	1.1	0.1	0.1	8	0.3	0.1	3.3	0.8	3.3	0.1	0.4	0.0	0.0	0.3	36
63	WAPA U.M.	WU	60.0	0.1	0.1	0.0	1	0.1	0.1	0.0	0.0	1	0.1	0.0	-0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1

23'HS Base Case

2023HS Base Case - Renewable Conditions



US only

~ 7.2 GW of wind and solar

	WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Wind (GW)	5.6	2.1	0.8	1.7	0.0
(GW)	1.2	1.1	0.1	0.0	0.0
CSP (GW)	0.4	0.4	0.0	0.0	0.0
DG (GW)	0.0	0.0	0.0	0.0	0.0
Others (GW)	196.2	64.9	53.0	18.0	33.3
total (GW)	203.4	68.5	53.9	19.7	33.3

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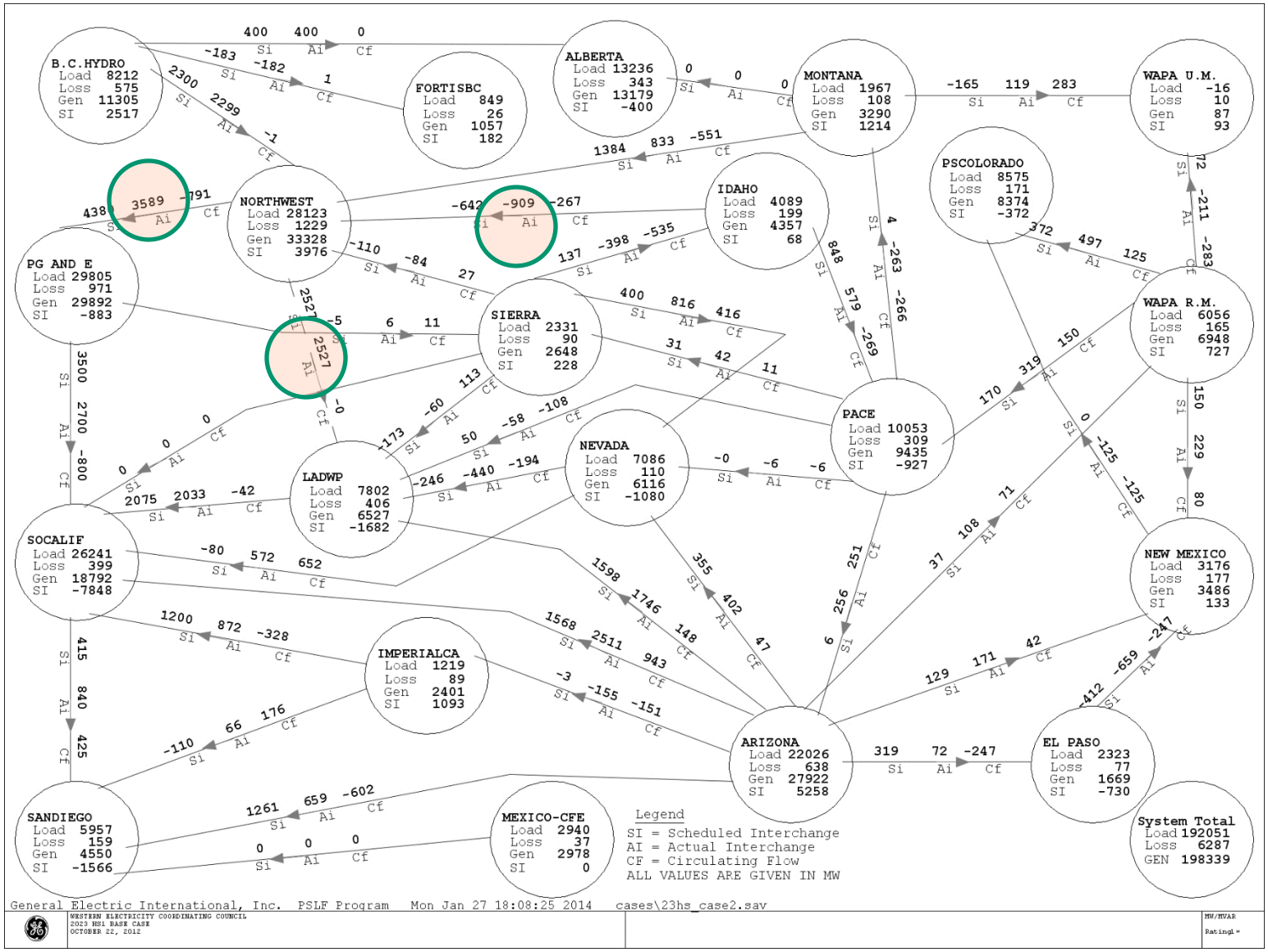
Preliminary Results: Not for Further Distribution or Citation

2023HS Base Case – PSLF Bubble Diagram



2023HS Base Case – Initial Condition Metrics

pg is 43.5 GW and nu is 800 in 2022LSP base case.

		WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Pgen of synchronous generators with GR (GW)	pg	84.8	26.5	17.0	3.2	24.4
Capacity of synchronous generators with GR (GW)	mc	109.1	32.3	21.4	4.1	32.6
Headroom on synchronous generators with GR (GW)	**hr**	**24.1**	**5.7**	**4.4**	**0.9**	**8.1**
Number of synchronous generators with GR (GW)	**nu**	**1135**	**295**	**242**	**89**	**301**
Mechanical power of synchronous generators with GR (GW)	pm	85.0	26.5	17.0	3.2	24.4
MVA rating of synchronous generators with GR (GW)	mv	112.3	34.8	24.4	4.5	29.8
Pgen of synchronous generators w/o GR (GW)	px	111.7	38.8	36.0	14.7	8.9
Mechanical synchronous generators w/o GR (GW)	mx	111.9	38.8	36.1	14.8	8.9
Number of synchronous generators w/o GR (GW)	nx	1251	509	236	145	129
Pgen of all synchronous generators (GW)	pq	196.5	65.2	53.0	18.0	33.3
Qgen of all synchronous generators (GVAr)	qg	22.6	8.8	7.9	1.9	2.3
P load (GW)	pl	184.6	67.9	47.8	18.0	27.2
Q load (GVAr)	ql	59.2	20.8	15.0	5.8	8.6
Pgen – Wind (GW)	**pw**	**5.6**	**2.1**	**0.8**	**1.7**	**0.0**
Qgen – Wind (GVAR)	qw	-0.6	-0.1	-0.2	-0.2	0.0
Pgen – Solar PV	**pv**	**1.2**	**1.1**	**0.1**	**0.0**	**0.0**
Qgen – Solar PV	qv	0.1	0.1	0.0	0.0	0.0
Pgen - CSP (GW)	**pc**	**0.4**	**0.4**	**0.0**	**0.0**	**0.0**
Pgen - DG (solar PV)	**dg**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Kt	Kt	0.48	0.43	0.37	0.20	0.78

Kt is low!

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2023HS Base Case – Initial Condition Metrics

	Name	ID	freq	Pgen_gov	mwcap	headroom	num_gov	mnech_gov	mva_gov	pgen_nogov	mva_nogen	num_nogov	pgs_tot	qgq_tot	pload	qload	pg_wind	qg_wind	pg_pv	qg_pvv	pg_csp	pg_dg	num_hrm
1	WECC	WE	60.0	84.8	109.1	24.1	1135	85.0	112.3	111.7	111.9	1251	196.5	22.6	184.6	59.2	5.6	-0.6	1.2	0.1	0.4	0.0	1135
2	CALIFORNIA	CA	60.0	26.5	32.3	5.7	295	26.5	34.8	38.8	38.8	509	65.2	8.8	67.9	20.8	2.1	-0.1	1.1	0.1	0.4	0.0	295
3	DSW	DS	60.0	17.0	21.4	4.4	242	17.0	24.4	36.0	36.1	236	53.0	7.9	47.8	15.0	0.8	-0.2	0.1	0.0	0.0	0.0	242
4	NORTHEAST	NE	60.0	3.2	4.1	0.9	89	3.2	4.5	14.7	14.8	145	18.0	1.9	18.0	5.8	1.7	-0.2	0.0	0.0	0.0	0.0	89
54	ALBERTA	AL	60.0	1.1	1.9	0.9	51	1.1	2.0	10.9	10.9	85	12.0	1.3	12.9	5.7	0.9	-0.1	0.0	0.0	0.0	0.0	51
14	ARIZONA	AZ	60.0	5.7	7.6	1.9	73	5.7	7.9	21.6	21.6	118	27.2	4.1	20.8	6.6	0.2	0.0	0.0	0.0	0.0	0.0	73
50	B.C.HYDRO	BC	60.0	10.5	13.9	3.3	127	10.6	13.7	0.7	0.7	124	11.2	-0.1	8.2	2.7	0.1	0.0	0.0	0.0	0.0	0.0	127
11	EL PASO	EL	60.0	1.1	1.3	0.2	14	1.1	1.8	0.5	0.5	4	1.6	0.2	2.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	14
60	IDAHO	ID	60.0	1.2	1.6	0.4	28	1.2	1.6	3.0	3.0	29	4.2	0.3	3.9	1.3	0.1	0.0	0.0	0.0	0.0	0.0	28
21	IMPERIALCA	IV	60.0	0.4	0.6	0.2	9	0.4	0.7	1.1	1.1	34	1.5	0.1	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9
26	LADWP	LA	60.0	3.8	4.6	0.8	25	3.8	5.1	2.3	2.3	14	6.1	1.2	7.2	2.4	0.2	0.0	0.0	0.0	0.0	0.0	25
20	MEXICO-CFE	MX	60.0	1.5	2.0	0.5	11	1.5	2.2	1.2	1.2	14	2.7	0.3	2.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	11
62	MONTANA	MT	60.0	0.5	0.7	0.3	30	0.5	0.8	2.7	2.7	18	3.2	0.6	1.9	0.6	0.1	0.0	0.0	0.0	0.0	0.0	30
18	NEVADA	NV	60.0	1.4	1.8	0.4	14	1.4	2.3	4.7	4.7	52	6.1	1.6	6.8	2.1	0.0	0.0	0.1	0.0	0.0	0.0	14
10	NEW MEXICO	NM	60.0	1.5	1.6	0.1	9	1.5	1.8	2.0	2.0	14	3.5	0.3	3.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	9
40	NORTHWEST	NW	60.0	24.4	32.6	8.1	301	24.4	29.8	8.9	8.9	129	33.3	2.3	27.2	8.6	0.0	0.0	0.0	0.0	0.0	0.0	301
65	PACE	PC	60.0	0.9	1.1	0.2	23	0.9	1.3	7.4	7.4	51	8.3	0.8	9.9	3.3	1.2	0.0	0.0	0.0	0.0	0.0	23
30	PG AND E	PG	60.0	13.1	16.2	3.1	169	13.2	17.2	17.8	17.8	322	30.9	2.9	29.0	9.7	0.8	-0.1	0.7	0.1	0.0	0.0	169
70	PSCOLORADO	CO	60.0	3.7	4.9	1.2	75	3.7	5.7	4.0	4.0	21	7.8	1.1	8.1	2.8	0.4	-0.2	0.1	0.0	0.0	0.0	75
22	SANDIEGO	SD	60.0	2.1	2.5	0.4	31	2.1	2.9	1.5	1.5	24	3.6	0.3	5.5	1.5	0.3	0.0	0.4	0.0	0.0	0.0	31
64	SIERRA	SP	60.0	0.6	0.7	0.0	8	0.6	0.8	1.7	1.7	47	2.3	0.1	2.3	0.6	0.3	-0.1	0.0	0.0	0.0	0.0	8
24	SOCALIF	SC	60.0	7.0	8.3	1.3	61	7.0	8.9	16.0	16.0	115	23.0	4.2	25.9	7.0	0.8	0.0	0.0	0.0	0.4	0.0	61
52	FORTISBC	FB	60.0	0.6	0.8	0.2	17	0.6	0.8	0.5	0.5	9	1.1	0.2	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	17
73	WAPA R.M.	WR	60.0	3.6	4.2	0.6	57	3.6	4.9	3.2	3.2	27	6.8	0.5	5.8	2.1	0.0	0.0	0.0	0.0	0.0	0.0	57
63	WAPA U.M.	WU	60.0	0.1	0.1	0.0	2	0.1	0.1	0.0	0.0	0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2

23'HS Base Case to 23'HS HiMix Case

2023HS Add Renewables – Capacity (nameplate rating)

Capacity of existing renewables from base case not changed. so Yellow is the MAX of green and blue

2023HS Base Case

2023HS HiMix Case

	2023HS Base				WWSIS2-HiMix				2023HS HiMix			
Area #	CSP	DG	PV	Wind	CSP	DG	PV	Wind	CSP	DG	PV	Wind
54	0		0	1061	0		0	0	0		0	1061
14	0		700	227	7654		5120	1440	7654		5202	1457
50	0		0	237	0		0	0	0		0	237
11	0		47	0	142		343	50	142		350	50
60	0		0	407	0		0	569	0		0	564
21	0		0	0	188		611	917	188		611	917
26	270		0	574	851		913	0	837		913	574
20	0		0	0	0		0	294	0		0	294
62	0		0	364	0		27	3988	0		27	3989
18	0		64	0	229		642	0	229		656	0
10	0		27	396	156		1160	3084	156		1157	3120
40	0		0	0	0		1607	11642	0		1607	11642
65	0		0	2309	0		409	4082	0		409	4032
30	0		2570	1033	0		1740	1799	0		2570	1758
70	0		79	2134	169		937	1830	169		960	2134
22	0		516	1562	0		275	0	0		516	1562
64	0		0	352	0		1511	821	0		1511	802
24	822		49	887	2813		6118	3149	2825		6100	3147
52	0		0	0	0		0	0	0		0	0
73	0		0	139	0		696	8149	0		696	8137
63	0		0	0	0		1	60	0		0	60
Total	1092		4052	11680	12201		22112	41871	12199		23286	45535

2023HS Add Renewables – Total Dispatch

(MW instantaneous production)

2023HS Base Case

Dispatch of existing renewables from base case not changed..so Yellow is the MAX of green and blue

Target for 2023HS HiMix Case

	2023HS Base Case				WWSIS2-HiMix				2023HS HiMix Case			
Area #	CSP	DG	PV	Wind	CSP	DG	PV	Wind	CSP	DG	PV	Wind
54	0		0	869	0		0	0	0		0	869
14	0		210	227	3182		2689	111	3182		2689	227
50	0		0	101	0		0	0	0		0	101
11	0		47	0	0		190	21	0		190	21
60	0		0	142	0		0	167	0		0	167
21	0		0	0	187		387	27	187		387	27
26	270		0	325	1147		563	0	1147		563	325
20	0		0	0	0		0	5	0		0	5
62	0		0	108	0		14	762	0		14	762
18	0		61	0	197		321	0	197		321	0
10	0		18	20	0		382	106	0		382	106
40	0		0	0	0		477	6908	0		477	6908
65	0		0	1154	0		223	1448	0		223	1448
30	0		1149	388	0		1177	102	0		1177	388
70	0		52	444	186		522	60	186		522	444
22	0		388	325	0		190	0	0		388	325
64	0		0	320	0		1067	95	0		1067	320
24	770		45	797	3095		3923	73	3095		3923	797
52	0		0	0	0		0	0	0		0	0
73	0		0	31	0		389	873	0		389	873
63	0		0	0	0		1	0	0		1	0
Total	1040		1969	5249	7994		12515	10758	7994		12713	14112

This is WECC HS'23 base case

This is from the Plexos Hi-Mix cases

This is where we tried to drive the HS'23 Hi-Mix cases

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T rther Distribution

2023HS Add Renewables – Dispatch Delta

	Delta Renewable Generation Only				Delta Renewable Capacity Only				Target Capacity Factor of Added Renewable			
Area #	CSP	DG	PV	Wind	CSP	DG	PV	Wind	CSP	DG	PV	Wind
54	0		0	0	0		0	0	0%		0%	0%
14	3182		2479	0	7654		4502	1230	42%		55%	0%
50	0		0	0	0		0	0	0%		0%	0%
11	0		143	21	142		303	50	0%		47%	42%
60	0		0	25	0		0	157	0%		0%	16%
21	187		387	27	188		611	917	100%		63%	3%
26	877		563	0	567		913	0	155%		62%	0%
20	0		0	5	0		0	294	0%		0%	2%
62	0		14	655	0		27	3625	0%		52%	18%
18	197		260	0	229		592	0	86%		44%	0%
10	0		364	86	156		1130	2724	0%		32%	3%
40	0		477	6908	0		1607	11642	0%		30%	59%
65	0		223	294	0		409	1723	0%		54%	17%
30	0		28	0	0		0	725	0%		0%	0%
70	186		470	0	169		881	0	110%		53%	0%
22	0		0	0	0		0	0	0%		0%	0%
64	0		1067	0	0		1511	450	0%		71%	0%
24	2325		3878	0	2003		6051	2260	116%		64%	0%
52	0		0	0	0		0	0	0%		0%	0%
73	0		389	843	0		696	7999	0%		56%	11%
63	0		1	0	0		0	60	0%		0%	0%
Total	6954		10744	8863	11107		19234	33855	63%		56%	26%

Trying to ADD ~27 GW more wind and solar (DG not included) to the HS'23 case.

Area 24 CSP dispatch only to 100%.

Dispatch of existing renewables from HS'23 base case not changed. Largely meet the targets respecting capacity.

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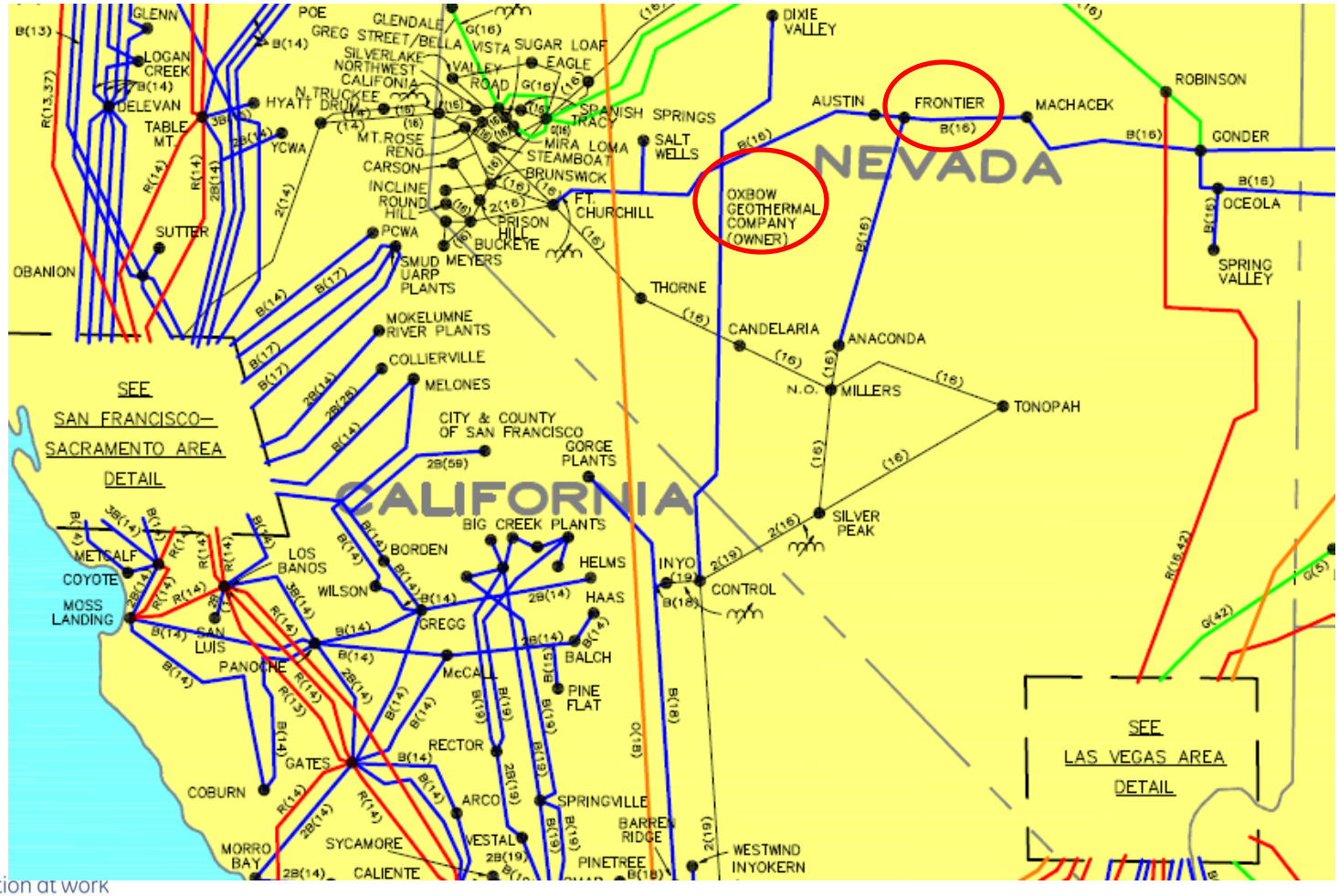
2023HS HiMix Development

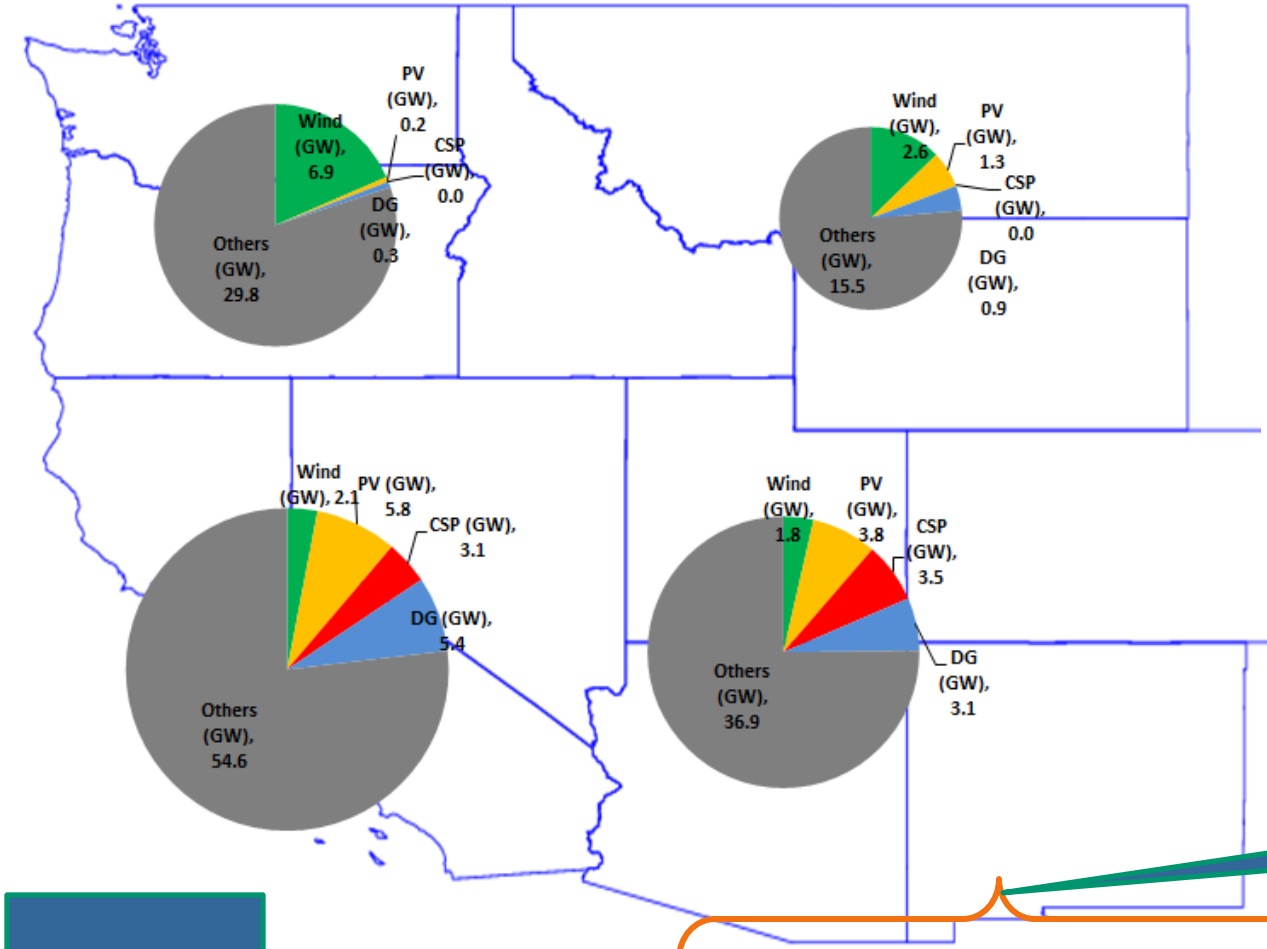
System are stressed when add wind and solar

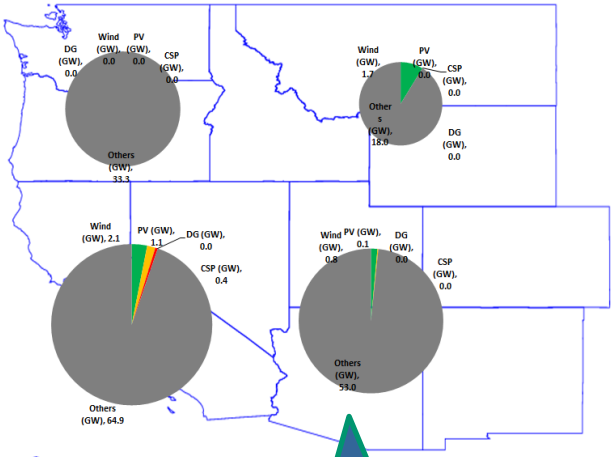
- Add synchronous condenser at FRONTIER
- Remove two PV plant (100 MVA and 108 MVA) near OXBOW



Preliminary Results: Not for Further Distribution or Citation

2023HS HiMix Case - Renewable Conditions





~ 7.2 GW of wind and solar in US in Base Case

US only

~ 41.5 GW of wind and solar

	WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Wind (GW)	14.3	2.1	1.8	2.6	6.9
PV (GW)	11.2	5.8	3.8	1.3	0.2
CSP (GW)	6.6	3.1	3.5	0.0	0.0
DG (GW)	9.4	5.4	3.1	0.9	0.3
Others (GW)	162.7	54.6	36.9	15.5	29.8
total (GW)	204.2	71.0	49.1	20.3	37.2

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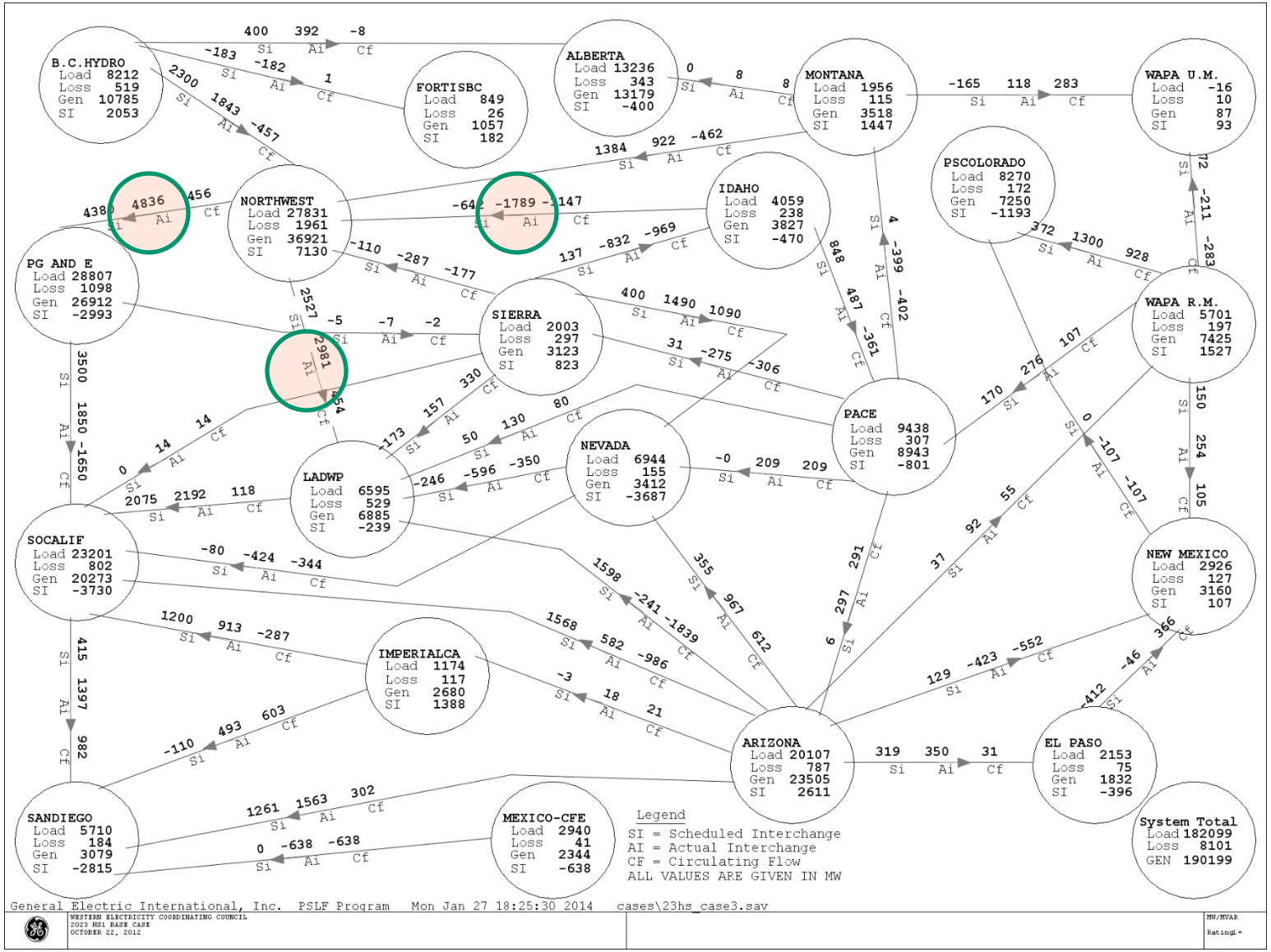
Preliminary Results: Not for Further Distribution or Citation

2023HS HiMix Case – PSLF Bubble Diagram



2023HS HiMix Case – Initial Condition Metrics

		WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Pgen of synchronous generators with GR (GW)	pg	83.6	26.4	18.1	3.0	23.4
Capacity of synchronous generators with GR (GW)	mc	111.2	31.8	26.4	3.9	31.9
Headroom on synchronous generators with GR (GW)	**hr**	**27.2**	**5.1**	**8.2**	**0.9**	**8.4**
Number of synchronous generators with GR (GW)	**nu**	**1152**	**298**	**267**	**87**	**298**
Mechanical power of synchronous generators with GR (GW)	pm	84.0	26.6	18.2	3.0	23.5
MVA rating of synchronous generators with GR (GW)	mv	113.7	33.9	29.2	4.2	29.2
Pgen of synchronous generators w/o GR (GW)	px	85.7	31.2	22.4	12.5	6.3
Mechanical synchronous generators w/o GR (GW)	mx	85.9	31.3	22.4	12.6	6.4
Number of synchronous generators w/o GR (GW)	nx	1094	467	158	143	94
Pgen of all synchronous generators (GW)	pq	169.3	57.7	40.5	15.5	29.8
Qgen of all synchronous generators (GVAr)	qg	29.1	11.9	8.2	2.8	4.4
P load (GW)	pl	186.2	68.8	48.3	18.1	27.4
Q load (GVAr)	ql	60.4	21.4	15.3	5.9	8.7
Pgen – Wind (GW)	**pw**	**14.3**	**2.1**	**1.8**	**2.6**	**6.9**
Qgen – Wind (GVAR)	qw	-2.6	0.3	-0.8	-0.4	-1.6
Pgen – Solar PV	**pv**	**11.2**	**5.8**	**3.8**	**1.3**	**0.2**
Qgen – Solar PV	qv	-0.3	0.4	-0.5	0.0	-0.2
Pgen - CSP (GW)	**pc**	**6.6**	**3.1**	**3.5**	**0.0**	**0.0**
Pgen - DG (solar PV)	**dg**	**9.4**	**5.4**	**3.1**	**0.9**	**0.3**
Kt	Kt	0.50	0.45	0.49	0.19	0.70

Kt was 0.48 in the Base case.

Kt is still low (was 0.20 in base case)

DG was not included in the Kt calculation.

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Preliminary Results: Do not Cite - Not for Further Distribution

2023HS HiMix Case – Initial Condition Metrics

	Name	ID	freq	Pgen_gov	mwcap	headroom	num_gov	mnech_gov	mva_gov	pgen_nogov	mva_nogen	num_nogov	pgs_tot	qgq_tot	pload	qload	pg_wind	qg_wind	pg_pv	qg_pvv	pg_csp	pg_dg	num_hrm
1	WECC	WE	60.0	83.6	111.2	27.2	1152	84.0	113.7	85.7	85.9	1094	169.3	29.1	186.2	60.4	14.3	-2.6	11.2	-0.3	6.6	9.4	1152
2	CALIFORNIA	CA	60.0	26.4	31.8	5.1	298	26.6	33.9	31.2	31.3	467	57.7	11.9	68.8	21.4	2.1	0.3	5.8	0.4	3.1	5.4	298
3	DSW	DS	60.0	18.1	26.4	8.2	267	18.2	29.2	22.4	22.4	158	40.5	8.2	48.3	15.3	1.8	-0.8	3.8	-0.5	3.5	3.1	267
4	NORTHEAST	NE	60.0	3.0	3.9	0.9	87	3.0	4.2	12.5	12.6	143	15.5	2.8	18.1	5.9	2.6	-0.4	1.3	0.0	0.0	0.9	87
54	ALBERTA	AL	60.0	1.1	1.9	0.9	51	1.1	2.0	10.9	10.9	85	12.0	1.3	12.9	5.7	0.9	-0.1	0.0	0.0	0.0	0.0	51
14	ARIZONA	AZ	60.0	7.8	14.0	6.1	116	7.9	14.5	13.0	13.0	72	20.8	4.4	21.1	6.7	0.2	0.0	2.1	-0.1	3.2	1.9	116
50	B.C.HYDRO	BC	60.0	10.0	13.2	3.2	125	10.0	13.1	0.7	0.7	124	10.7	-0.3	8.2	2.7	0.1	0.0	0.0	0.0	0.0	0.0	125
11	EL PASO	EL	60.0	1.1	1.3	0.2	14	1.1	1.8	0.5	0.5	4	1.6	0.2	2.2	0.5	0.1	0.0	0.1	-0.1	0.0	0.0	14
60	IDAHO	ID	60.0	1.2	1.6	0.4	28	1.2	1.6	2.4	2.4	28	3.6	0.6	3.9	1.4	0.2	0.0	0.0	0.0	0.0	0.0	28
21	IMPERIALCA	IV	60.0	0.5	0.7	0.1	10	0.5	0.7	0.9	0.9	30	1.4	0.2	0.3	0.1	0.0	0.1	0.4	0.0	0.2	0.0	10
26	LADWP	LA	60.0	3.9	4.6	0.6	28	4.0	5.1	2.1	2.1	12	6.0	2.0	7.4	2.5	0.2	0.0	0.6	0.0	0.6	1.2	28
20	MEXICO-CFE	MX	60.0	0.9	1.2	0.3	7	0.9	1.3	1.2	1.2	14	2.0	0.4	2.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	7
62	MONTANA	MT	60.0	0.5	0.7	0.3	30	0.5	0.8	2.4	2.4	17	2.9	0.5	1.9	0.6	0.7	-0.1	0.0	0.0	0.0	0.0	30
18	NEVADA	NV	60.0	1.3	1.6	0.3	11	1.3	1.9	1.9	1.9	32	3.2	1.2	6.9	2.2	0.0	0.0	0.3	0.0	0.2	0.1	11
10	NEW MEXICO	NM	60.0	1.5	1.6	0.1	9	1.5	1.8	1.2	1.2	9	2.7	0.4	3.1	0.6	0.1	-0.3	0.4	-0.1	0.0	0.2	9
40	NORTHWEST	NW	60.0	23.4	31.9	8.4	298	23.5	29.2	6.3	6.4	94	29.8	4.4	27.4	8.7	6.9	-1.6	0.2	-0.2	0.0	0.3	298
65	PACE	PC	60.0	0.9	1.1	0.2	23	0.9	1.3	6.4	6.4	48	7.3	0.6	9.9	3.3	1.4	-0.2	0.2	-0.1	0.0	0.6	23
30	PG AND E	PG	60.0	12.2	15.1	2.9	158	12.2	15.9	15.8	15.9	305	28.0	3.5	29.3	10.0	0.8	0.0	0.7	0.1	0.0	1.0	158
70	PSCOLORADO	CO	60.0	2.8	3.8	0.9	60	2.9	4.3	3.3	3.4	17	6.2	1.2	8.3	3.0	0.4	-0.1	0.5	-0.1	0.2	0.3	60
22	SANDIEGO	SD	60.0	1.5	1.8	0.3	27	1.5	2.0	0.7	0.7	20	2.2	0.5	5.6	1.5	0.3	0.1	0.4	0.1	0.0	0.2	27
64	SIERRA	SP	60.0	0.4	0.4	0.0	6	0.4	0.5	1.4	1.4	50	1.7	1.1	2.3	0.6	0.3	-0.1	1.1	0.1	0.0	0.3	6
24	SOCALIF	SC	60.0	8.4	9.6	1.2	75	8.5	10.2	11.8	11.8	100	20.1	5.6	26.2	7.3	0.8	0.1	3.8	0.2	2.4	2.9	75
52	FORTISBC	FB	60.0	0.6	0.8	0.2	17	0.6	0.8	0.5	0.5	9	1.1	0.2	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	17
73	WAPA R.M.	WR	60.0	3.6	4.2	0.6	57	3.6	4.9	2.5	2.5	24	6.1	0.8	5.8	2.1	0.9	-0.4	0.4	-0.1	0.0	0.3	57
63	WAPA U.M.	WU	60.0	0.1	0.1	0.0	2	0.1	0.1	0.0	0.0	0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2

2.1 Dynamics Introduction

Frequency Response and Transient Stability

- **Frequency response** is systemic;
- Points of particular concern with addition of wind and solar power include:
  - Displacement of responsive synchronous generation
  - Reduction of system inertia
  - Locational concerns (e.g. geographic concentration of responsive resources; geographic disparity of speed of response
- Broadly measures of performance are:
  - Avoid UFLS
  - Meet FRO
- **Transient Stability** can be both systemic and local
- We are *primarily* concerned with impacts on large-scale events that affect the security of the entire interconnection
- Points of particular concern with addition of wind and solar power include:
  - Changes in angle/speed swing behavior due to
    - reduced inertia
    - different power flow patterns
    - displacement of synchronous generation (at key locations)
  - Changes in voltage swing behavior due to
    - different voltage control, flow patterns
    - locational differences
- Broadly measures of performance are:
  - Avoid separation
  - Meet voltage swing criteria

2.2 Frequency Response

Frequency Response Obligation (FRO)

- Frequency Response (FR) is calculated as

$$FR = \frac{\Delta P}{\Delta f}\left[\frac{MW}{0.1Hz}\right]$$

with ΔP and Δf averaged over time period of 20 to 52 sec after the event.

- Frequency Response Obligation (FRO) for the Interconnection is established in of BAL-003-1 Frequency Response & Frequency Bias Setting Standard
- For Western Interconnection FRO is 840 MW/0.1Hz
- Balancing Authority FRO allocation is determined by following equation

$$FRO_{BA} = FRO_{Int}\frac{Pgen_{BA} + Pload_{BA}}{Pgen_{Int} + Pload_{Int}}$$

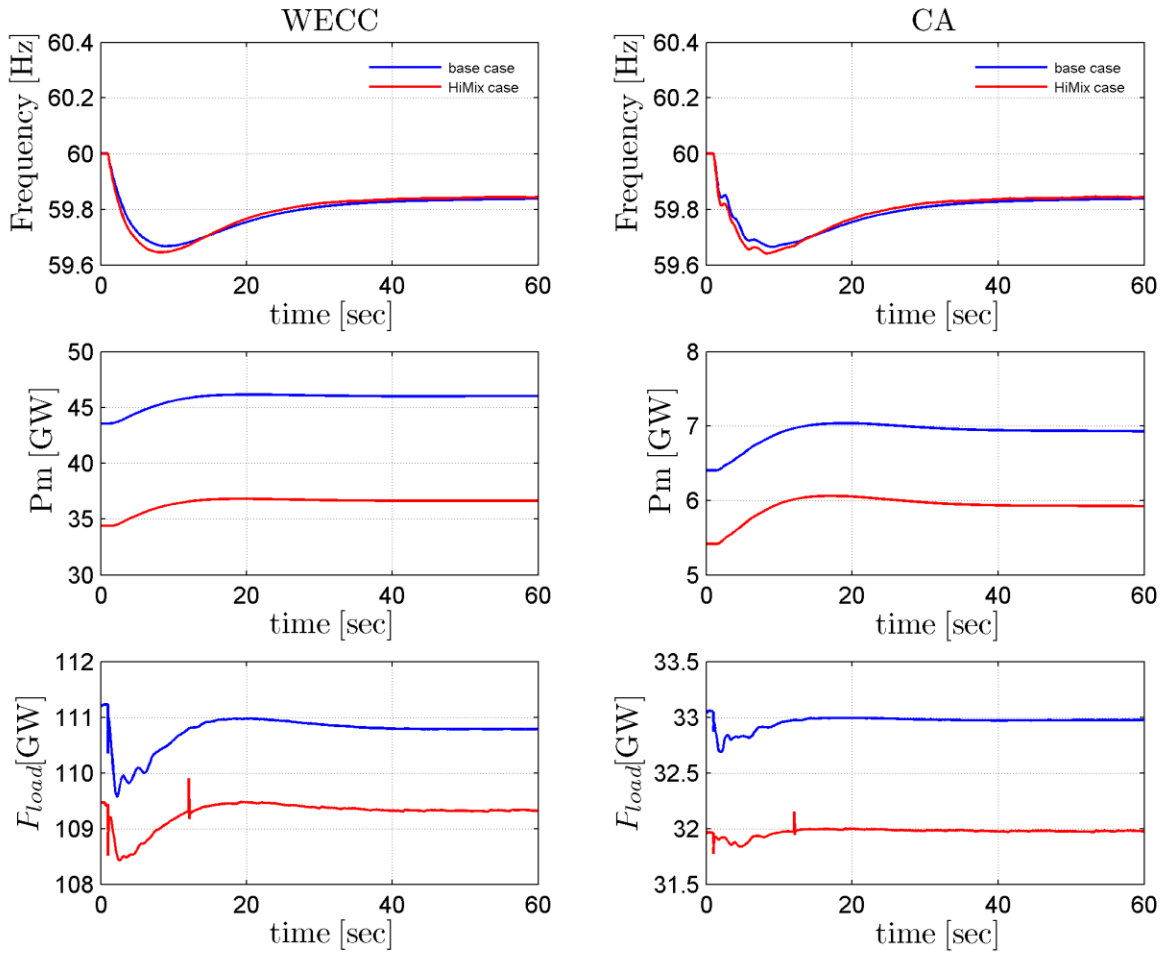
Frequency Response Obligation (FRO)

- Frequency Response obligation (FRO) is determined based on 23HS Base Case simulation for the design event of tripping two Palo Verde units.
- This is for reference only: FRO are assigned by Balancing Authority. This calculation is only an approximation, and should not be used to determine whether any BA is in compliance.
- WECC totals include approximation for Canada and Mexico.

ID	Name	ID	PGEN [GW]	PLOAD [GW]	FRO [MW/0.1Hz]
1	WECC	WE	203.7	184.6	840
2	CALIFORNIA	CA	68.8	67.9	296
3	DSW	DS	53.9	47.8	220
4	NORTHEAST	NE	19.7	18.0	82
54	ALBERTA	AL	12.9	12.9	0
14	ARIZONA	AZ	27.5	20.8	104
50	B.C.HYDRO	BC	11.3	8.2	0
11	EL PASO	EL	1.7	2.3	9
60	IDAHO	ID	4.3	3.9	18
21	IMPERIALCA	IV	1.5	0.3	4
26	LADWP	LA	6.3	7.2	29
20	MEXICO-CFE	MX	2.7	2.6	0
62	MONTANA	MT	3.3	1.9	11
18	NEVADA	NV	6.1	6.8	28
10	NEW MEXICO	NM	3.5	3.1	14
40	NORTHWEST	NW	33.3	27.2	131
65	PACE	PC	9.4	9.9	42
30	PG AND E	PG	32.4	29.0	133
70	PSCOLORADO	CO	8.3	8.1	36
22	SANDIEGO	SD	4.4	5.5	21
64	SIERRA	SP	2.6	2.3	11
24	SOCALIF	SC	24.2	25.9	108
52	FORTISBC	FB	1.1	0.9	0
73	WAPA R.M.	WR	6.9	5.8	27
63	WAPA U.M.	WU	0.1	0.0	0

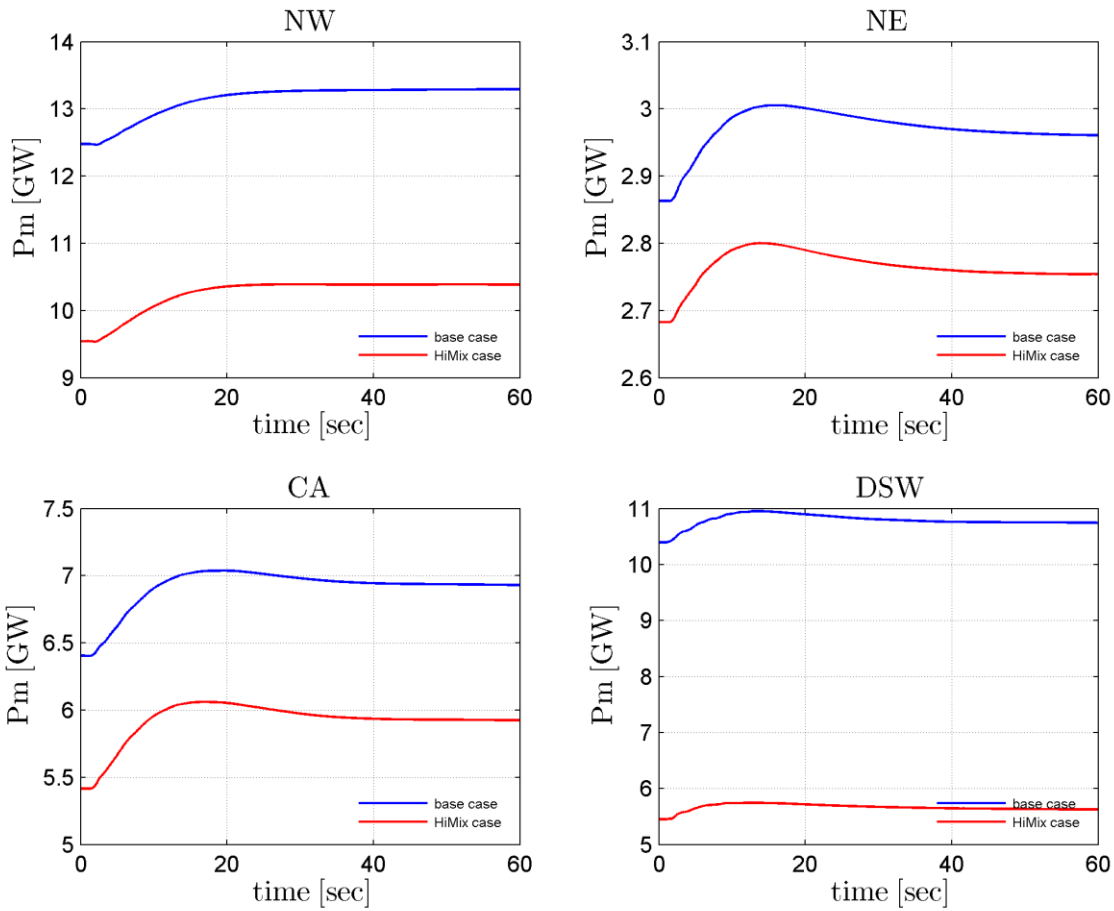
LSP '22 Frequency Response Simulation

- Frequency for WECC and California for Palo Verde event



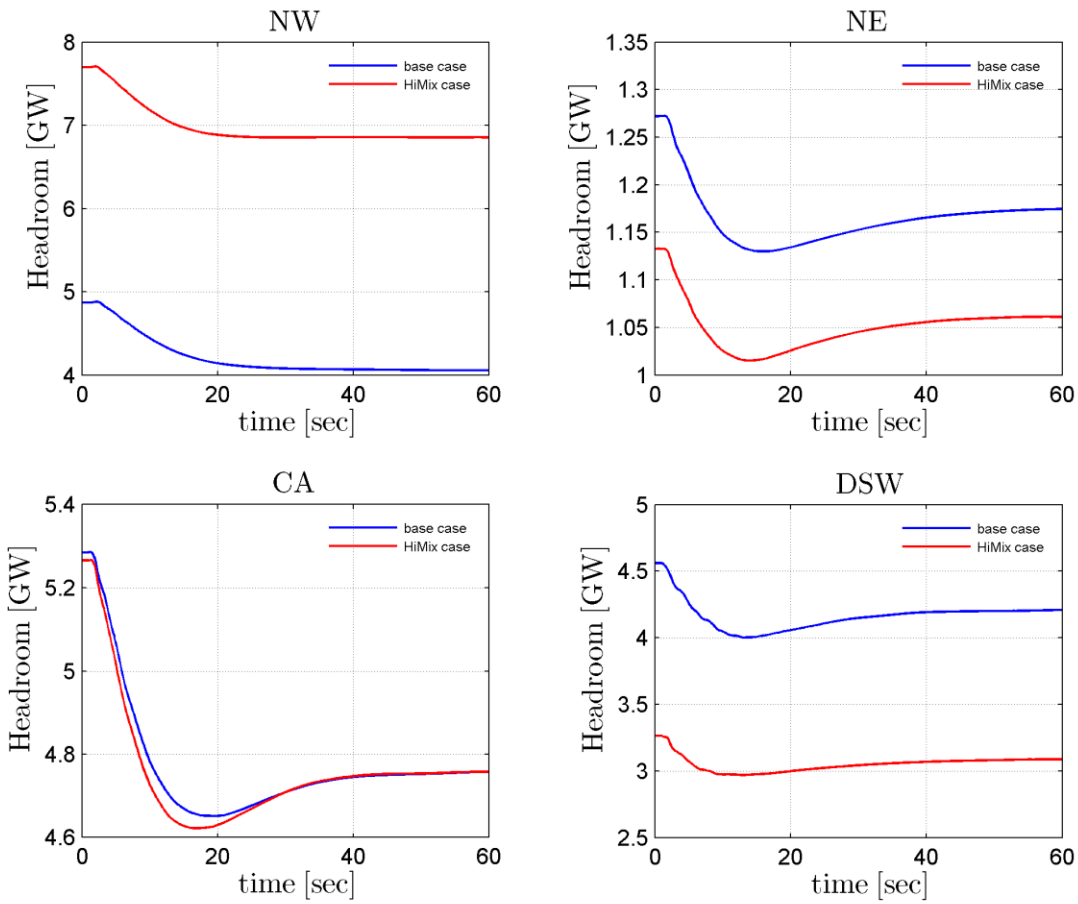
LSP '22 Frequency Response Simulation

- Frequency Response Headroom for 4 regions for Palo Verde event



LSP '22 Frequency Response simulation

- Frequency Response Headroom for 4 regions for Palo Verde event



Frequency Response

ID	Name	ID	FRO [MW/0.1Hz]	FR [MW/0.1Hz]	%of WECC FR	FR margin [MW/0.1Hz]	Freq. Nadir [Hz]	Nadir time [s]	Setl. Freq. [Hz]	Kt
1	WECC	WE	840	1352	100.00	512.2	59.668	7.77	59.839	0.46
2	CALIFORNIA	CA	296	305	22.56	9.4	59.665	7.86	59.839	0.34
3	DSW	DS	220	215	15.88	-5.2	59.662	7.48	59.839	0.44
4	NORTHEAST	NE	82	61	4.53	-20.2	59.665	7.67	59.838	0.26
54	ALBERTA	AL	0	0	0.00	0.0	59.655	6.71	59.838	0.22
14	ARIZONA	AZ	104	69	5.11	-35.3	59.664	7.96	59.838	0.37
50	B.C.HYDRO	BC	0	0	0.00	0.0	59.657	6.33	59.838	0.93
11	EL PASO	EL	9	4	0.26	-5.1	59.663	8.05	59.838	0.42
60	IDAHO	ID	18	21	1.55	3.1	59.665	7.77	59.838	0.38
21	IMPERIALCA	IV	4	14	1.05	10.2	59.664	7.67	59.839	0.24
26	LADWP	LA	29	31	2.26	1.3	59.666	7.67	59.839	0.60
20	MEXICO-CFE	MX	0	0	0.00	0.0	59.665	7.96	59.838	0.69
62	MONTANA	MT	11	10	0.72	-1.5	59.666	8.44	59.838	0.17
18	NEVADA	NV	28	44	3.24	16.0	59.661	7.86	59.839	0.72
10	NEW MEXICO	NM	14	50	3.68	35.5	59.664	7.38	59.838	0.49
40	NORTHWEST	NW	131	434	32.10	303.2	59.665	8.34	59.839	0.62
65	PACE	PC	42	23	1.71	-18.7	59.662	7.57	59.839	0.22
30	PG AND E	PG	133	190	14.06	57.4	59.665	8.05	59.839	0.40
70	PSCOLORADO	CO	36	-14	-1.05	-49.8	59.652	7.48	59.839	0.34
22	SANDIEGO	SD	21	7	0.52	-14.3	59.666	7.77	59.838	0.15
64	SIERRA	SP	11	7	0.55	-3.1	59.664	8.15	59.838	0.23
24	SOCALIF	SC	108	63	4.67	-45.3	59.665	7.67	59.839	0.23
52	FORTISBC	FB	0	0	0.00	0.0	59.658	6.33	59.839	0.67
73	WAPA R.M.	WR	27	63	4.63	35.2	59.657	7.48	59.839	0.67
63	WAPA U.M.	WU	0	3	0.20	2.6	59.669	8.44	59.838	0.94

- Frequency Response metric for 22LSP Base case for 2xPV event

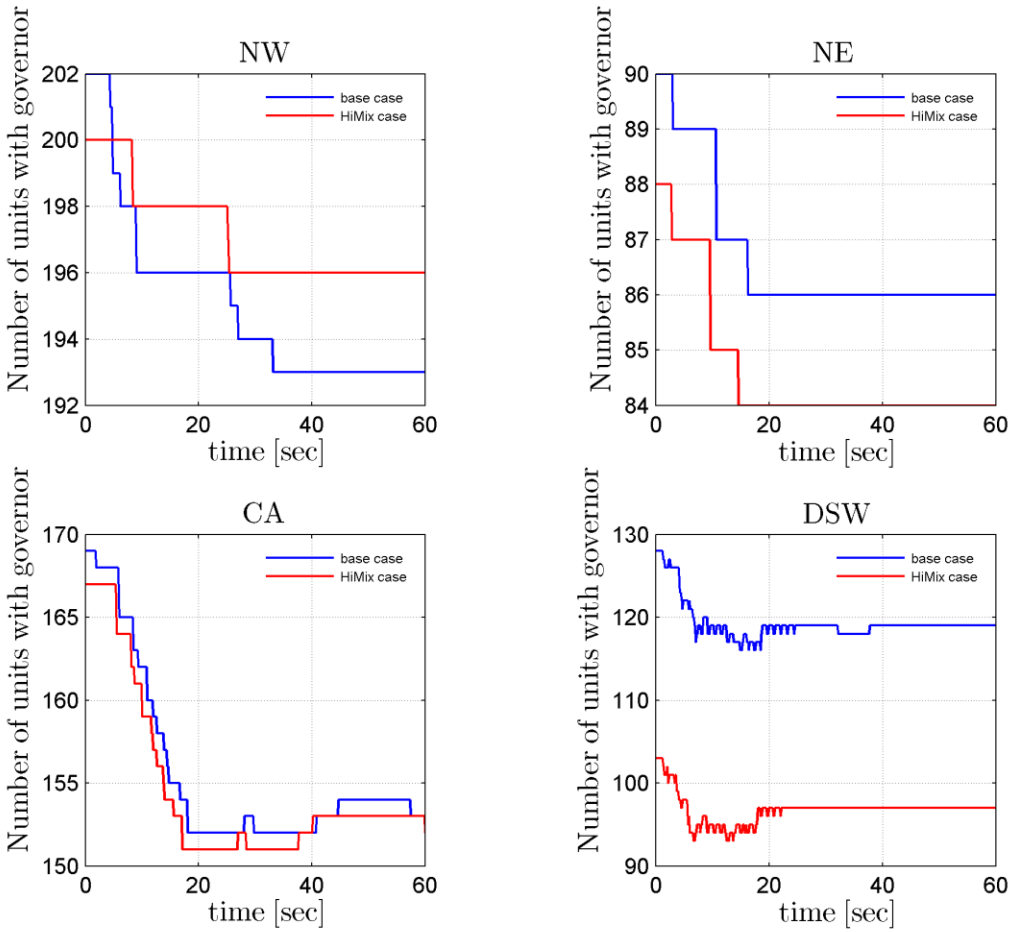
Frequency Response

ID	Name	ID	FRO [MW/0.1Hz]	FR [MW/0.1Hz]	%of WECC FR	FR margin [MW/0.1Hz]	Freq. Nadir [Hz]	Nadir time [s]	Setl. Freq. [Hz]	Kt
1	WECC	WE	840	1311	100.00	471.4	59.646	7.19	59.844	0.42
2	CALIFORNIA	CA	296	312	23.76	15.9	59.642	7.29	59.844	0.33
3	DSW	DS	220	119	9.09	-100.8	59.641	7.38	59.844	0.27
4	NORTHEAST	NE	82	47	3.60	-34.2	59.642	7.38	59.843	0.30
54	ALBERTA	AL	0	0	0.00	0.0	59.627	6.23	59.842	0.23
14	ARIZONA	AZ	104	50	3.79	-54.7	59.640	7.38	59.844	0.29
50	B.C.HYDRO	BC	0	0	0.00	0.0	59.635	5.95	59.844	0.95
11	EL PASO	EL	9	4	0.29	-4.8	59.635	6.71	59.844	0.30
60	IDAHO	ID	18	22	1.66	3.9	59.643	7.77	59.843	0.68
21	IMPERIALCA	IV	4	14	1.10	10.5	59.638	7.38	59.844	0.16
26	LADWP	LA	29	30	2.27	0.5	59.641	7.10	59.844	0.42
20	MEXICO-CFE	MX	0	0	0.00	0.0	59.641	7.10	59.844	0.59
62	MONTANA	MT	11	10	0.78	-1.0	59.645	7.86	59.843	0.23
18	NEVADA	NV	28	34	2.59	6.0	59.637	7.00	59.844	0.52
10	NEW MEXICO	NM	14	2	0.14	-12.6	59.641	7.77	59.844	0.03
40	NORTHWEST	NW	131	483	36.86	352.6	59.644	7.77	59.844	0.62
65	PACE	PC	42	8	0.62	-33.6	59.641	7.29	59.843	0.19
30	PG AND E	PG	133	197	14.98	63.8	59.643	7.38	59.844	0.46
70	PSCOLORADO	CO	36	6	0.45	-29.7	59.638	7.10	59.843	0.25
22	SANDIEGO	SD	21	7	0.55	-14.1	59.640	7.00	59.844	0.16
64	SIERRA	SP	11	7	0.53	-3.6	59.639	7.29	59.844	0.18
24	SOCALIF	SC	108	63	4.84	-45.0	59.640	7.19	59.845	0.21
52	FORTISBC	FB	0	0	0.00	0.0	59.635	5.95	59.843	0.67
73	WAPA R.M.	WR	27	24	1.85	-3.2	59.641	7.19	59.843	0.19
63	WAPA U.M.	WU	0	3	0.20	2.5	59.646	6.04	59.843	0.76

- Frequency Response metric for 22LSP HiMix case for 2xPV event

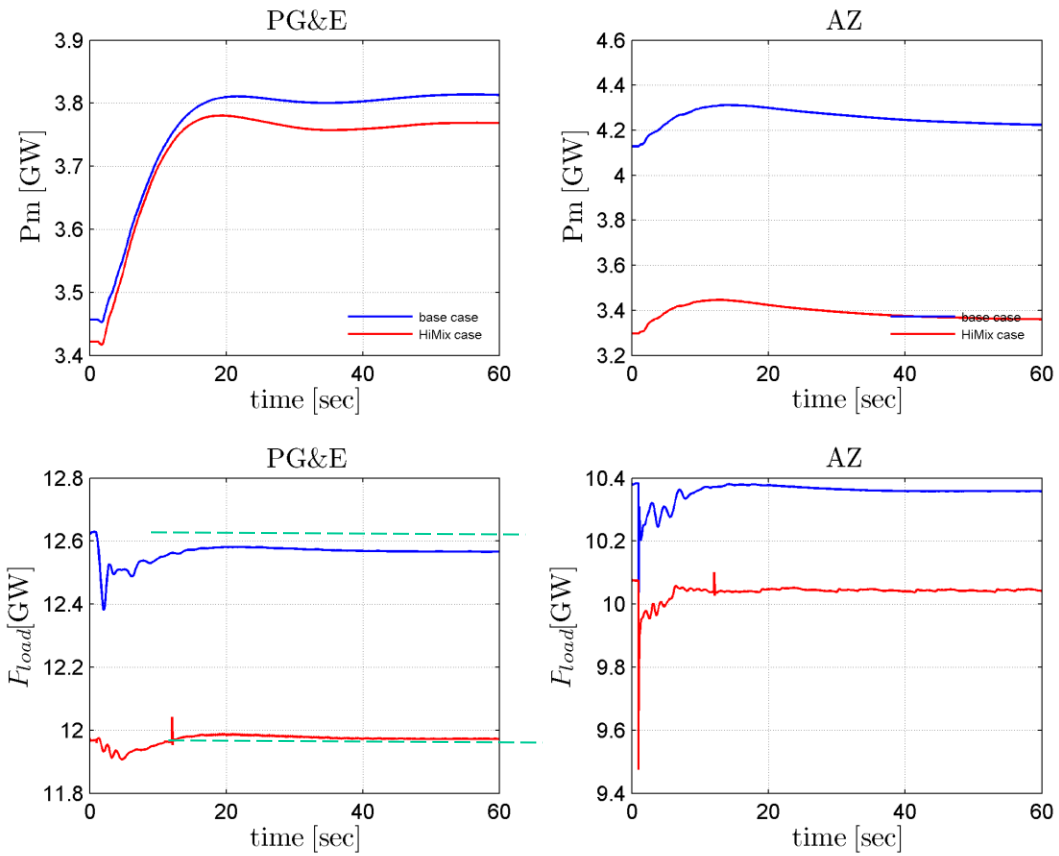
LSP '22 Frequency Response Simulation

- Count of Plants with Headroom for 4 regions for Palo Verde event



LSP '22 Frequency Response Simulation

- Frequency Response of Responsive machines for 4 areas for Palo Verde event



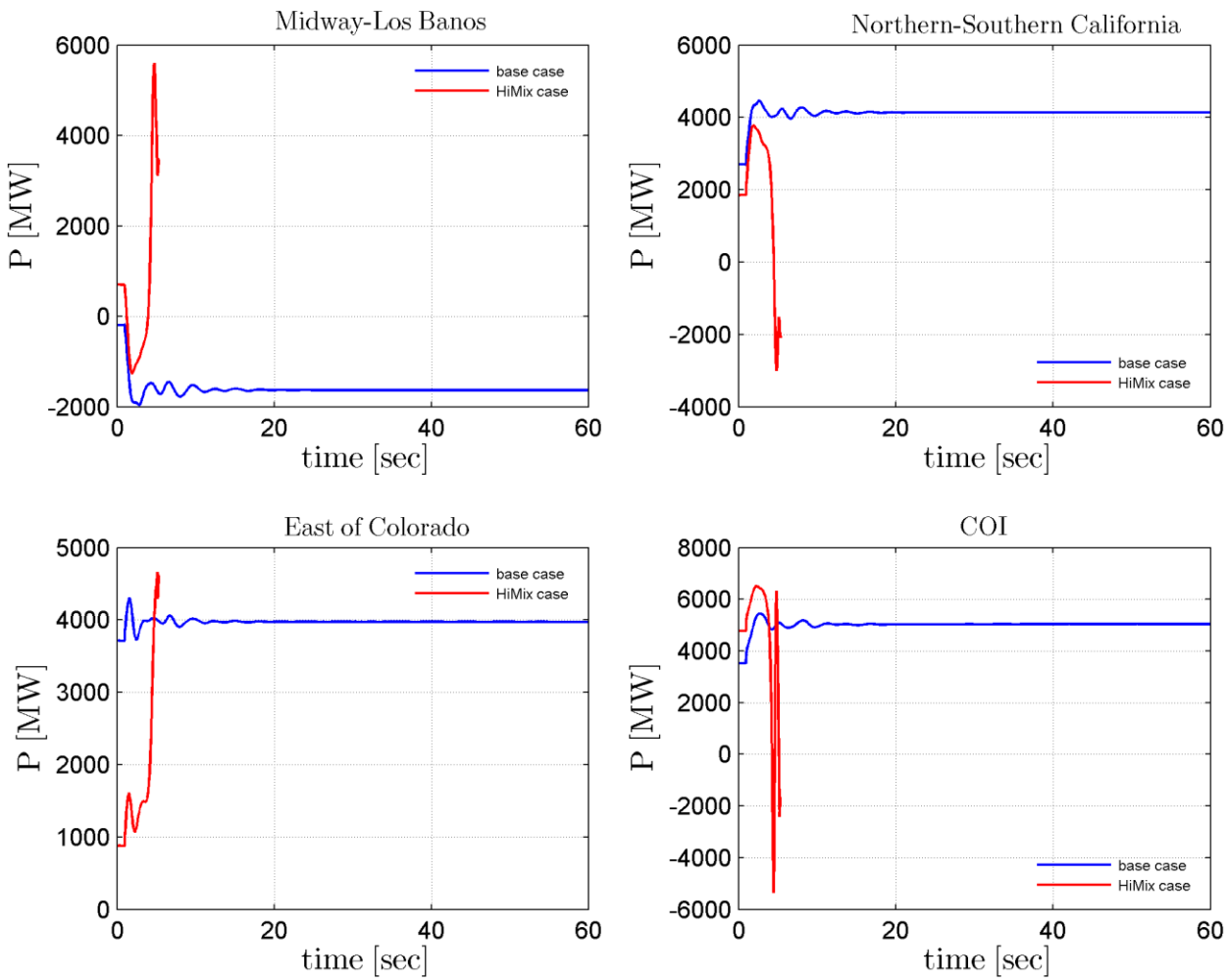
2.3 COI Stability

PDCI fault for '23 HS Base and Hi-Mix cases

- Block Bi-Pole of PDCI
- No RAS of any type in this simulation

- Base case stable
- HiMix case unstable

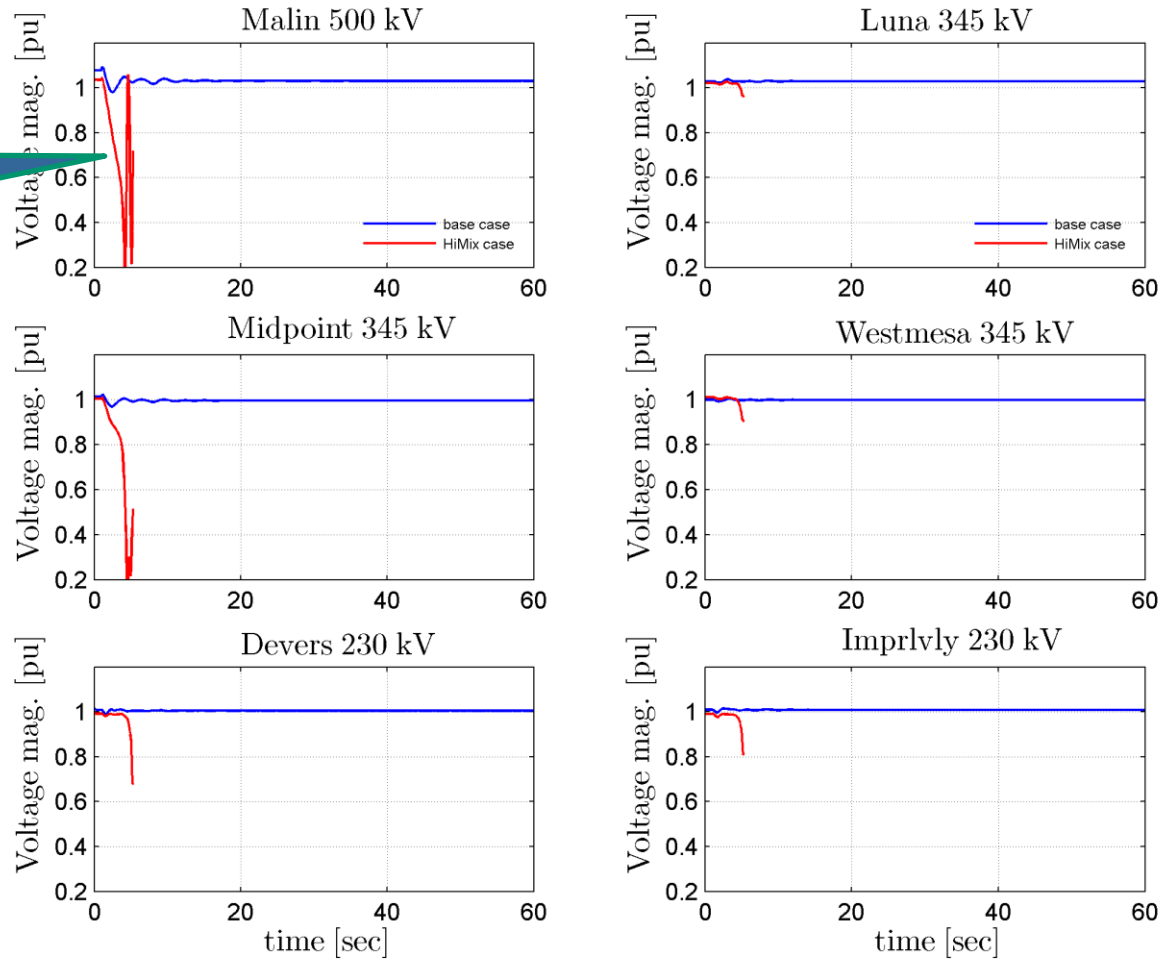
- Initial loading of COI in Base case << limit
- Initial loading of COI in HiMix = limit



PDCI fault for '23 HS Base and Hi-Mix cases

Voltage Collapse – center of swing near Malin. No surprise

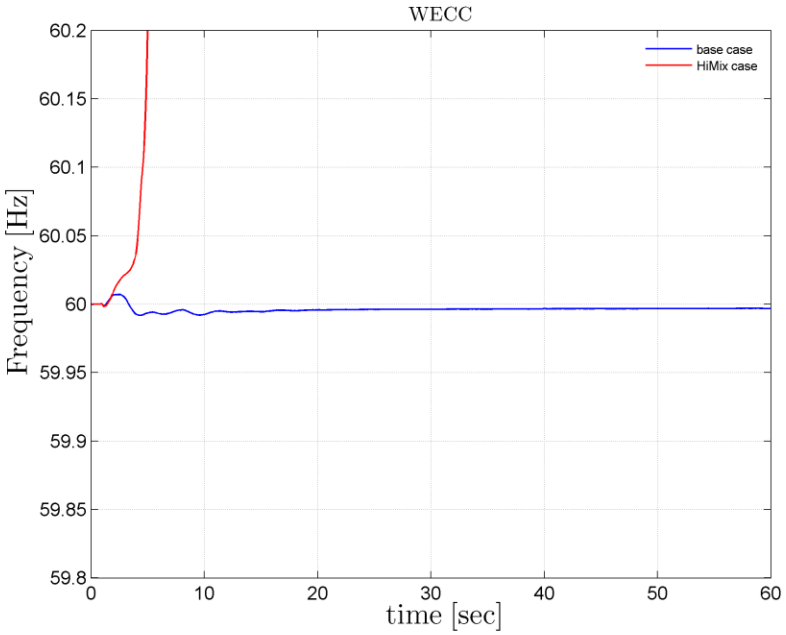
- Base case stable; HiMix case unstable

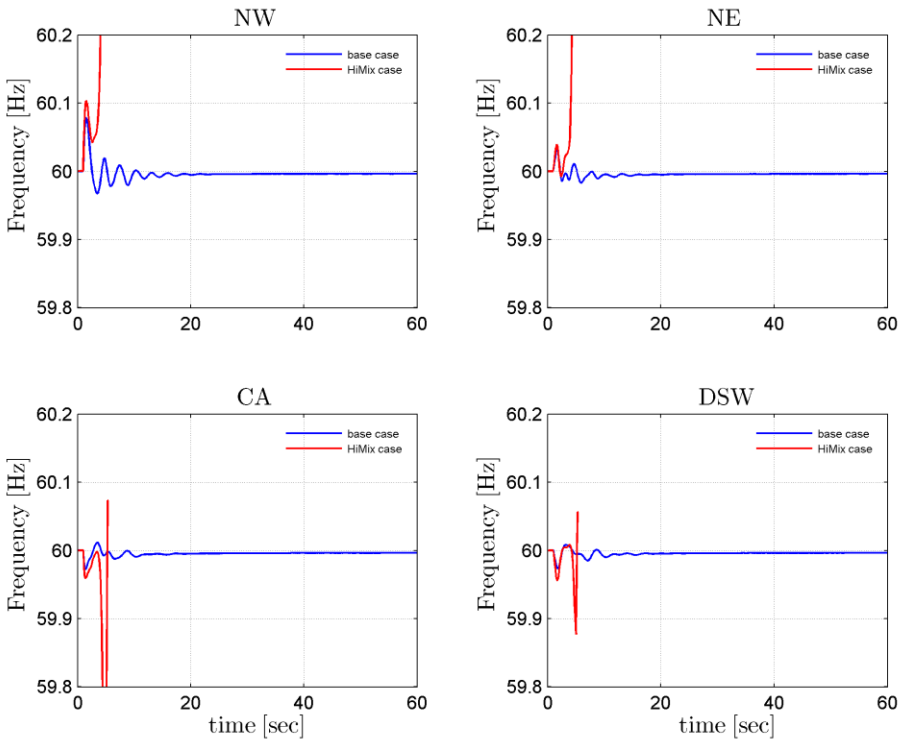


PDCI fault for '23 HS Base and Hi-Mix cases

- Base case stable; HiMix case unstable

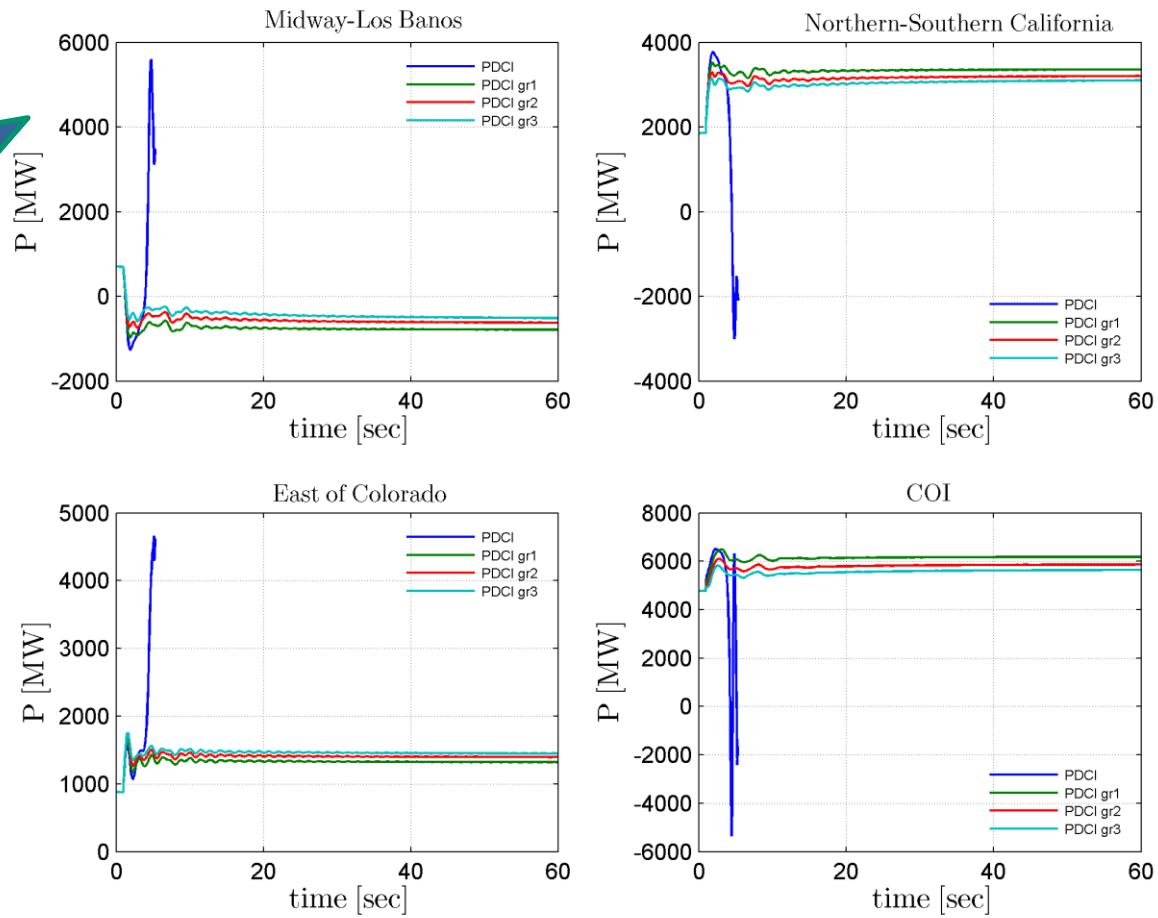
Frequencies reflect north-south separation





PDCI '23 HS Hi-Mix with Generation Trip RAS

- Present practice is to trip generation in NW for PDCI, depending on initial COI and other conditions
- These tests are for a range of tripping



Plots of Hi-Mix case, PDCI (unstable) and three cases with increasing level of unit tripping.

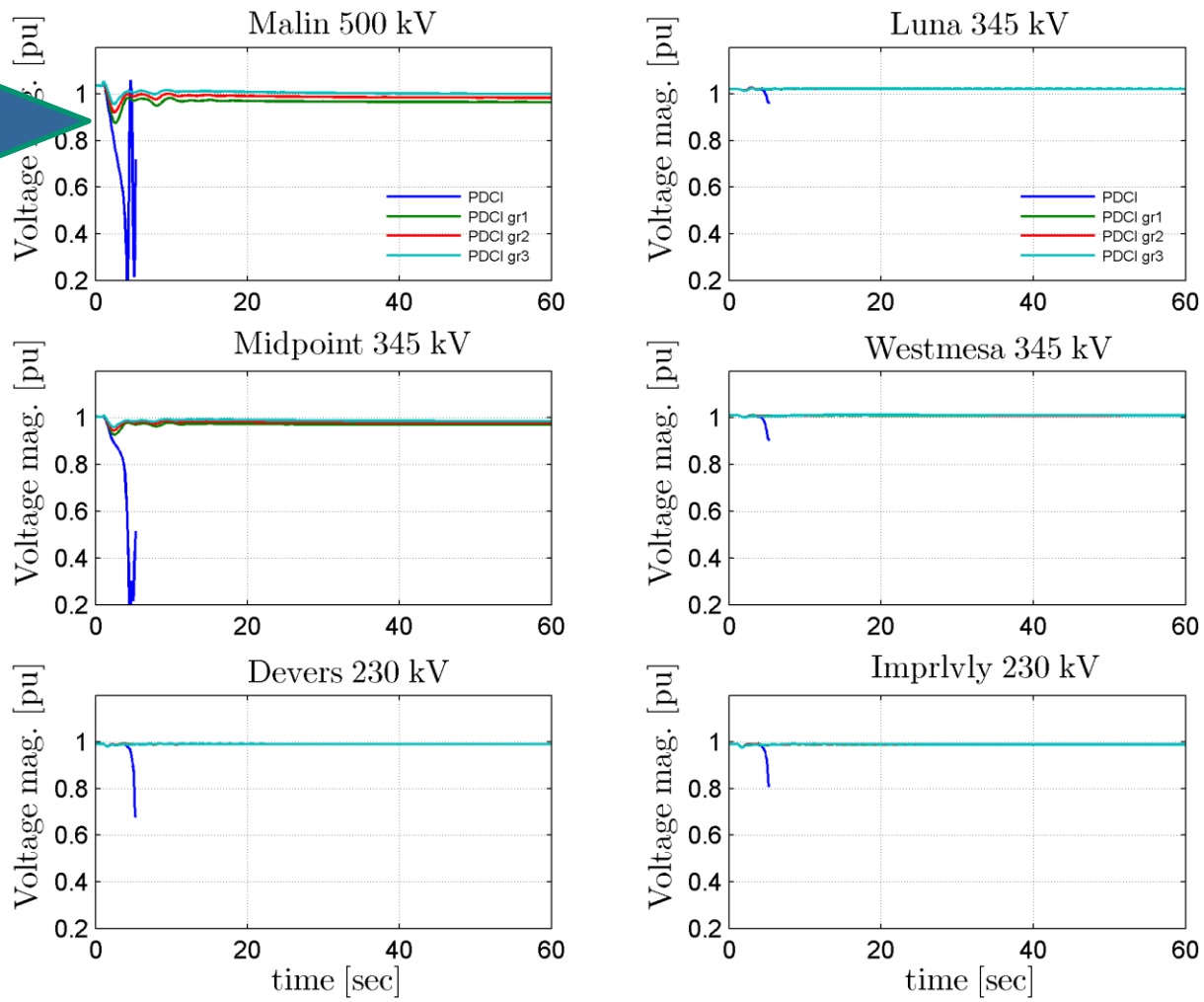
Group 1, tripping JDA 01 through 08 approximately 1108 MW

Group 2, group 1 + tripping JDA 09 through 08 approximately 2076 MW

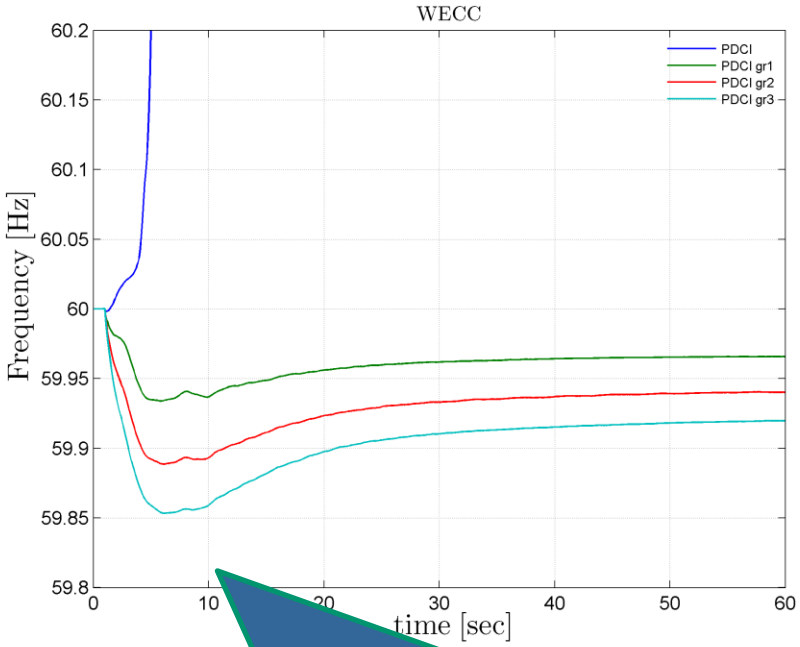
Group 3, group1+ group 2+ tripping MCN 01 through 04 + LMN 2 through 4 approximately 2776 MW

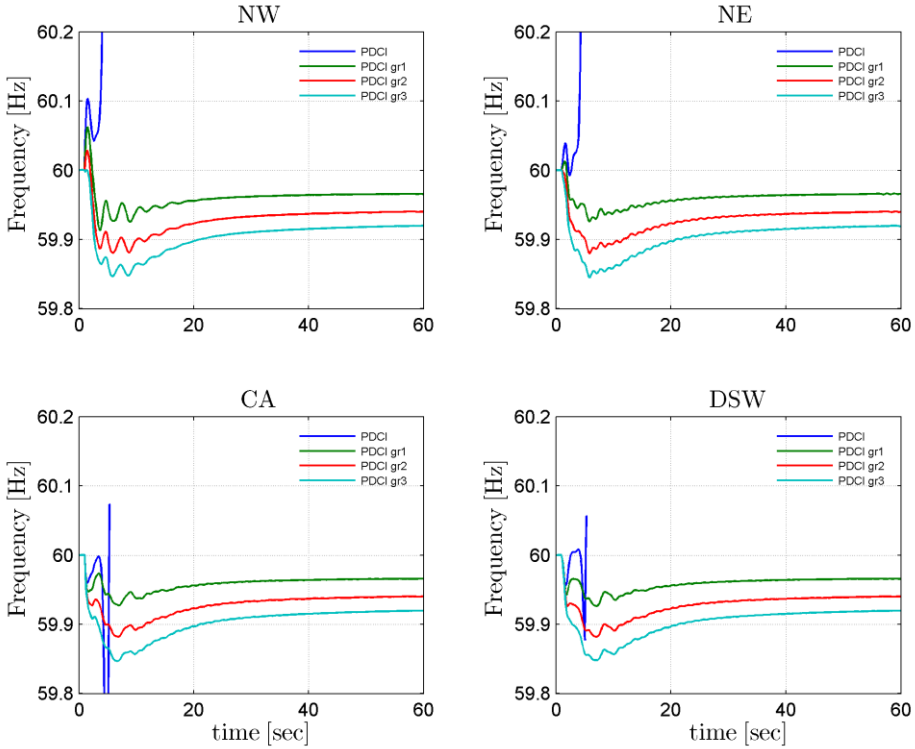
PDCI '23 HS Hi-Mix with Generation Trip RAS

Once system is well stabilized, difference in voltage swings is small



PDCI '23 HS Hi-Mix with Generation Trip RAS



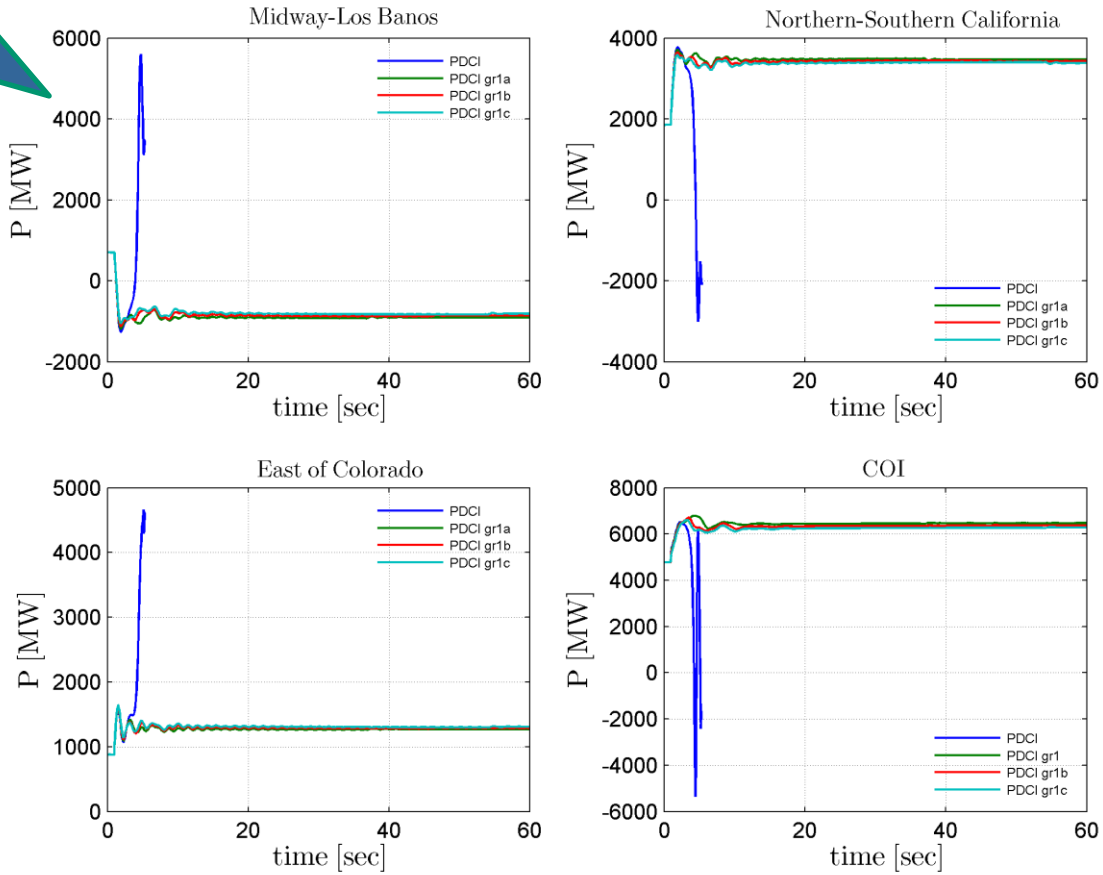


- More generation tripped = deeper nadir. No surprise
- Generous tripping (from synchronism perspective) still results in acceptable frequency swing
- No obvious need to be timid with tripping

PDCI '23 HS Hi-Mix with less Generation Trip RAS

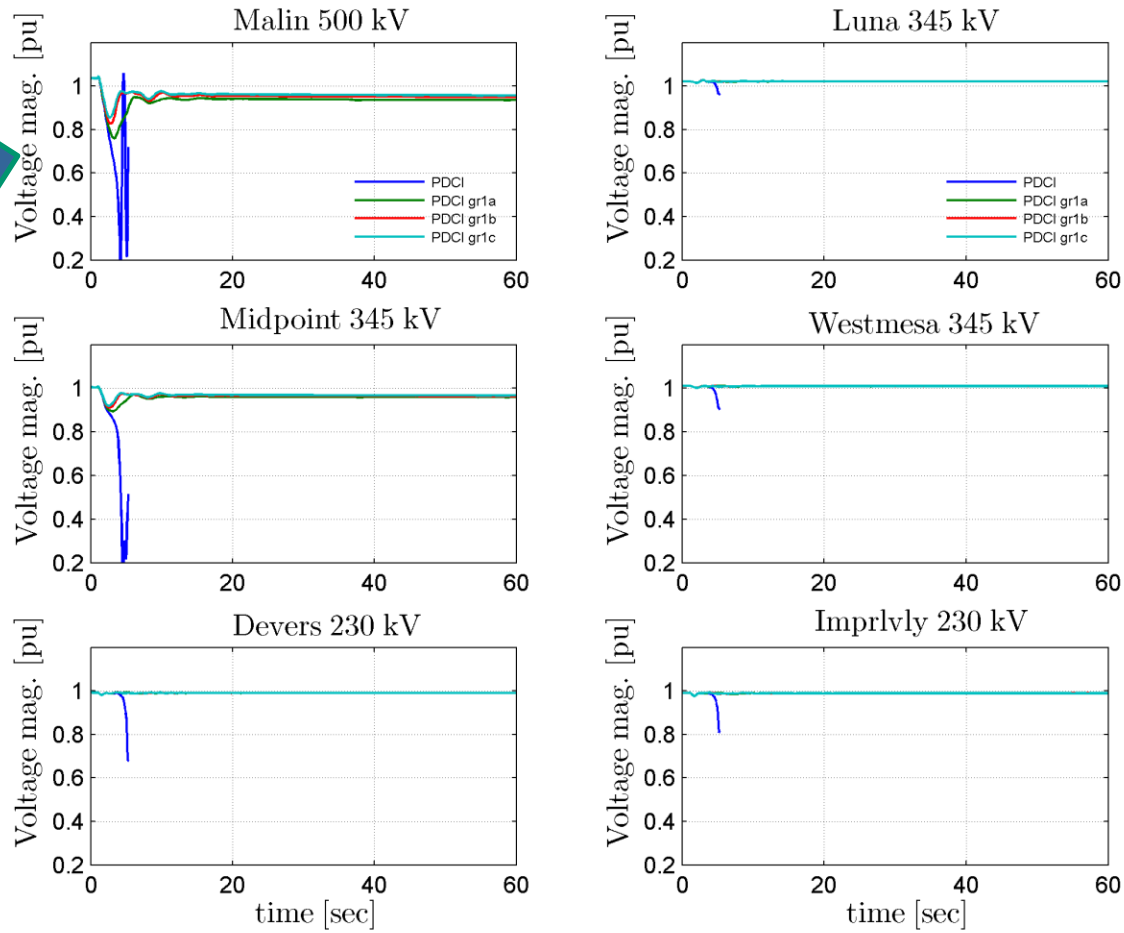
Greatly less generation tripping can still stabilize the system

- Group 1a: Trip JDA units 01 and 02 only. Total tripped generation 2*138.5
- Group 1b: Trip JDA 01 through 04. Total tripped generation = 4*138.5
- Group 1c: Trip JDA 01 through 06. Total tripped generation = 6*138.5



PDCI '23 HS Hi-Mix with less Generation Trip RAS

- As we refine/search for minimum genreation trip that will stabilize the system, the difference in voltage swings becomes more apparent
- These are "small" steps



- Group 1a: Trip JDA units 01 and 02 only. Total tripped generation 2*138.5
- Group 1b: Trip JDA 01 through 04. Total tripped generation = 4*138.5
- Group 1c: Trip JDA 01 through 06. Total tripped generation = 6*138.5

imagination at work

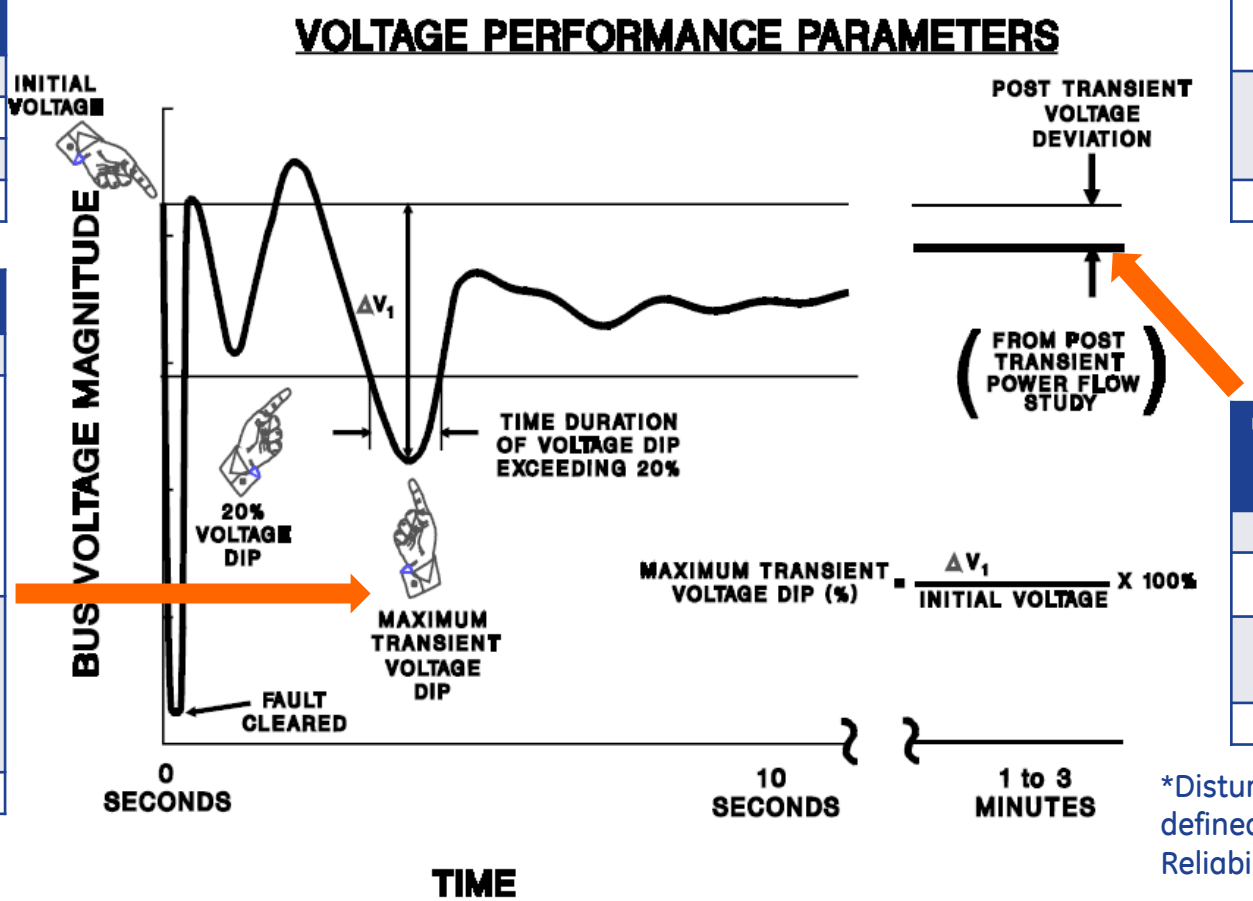
TRC Call: Do not Cite - Not for Further Distribution

WECC Reliability Criteria

- Addition to NERC requirement

Disturbance Class	Outage Frequency Associated with Performance Category
A	NA
B	≥ 0.33
C	0.033-0.33
D	<0.033

Disturbance Class	Transient Voltage Dip
A	NERC
B	Not to exceed 25% at load buses or 30% at non-load buses. Not to exceed 20% for more than 20 cycles at load buses.
C	Not to exceed 30% at any bus. Not to exceed 20% for more than 40 cycles at load buses.
D	NERC



Disturbance Class	Minimum Transient Frequency Standard
A	NERC
B	Not below 59.6 Hz for 6 cycles or more at a load bus.
C	Not below 59.0 Hz for 6 cycles or more at a load bus.
D	NERC

Disturbance Class	Post Transient Voltage Deviation Standard
A	NERC
B	Not to exceed 5% at any bus
C	Not to exceed 10% at any bus
D	NERC

*Disturbance category is defined in the WECC Reliability Criteria, April 2003

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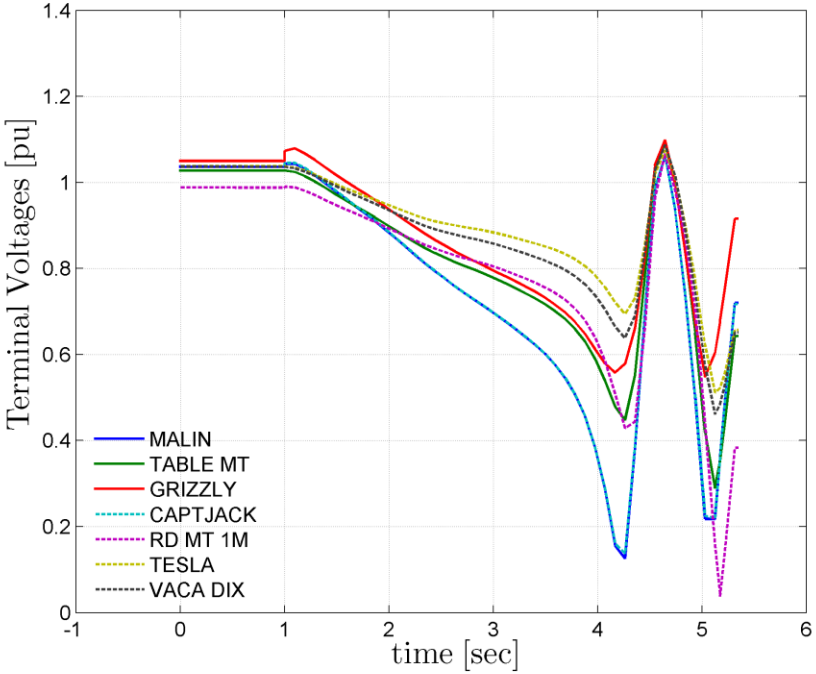
PDCI '23 HS Hi-Mix with less Generation Trip RAS

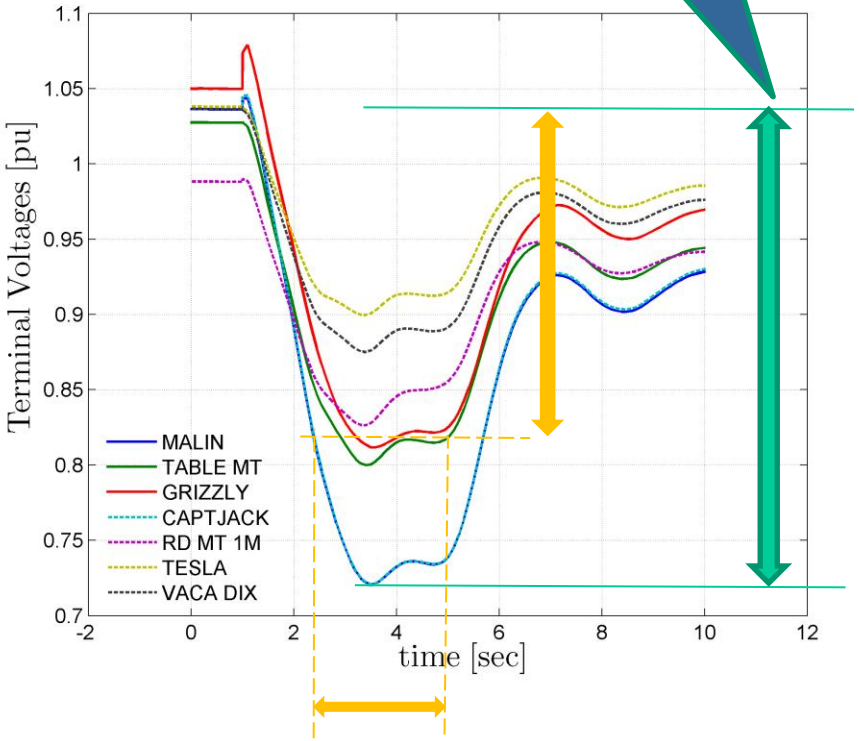
New Discussion

Voltage Δ slightly >30%, not 70% abs.... but >2 sec >20%...so misses WECC criteria. Need to trip more to meet WECC criteria

Hi-Mix case unstable



Hi-Mix case with 1xJDA – 138MW tripping (gr1a1) stable



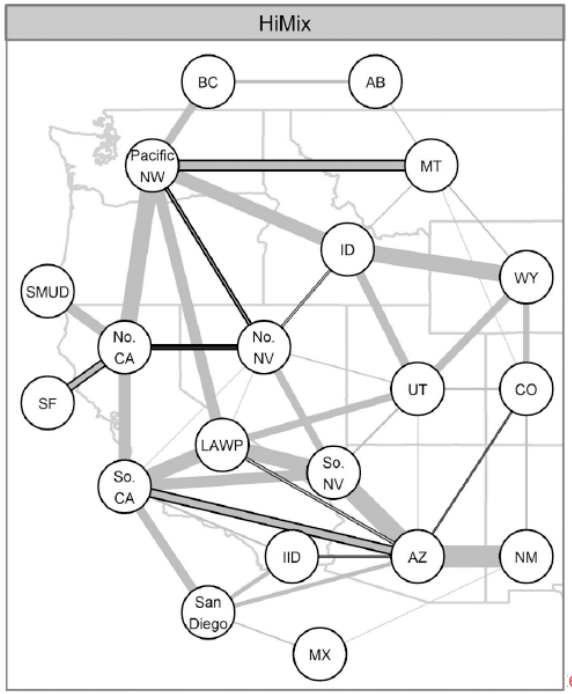
2.4 Transmission Adds

Transmission Build-out

WWSIS II Interface Name	Initial Rating	TEPPC $10 delta	Hi Mix $10 delta
Az to CA so	1600	1000	1000
Az to CO	200	0	500
Az to IID	195	500	500
Az to DWP	468		500
Az to UT	250		500
CA no to NV no	100	500	1500
CA no to SF	1272	500	1500
ID to NV no	350	500	500
MO to NW	2000		1000
NV no to NW	300	1000	1000
UT to WY	2100		500
		4000	9000

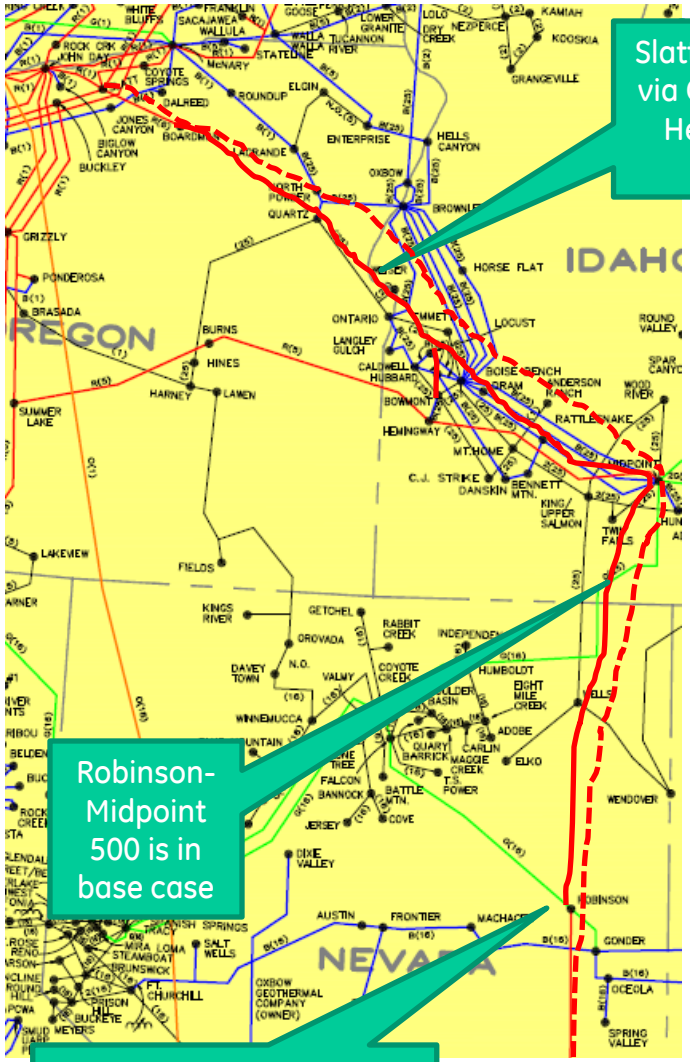
- This table adopted from Transmission build-out work from WWSIS II used 500MW increments on PLEXOS "straws"
- Mapping to actual new lines is not straightforward
- For this exercise we limited ourselves to duplicating/doubling circuits in the data set
- Explicitly did not consider other WECC projects on the possible future list
- Highlighted improvement vary approximate proxy for build-out shown next

- WWSIS II showed significant economic benefit of adding transmission
- Enough to pay for the new lines,, and still save on variable operating cost
- Here we are adding a portion of the WWSISII transmission additions, to examine their impact on stability



New Discussion

New NW to NV to AZ Transmission



Slatt-Midpoint 500 via Grassland and Hemingway in base case

Robinson-Midpoint 500 is in base case

Midpoint – Harry Allan is: 60240 to 64668 to 64669 to 64670 to 64895 (Robinson) to 18896 to 18897 to 18459 (H Allen)

- WECC base case includes significant new transmission, including new 500kV from Grassland (~Slatt) to Harry Allen, via Hemingway, Midpoint, Robinson.
- Transmission add (dotted red line)
- Doubled planned new single circuit 500kV to a double circuit:

Slatt-Hemingway-Midpoint-Robinson-Harry Allen

2023HS HiMix Case with Transmission Build-out

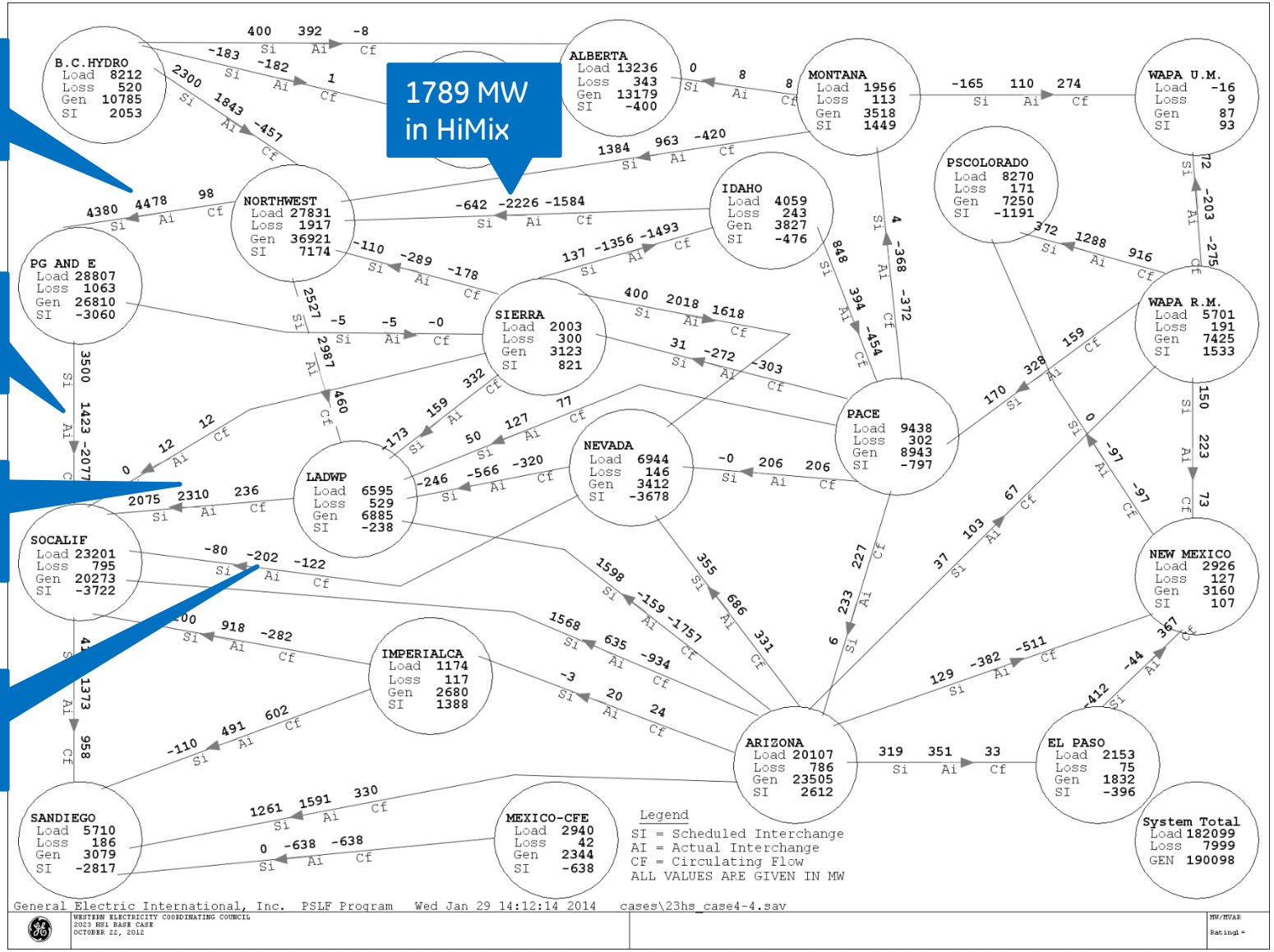
4836 MW in HiMix case

1789 MW in HiMix

1850 MW in HiMix case

2192 MW in HiMix case

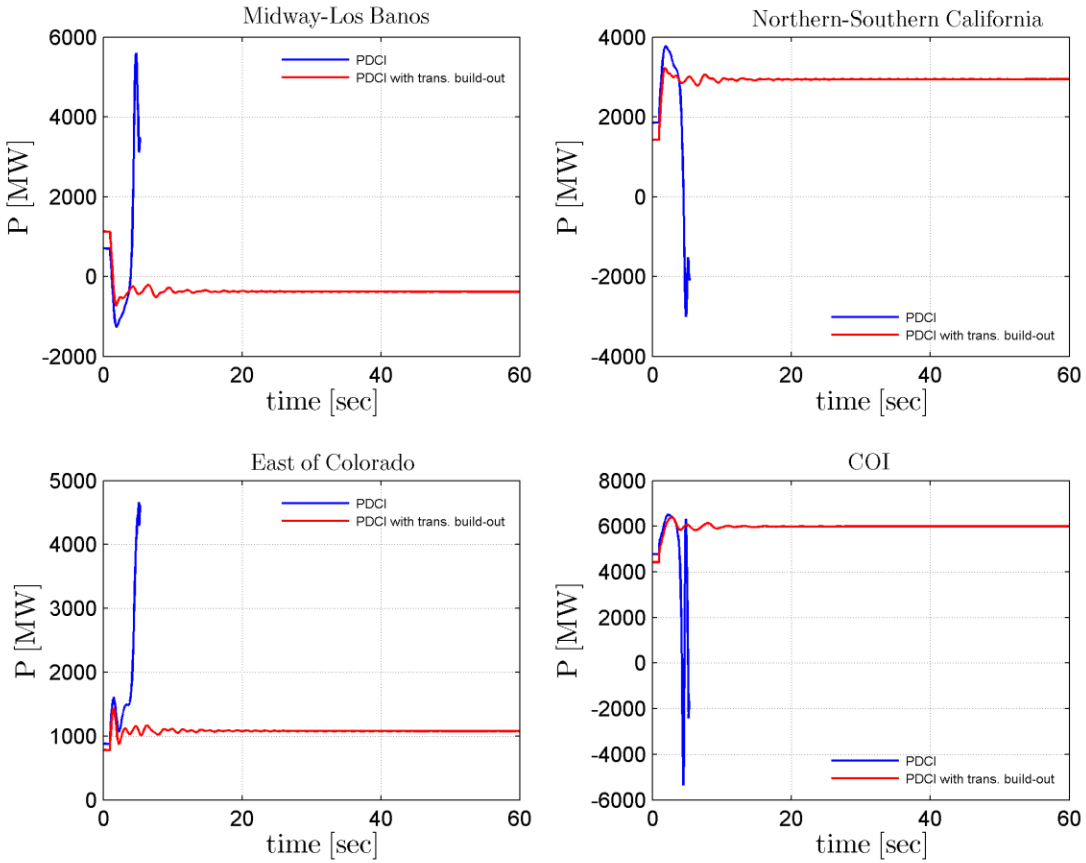
-424 MW in HiMix case



‘23 HS PDCI event with added transmission

Hi-Mix case vs. case with added transmission

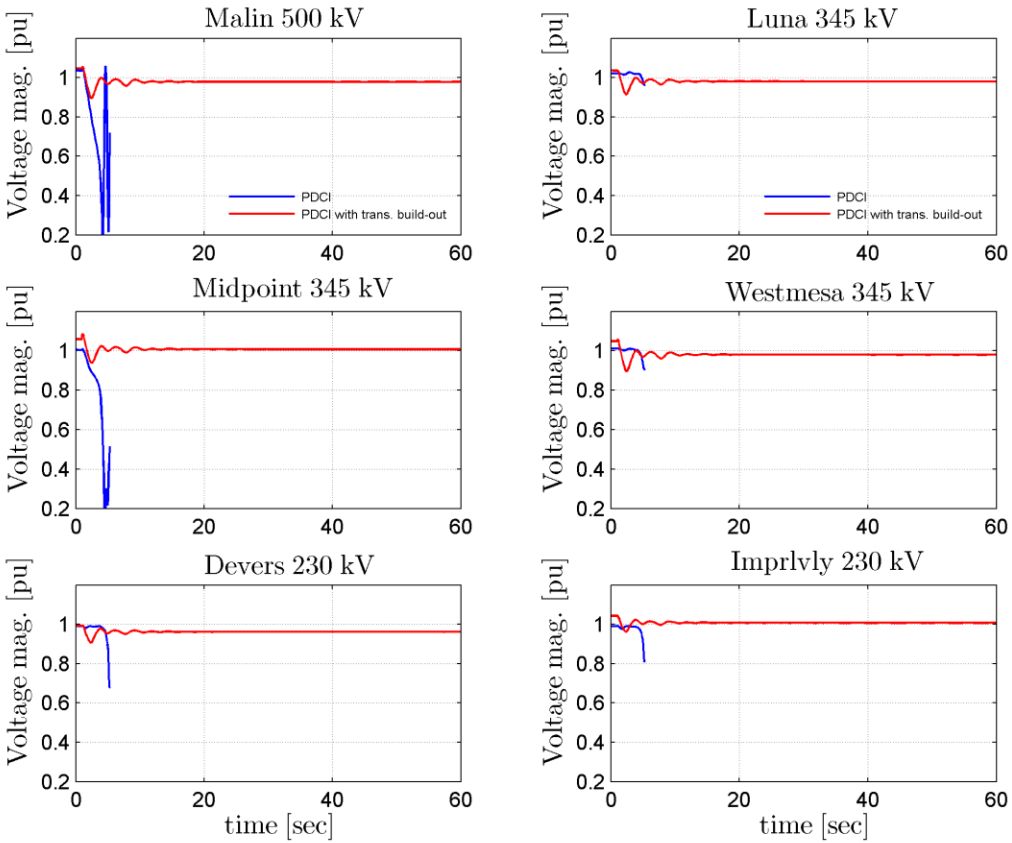
Added transmission stabilizes the system without generation tripping RAS



PDCI Event with Added Transmission

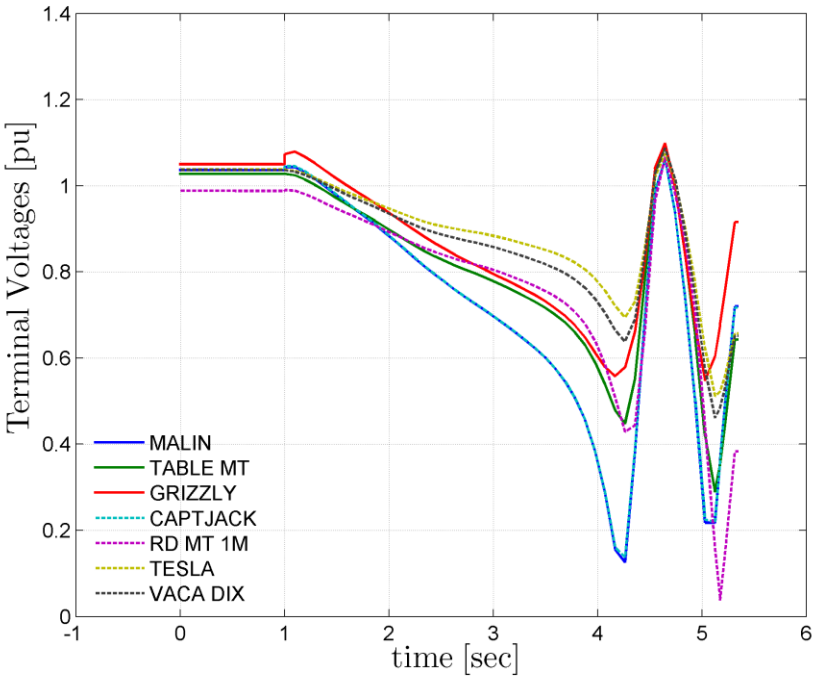
Hi-Mix case vs. case with added transmission

Added transmission stabilizes the system without generation tripping RAS

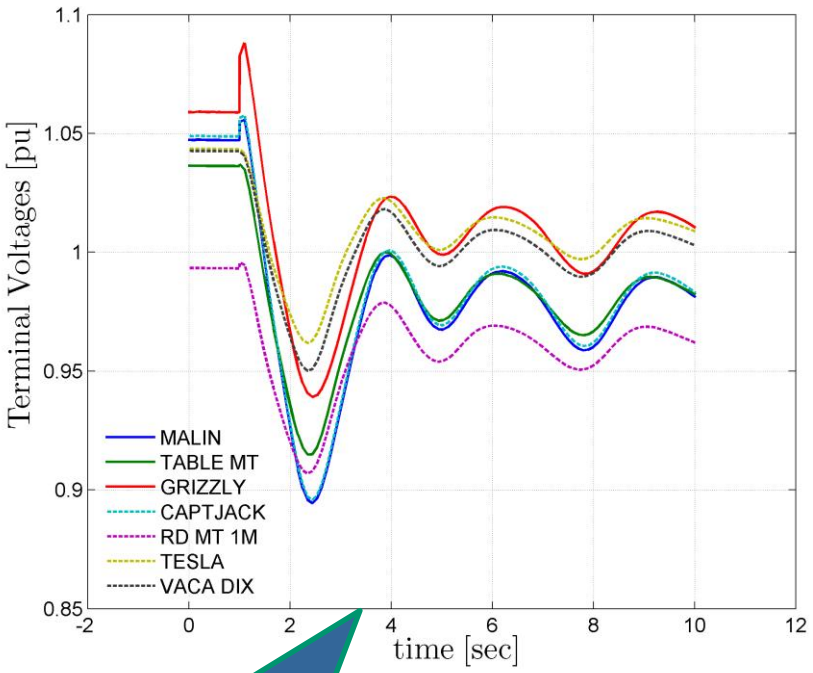


PDCI with Added Transmission

Hi-Mix case unstable



Hi-Mix case with transmission build-out stable



Comfortably meets WECC voltage criteria. Do interface limits change?

2.5 Load impacts/FIDVR/IEEE 1547 impact

- Effect of load response on fault recovery
- Voltage recovery of base case vs Hi Mix
- Effect of distributed PV low voltage tripping/ride through (IEEE 1547)
- Effective of IEEE 1547 during power swings (PDCI Event)

Composite Load Model

Original (case 1) modeled load as induction motor (motorw) + static

For HS23: 5848 loads modeled as 20% induction motor (~36 GW) + static (~156 GW), total load is ~192 GW

Added composite load model based on WECC Modeling & Validation WG Load Model Data Tool

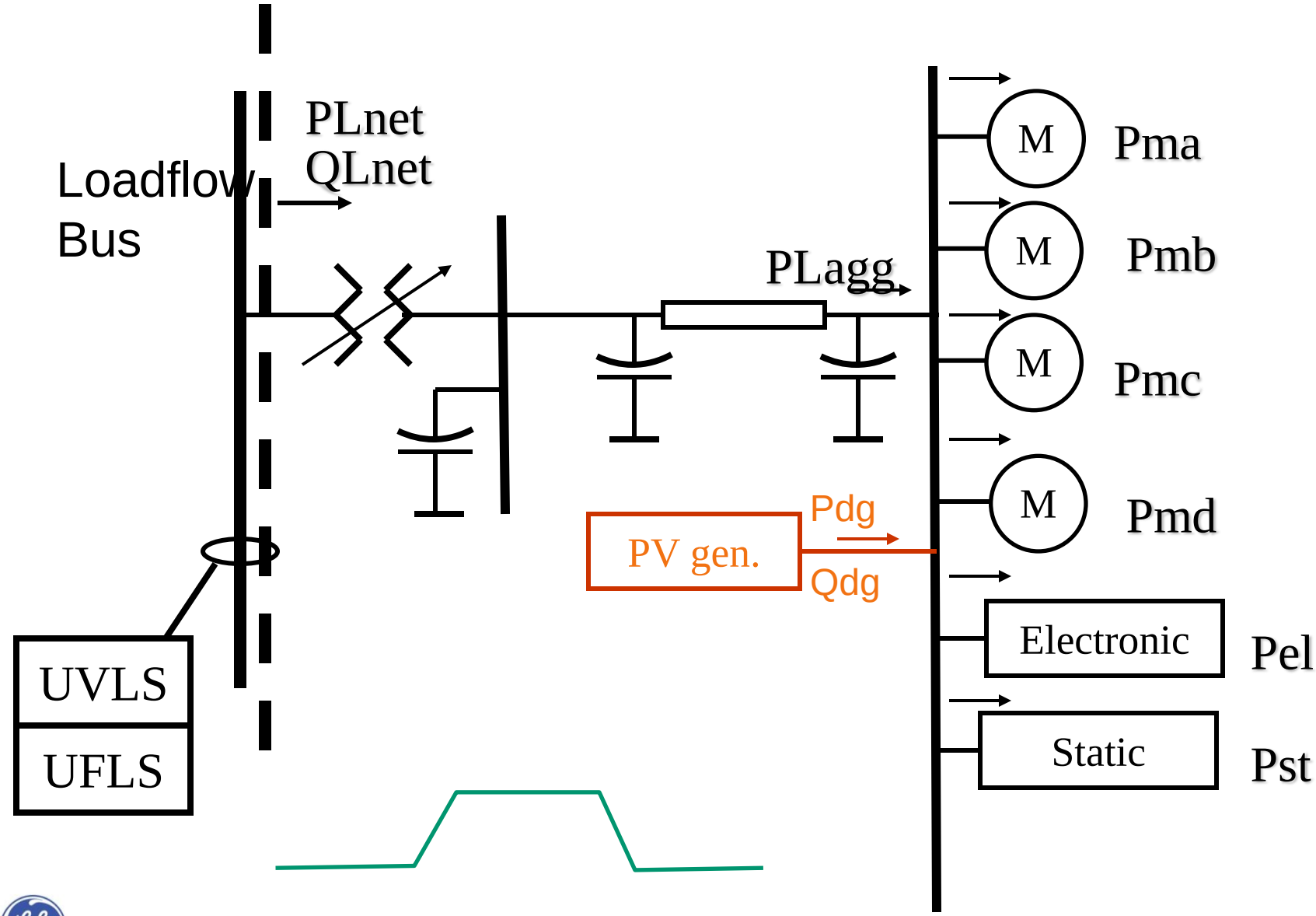
LSP: 4420 composite load models, 95.1 GW total load + distribution losses

22.3 GW of load not modified (modeled as static)

HS: 4408 composite load models, 143.9 GW total load + distribution losses

48.2 GW of load not modified (modeled as static)

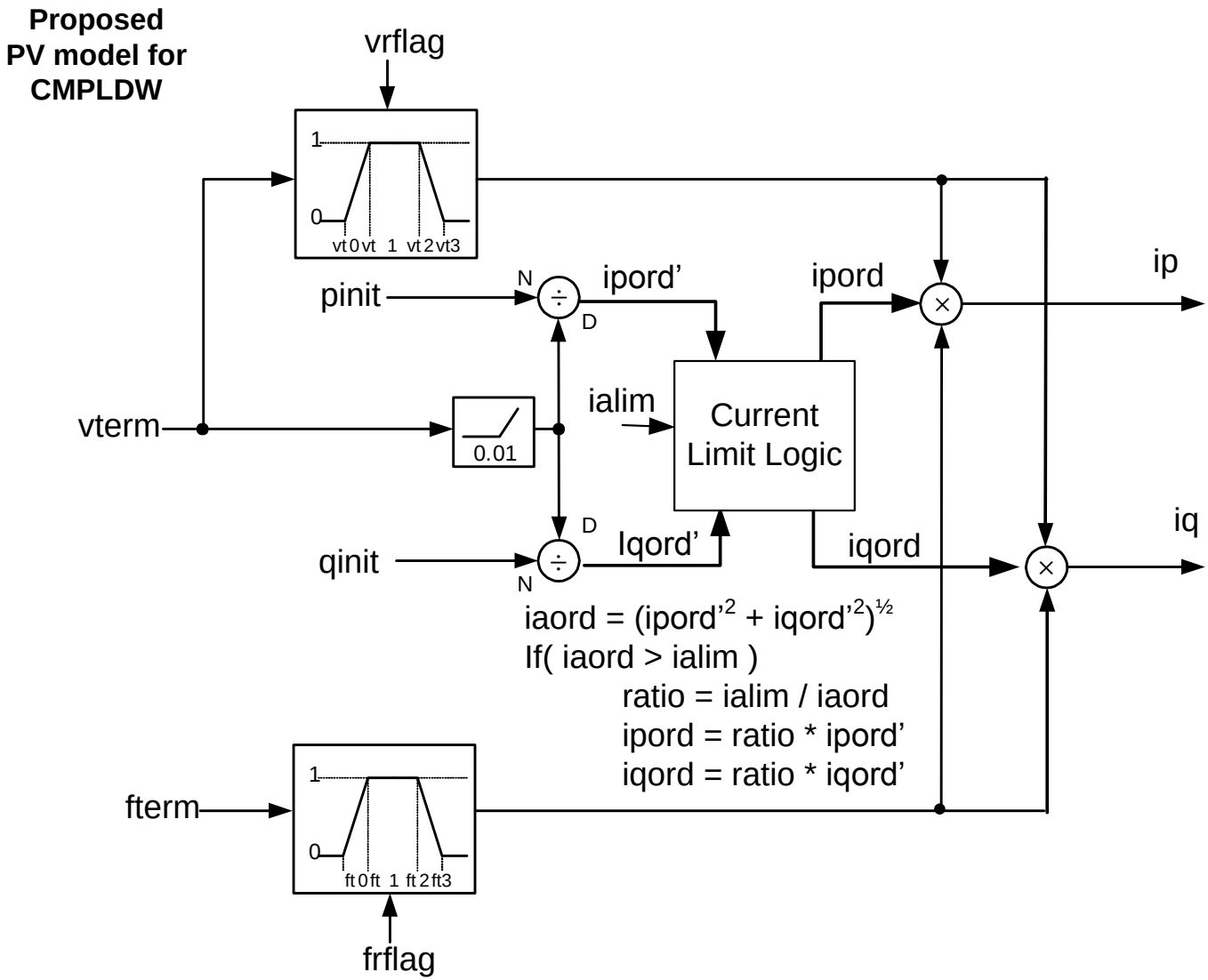
CMPLWG Model Structure with Distributed Generation



imagination at work

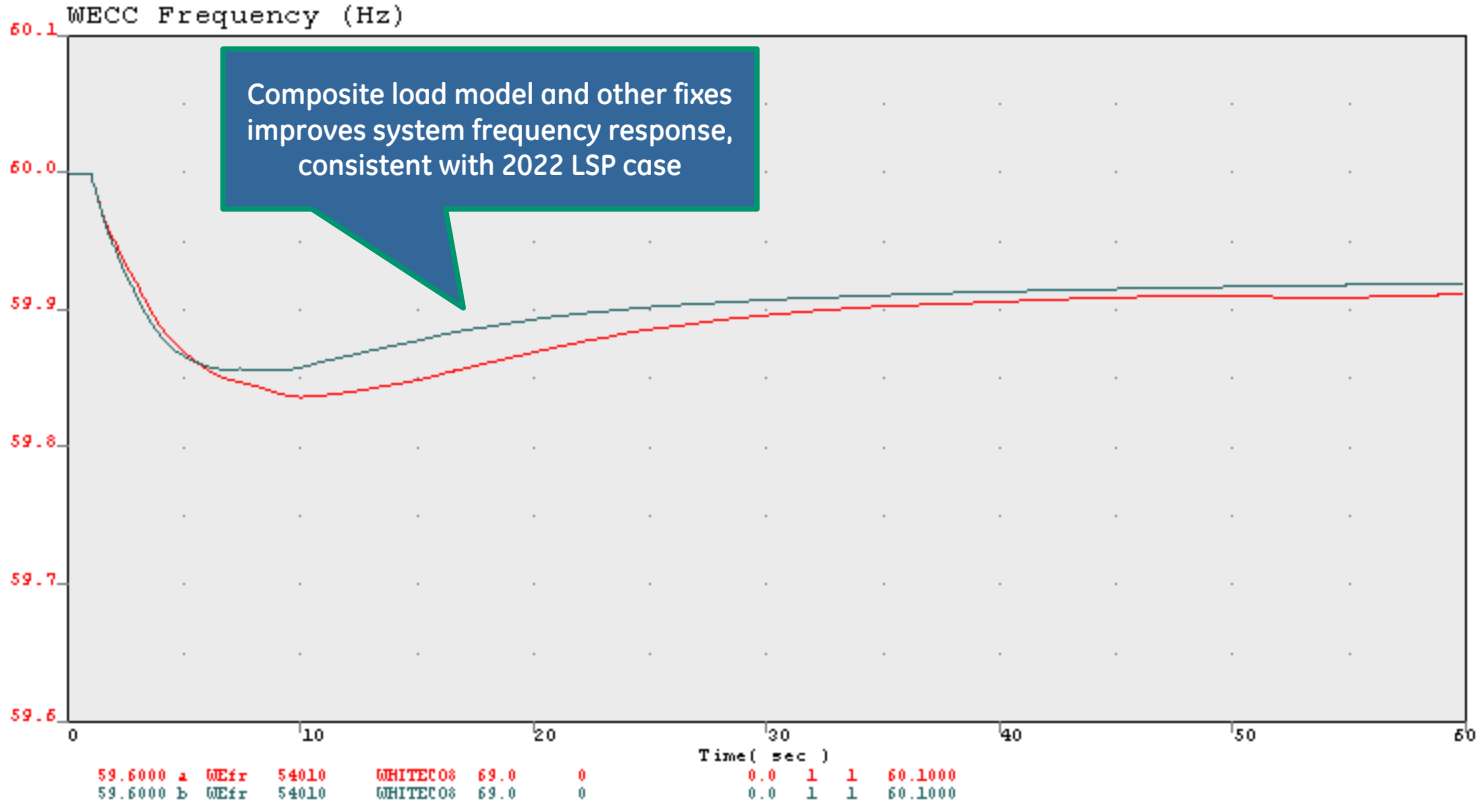
Proposed PV Dynamic Model for Inclusion in CMPLDWG

New Slide



imagination at work

WECC Frequency Response to Loss of 2 PV – 2023HS Standard Load (red) vs 2023HS Base Case (green)



imagination at work

TRC Call: Do not Cite - Not for Further Distribution

Midway-Vincent Fault with Composite Load Model HS23 Standard Load (blue) vs Base Case (red)

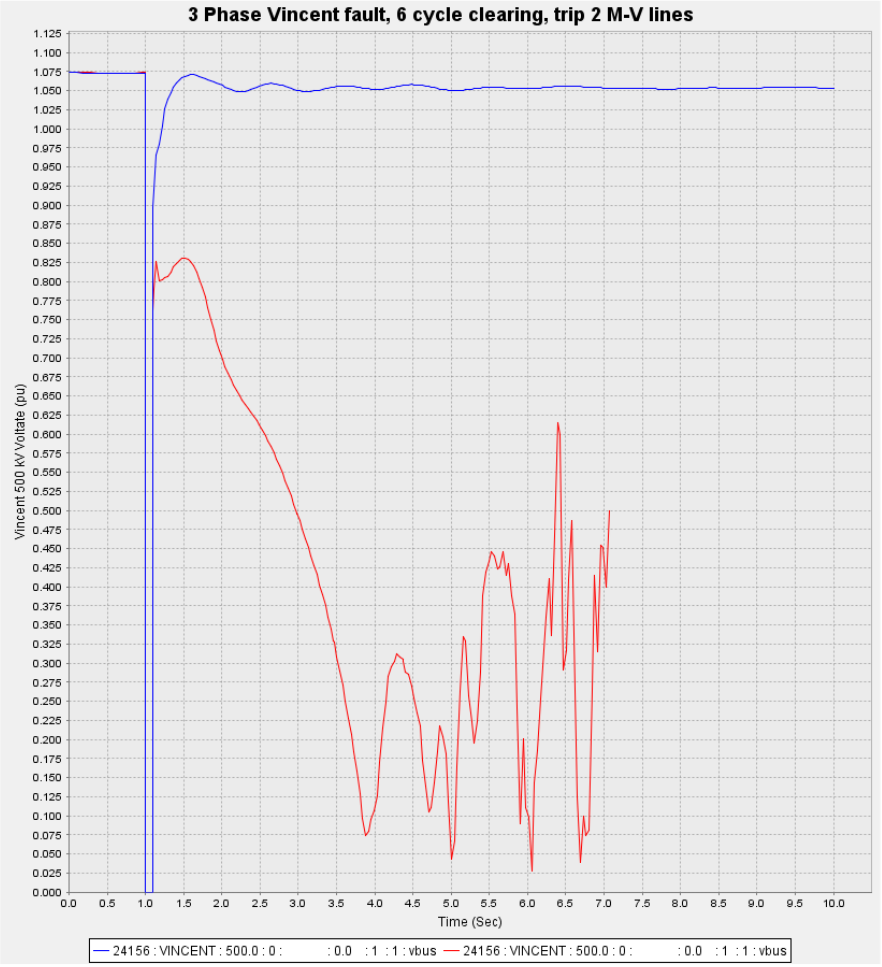
3Φ fault at Vincent 500 kV

Clear fault and trip 2 Midway-Vincent lines in 6 cycles

No load shedding in either case

C1 (blue): 192GW total load (in load table), modeled as induction motor (18% overall) + static – fast voltage recovery, very stable response

C2 (red): 143.9 GW modeled as composite load – fails to recover



Load behavior dominates system response for HS23 – Delayed/failed voltage recovery (FIDVR)

imagination at work

Midway-Vincent 23HS HiMix with Distributed PV

Base case C2 (blue) vs. HiMix case C3 (red)

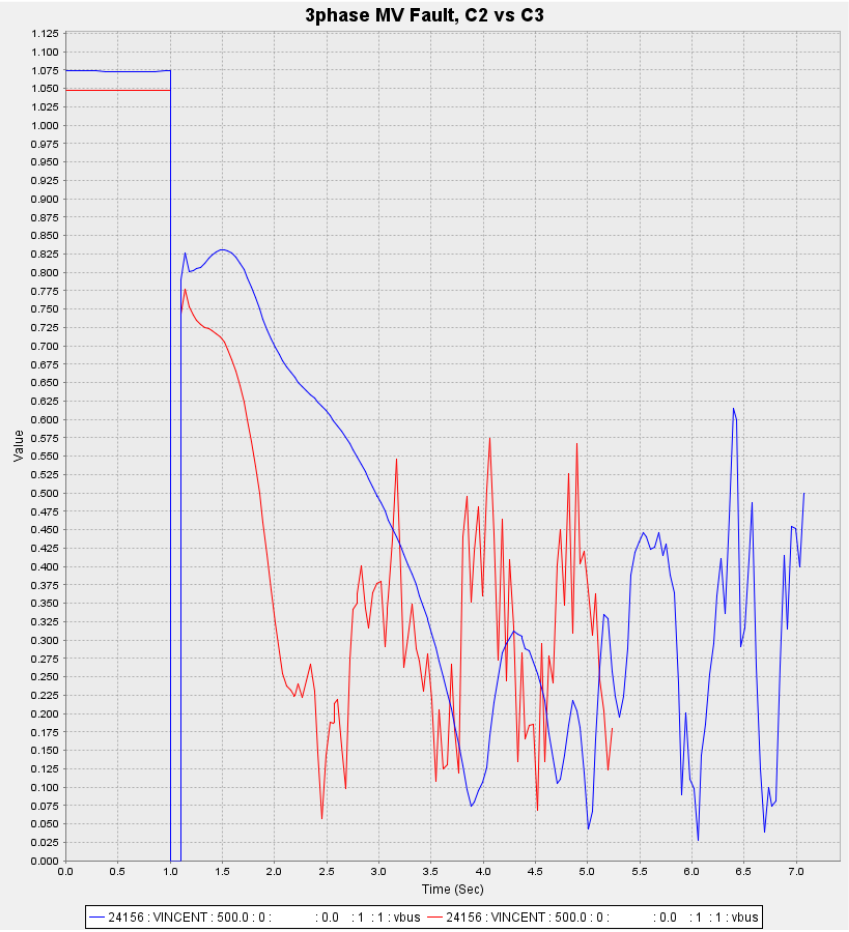
Fault current essentially the same for both cases

DPV voltage tripping response:

Full output between 0.8 and 1.1 pu
Trip below 0.7 pu, above 1.2 pu,
<u>no time delay</u>

~4.4 GW of DG tripped (of 9.3 GW total) within 100 ms throughout WECC, 4GW of tripped DG in LADWP and SCE alone

Response w/o DG tripping is between base case and HiMix case



Voltage fails to recover for Base and HiMix

Midway-Vincent 3Φ vs 1Φ Fault

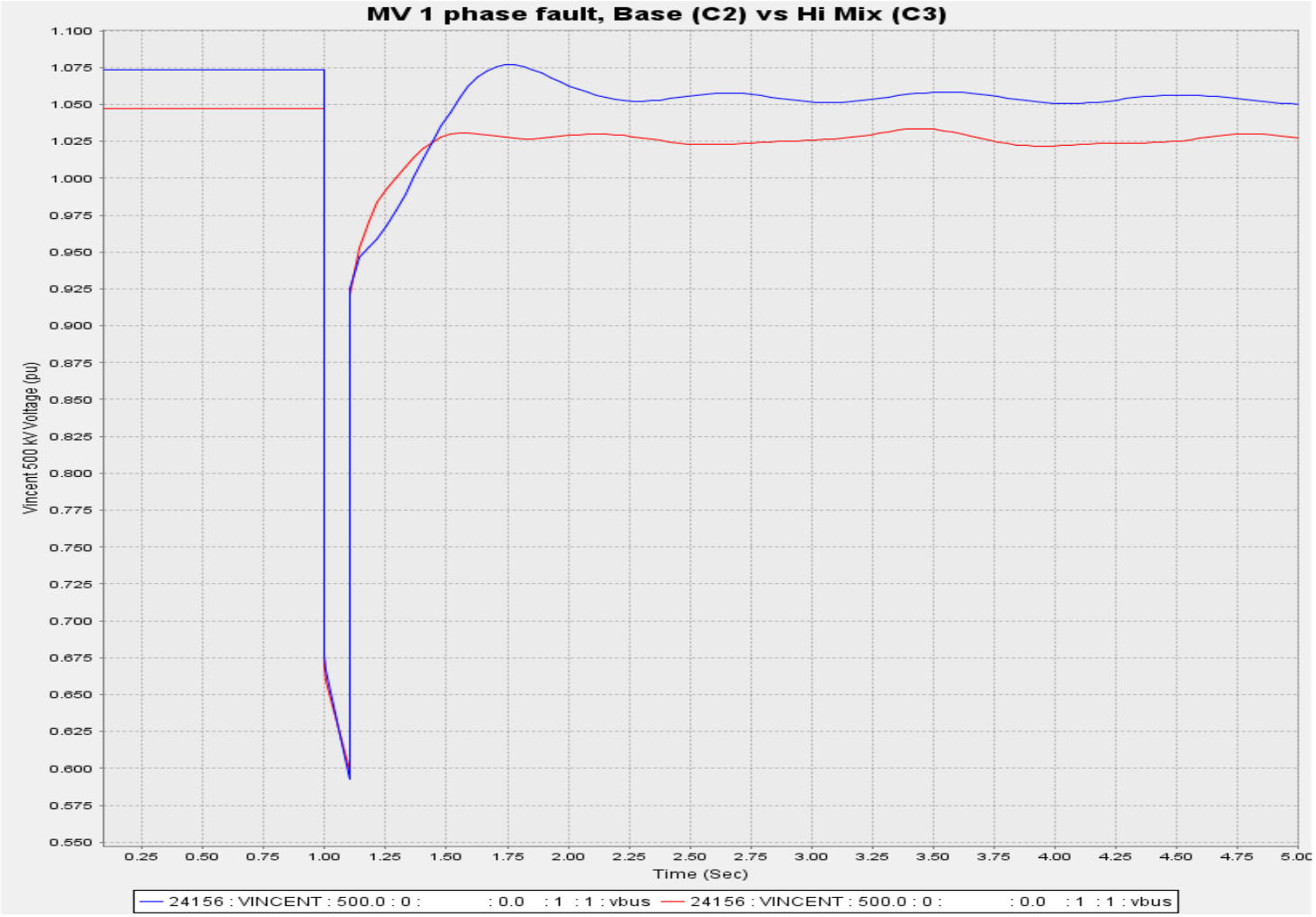
Fault impedance of .00005 + j.005 to approximate 1Φ fault.

No FIDVR issue with impedance fault

Load recovered within 50ms of fault clearing

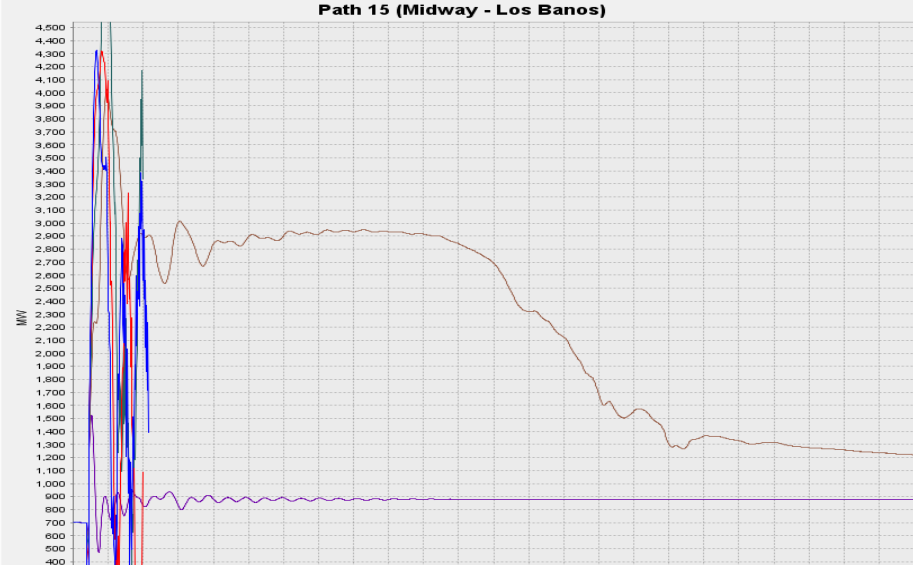
DG runback ~900 MW, fully recovers upon fault clearing

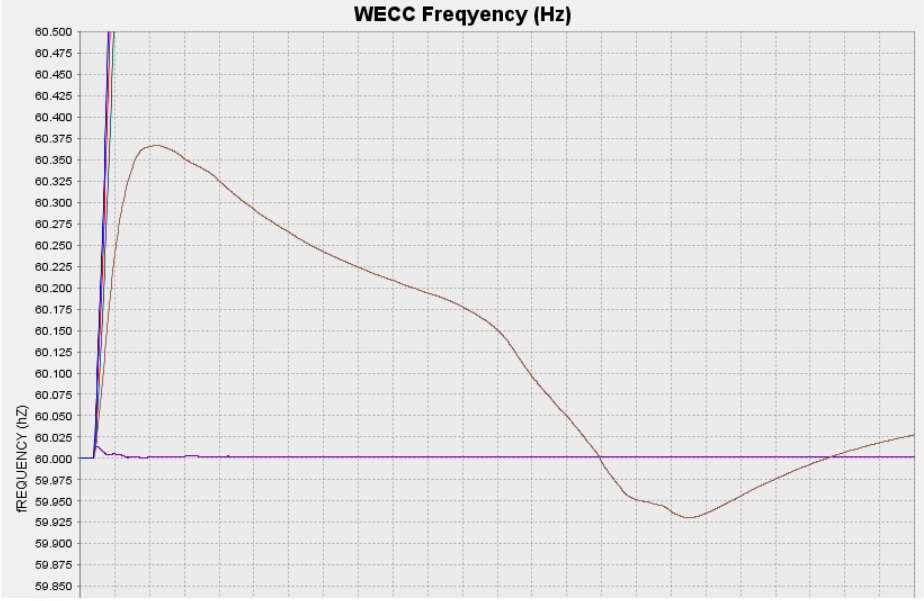
Midway-Vincent 1Φ Fault, 23HS Base (blue) vs HiMix (red)

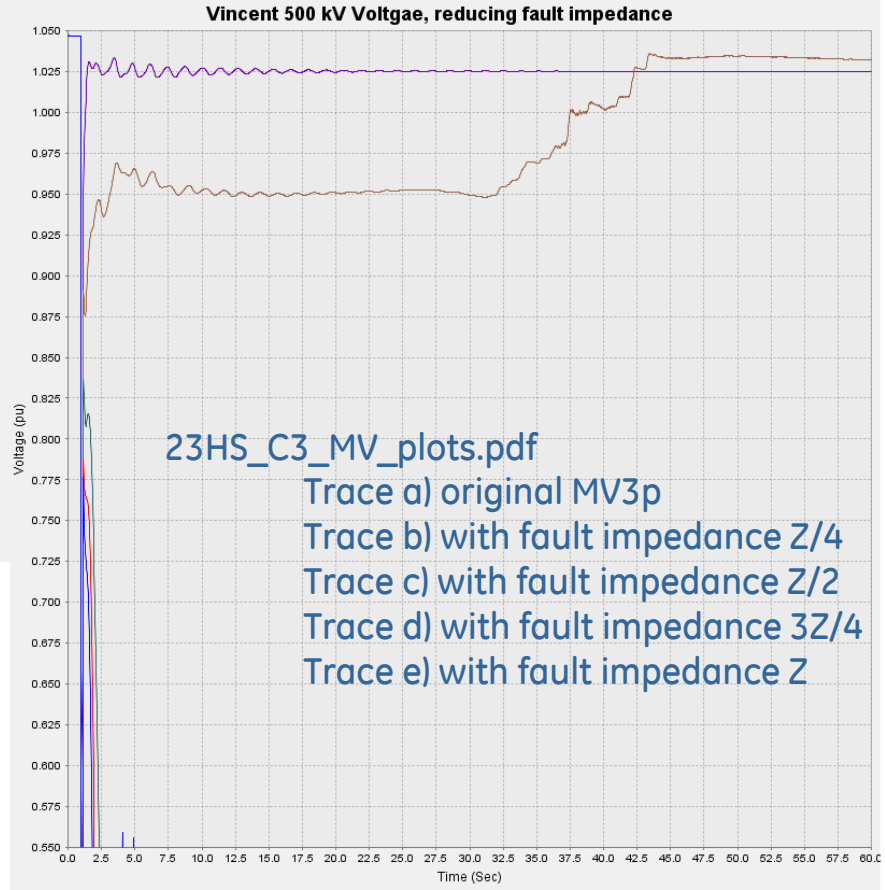


Renewables have little impact on voltage recovery

Midway–Vincent Fault Impedance Sensitivity







Fault impedance: reduced from .005 to 0.0 in 0.00125 pu steps

System is on the edge, regardless of renewable generation

IEEE 1547 Sensitivity

IEEE 1547a – Voltage Ride Through

…

When any voltage is in a range given in Table 1, the DR shall cease to energize the Area EPS 16 within the clearing time as indicated. Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted. Clearing time is the time between the start of the abnormal condition and the DR ceasing to energize the Area EPS. For DR less than or equal to 300 kW in peak capacity, the voltage set points and clearing times shall be either fixed or field adjustable. For DR greater than 300 kW, the voltage set points and clearing times shall be field adjustable.

…

Composite load model with DG does NOT have time delays for tripping

Default settings [a]		
Voltage range (% of base voltage [b])	Clearing time(s)	Clearing time: adjustable up to and including (s)
V<45	0.16	0.16
45≤V<60	1.00	11
60<V<88	2.00	21
110≤V<120	1.00	13
V≥120	0.16	0.16

[a] Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted

[b] Base voltages are the nominal system voltages stated in ANSI C84.1-2011, Table 1.

IEEE 1547a – Frequency Ride Through

~~Table 4.3 Interconnection system response to abnormal frequencies~~

~~DR size~~	~~Frequency range (Hz)~~	~~Clearing time(s)~~ [a]
~~≤ 30 kW~~	~~>60.5~~	~~0.16~~
	~~<59.3~~	~~0.16~~
~~>30 kW~~	~~>60.5~~	~~0.16~~
	~~<{59.8 – 57.0}~~ ~~(adjustable set point)~~	~~Adjustable 0.16 to 300~~
	~~<57.0~~	~~0.16~~

Table 4.4 Interconnection system default response to abnormal frequencies

	Default settings		Ranges of adjustability	
Function	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s) adjustable up to and including
UF1	57	0.16	56 – 60	10
UF2	59.5	2	56 – 60	300
OF1	60.5	2	60 - 64	300
OF2	62	0.16	60 – 64	10

Composite load model with DG does NOT have time delays for tripping

imagination at work

Midway-Vincent Fault, Impact of Distributed PV Recovery

Fault impedance of .00005 + j.005 to approximate 1Φ fault.

DPV voltage tripping response:

Full output between 0.8 and 1.1 pu

Trip below 0.7 pu, above 1.2 pu

Blue Trace – full recovery (runback)

Red Trace - no recovery (trip)

825 MW of DPV tripped (out of 9.4 GW) , roughly 530 MW picked up by responsive generation

imagination at work

Midway-Vincent Fault, Impact of Distributed PV Recovery

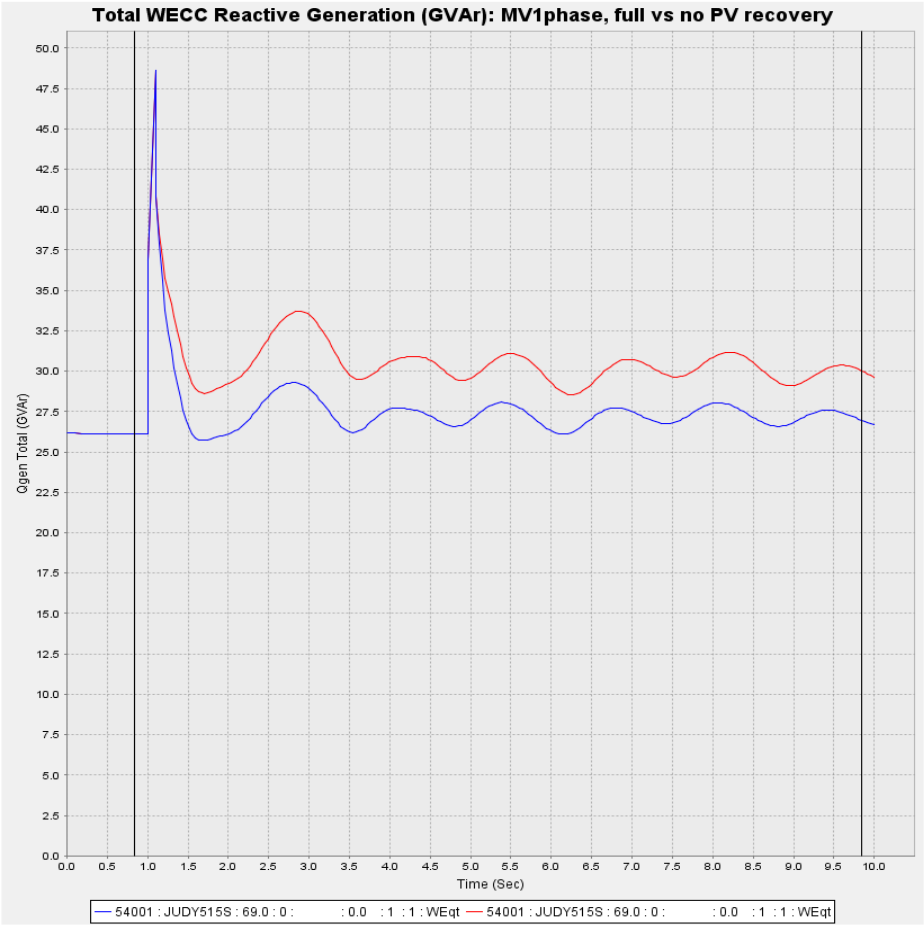
Impact on Reactive Generation

Plots show total WECC Qgen

Blue Trace – DPV full recovery

Red Trace - 825 MW of DPV tripped

Voltage recovers 0.012pu lower with tripped DG, slightly slower recovery

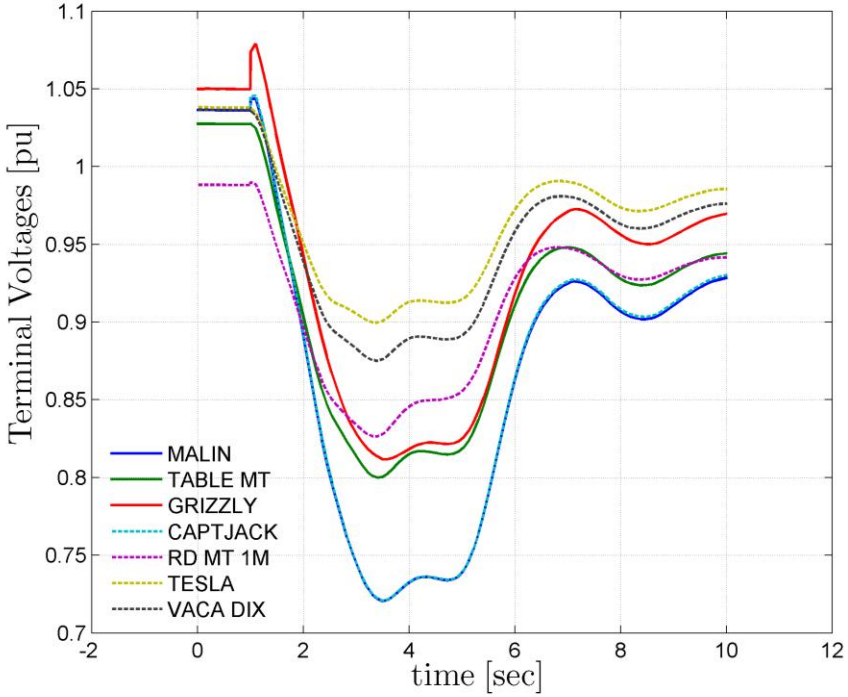


825 MW of tripped DPV "costs" system ~3100 MVAr

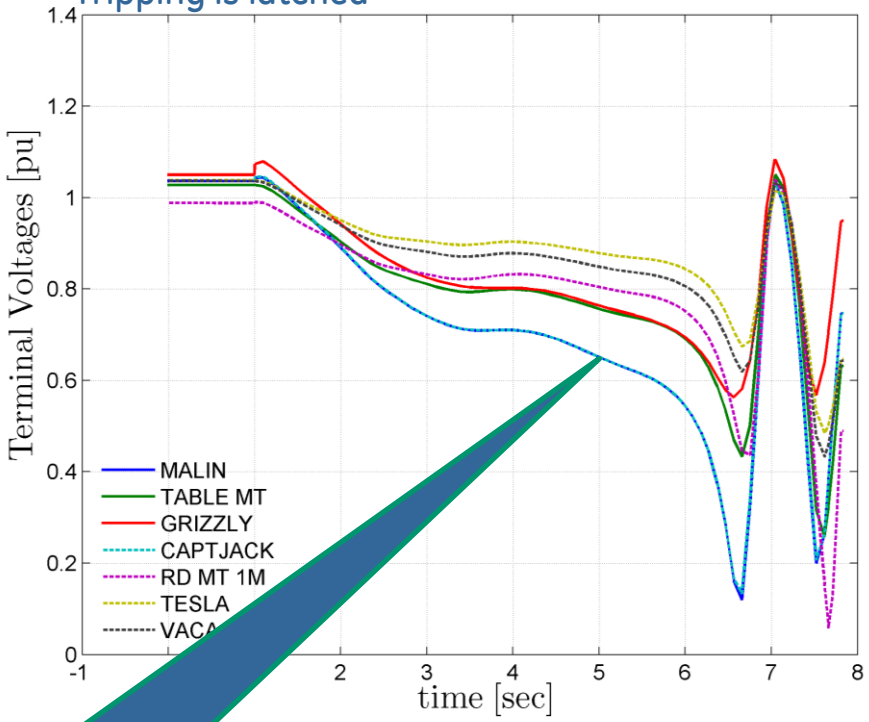
PDCI with Minimum Generation Trip

Hi-Mix case with 1xJDA tripping (gr1a1)

DPV voltage tripping response:
Full output between 0.8 and 1.1 pu
DG Trip below 0.7 pu, above 1.2 pu
Full output upon voltage recovery



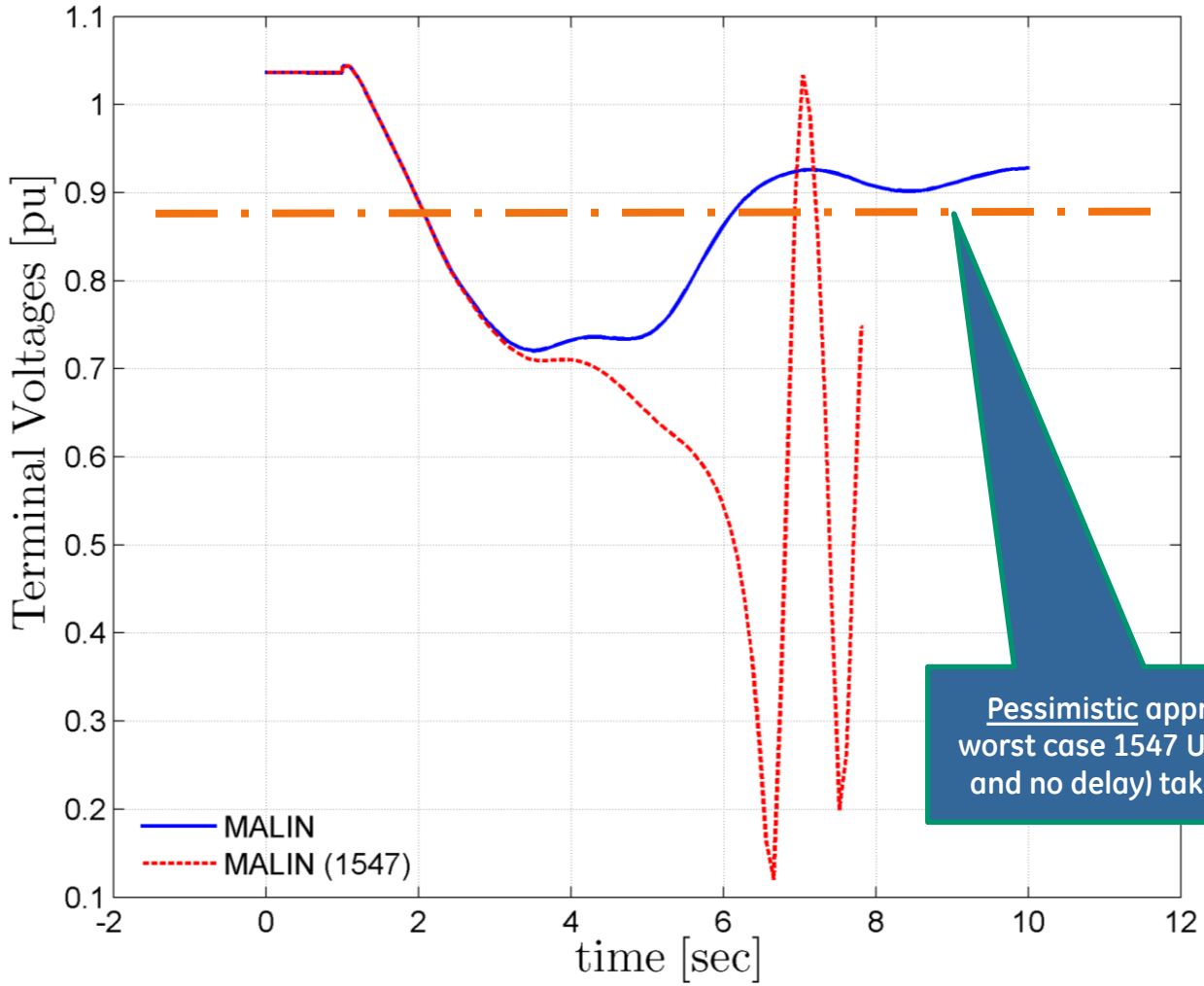
DPV voltage tripping approximates IEEE 1547:
Full output between 0.88 and 1.1 pu
DG Trip below 0.83 pu, above 1.2 pu (no time delay)
Tripping is latched



Pessimistic approximation to worst case 1547 UV tripping (88% and no delay) takes down WECC

PDCI with Minimum Generation Trip

DG LV tripping drives response unstable

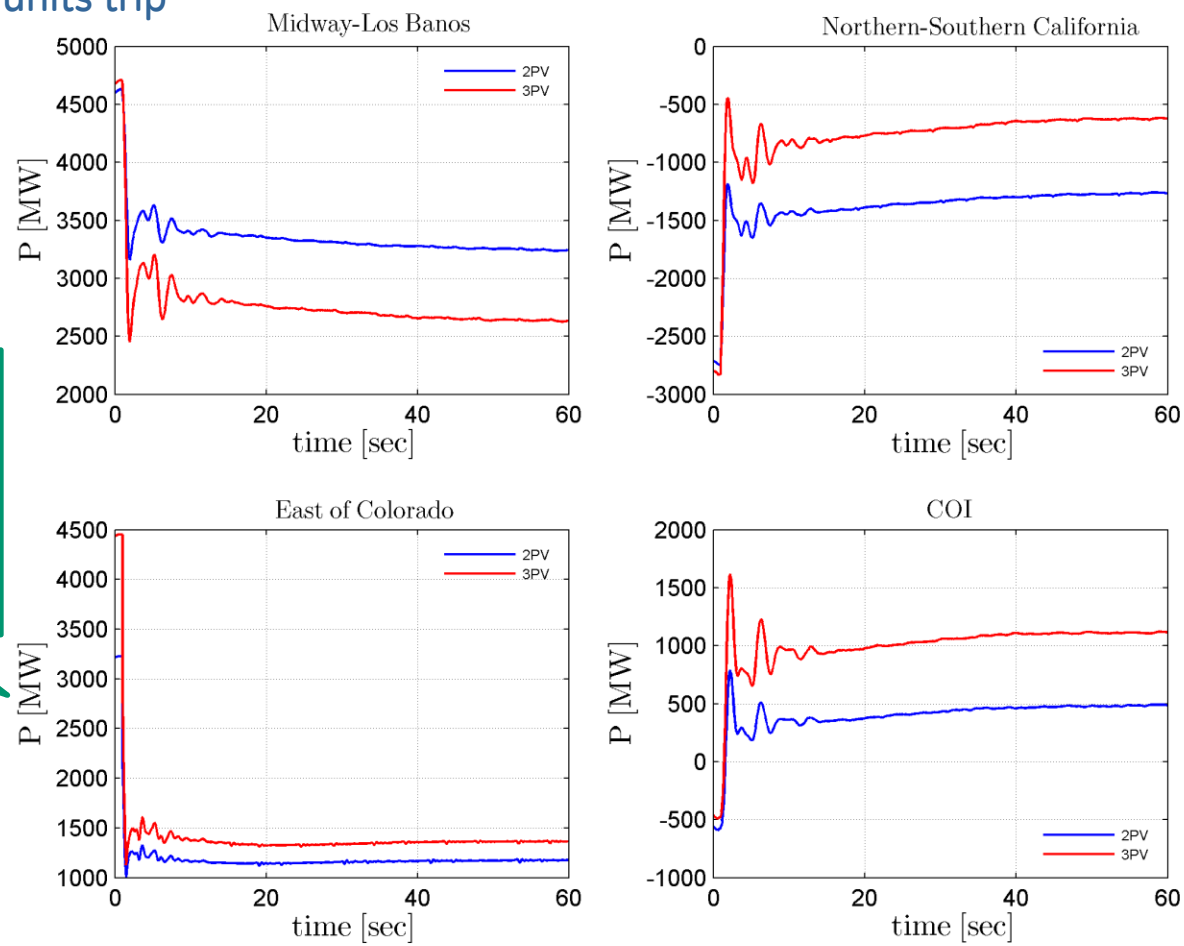


Pessimistic approximation to worst case 1547 UV tripping (88% and no delay) takes down WECC

Extreme Generation Tripping

Extreme Generation Tripping

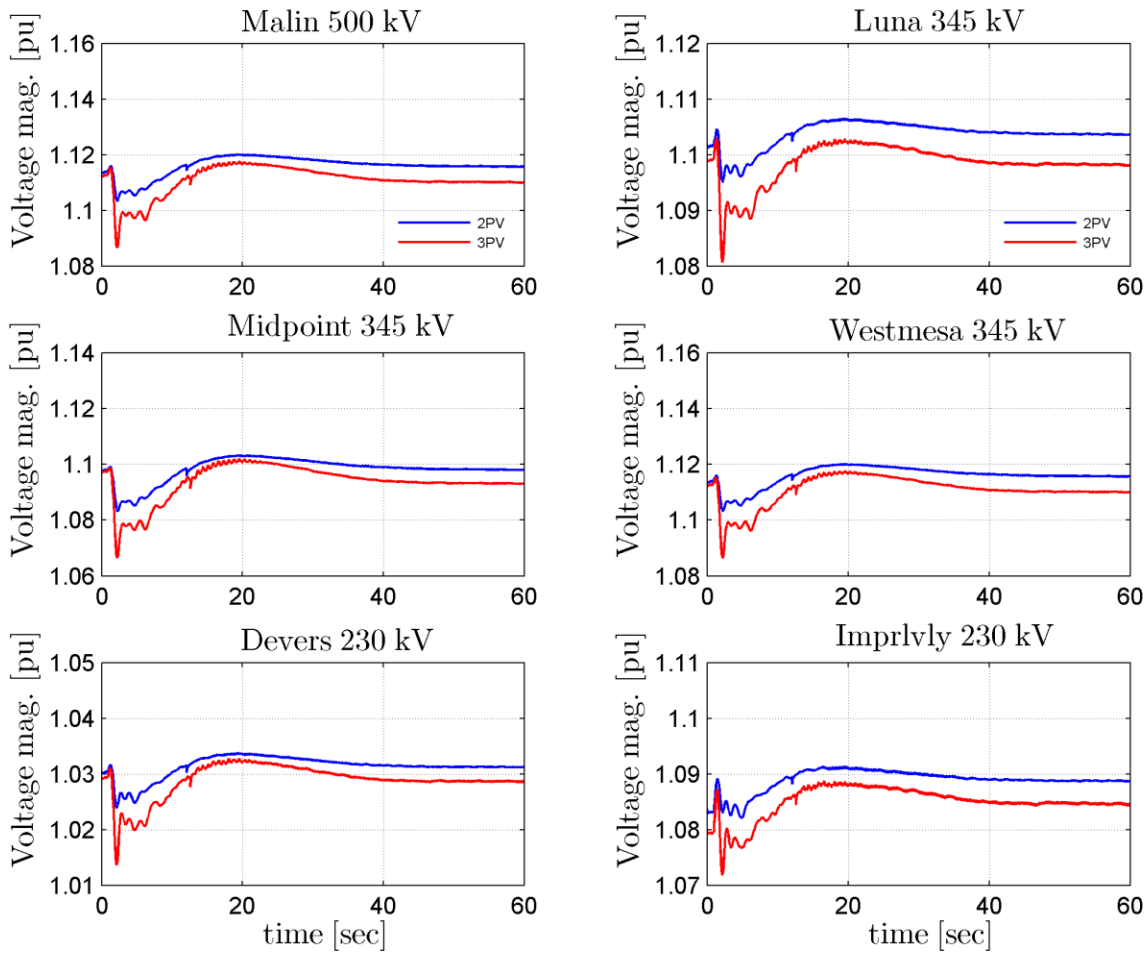
Hi-Mix case - 2Palo Verde units trip vs Slightly modified Hi-Mix case and 3Palo Verde units trip



Cases do not start from the same point, since we had to turn on Palo Verde #1 and turn off SONGS unit

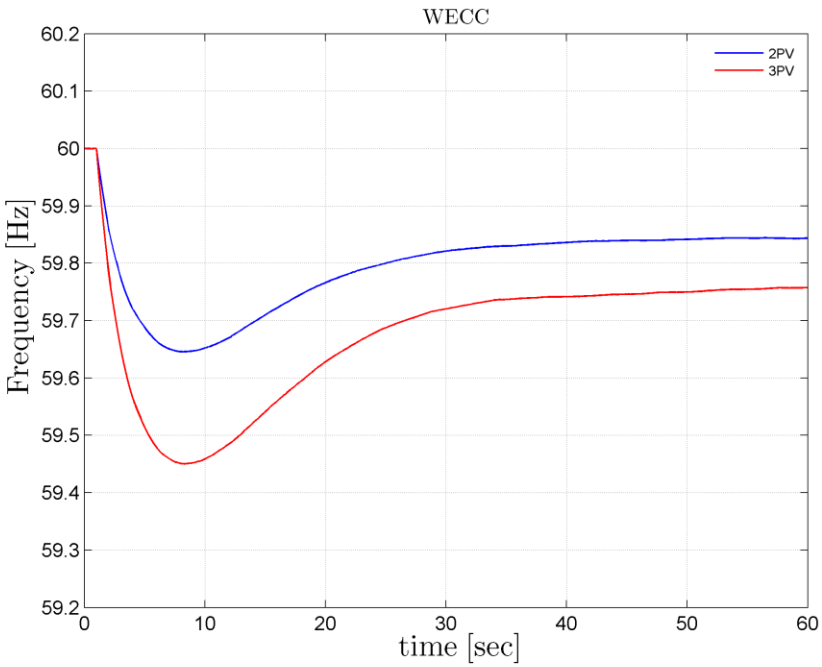
Extreme Generation Tripping

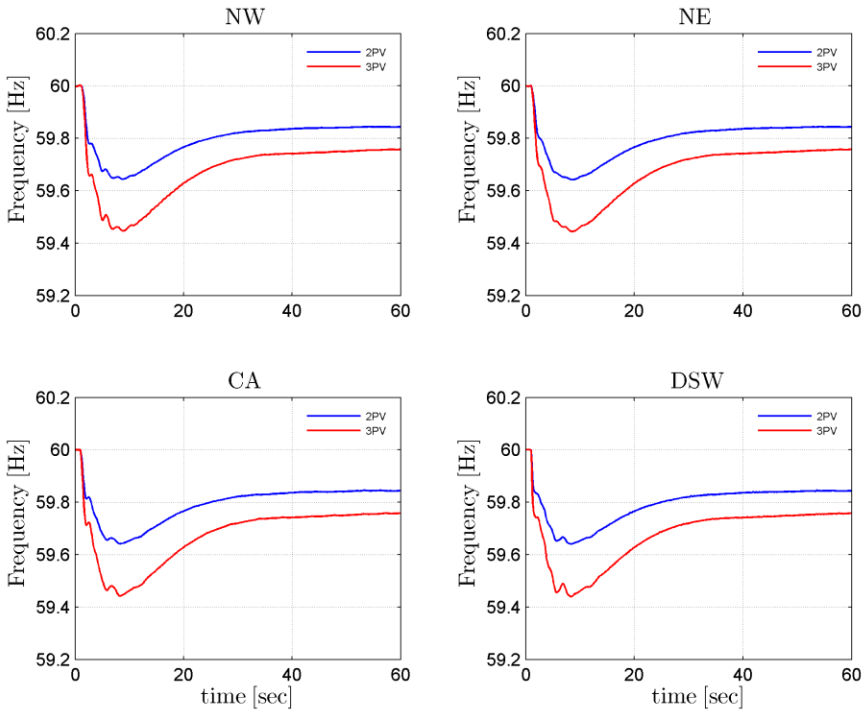
2 Palo Verde Trip
vs
3 Palo Verde Trip



Extreme Generation Tripping

2 Palo Verde Trip
vs
3 Palo Verde Trip



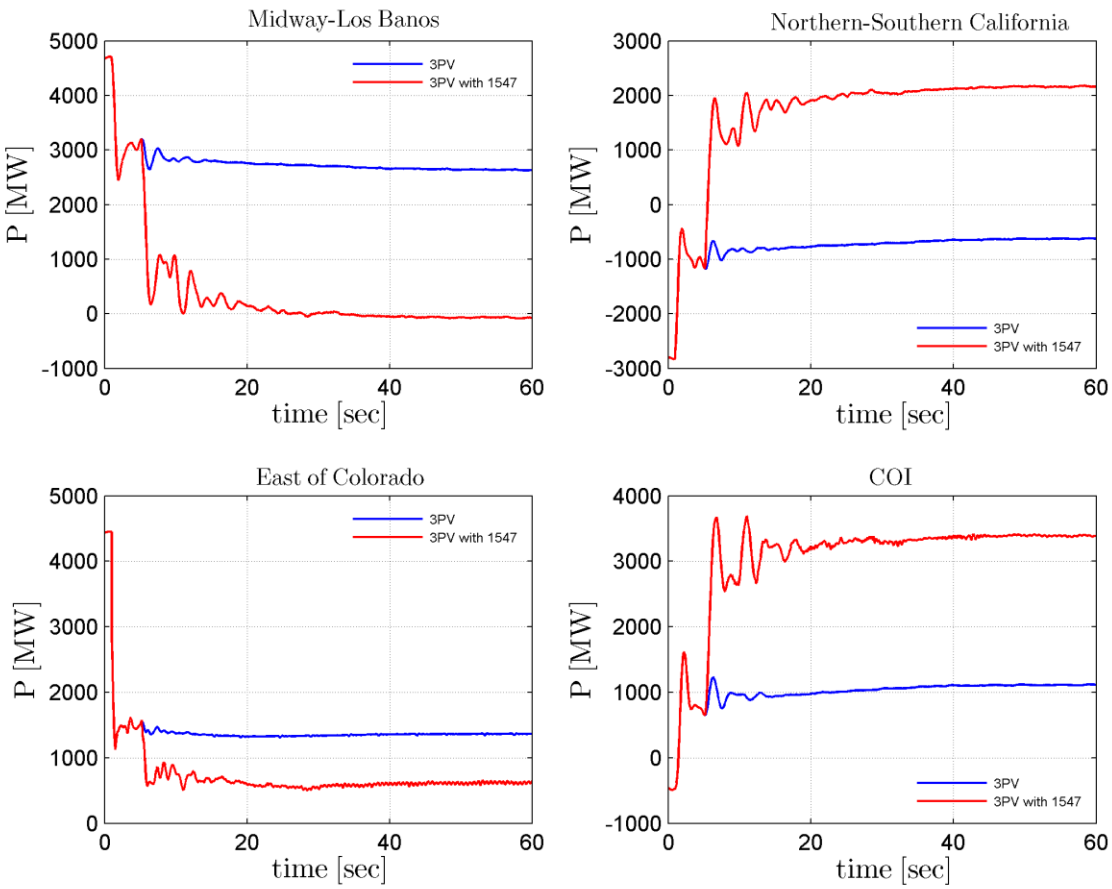


Extreme Generation Tripping

3PV vs 3PV with 1547 UF Tripping

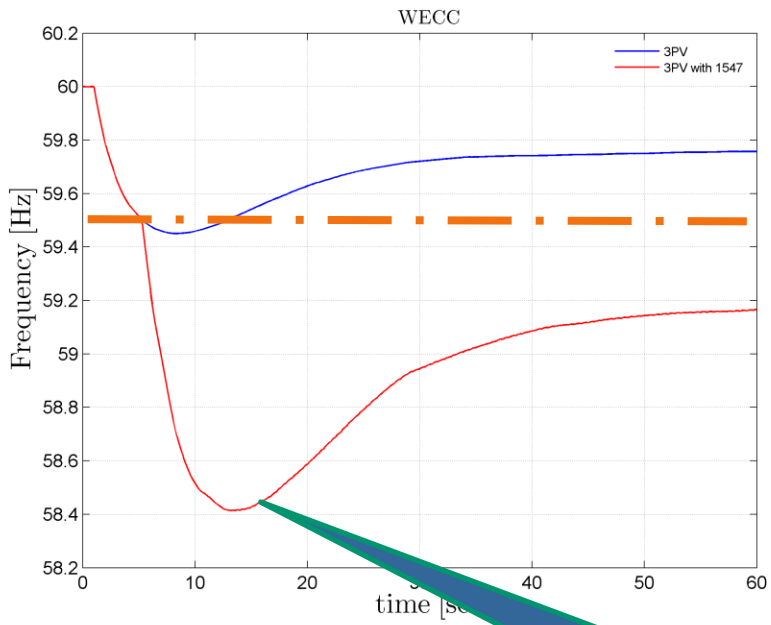
Slightly modified Hi-Mix case and 3PV event vs Slightly modified Hi-Mix case and 3PV event and 1547 under-frequency tripping (under-voltage 1547 as well)

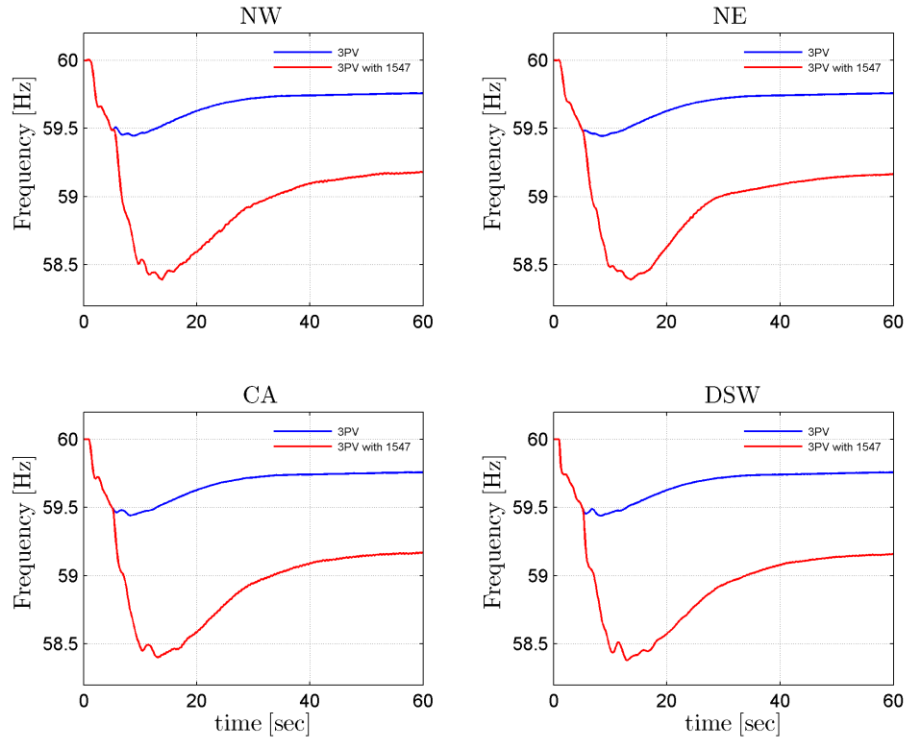
Settings for under-frequency:
Ft0=59.4
Ft1=59.5
Frequency tripping is instantaneous and latching



Extreme Generation Tripping

3 Palo Verde Trip
vs
3PV with 1547



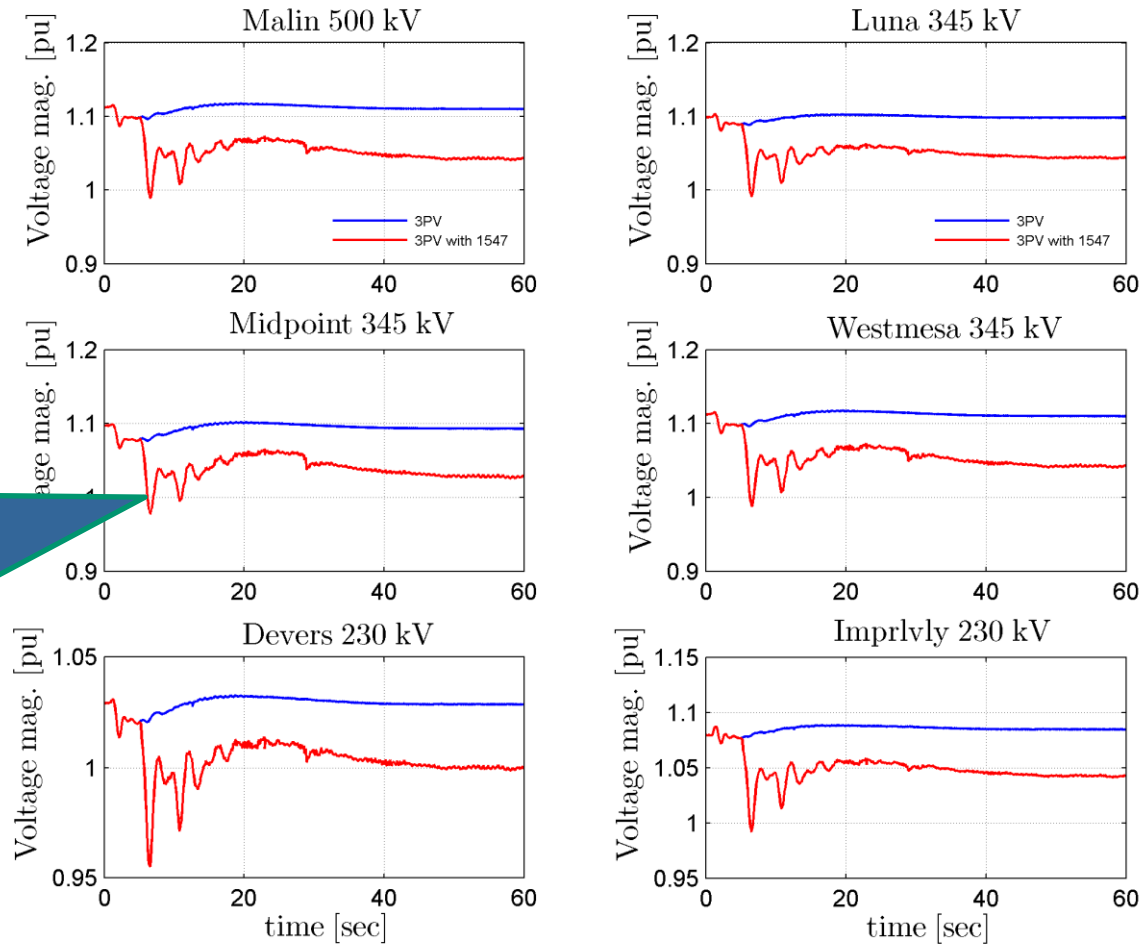


Pessimistic approximation to worst case 1547 UF tripping (59.5Hz and no delay) severely damages operations of WECC

imagination at work

Extreme Generation Tripping

3PV vs 3PV with 1547



Pessimistic approximation to worst case 1547 UF tripping (59.5Hz and no delay) messes up voltage. Could it be tolerated if necessary?

Extreme Generation Tripping

2 Palo Verde Trip

vs

3 Palo Verde Trip

			2PV	3PV
ID	Name	ID	FR [MW/0.1Hz]	FR [MW/0.1Hz]
1	WECC	WE	1311	1265
2	CALIFORNIA	CA	312	302
3	DSW	DS	119	107
4	NORTHEAST	NE	47	52
54	ALBERTA	AL	0	0
14	ARIZONA	AZ	50	42
50	B.C.HYDRO	BC	0	0
11	EL PASO	EL	4	2
60	IDAHO	ID	22	24
21	IMPERIALCA	IV	14	14
26	LADWP	LA	30	30
20	MEXICO-CFE	MX	0	0
62	MONTANA	MT	10	14
18	NEVADA	NV	34	33
10	NEW MEXICO	NM	2	2
40	NORTHWEST	NW	483	463
65	PACE	PC	8	7
30	PG AND E	PG	197	191
70	PSCOLORADO	CO	6	5
22	SANDIEGO	SD	7	7
64	SIERRA	SP	7	7
24	SOCALIF	SC	63	59
52	FORTISBC	FB	0	0
73	WAPA R.M.	WR	24	23
63	WAPA U.M.	WU	3	3

- FR should be nominally be the same, since the initial conditions are the same.
- But for larger events, some resources are exhausted, so FR declines slightly, as expected

2.6 More Localized Stability Issues

Preliminary Results: Not for Further Distribution or Citation

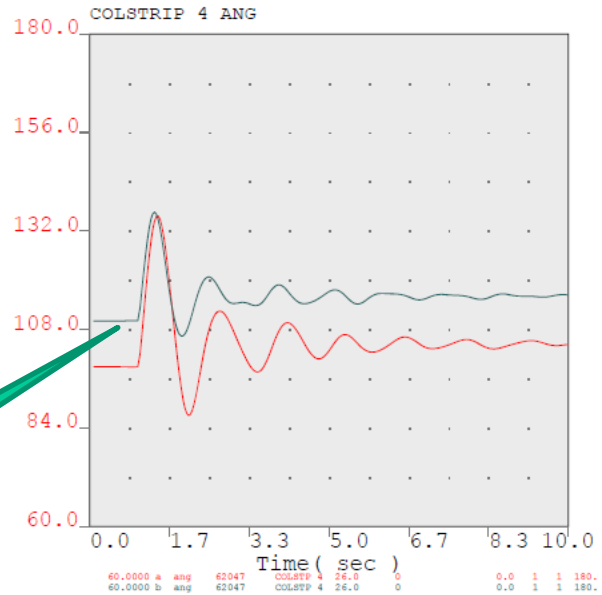
Local Stability

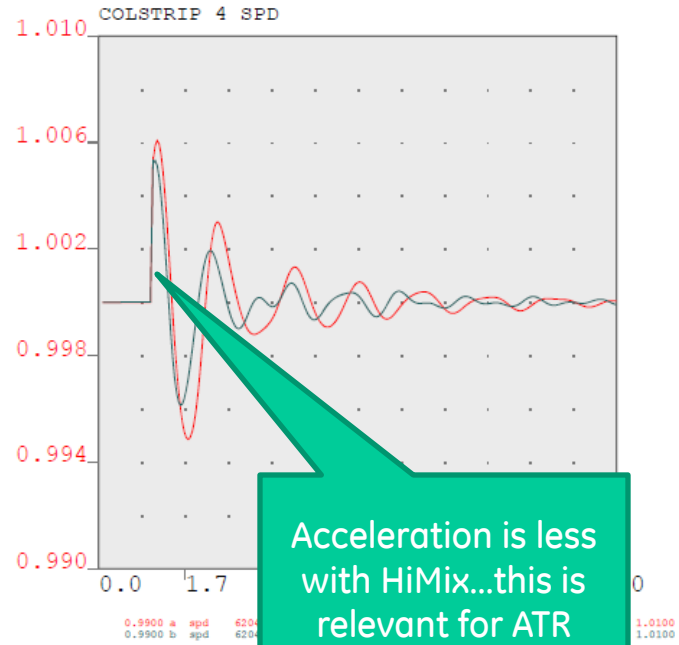
- Colstrip Cases (Broadview fault)
  - 3ph fault @ Broadview 500 kV, cleared after 3 cycle and trip line Broadview – Town – Garrison
- Laramie River Cases
  - 3ph fault @ Laramie River 345 kV, cleared after 4 cycle and trip line Laramie River – Archer TS - Story

TRC Call: Do not Cite - Not for Further Distribution

Colstrip

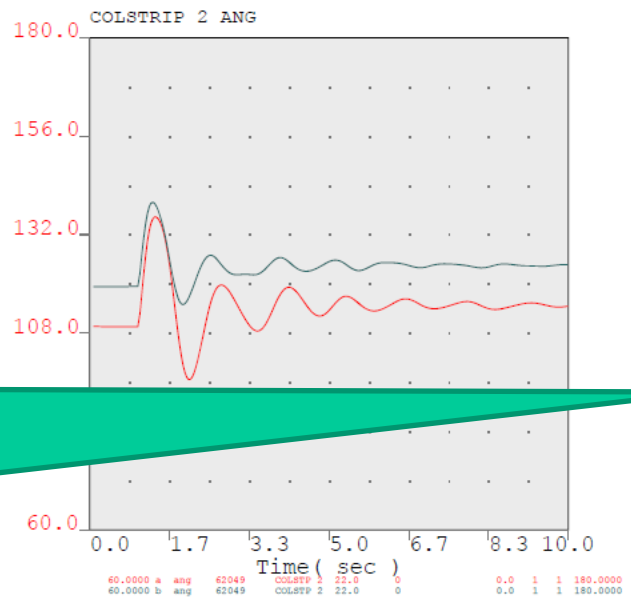
- Base Case vs HiMix Case

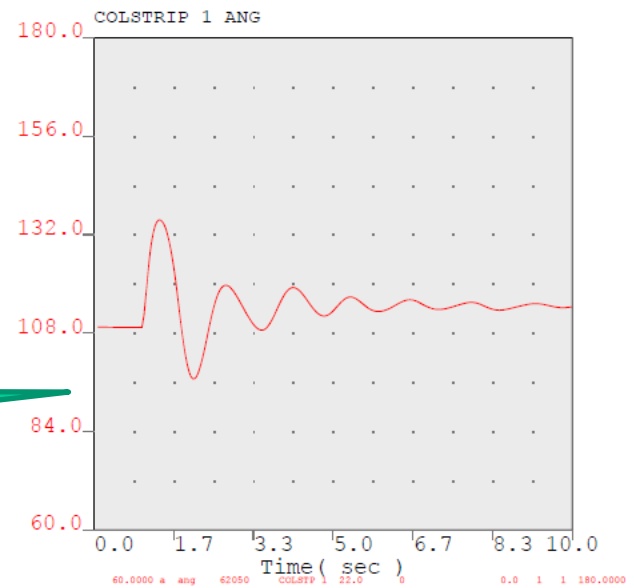




Angle swing delta less with hi-mix

Acceleration is less with HiMix...this is relevant for ATR



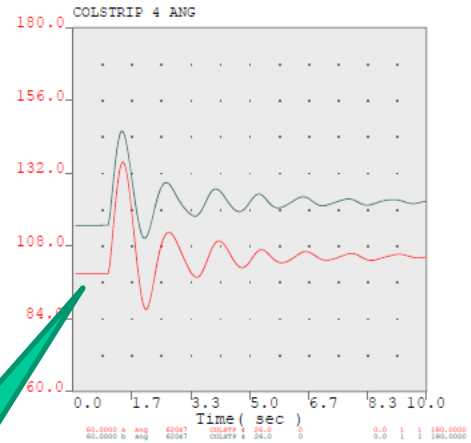


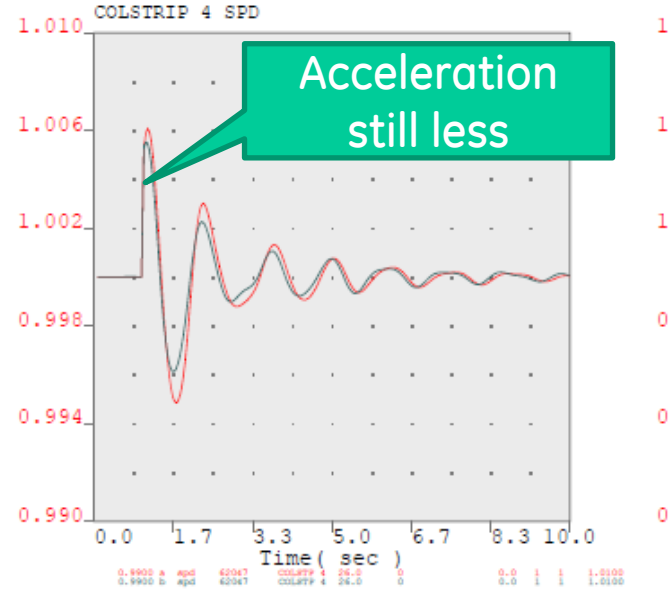
Colstrip 1 decommited for high mix. Makes economic sense...

TRC Call: Do not Cite - Not for Further Distribution

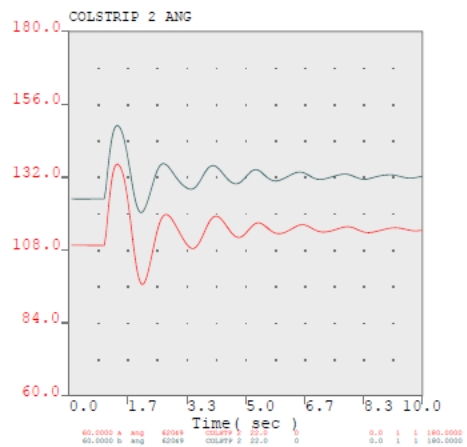
Colstrip

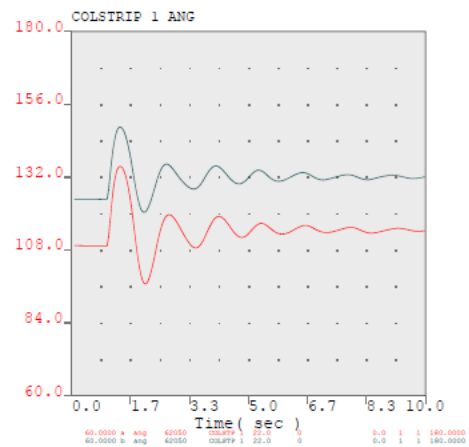
- HiMix Case vs HiMix Case with Colstrip 1 recommitted
- Forced commitment of Colstrip 1; might reflect other constraints





Acceleration still less





Angle swing delta still less, though greater than when Colstrip 1 is off-line.

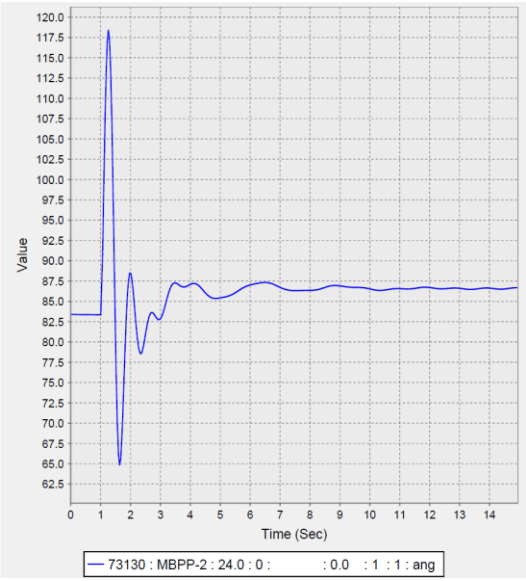
TRC Call: Do not Cite - Not for Further Distribution

Laramie River fault

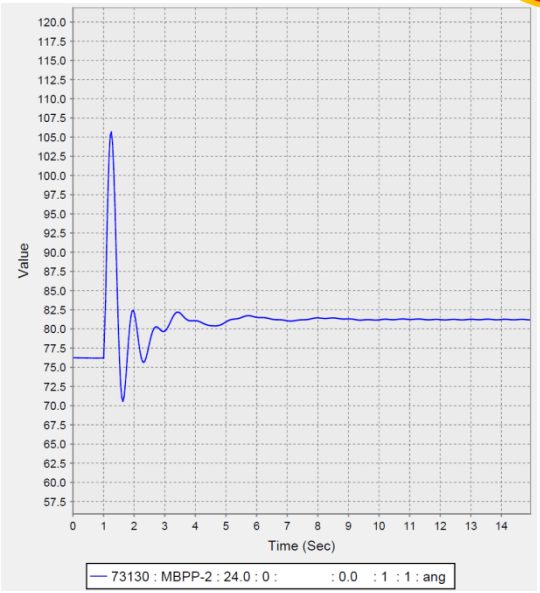
New Slide

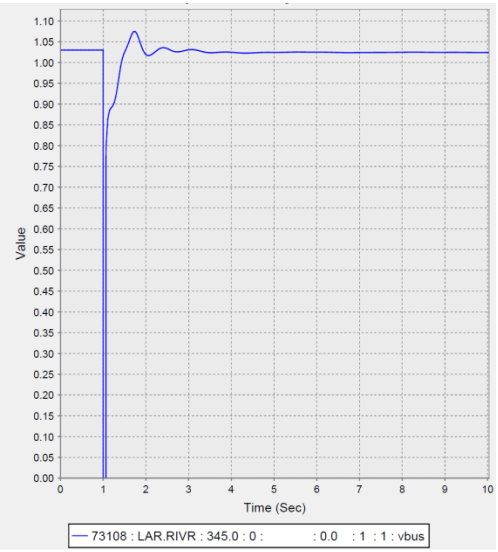
HS Base case
and
Hi-Mix case

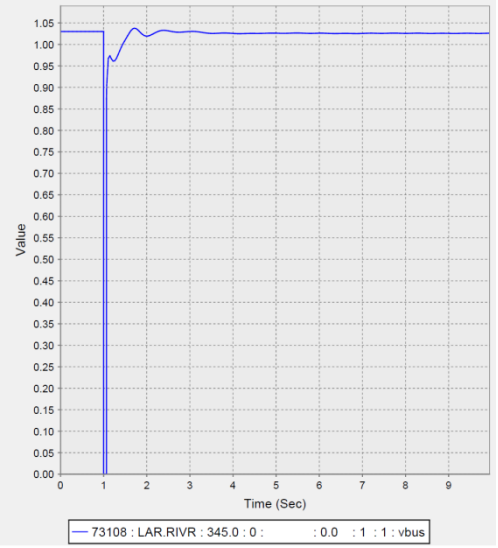
23HS Base Case



23HS Hi-Mix case

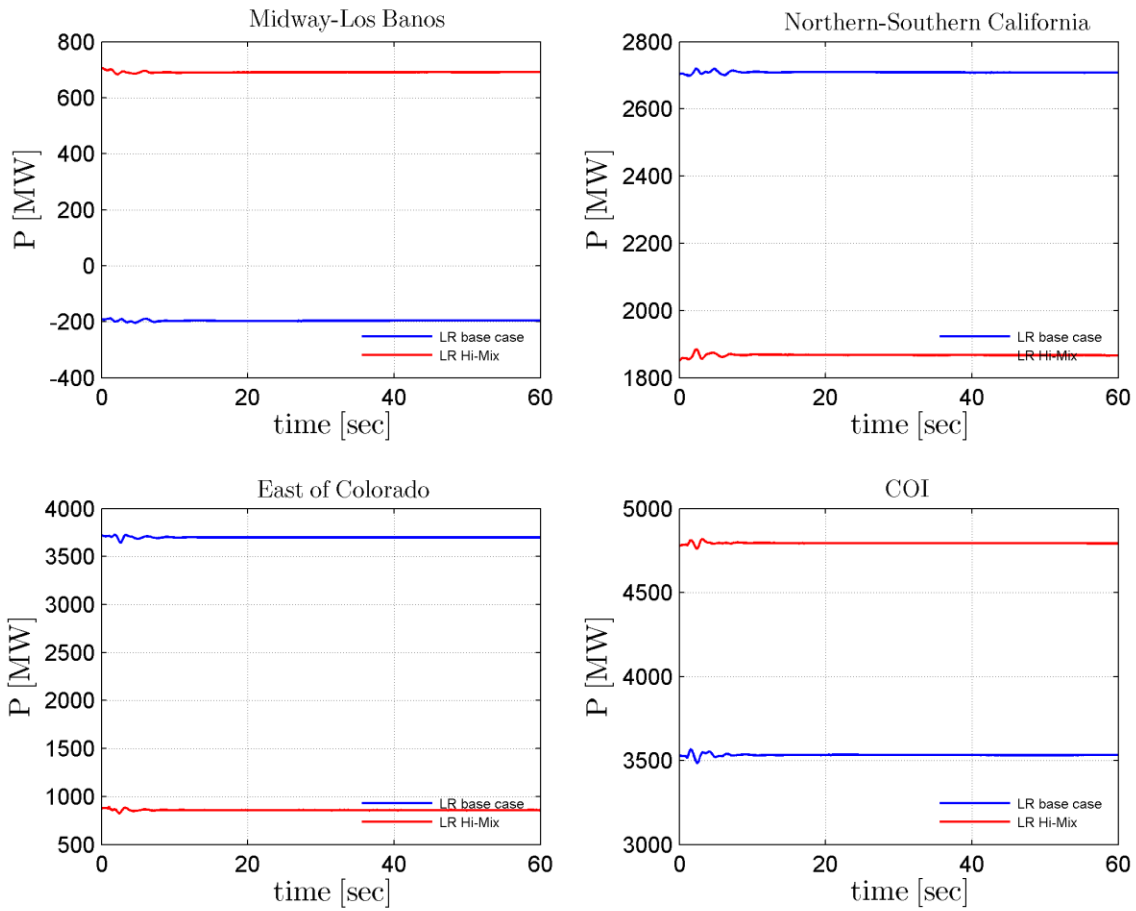




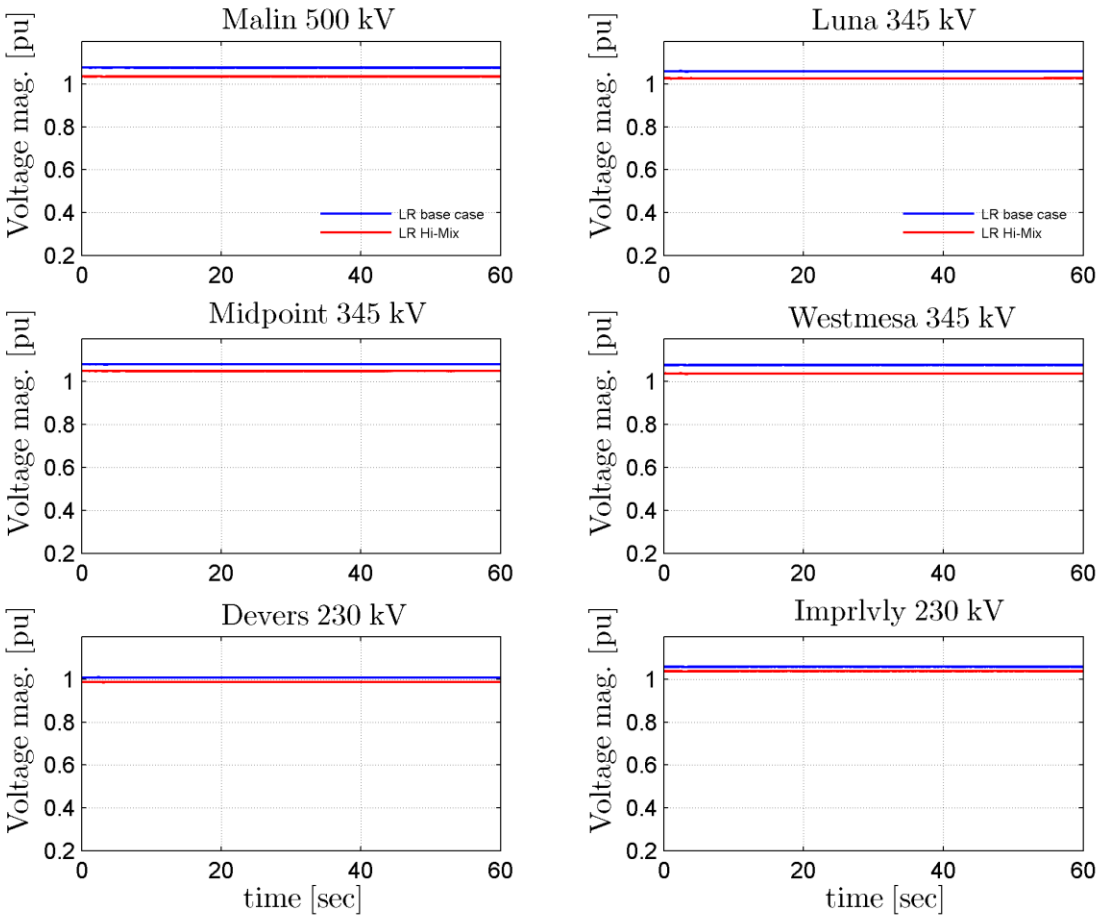


Laramie River fault

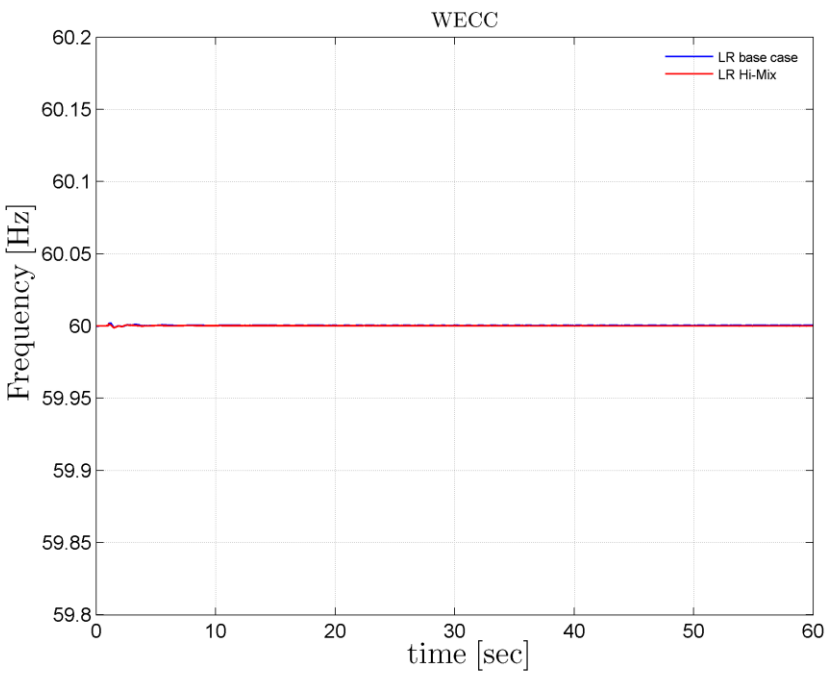
HS Base case and Hi-Mix case

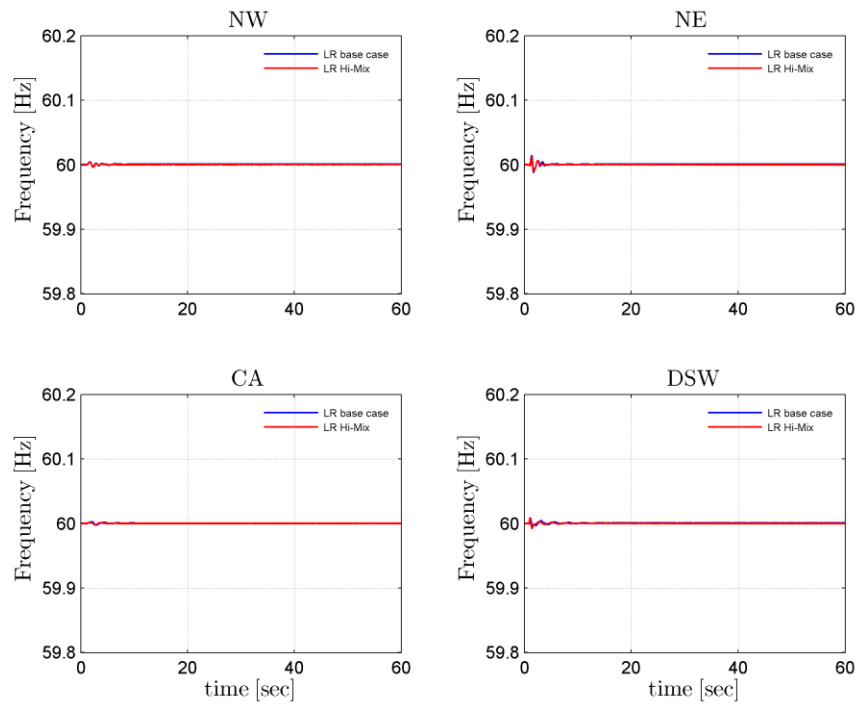


Laramie River fault



Laramie River fault





2.7 Extreme LSP W+S

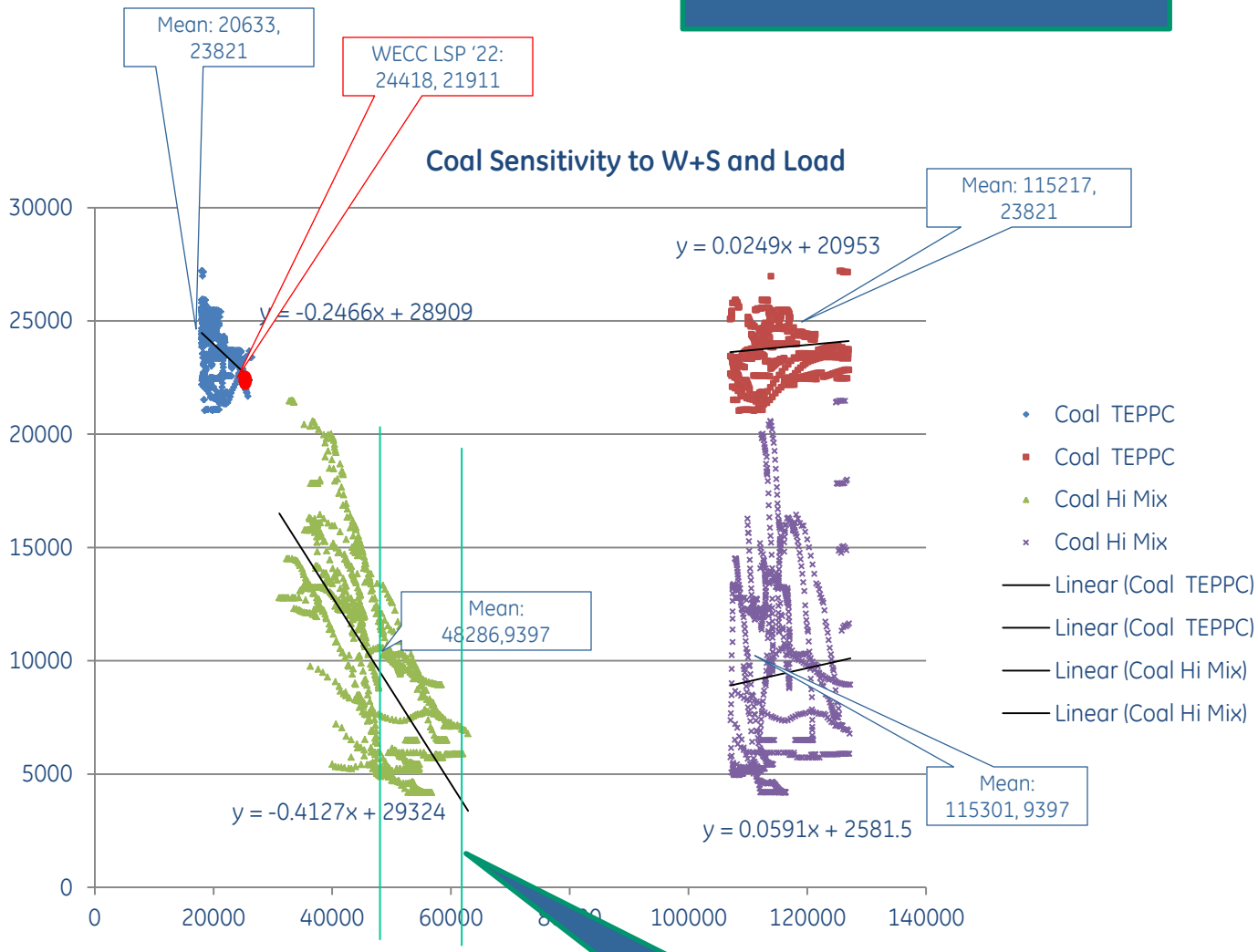
22'LSP HiMix Extreme Case

Mining Plexos: Coal Plants

This slide from Last summer TRC

TEPPC vs HiMix

- In TEPPC case, the coal plants do essential no load following – base load
- But the do about ¼ of the W+S following
- Reduction to HiMix; plants do about 40% of the wind following

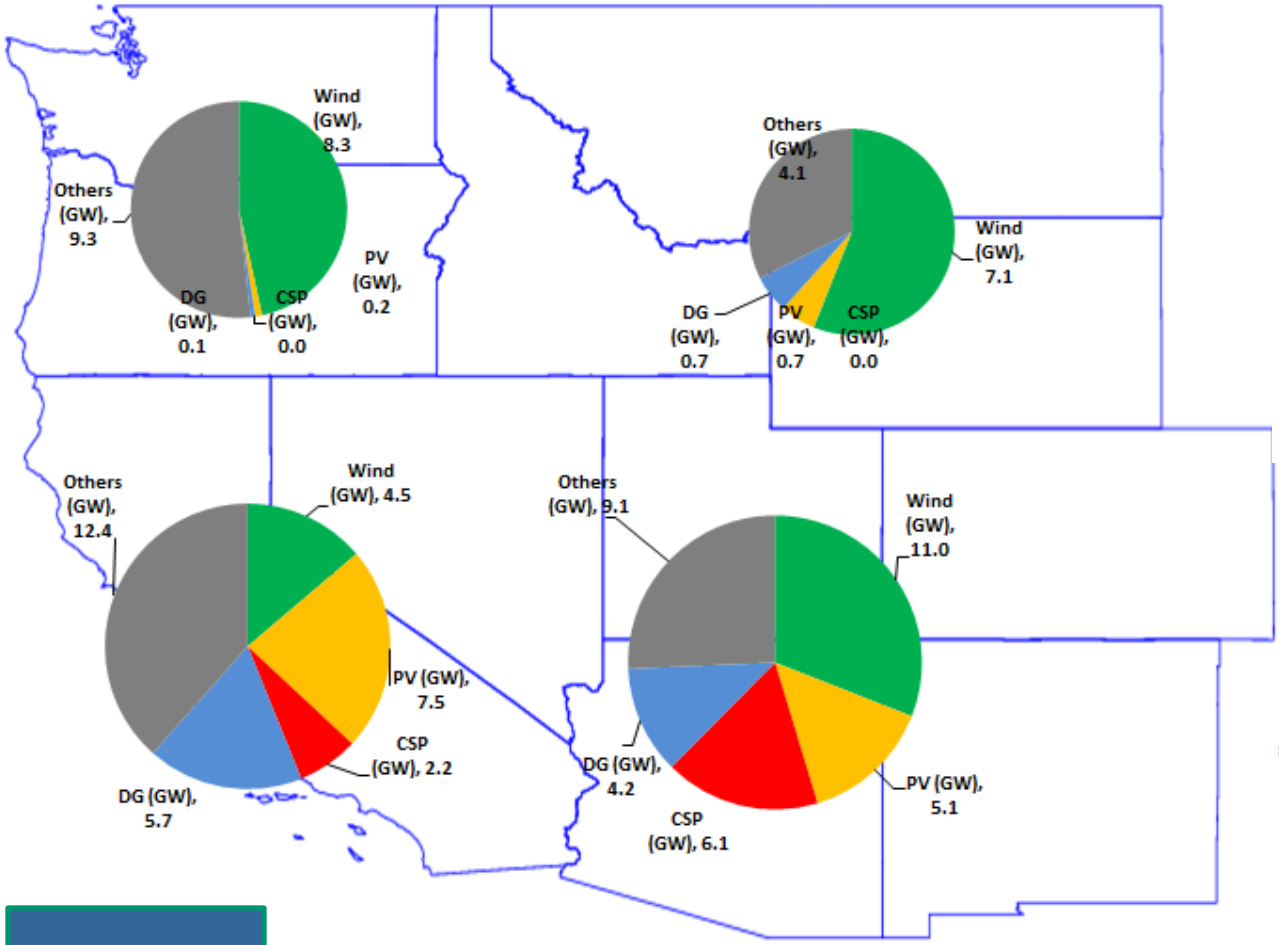


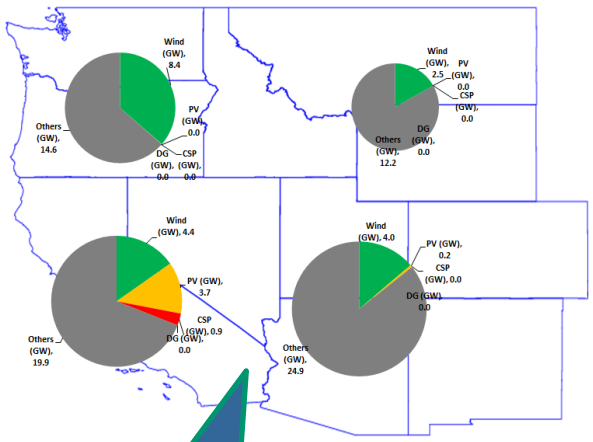
- Speculate roughly 10 GW decommited, and o[illegible]erage another 5GW dispatched down

2-4-2014: Extreme!

imagination at work

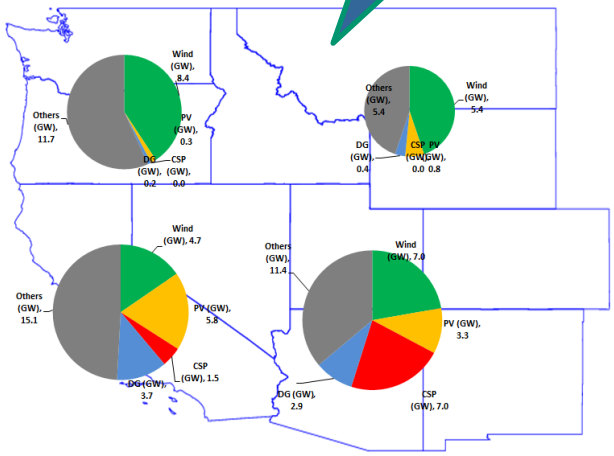
LSP HiMix Extreme Case - Renewable Conditions





~ 25 GW of wind and solar total in Base Case

~ 52.8 GW of wind and solar total in HiMix Case

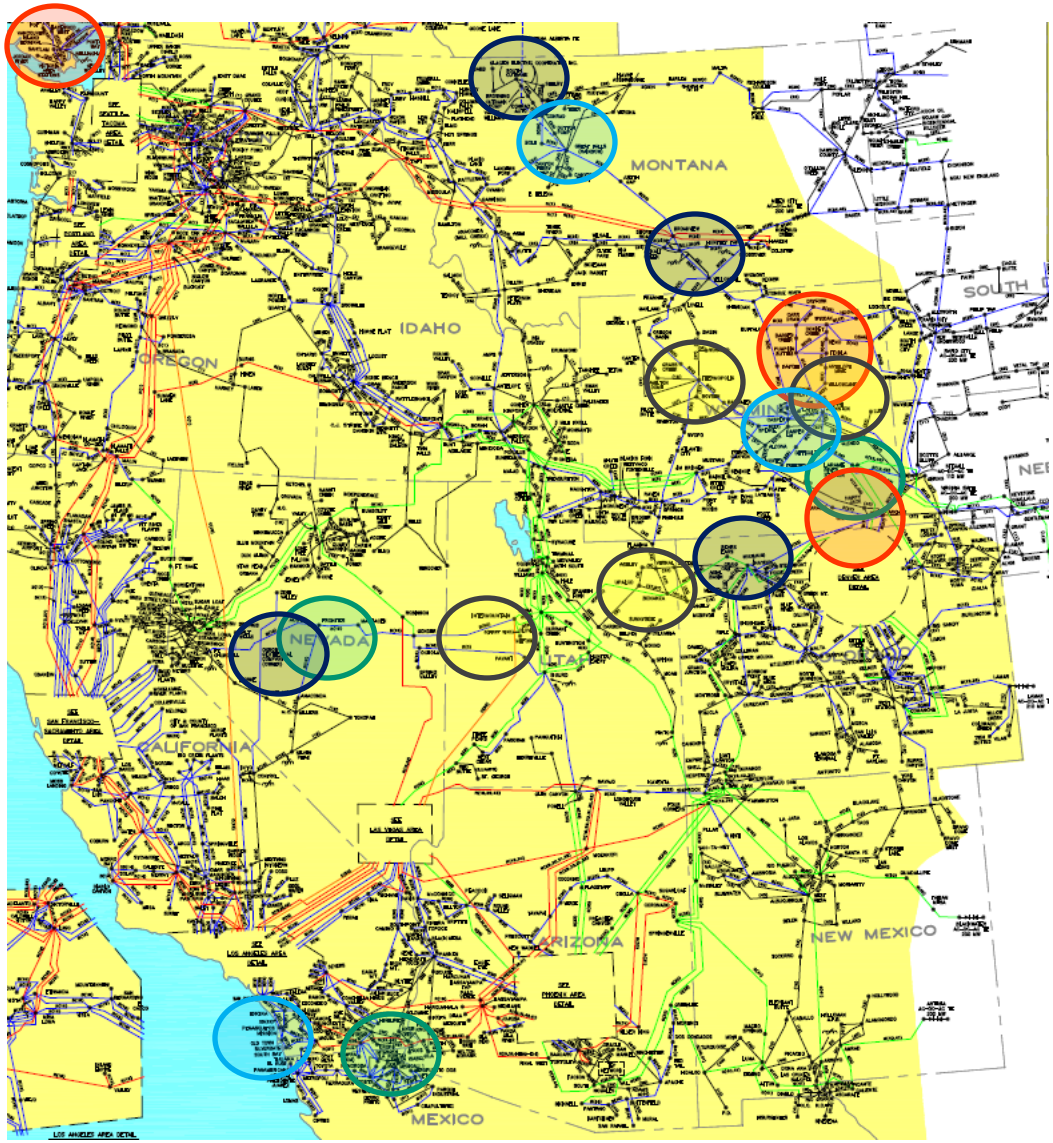


~ 64.8 GW of wind and solar

	WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST
Wind (GW)	32.6	4.5	11.0	7.1	8.3
PV (GW)	13.5	7.5	5.1	0.7	0.2
CSP (GW)	8.3	2.2	6.1	0.0	0.0
DG (GW)	10.4	5.7	4.2	0.7	0.1
Others (GW)	56.6	12.4	9.1	4.1	9.3
total (GW)	121.4	32.3	35.6	12.6	17.9

Preliminary Results: Not for Further Distribution or Citation

Local Reinforcement for Extreme Spring



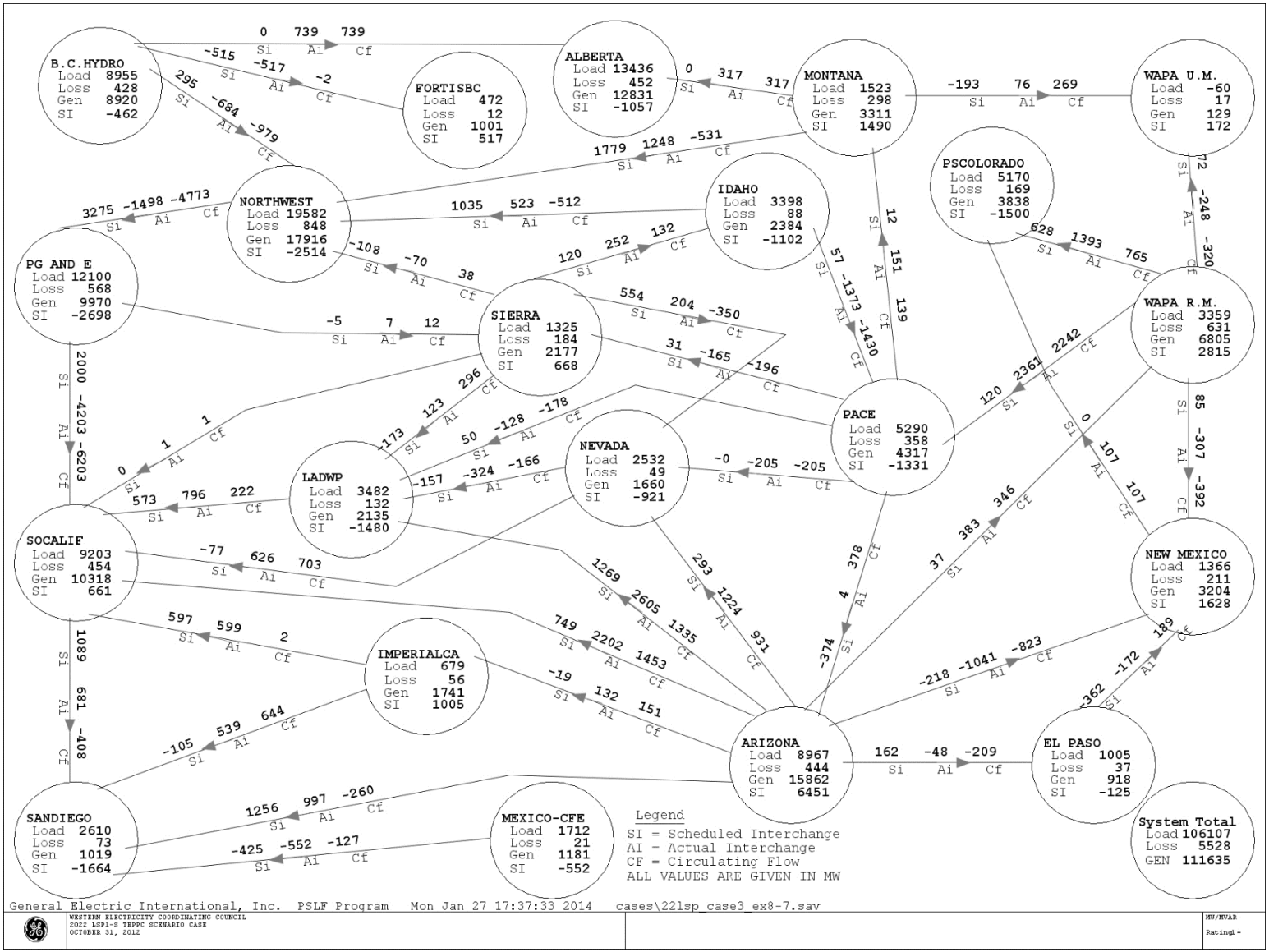
We had to inch up on last 10GW of wind and solar. Local fixes mounted with each successive step

- 1st pass
- 2nd pass
- 3rd pass
- 4th pass
- 5th pass

imagination at work

TRC Call: Do not Cite - Not for Further Distribution

LSP HiMix Extreme Case – PSLF Bubble Diagram



imagination at work

Extreme LSP- Mining Plexos Case

Means "utility scale" PV

HiMix @ 31775

2022 LSP Hi-Mix				
Area #	CSP	DG	PV	Wind
54				
14	6375	1471	2061	560
50				
11	143	202	227	2
60			0	150
21	124	32	277	337
26	493	864	403	0
20				
62	0	2	3	1593
18	113	166	376	0
10	162	217	333	27
40	0	204	334	4551
65	0	239	87	2772
30	0	584	690	30
70	178	355	608	594
22	0	116	89	0
64	0	208	728	661
24	1378	2287	2951	2746
52				
73	0	364	428	3346
63		0	0	27
Total	8967	7312	9592	17395

Extreme @ 30692

2022 Extrem case				
Area #	CSP	DG	PV	Wind
54				
14	5477	2418	3387	411
50				
11	156	163	183	2
60			0	152
21	28	50	428	56
26	806	1369	638	0
20				
62	0	2	3	2989
18	127	278	627	0
10	172	428	655	1200
40	0	125	205	4116
65	0	646	235	3716
30	0	1022	1206	80
70	186	354	607	954
22	0	253	195	0
64	0	132	461	530
24	1933	3303	4263	186
52				
73	0	377	442	6309
63		0	0	59
Total	8885	10920	13536	20759

Difference

Delta				
Area #	CSP	DG	PV	Wind
54	0	0	0	0
14	-898	947	1326	-149
50				
11	13	-39	-44	-1
60	0	0	0	2
21	-96	18	152	-281
26	313	505	235	0
20				
62	0	0	0	1396
18	14	112	252	0
10	10	211	323	1173
40	0	-79	-129	-435
65	0	407	148	944
30	0	438	517	50
70	8	0	0	360
22	0	137	106	0
64	0	-76	-267	-131
24	555	1016	1312	-2560
52				
73	0	13	15	2963
63	0	0	0	33
Total	-81	3608	3944	3364

Remember these are from the Plexos case, NOT the WECC LSP base case

imagination at work

TRC Call: Do not Cite - Not for Further Distribution

Extreme LSP

Based on Plexos TEPCC and HiMix cases, using the same rules develop rules for decommiting and redispatching generation, for periods of operation that look like the LSP'22 condition.

- Select Coal and Combined Cycle units, total 583 units
- For each of 583 units in 487 sample space look at pattern of its operation
- Develop rules for redispatch and decommitment of Coal and Combined cycle units and come up with list of units to be used in development of the extreme cases (from base and HiMix)
- If short in redispatch capacity, consider redispatch of hydro units in Northwest and BC Hydro areas and other CC units

- Sample that represent the mean of the sample space is sample # 31775 (April 4, 2020 at 7:50) used for Hi-Mix
- Sample that represent the peak in the the sample space is sample # 30692 (April 16, 2020 at 13:35) used for Extreme case

TRC Call: Do not Cite - Not for Further Distribution

Hi-Mix – decomitment rules

- Decomitment units based on the list developed for HiMix
- For each unit:
  - Set commitment flag for all units in sample space *{i.e. is the plant committed?}*

$$CF = \begin{cases} 1, & P>0 \\ 0, & P=0 \end{cases}$$

  - If $TEPCC_{CF}$ =1 and $HiMix_{CF}$=0, find set decommitment flag (DF) to 1 and calculate $\Delta P = P_{TEPCC} - P_{HiMix}$ *{i.e. does the plant get decommitted as wind & solar added?}*
  - Note: Δ P>0 means the unit is turned off
  - count # of times/percent DF=1 and $\Delta P <> 0$
  - count # of times/percent DF=1 $\Delta P>0$ (turned off)
  - count # of times/percent DF=1 $\Delta P<0$ (turned on)
- Decommitment rule for HiMix: Take units that have DF<>0 for more than 30% of the time in the sample space *{i.e. plants that are often decommitted should be shutdown}*

imagination at work

TRC Call: Do not Cite - Not for Further Distribution

Extreme LSP - decomitment

- Need to lower the bar
- Decommitment rule for Extreme case: Take units that have DF<>0 for more than 1% of the time in the sample space
- The list total of: 3580 MW (not enough !)
- Need more than what have based on Plexos decommitment list
- Additional units considered for decomitment
  - hydro units in Northwest areas (total hydro committed in Hi-Mix case: 4990 MW
  - CC units in that didn't make Plexos list

- Used in building Extreme case:
  - Plexos based list: ≈ 3100 MW
  - Hydro units: ≈ 2000 MW
  - Other CC unis across WECC ≈ 5000 MW

- Differences between PLEXOS and WECC cases became important as we moved to Extreme case
- Case is credible, but does not have the degree of economic rigor applied to the HiMix cases
- Some out-of-merit or other deviations are likely

TRC Call: Do not Cite - Not for Further Distribution

LSP HiMix Extreme Case – Initial Condition Metrics

1.0 low

		WECC	CALIFORN	DSW	NORTHEAST	NORTHWEST
Pgen of synchronous generators with GR (GW)	pg	30.7	5.2	4.6	2.5	7.2
Capacity of synchronous generators with GR (GW)	mc	48.9	10.2	7.6	3.5	11.8
Headroom on synchronous generators with GR (GW)	**hr**	**18.1**	**5.0**	**3.0**	**1.0**	**4.6**
Number of synchronous generators with GR (GW)	**nu**	**699**	**166**	**94**	**86**	**144**
Mechanical power of synchronous generators with GR (GW)	pm	30.7	5.2	4.6	2.5	7.2
MVA rating of synchronous generators with GR (GW)	mv	48.9	10.9	8.1	3.7	10.5
Pgen of synchronous generators w/o GR (GW)	px	34.2	9.5	10.7	1.6	2.1
Mechanical synchronous generators w/o GR (GW)	mx	34.7	9.6	10.9	1.6	2.1
Number of synchronous generators w/o GR (GW)	nx	711	272	87	99	59
Pgen of all synchronous generators (GW)	pq	64.9	14.7	15.2	4.1	9.3
Qgen of all synchronous generators (GVAr)	qg	8.5	-0.2	1.8	0.7	2.5
P load (GW)	pl	111.8	32.7	26.0	11.6	19.0
Q load (GVAr)	ql	29.6	7.7	6.0	3.1	4.2
Pgen – Wind (GW)	**pw**	**32.6**	**4.5**	**11.0**	**7.1**	**8.3**
Qgen – Wind (GVAR)	qw	0.2	0.2	0.9	0.4	-1.0
Pgen – Solar PV	**pv**	**13.5**	**7.5**	**5.1**	**0.7**	**0.2**
Qgen – Solar PV	qv	-1.7	-0.4	-1.0	-0.2	-0.1
Pgen - CSP (GW)	**pc**	**8.3**	**2.2**	**6.1**	**0.0**	**0.0**
Pgen - DG (solar PV)	**dg**	**10.4**	**5.7**	**4.2**	**0.7**	**0.1**
Kt	Kt	0.38	0.32	0.22	0.27	0.53

Kt was 0.42 in the HiMix case.

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Preliminary Results: Do not Cite - Not for Further Distribution

2022LSP HiMix Extreme Case – Initial Condition Metrics

	Name	ID	freq	Pgen_gov	mwcap	headroom	num_gov	mnech_gov	mva_gov	pgen_nogov	mva_nogen	num_nogov	pgs_tot	qgq_tot	pload	qload	pg_wind	qg_wind	pg_pv	qg_pvv	pg_csp	pg_dg	num_hrm
1	WECC	WE	60.0	30.7	48.9	18.1	699	30.7	48.9	34.2	34.7	711	64.9	8.5	111.8	29.6	32.6	0.2	13.5	-1.7	8.3	10.4	699
2	CALIFORNIA	CA	60.0	5.2	10.2	5.0	166	5.2	10.9	9.5	9.6	272	14.7	-0.2	32.7	7.7	4.5	0.2	7.5	-0.4	2.2	5.7	166
3	DSW	DS	60.0	4.6	7.6	3.0	94	4.6	8.1	10.7	10.9	87	15.2	1.8	26.0	6.0	11.0	0.9	5.1	-1.0	6.1	4.2	94
4	NORTHEAST	NE	60.0	2.5	3.5	1.0	86	2.5	3.7	1.6	1.6	99	4.1	0.7	11.6	3.1	7.1	0.4	0.7	-0.2	0.0	0.7	86
54	ALBERTA	AL	60.0	1.9	3.3	1.3	66	1.9	3.5	9.2	9.2	77	11.1	2.2	13.4	6.1	1.7	-0.3	0.0	0.0	0.0	0.0	66
14	ARIZONA	AZ	60.0	2.7	4.7	2.0	44	2.7	4.4	9.2	9.4	65	11.9	1.3	10.4	3.0	0.6	-0.2	2.7	-0.6	5.5	2.3	44
50	B.C.HYDRO	BC	60.0	8.4	11.1	2.8	118	8.4	10.9	0.5	0.5	106	8.9	1.1	9.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	118
11	EL PASO	EL	60.0	0.2	0.3	0.1	3	0.2	0.4	0.4	0.5	6	0.7	0.0	1.1	0.2	0.0	0.0	0.2	-0.1	0.1	0.2	3
60	IDAHO	ID	60.0	1.4	1.9	0.5	29	1.4	1.8	0.5	0.5	31	1.9	0.2	3.2	0.6	0.4	-0.1	0.0	0.0	0.0	0.0	29
21	IMPERIALCA	IV	60.0	0.2	0.3	0.1	2	0.2	0.3	1.0	1.0	36	1.2	0.1	0.6	0.2	0.1	0.0	0.4	0.0	0.0	0.0	2
26	LADWP	LA	60.0	0.5	0.8	0.3	8	0.5	0.9	0.9	0.9	12	1.4	-0.1	4.6	0.9	0.2	-0.1	0.6	-0.2	0.8	1.3	8
20	MEXICO-CFE	MX	60.0	0.3	0.5	0.2	6	0.3	0.5	0.3	0.3	2	0.6	0.1	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	6
62	MONTANA	MT	60.0	0.3	0.6	0.3	28	0.3	0.6	0.0	0.0	10	0.3	0.1	1.5	0.5	3.0	0.5	0.0	0.0	0.0	0.0	28
18	NEVADA	NV	60.0	0.5	0.7	0.2	4	0.5	1.0	0.3	0.3	4	0.8	0.1	2.4	0.4	0.0	0.0	0.6	-0.1	0.1	0.3	4
10	NEW MEXICO	NM	60.0	0.0	0.0	0.0	3	0.0	0.0	0.2	0.2	1	0.2	0.0	1.6	-0.1	2.3	0.2	0.6	-0.1	0.2	0.4	3
40	NORTHWEST	NW	60.0	7.2	11.8	4.6	144	7.2	10.5	2.1	2.1	59	9.3	2.5	19.0	4.2	8.3	-1.0	0.2	-0.1	0.0	0.1	144
65	PACE	PC	60.0	0.5	0.5	0.1	23	0.5	0.7	0.3	0.3	10	0.7	0.2	5.5	1.8	3.1	0.1	0.2	-0.1	0.0	0.6	23
30	PG AND E	PG	60.0	3.4	6.6	3.2	123	3.4	7.0	4.8	4.8	157	8.2	0.0	12.3	3.4	0.8	0.0	1.9	-0.1	0.0	1.0	123
70	PSCOLORADO	CO	60.0	0.9	1.0	0.1	4	0.9	1.2	0.5	0.5	3	1.4	0.3	5.3	1.3	1.8	0.3	0.6	-0.1	0.2	0.3	4
22	SANDIEGO	SD	60.0	0.1	0.2	0.1	1	0.1	0.2	0.1	0.1	12	0.2	0.0	2.7	0.6	0.3	0.1	0.5	0.1	0.0	0.2	1
64	SIERRA	SP	60.0	0.4	0.5	0.1	6	0.4	0.6	0.8	0.8	48	1.2	0.1	1.4	0.3	0.5	-0.1	0.5	-0.1	0.0	0.1	6
24	SOCALIF	SC	60.0	1.0	2.3	1.3	32	1.0	2.4	2.7	2.8	55	3.7	-0.2	12.5	2.7	3.2	0.2	4.0	-0.3	1.4	3.2	32
52	FORTISBC	FB	60.0	0.6	0.8	0.2	18	0.6	0.8	0.4	0.4	8	1.0	0.2	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	18
73	WAPA R.M.	WR	60.0	0.2	0.9	0.7	36	0.2	1.1	0.1	0.1	8	0.3	0.1	3.8	0.8	6.3	0.6	0.4	0.0	0.0	0.4	36
63	WAPA U.M.	WU	60.0	0.1	0.1	0.0	1	0.1	0.1	0.0	0.0	1	0.1	0.0	-0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1

!!!

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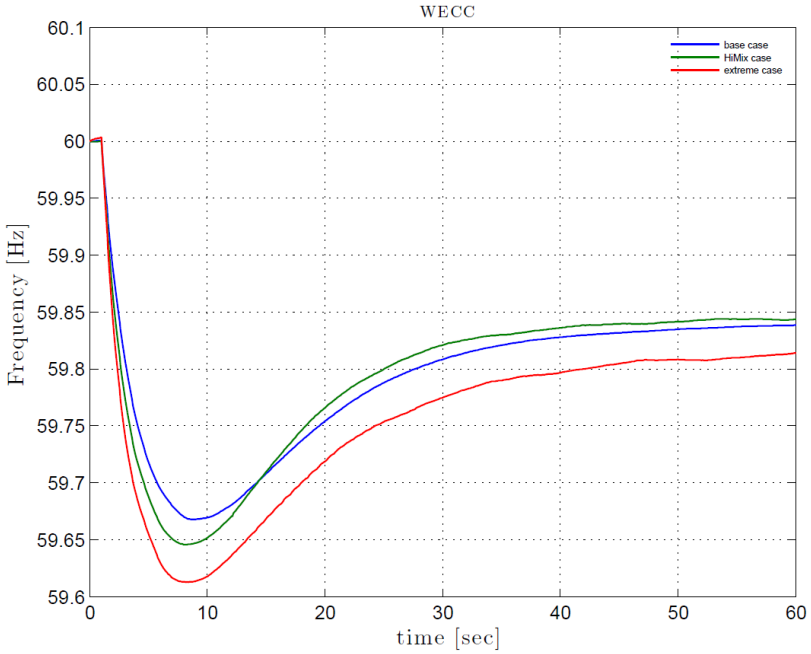
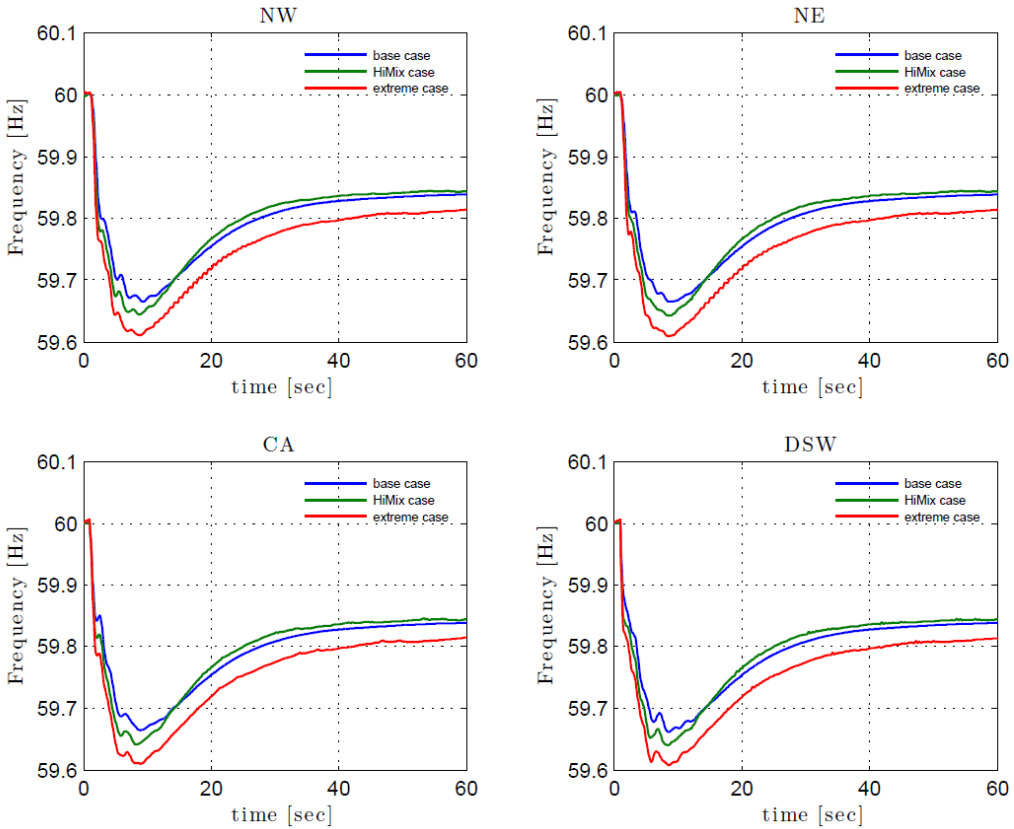
Preliminary Results: Do not Cite - Not for Further Distribution

LSP Frequency Response simulation

New Slide



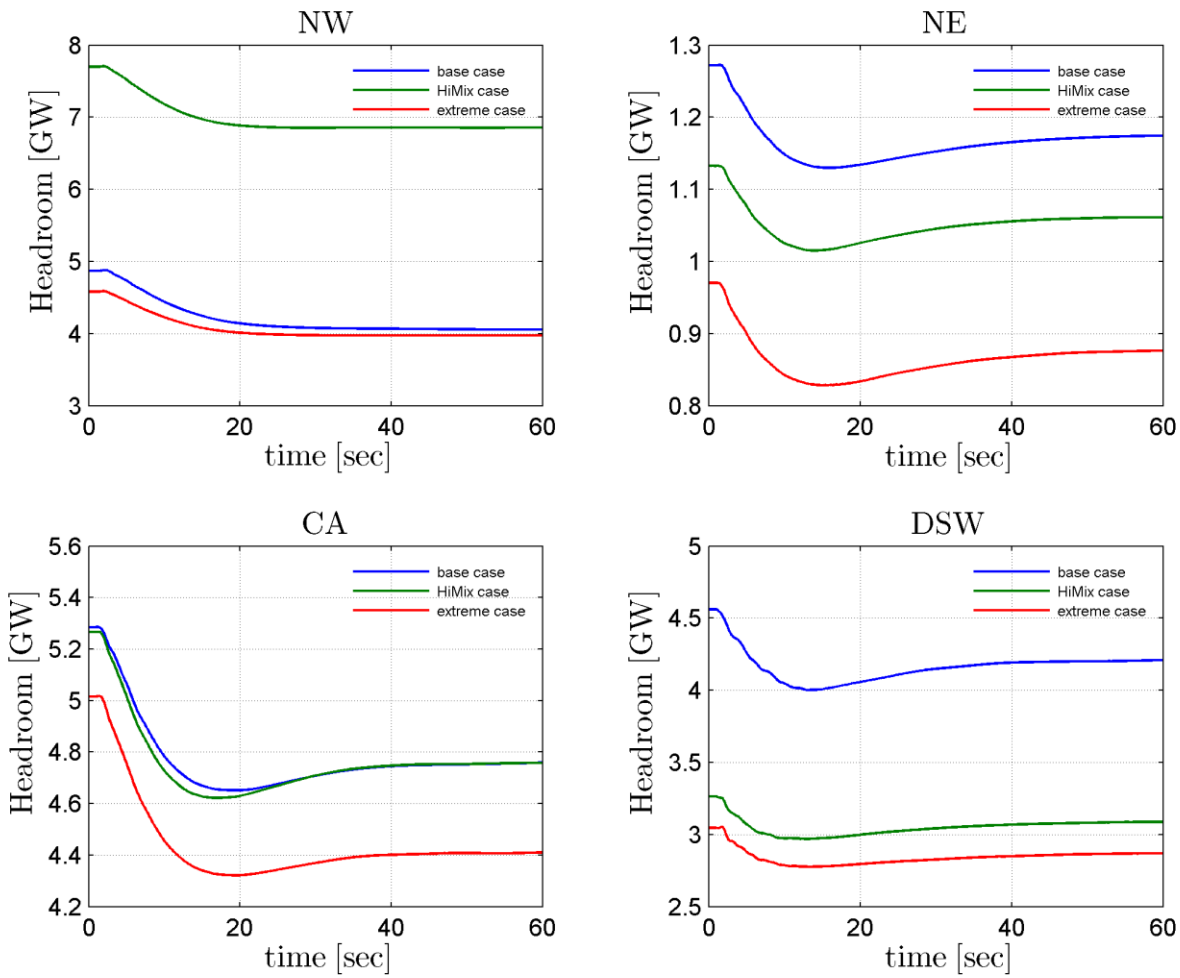


- Base Case
- HiMix Case
- HiMix Extreme Case

Frequency Response for 2xPV event

LSP Frequency Response simulation

- Base Case
- HiMix Case
- HiMix Extreme Case



Frequency Response for 2xPV event

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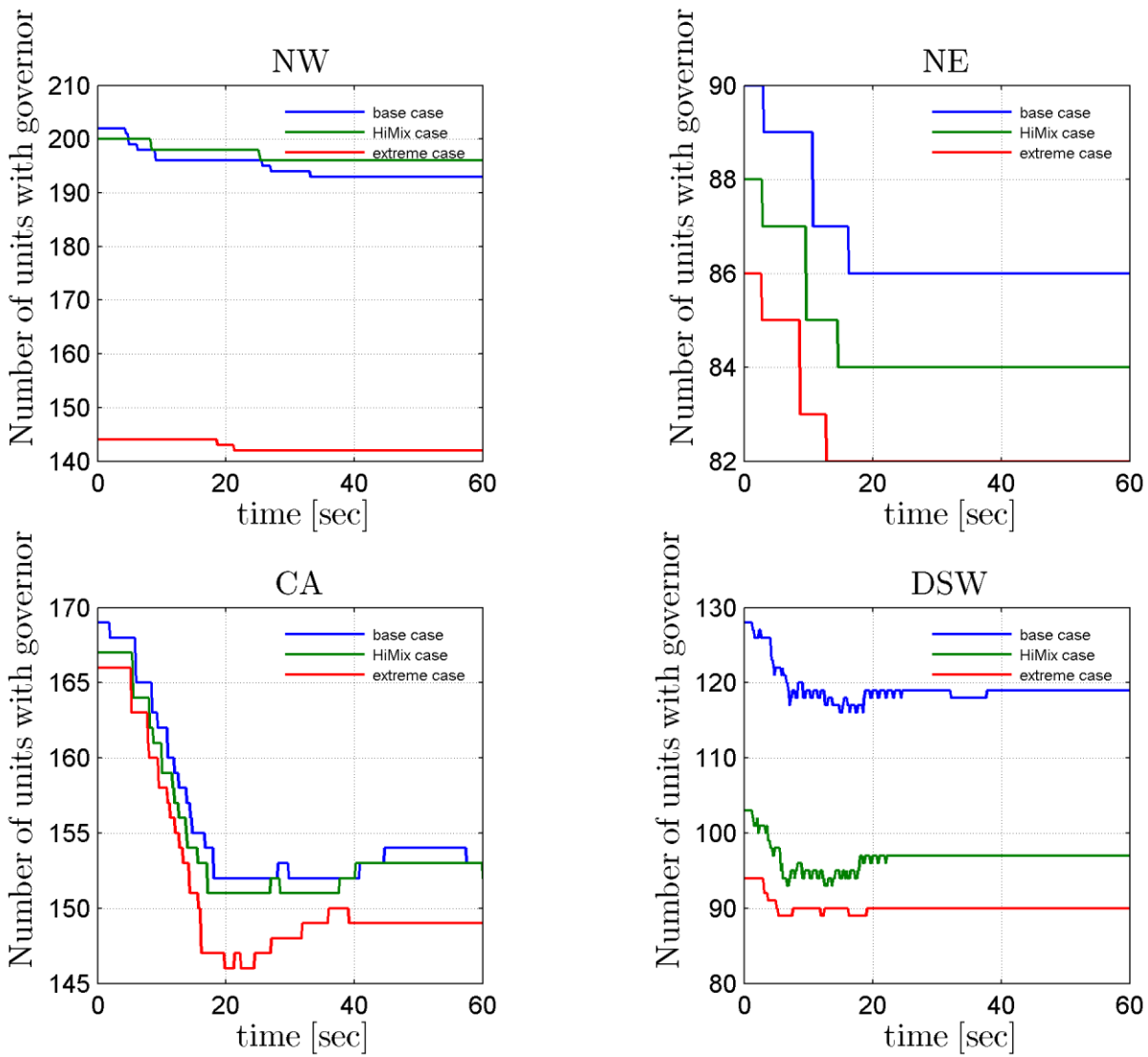
TRC Call: Do not Cite - Not for Further Distribution

LSP Frequency Response simulation

- Base Case
- HiMix Case
- HiMix Extreme Case



Frequency Response for 2xPV event

LSP Extreme Frequency Response

ID	Name	ID	FRO [MW/0.1Hz]	FR [MW/0.1Hz]	%of WECC FR	FR margin [MW/0.1Hz]	Freq. Nadir [Hz]	Nadir time [s]	Setl. Freq. [Hz]	Kt
1	WECC	WE	840	1055	100.00	214.7	59.613	7.38	59.814	0.38
2	CALIFORNIA	CA	296	295	27.98	-0.6	59.611	7.96	59.815	0.32
3	DSW	DS	220	97	9.15	-123.4	59.609	7.57	59.813	0.22
4	NORTHEAST	NE	82	51	4.81	-30.8	59.609	7.38	59.814	0.27
54	ALBERTA	AL	0	0	0.00	0.0	59.590	6.33	59.813	0.23
14	ARIZONA	AZ	104	45	4.24	-59.7	59.610	7.57	59.813	0.27
50	B.C.HYDRO	BC	0	0	0.00	0.0	59.604	5.85	59.814	0.95
11	EL PASO	EL	9	3	0.29	-5.6	59.607	4.51	59.813	0.32
60	IDAHO	ID	18	21	2.00	3.2	59.609	7.57	59.814	0.68
21	IMPERIALCA	IV	4	14	1.34	10.2	59.606	4.80	59.814	0.18
26	LADWP	LA	29	29	2.76	-0.1	59.610	7.96	59.814	0.33
20	MEXICO-CFE	MX	0	0	0.00	0.0	59.611	7.96	59.814	0.59
62	MONTANA	MT	11	11	1.04	-0.3	59.612	7.77	59.814	0.16
18	NEVADA	NV	28	19	1.76	-9.3	59.602	7.86	59.813	0.45
10	NEW MEXICO	NM	14	2	0.16	-12.7	59.608	7.67	59.813	0.01
40	NORTHWEST	NW	131	280	26.58	149.5	59.611	7.96	59.814	0.53
65	PACE	PC	42	11	1.07	-30.5	59.610	7.38	59.814	0.13
30	PG AND E	PG	133	189	17.87	55.8	59.610	8.05	59.814	0.47
70	PSCOLORADO	CO	36	6	0.54	-29.8	59.603	7.57	59.812	0.25
22	SANDIEGO	SD	21	7	0.66	-14.4	59.612	7.96	59.814	0.16
64	SIERRA	SP	11	7	0.70	-3.2	59.608	7.29	59.814	0.21
24	SOCALIF	SC	108	56	5.32	-52.3	59.611	7.10	59.818	0.19
52	FORTISBC	FB	0	0	0.00	0.0	59.604	5.85	59.814	0.67
73	WAPA R.M.	WR	27	23	2.17	-4.5	59.607	7.57	59.813	0.12
63	WAPA U.M.	WU	0	3	0.25	2.5	59.612	7.77	59.813	0.61

- Frequency Response metric for 22LSP Extreme case for 2xPV event

2.8 CSP Sensitivity

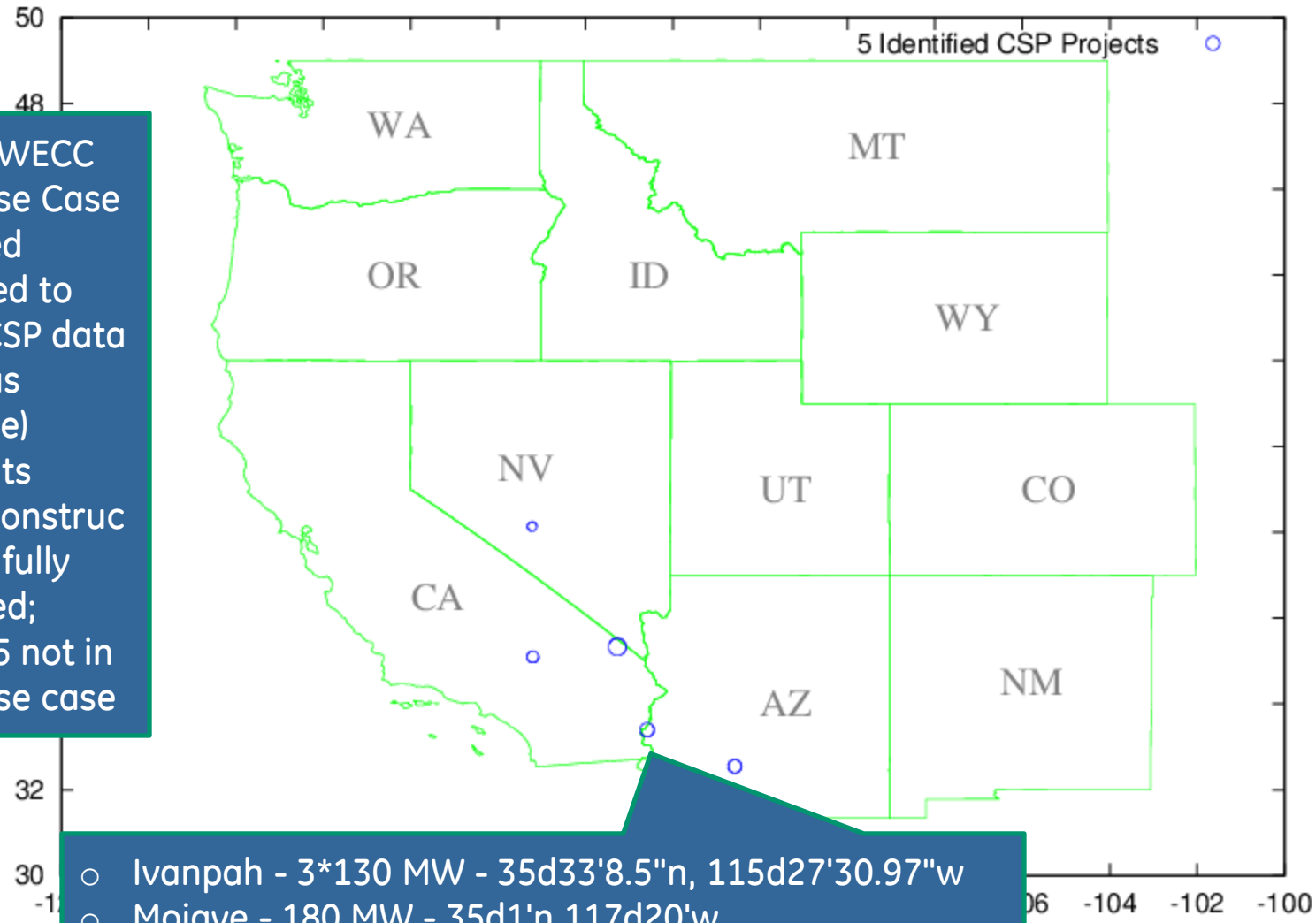
CSP Sensitivity

- Amount of CSP in Hi-Mix seems at odds with current outlook
- Addition of lots of well mannered synchronous generation in AZ (especially) and CA may give unreasonably optimistic stability results.
- Investigation to:
  - Identify CSP in LSP'22, Hi-Mix that are most likely to be built (Thanks for support from Mark Mehos, NREL for source material/CSP database)
  - Convert all *others* to utility scale PV
  - Test impact on dynamic performance
- Next set of pages has some details on the change of some CSP to PV

TRC Call: Do not Cite - Not for Further Distribution

Five Identified CSP Plants

- CSP in WECC LSP base Case retained
- Matched to NREL CSP data base (as possible)
- ID plants underconstruction or fully financed;
- These 5 not in LSP base case

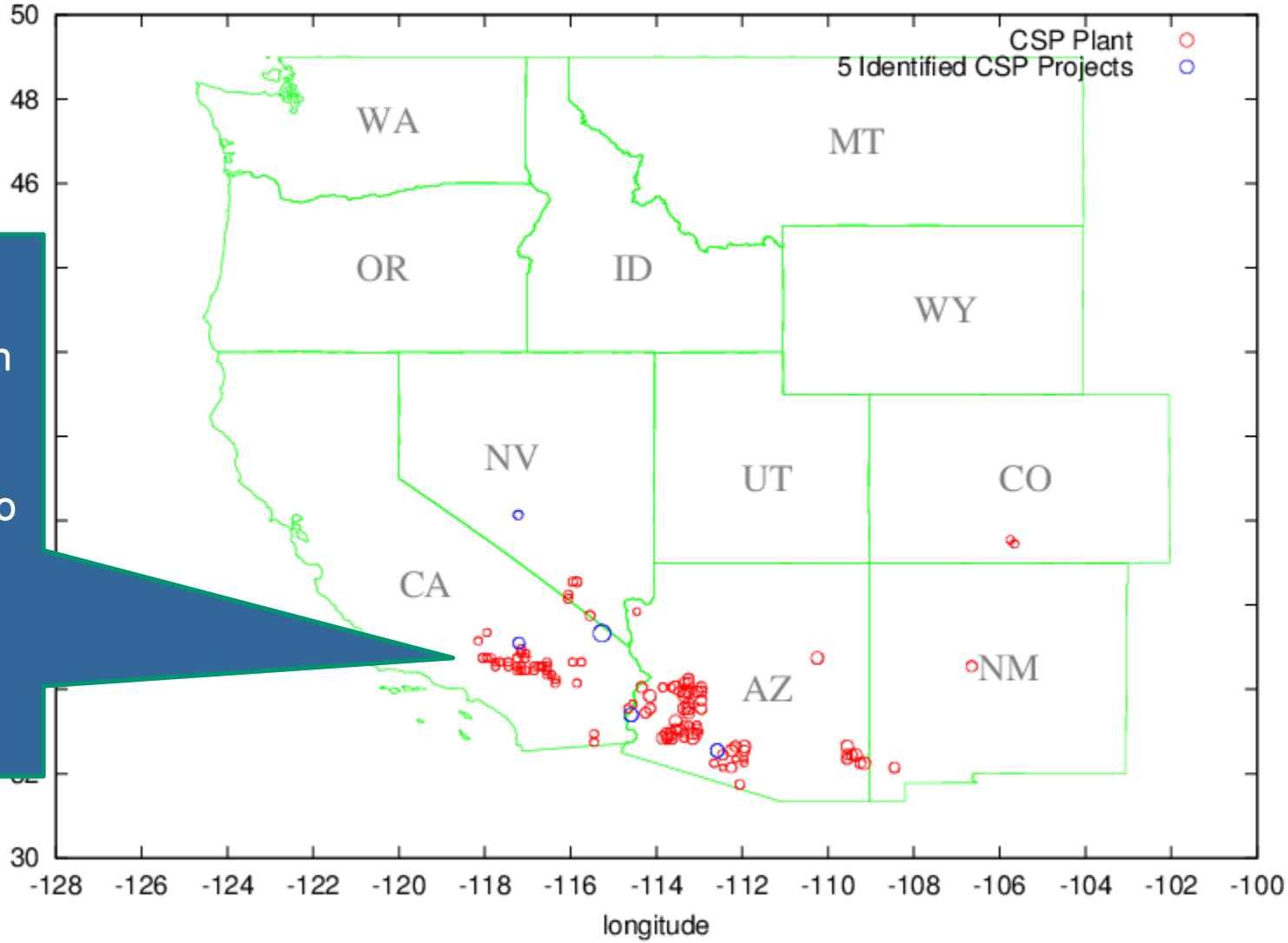


- Ivanpah - 3*130 MW - 35d33'8.5"n, 115d27'30.97"w
- Mojave - 180 MW - 35d1'n 117d20'w
- Tonopah - 110 MW - 38d14'n x 117d22' w
- Genesis - 250 MW - 33d40', 114d59w
- Solana - 250 MW - 32d55'n 112d58'w

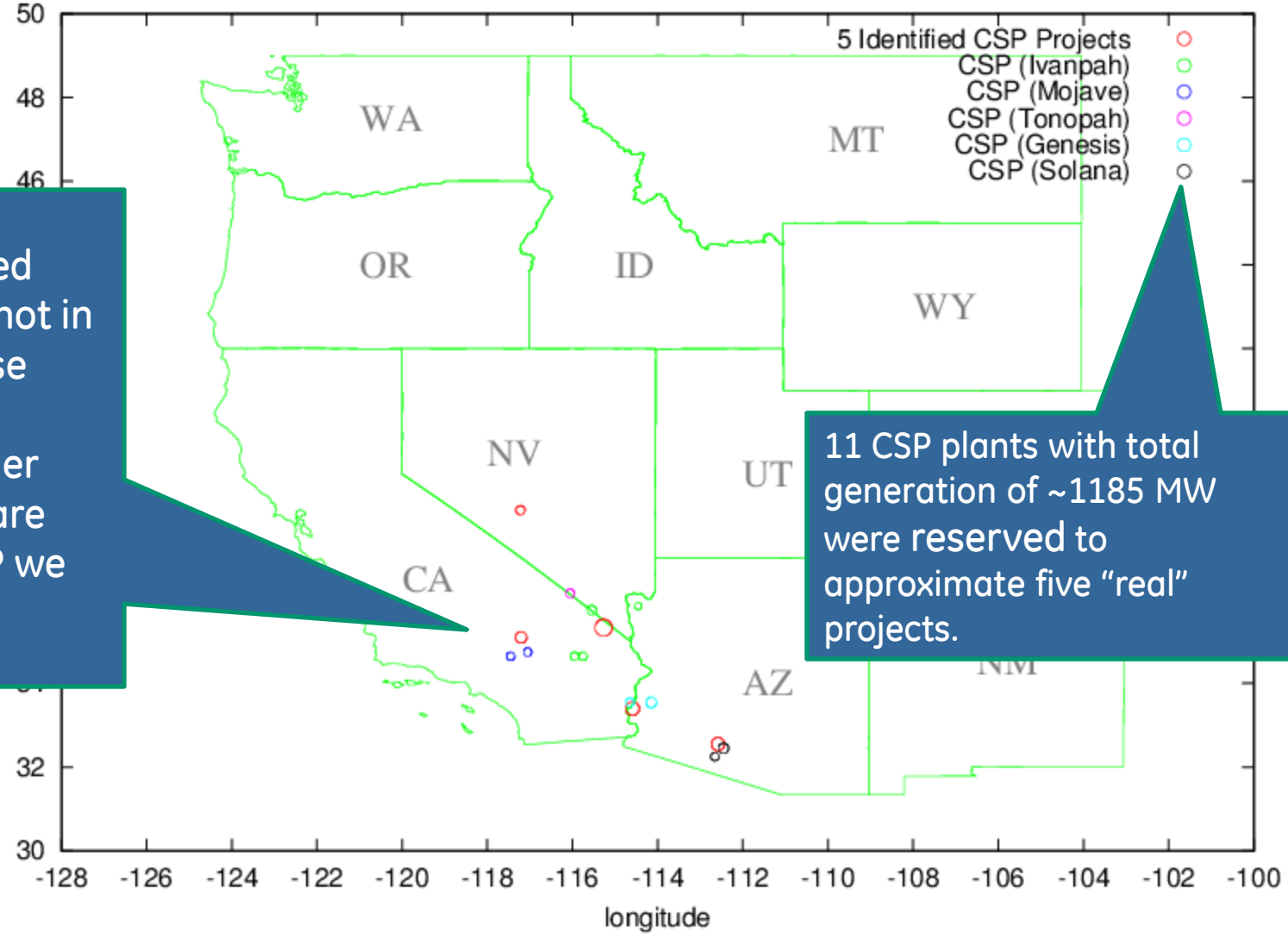
Do not Cite - Not for Further Distribution

Five Identified CSP Plants

- The 5 blue circles not in LSP base case
- They need to be "kept"
- Red are CSP plants from WWSIS 2



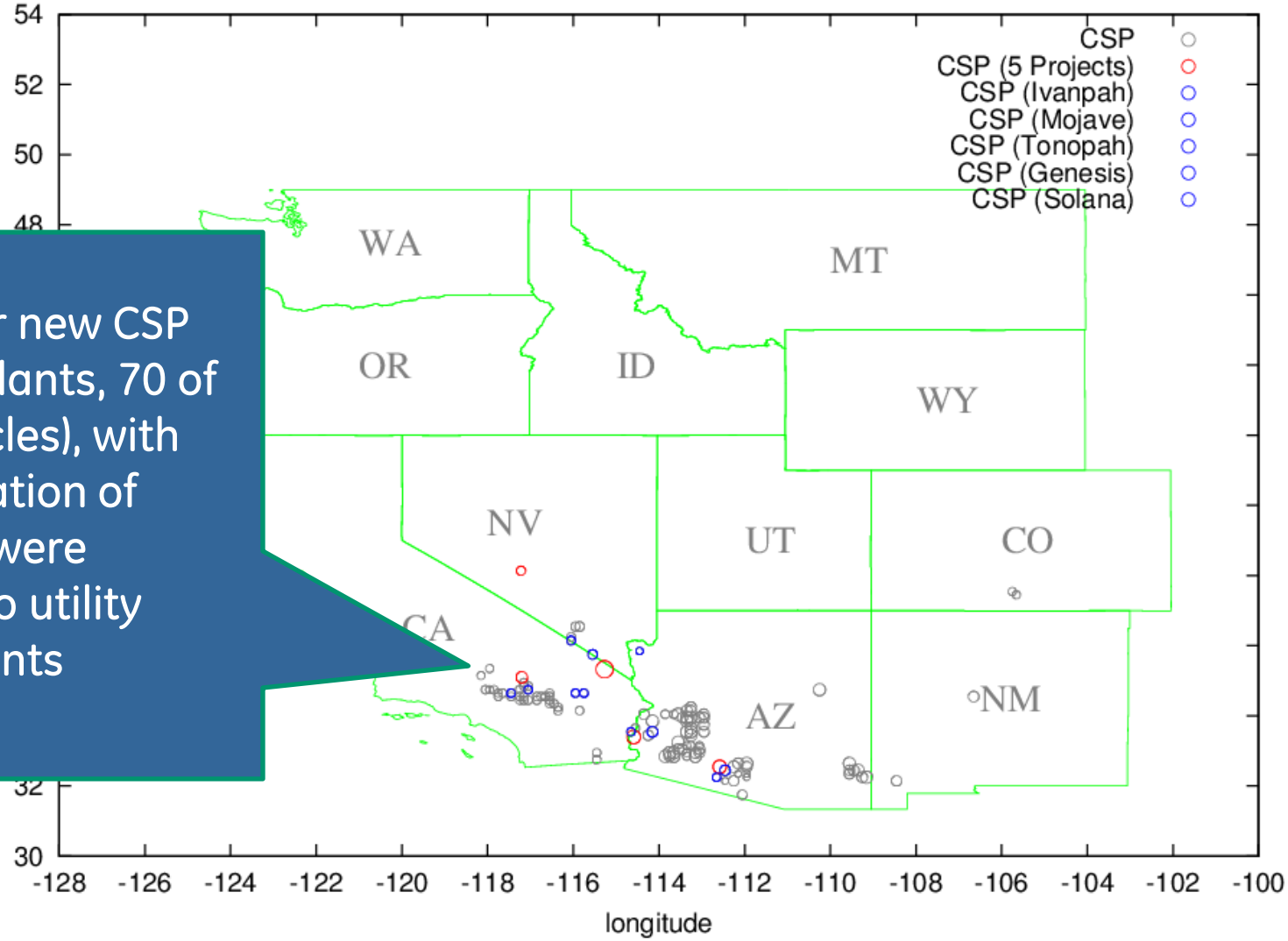
Five Identified CSP Plants



- The 5 red circles not in LSP base case
- The other colors are the CSP we kept

11 CSP plants with total generation of ~1185 MW were reserved to approximate five "real" projects.

Sensitivity Case – CSP to PV Case



All the other new CSP HiMix CSP plants, 70 of 81 (grey circles), with total generation of ~5100 MW were converted to utility scale PV plants

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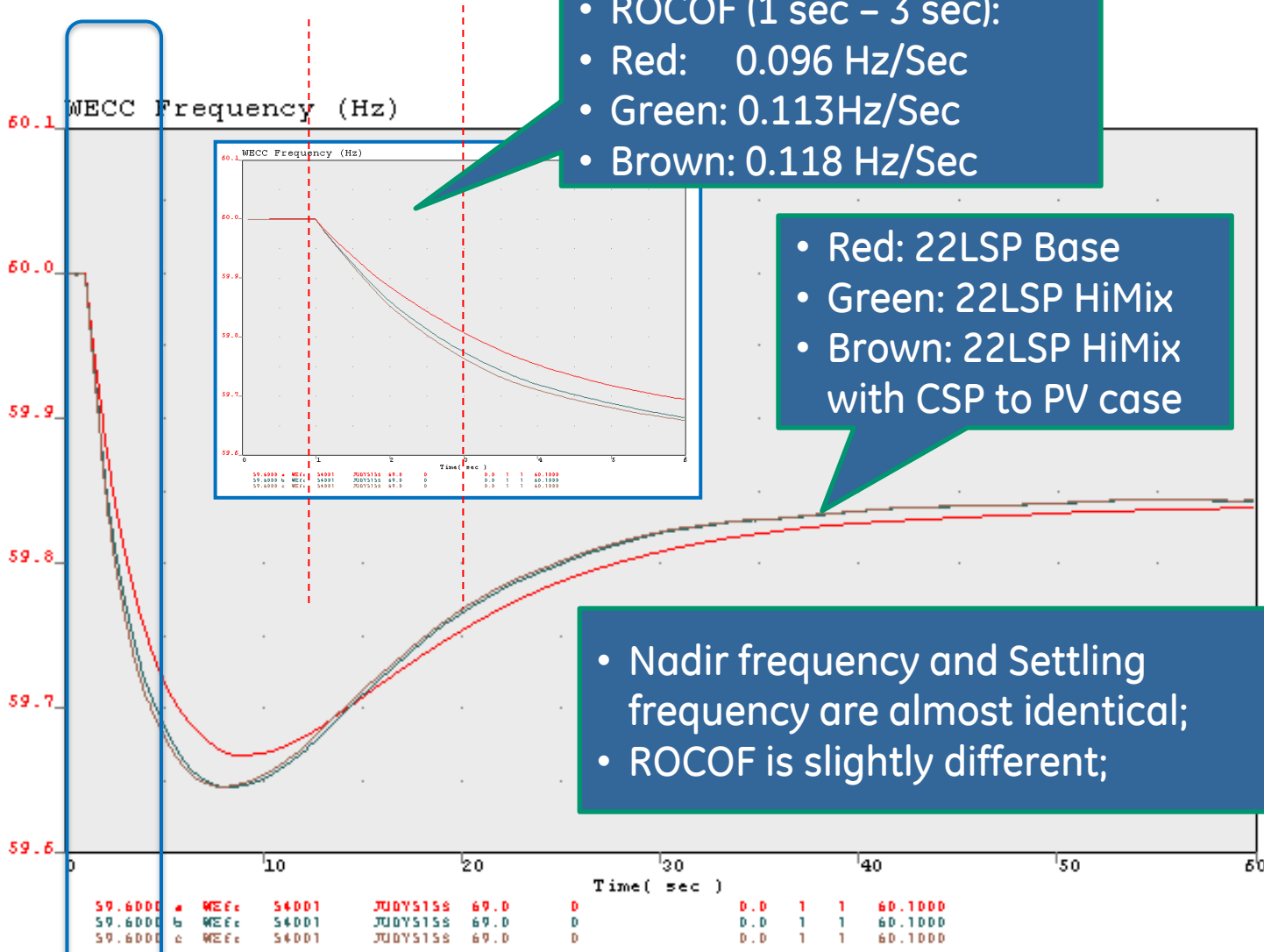
WECC Frequency to loss of 2 PV – 2022LSP HiMix with CSP to PV Case



- ROCOF (1 sec – 3 sec):
- Red: 0.096 Hz/Sec
- Green: 0.113Hz/Sec
- Brown: 0.118 Hz/Sec

- Red: 22LSP Base
- Green: 22LSP HiMix
- Brown: 22LSP HiMix with CSP to PV case

- Nadir frequency and Settling frequency are almost identical;
- ROCOF is slightly different;

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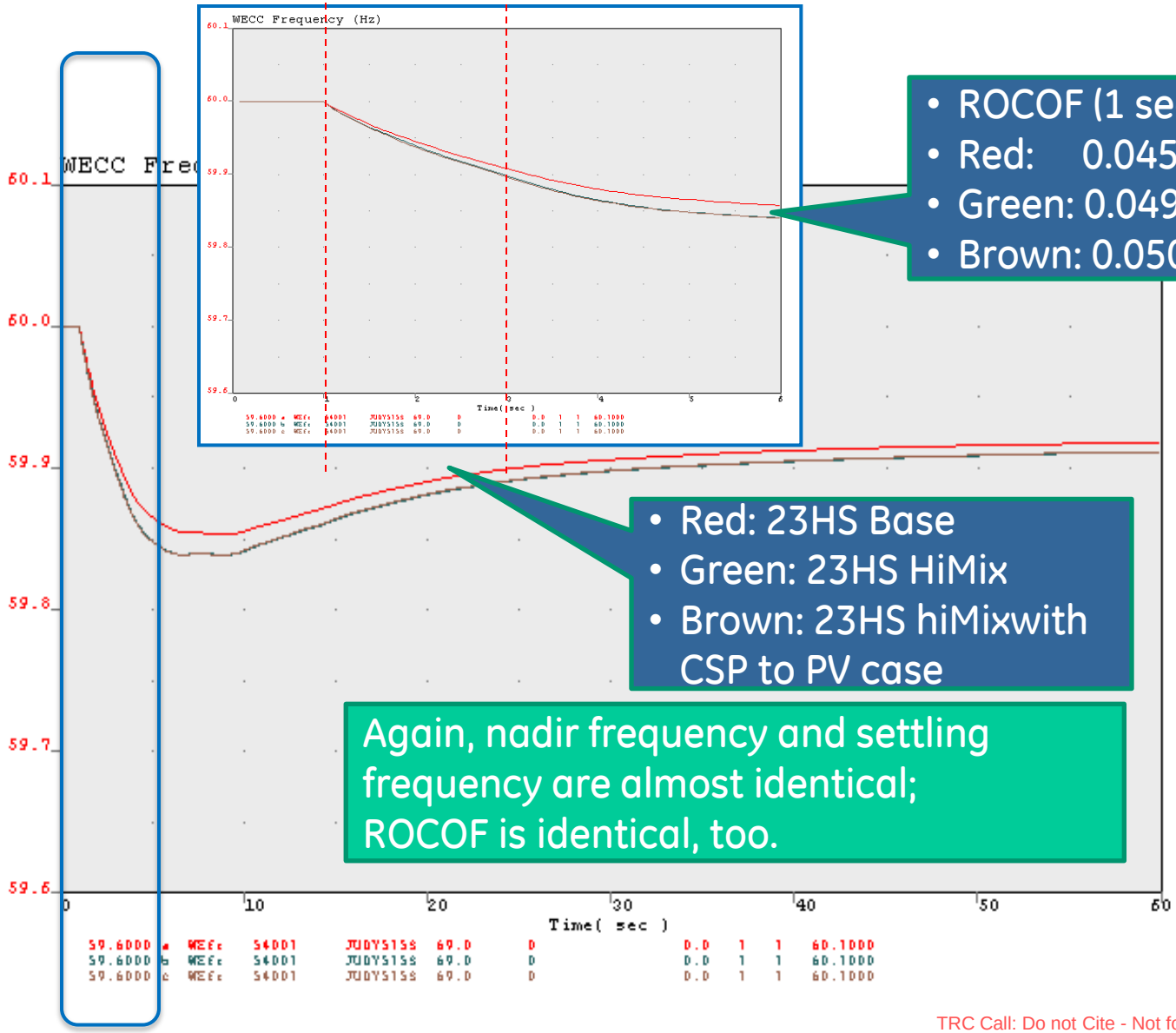
TRC Call: Do not Cite - Not for Further Distribution

WECC Frequency to loss of 2 PV - 2023HS HiMix with CSP to PV Case



- ROCOF (1 sec – 3 sec):
- Red: 0.045Hz/Sec
- Green: 0.049Hz/Sec
- Brown: 0.050 Hz/Sec

- Red: 23HS Base
- Green: 23HS HiMix
- Brown: 23HS hiMixwith CSP to PV case

Again, nadir frequency and settling frequency are almost identical; ROCOF is identical, too.

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CSP Governor Response Sensitivity

- CSP modeled as baseload.
  - Existing CSP plant models are base load
  - Throttling steam from HRSGs tends to be less efficient
- But, CSP *could* provide primary frequency response,
  - Especially since WWSIS II work assumed that all CSP had significant amounts of thermal storage
- Following tests show CSP with governor response

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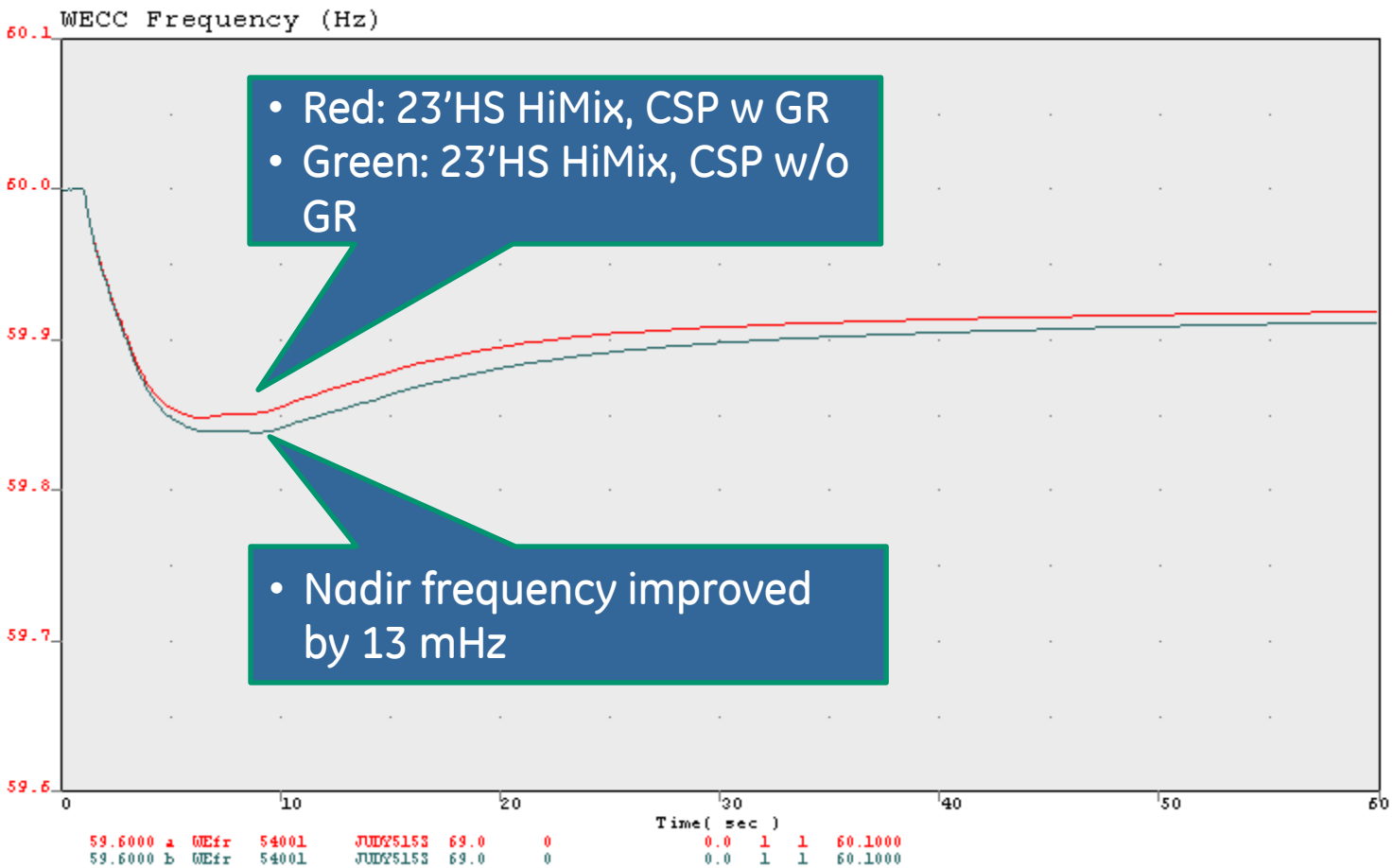
WECC Frequency to loss of 2 PV – 23'HS HiMix Case CSP with and without GR



- Red: 23'HS HiMix, CSP w GR
- Green: 23'HS HiMix, CSP w/o GR

- Nadir frequency improved by 13 mHz

imagination at work

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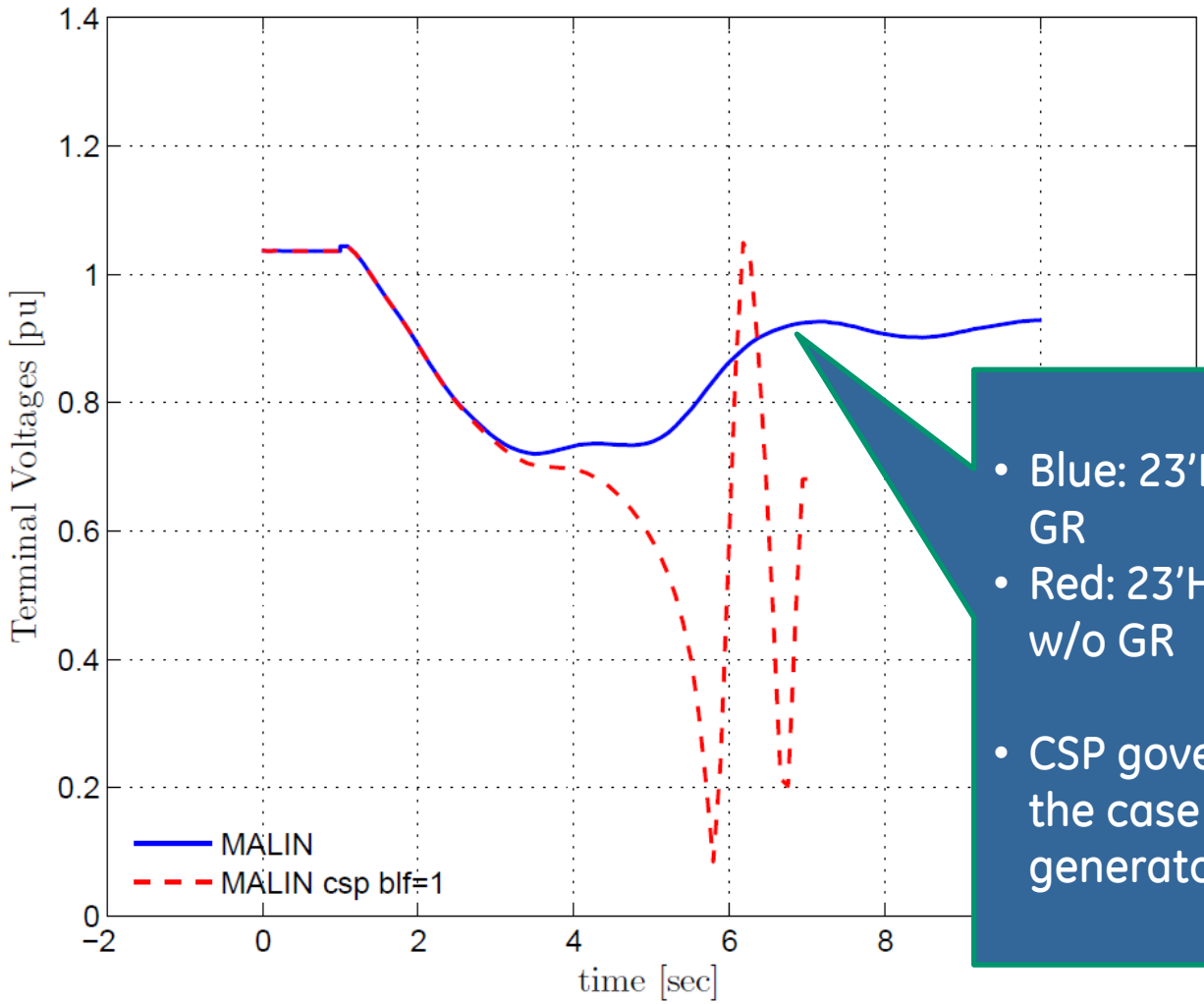
Transient Stability to loss of PDCI – 2023HS HiMix Case CSP with and without GR



- Blue: 23'HS HiMix, CSP w GR
- Red: 23'HS HiMix, CSP w/o GR

- CSP governors stabilize the case with no generator tripping RAS

imagination at work

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2.9 Depleted Headroom Investigation

- This is a work-in-progress

Loss of headroom: Ducks

- Discussion with CAISO (thanks Clyde Loutan)
- Recent concern over emerging net load profile with strong mid-day solar…Duck Curves
- Commitment and dispatch to accept high solar can leave system short of responsive resources in the evening when solar drops off and before wind picks up
- Particular concern that FRO will not be met, especially for some individual BAs

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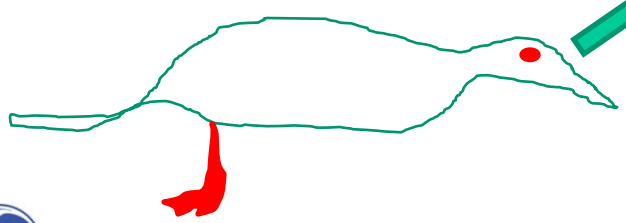
Spring Ducks

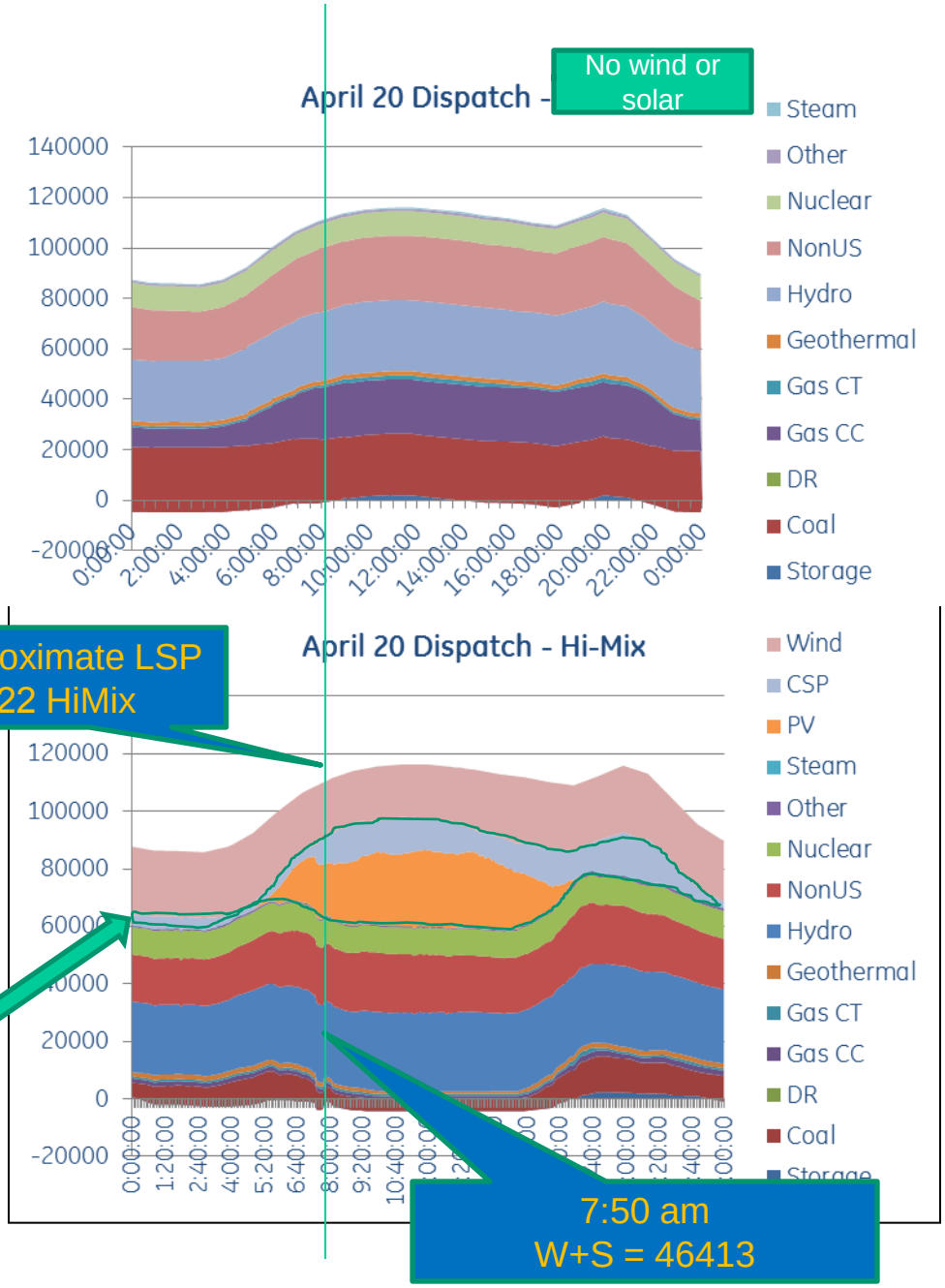
- These are from PLEXOS
- LSP HiMix was developed to investigate very instantaneous penetration:

Load = 109.5GW

W+S = 52.8 (48% penetration)

Headroom = 21.9GW





imagination at work

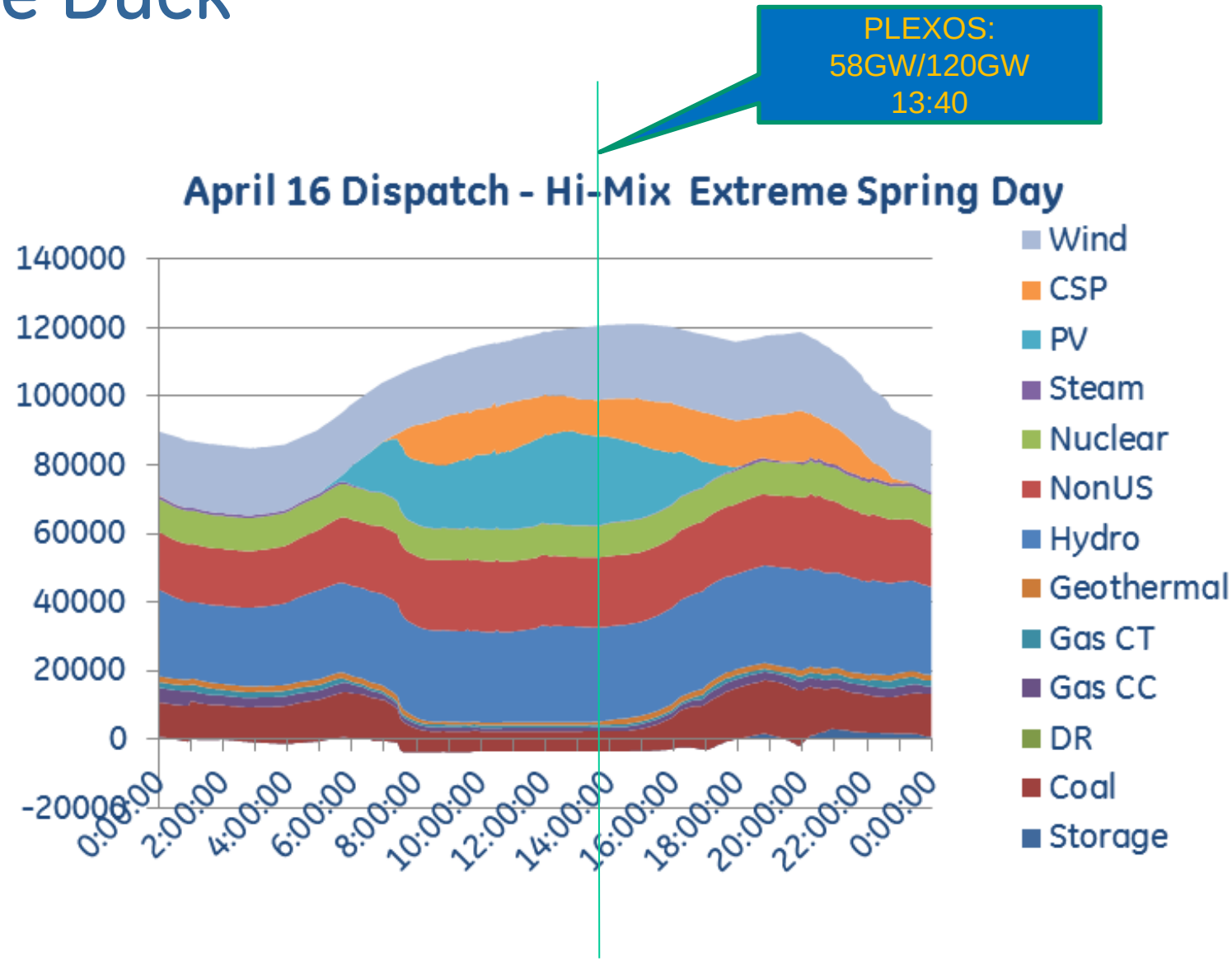
Extreme Duck

LSP Extreme:

Load = 109.5GW

W+S = 64.8 (59% penetration)

Headroom = 18GW



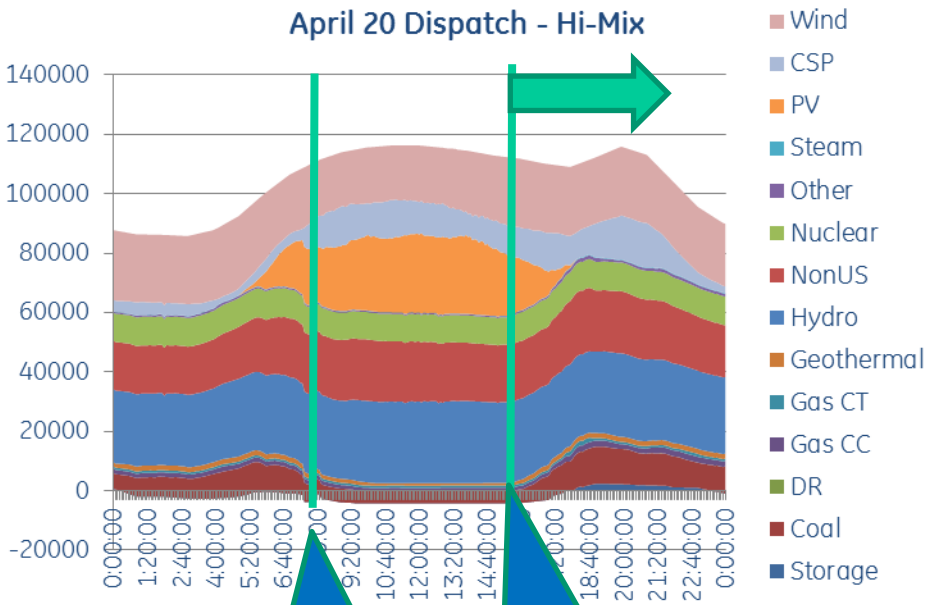
imagination at work

Squeezing the Duck: Headroom experiments

Proposed investigation

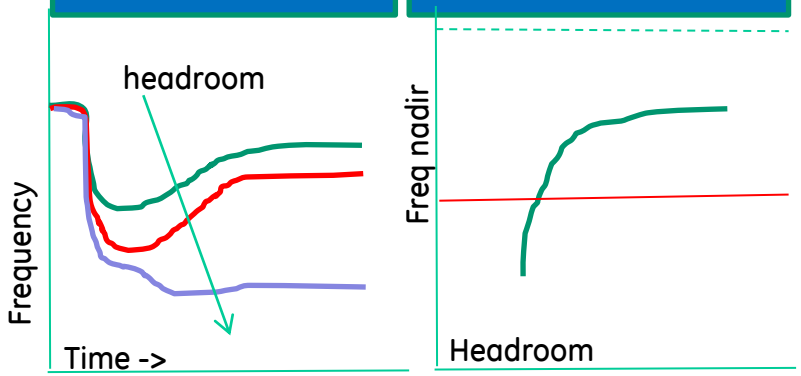
- Fix Commitment
- In steps (of say 4000MW)
  - Decrease wind & solar
  - Dispatch up units (identified by Plexos dispatch sensitivity
  - Recalculate headroom, Kt, etc.
- Run Palo Verde 2 event
  - Observe frequency
  - Calculate FR
- Repeat until UFLS or other fail
- Plot performance
  - vs. renewable power
  - vs. headroom

- NB: suggest this be done on the CSP sensitivity case, and disregard CSP thermal storage



7:50 am
W+S = 46413
Roughly our nominal LSP HiMix condition

Later, when the renewables are getting ready to drop looks very similar



imagination at work

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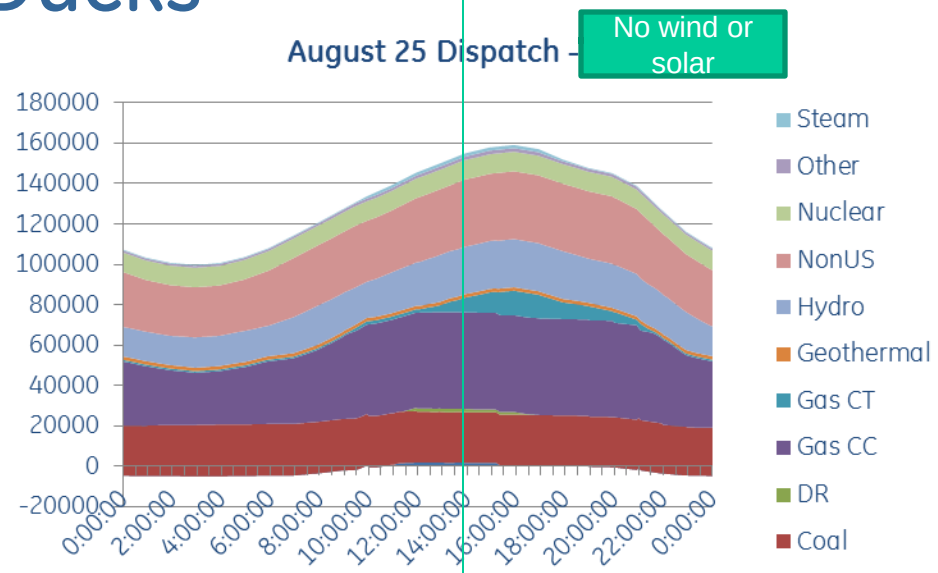
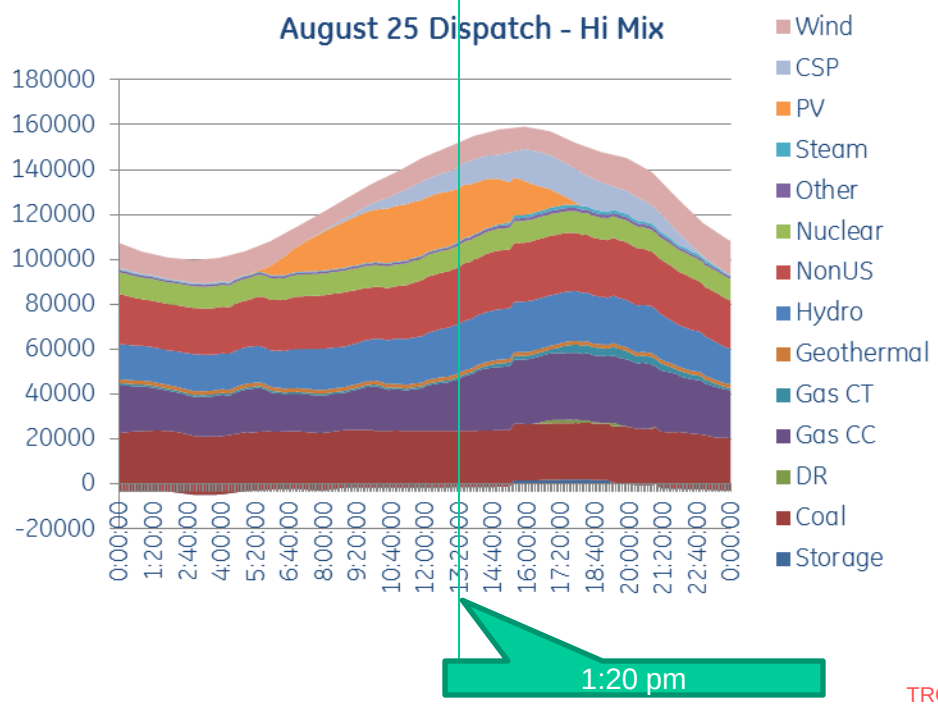
Summer Ducks





imagination at work

3. Preliminary Conclusion and Summary

What have learned/observed?

- Initial conditions/commitment & dispatch
  - Massive effort is required to get meaningful commitment and dispatch when huge amounts of wind & solar are added
  - Solution of Hi-Mix cases broadly reasonable, <u>without</u> significant transmission additions
  - Existing path limits and RAS respected for this work, but will likely change with W + S
  - Economics may support significant transmission additions, per WWSIS II
  - Some localized problems need to be corrected; certainly more are buried in the results
  - Solution for <u>extreme</u> LSP case was tricky; decommitting units that normally run creates local issues, especially of voltage support; local thermal
  - We fixed some glitches in the WECC cases, but they were generally very good

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What have learned/observed?

- Frequency response
  - Overall headroom tends to be around 20GW or higher
  - Overall Kt tends to be around .45 - .50
  - Pockets of much lower Kt, especially in NE.
  - Addition of wind & solar can increase as well as decrease Kt
  - Contribution of NW and Canada to FR is dominant, and increases as wind and solar dispatch increases
  - Overall FR not much different with W+S, but some regions and areas drop noticeably.
  - Some regions and areas appear to be short, relative to FRO. Gets worse with W+S for some
  - Overall system behavior looks OK.
  - No obvious problems associated with locational shift of responsive resources

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What have learned/observed?

- Transient stability
  - Overall transient stability not obviously substantially different
  - Some RAS needed for PDCI event, when COI loaded to present limit. Qualitatively similar to present behavior
  - No obvious massive differences in transient stability with addition of W+S.
  - Load modeling (composite load) has HUGE impact – not news, but still a bit surprising. Impact appears to greatly exceed differences associated with added wind and solar
  - Supply of reactive power; short circuit strength important (not new)
  - Local issues will change, some improve and some get worse
  - Tripping of distributed generation (due to lack of LVRT or LFRT from 1547 or otherwise) can cause serious problems
  - Massively different load flow patterns suggest that other transient stability concerns could exist

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4. What's next

- Headroom work (ducks)
- Mitigation
- Discussion of priorities with TRC
- Cataloging of ideas for future work (i.e interesting but out of scope for this project)

imagination at work

Preliminary Results: Not for Further Distribution or Citation

Mitigation/Renewables Functionality

- Mitigation (is part of study scope)
  - So far, mitigation not *needed*, in the sense that results have not shown *fundamental* changes in system behavior
  - But, performance does change.
  - Propose that next steps focus on changes to the renewable that might affect the findings, to date…looking at the same initial conditions and events, with changes in the assumptions about the renewables:
- Wind plant active power controls
  - Primary frequency response
  - Inertial response
- Solar plant active power controls
  - Primary frequency response (from PV as well as CSP)
- Reactive power control
  - Different control strategies (e.g. reach) and capabilities (e.g. dynamic range)

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Location Aspects of FR

- Deeper dive into FR and FRO may be warranted
- Specifically locational aspects.
- What are consequences of meeting overall IFRO while missing local FRO?
- Are there other big generation trip events that we should be worrying about?
- Are there other performance or system variables we should be monitoring, reporting?
- Should we look at over-frequency events?
- More investigation of Canada contribution/behavior?
- Other sources of FR, e.g. loads or storage?

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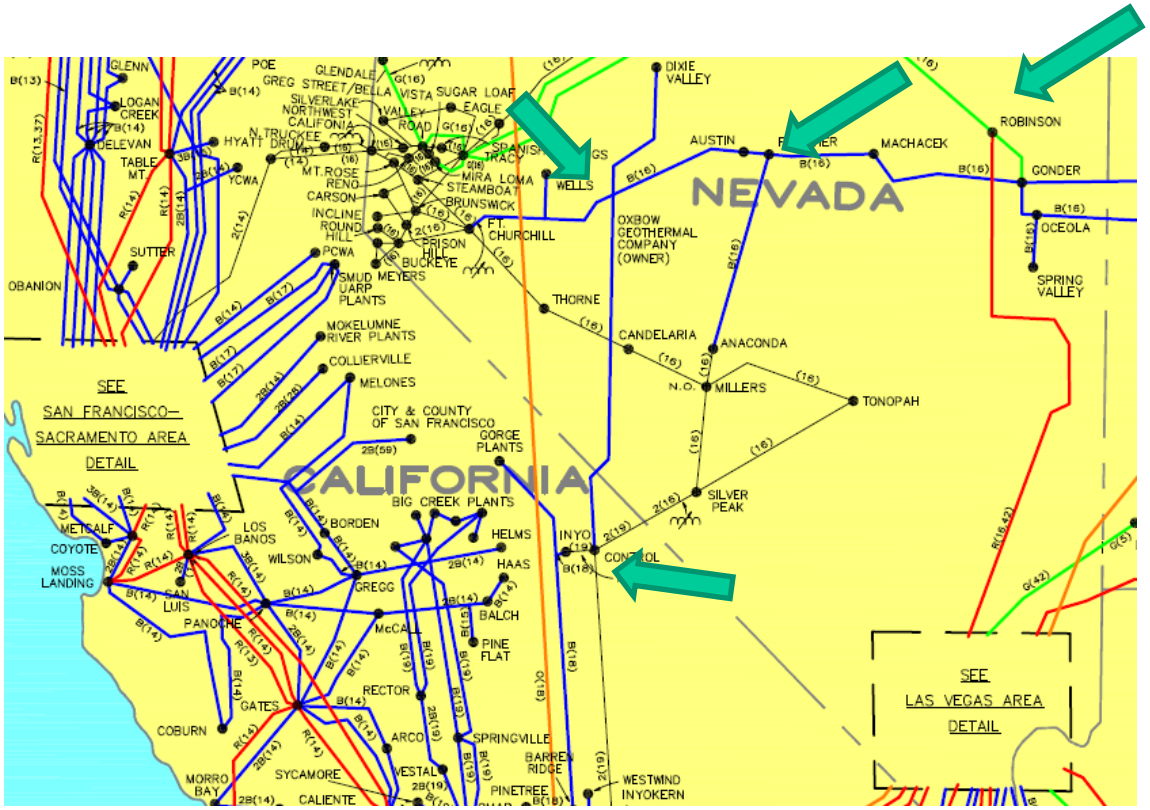
Nevada Desert

- Transmission in region between Reno and LV seems ill-suited to huge additions of solar
- A deeper look at that region might be interesting…including possible topology changes.



imagination at work
TRC Call: Do not Cite - Not for Further Distribution

Northeast Mega Wind

- Deeper investigation of Transmission adds
  - Wyoming/Montana/Idaho, maybe Colorado, too
  - New big lines in WECC database not fully explored
  - Interesting on many fronts
  - Topic of concern at NERC; some WECC parties
- AC vs DC
  - Also subject of considerable (practical) interest
- CSP to Northeast Wind
  - Less solar in SW, more wind in NE
  - Closer to WWSIS II HiWind case
  - Will be a lot of work; a priority?

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Complex Loads, Distributed PV and 1547

- Composite Load w/ DG model has huge capabilities…and some limitations
- We showed
  - preliminary experiments with LVRT and LFRT
  - Some investigation of complex load behavior
  - This is of considerable interest to the seems to be a high priority to the industry… it will have a pivotal effect on the viability of widespread embedded PV
- But, the core issues, complex load and 1547 behavior, are out of the scope of this work
- We think this very important topic warrants follow-on work (ASAP).

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Other Investigations

- This is good time for TRC members to suggest cases, sensitivities, investigations
- We have finite resources ☺

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Distillation of Insights and Final Report

- We have more work to wring information and insight out of the simulations to-date and from additional simulation work we will do following this meeting
- This is not a planning study, it is research. We're looking for understanding, not a plan
- Careful documentation will be the ultimate measure of this project's worth
- We'll need the TRC to help make our final report 1st class

thanks

TRC Call: Do not Cite - Not for Further Distribution

Schedule Slide

TRC Call: Do not Cite - Not for Further Distribution

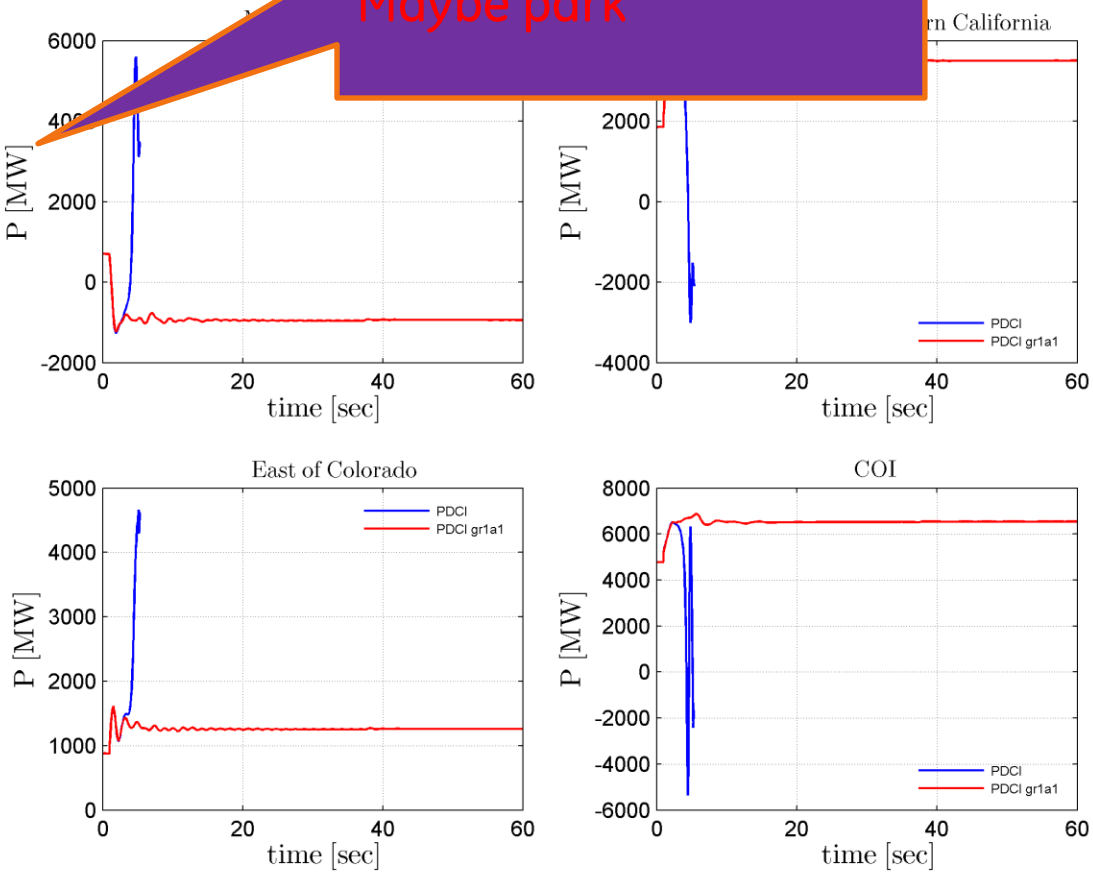
Parked

TRC Call: Do not Cite - Not for Further Distribution

PDCI '23 HS Hi-Mix with even less Generation Trip RAS

Nick.

Maybe park

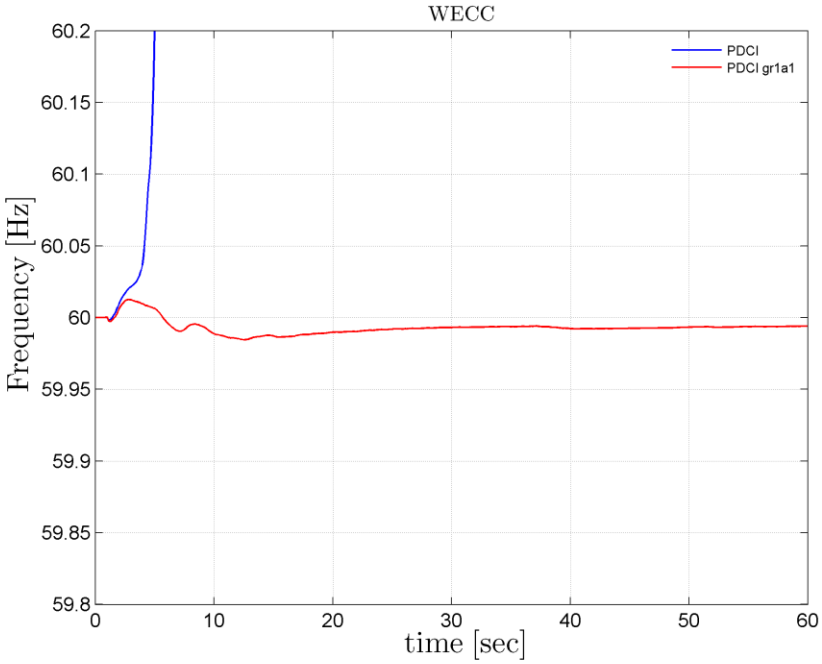


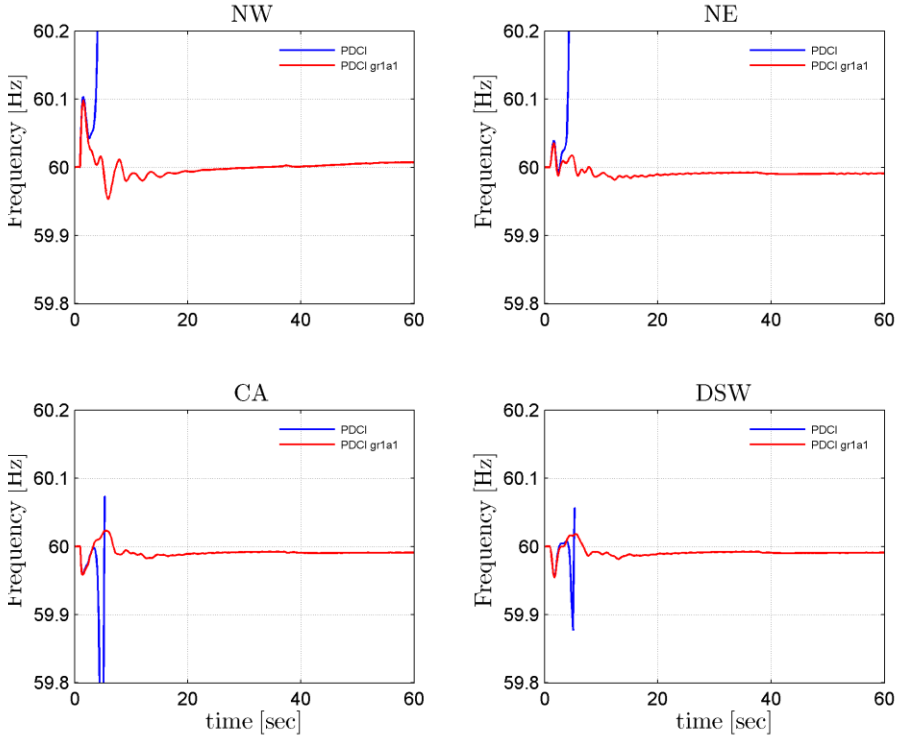
Group 1d1: Trip JDA units 1 only. Total tripped generation 138.5

PDCI '23 HS Hi-Mix with even less Generation Trip RAS

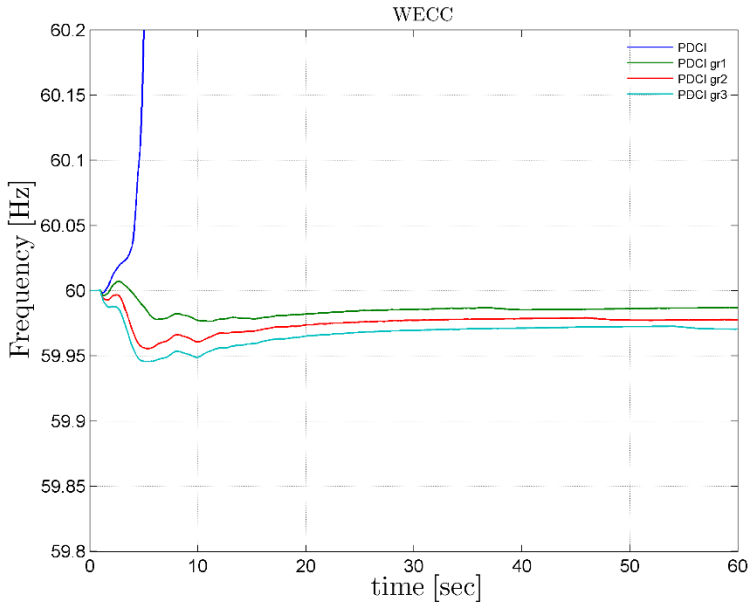
Nick.

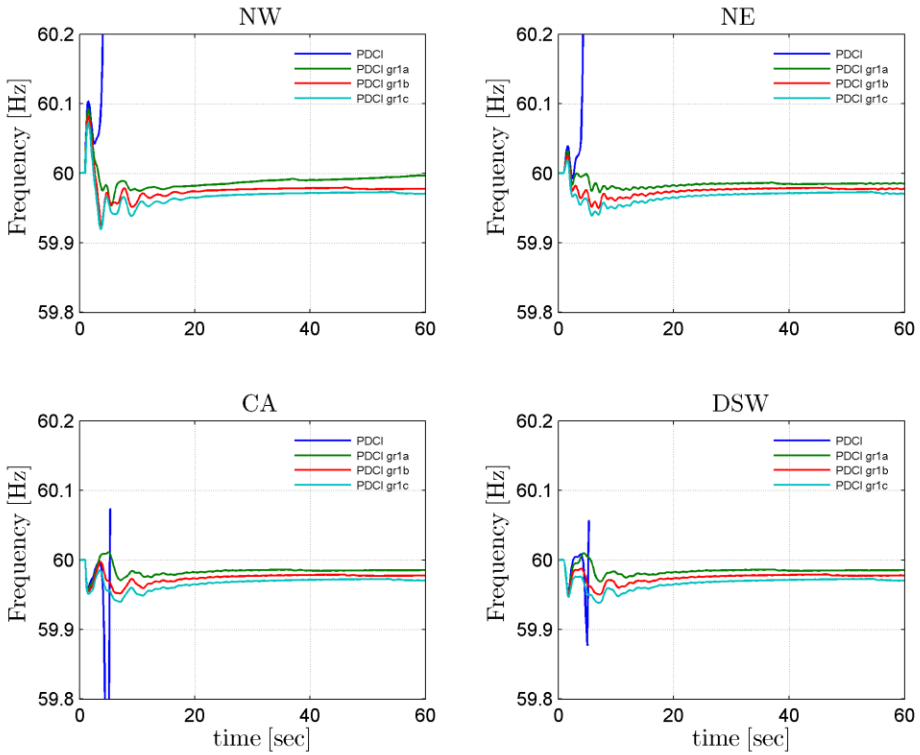
Maybe park





PDCI '23 HS Hi-Mix with less Generation Trip RAS





PDCI '23 HS Hi-Mix with even less Generation Trip RAS

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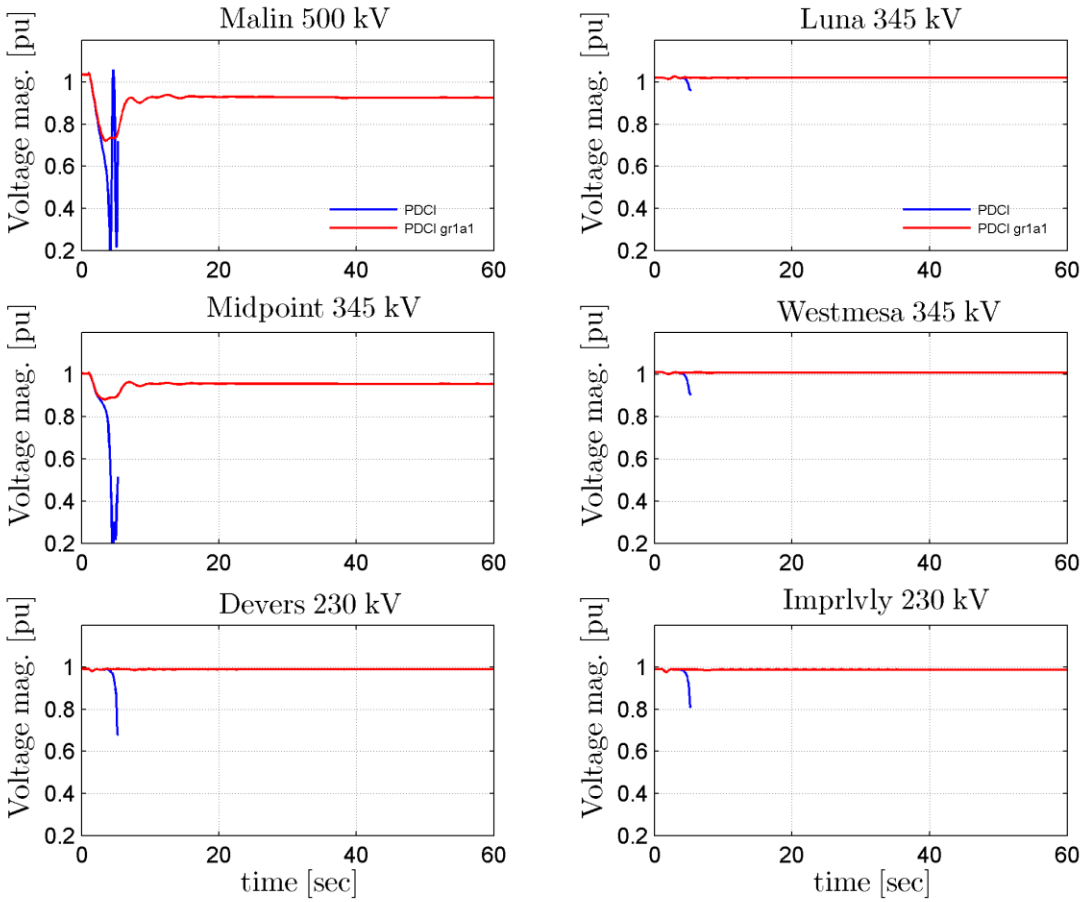
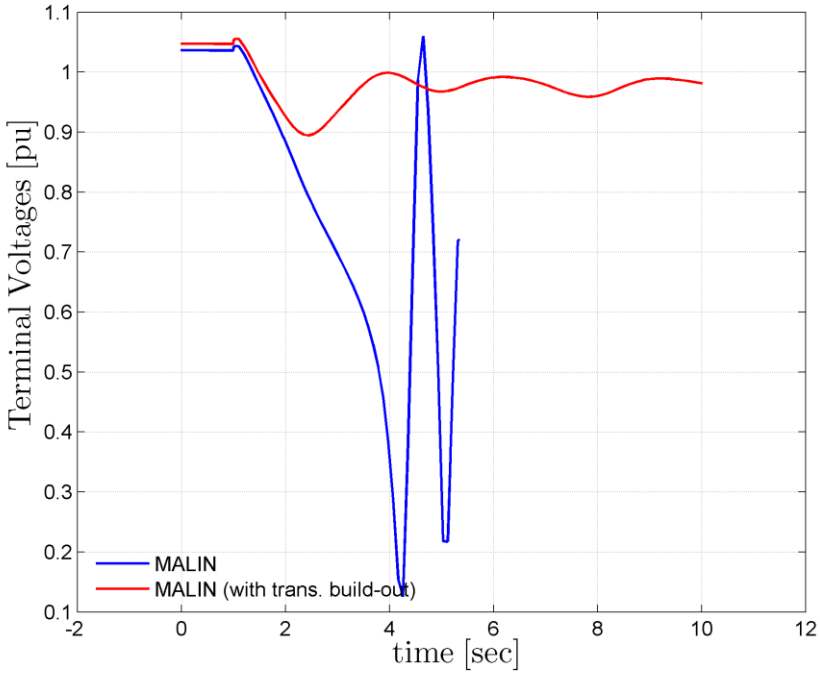


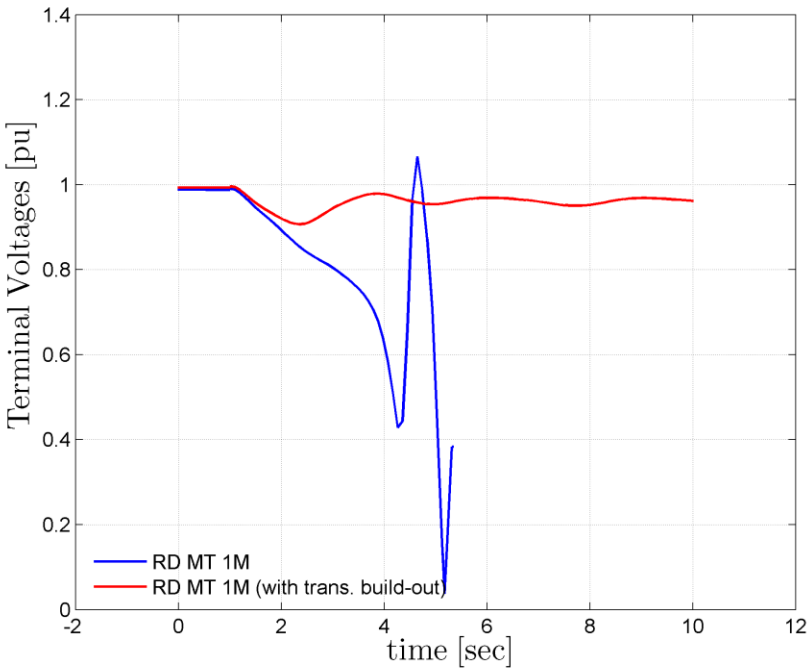
PDCI with Added Transmission

Nick.

Maybe park

Hi-Mix case unstable





PDCI with Added Transmission

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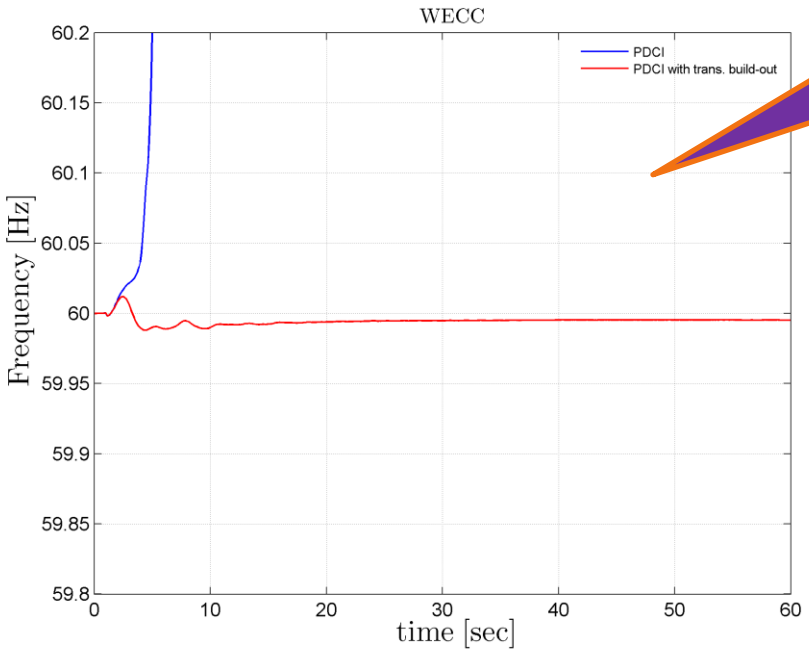
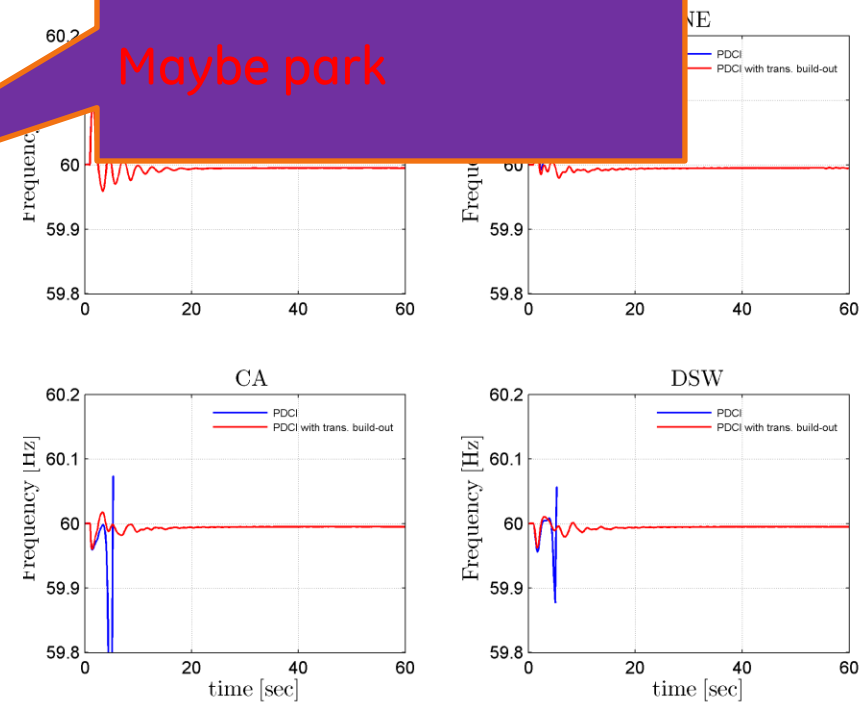
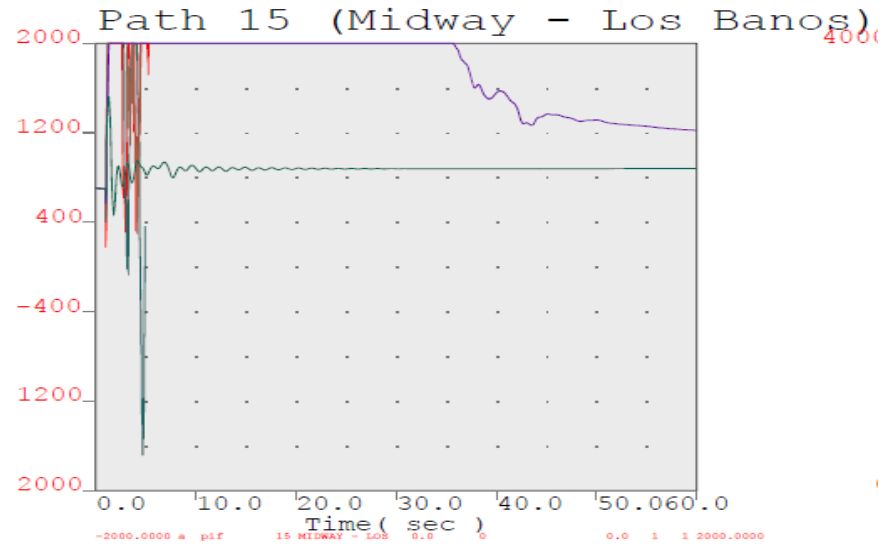
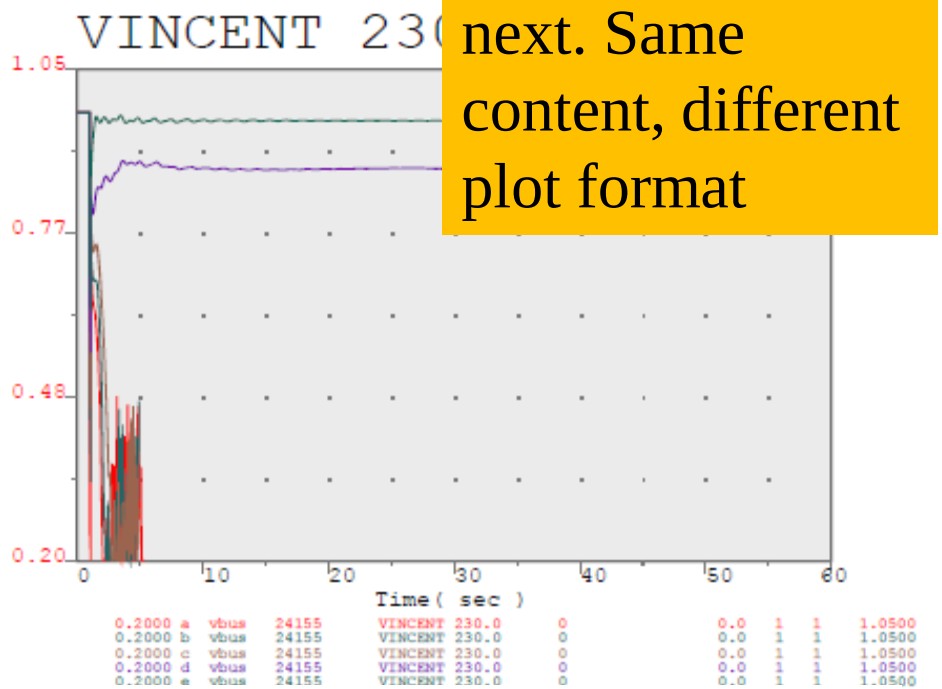


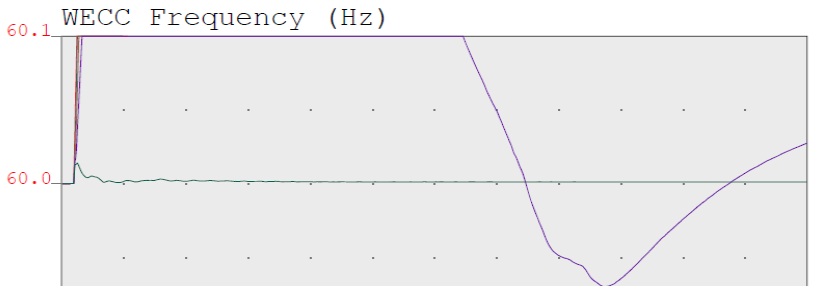


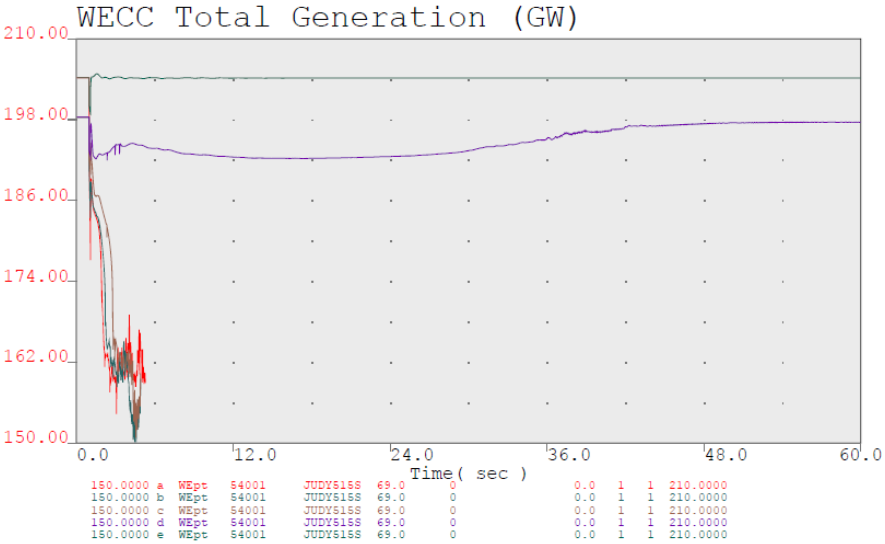
Midway–Vincent Fault Impedance

Pick this slide or next. Same content, different plot format





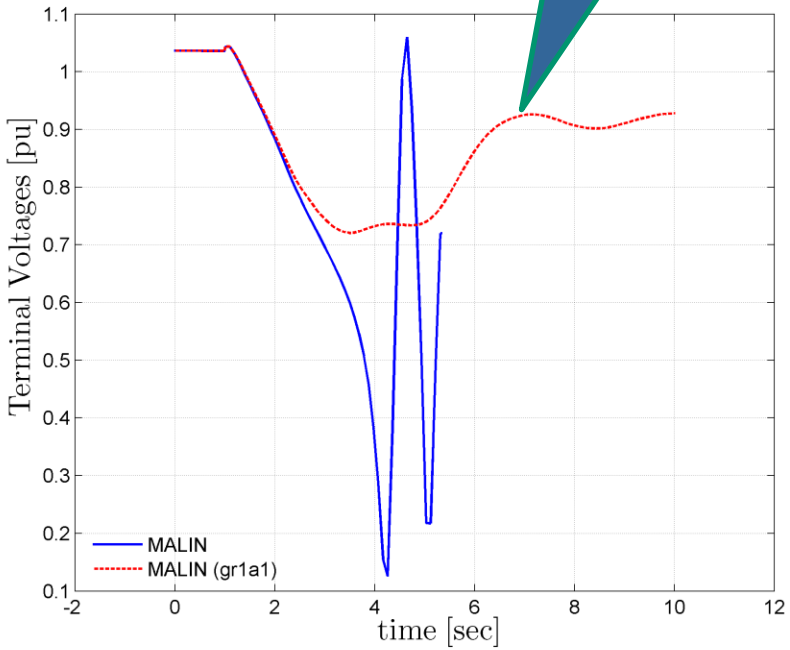
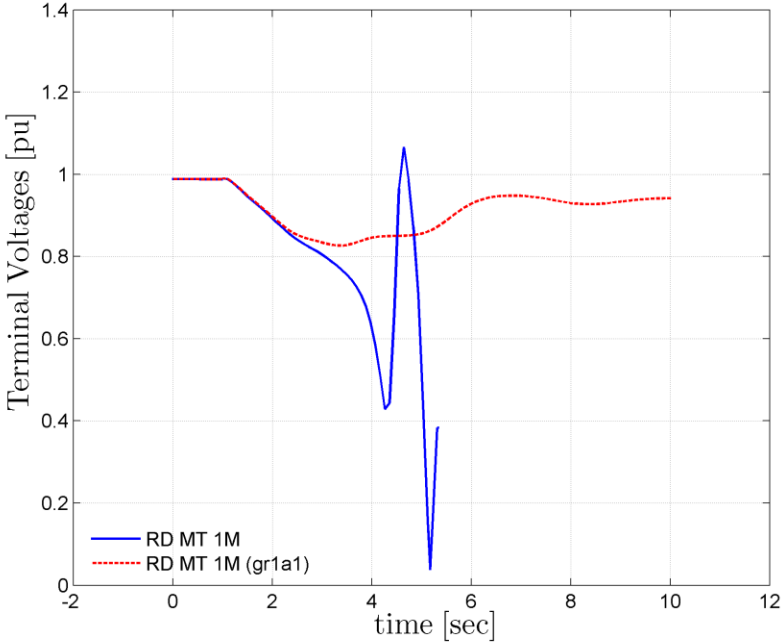




PDCI '23 HS Hi-Mix with less Generation Trip RAS

Barely stable voltage looks OK at first glance..
Only 138MW tripped!

Hi-Mix case unstable



Hi-Mix case with 1xJDA tripping (gr1a1) stable