DYNAMIC STABILITY ANALYSIS FOR THE SHORT-TERM UPGRADES OF THE STEP PROJECT

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1. EXECUTIVE SUMMARY

1.1. Background

This report is a part of the Southwest Transmission Expansion Plan (STEP) technical studies. The purpose of this study was to determine the amount and location of dynamic voltage support that would be required to support the transfer levels identified in the production cost studies that were previously conducted for STEP. In addition, the study evaluated the dynamic stability performance of the alternative upgrades, which would allow increase in the East-of-River (EOR) flow limit by shifting flow to the northern EOR transmission lines.

Dynamic stability simulations were performed for the short-term upgrades of the STEP Project and for the upgrades associated with increase of the East-of-River (EOR) flow limit to 8750 MW (so-called James Hsu Option). The short-term upgrades include thermal upgrades of the series capacitors on the Hassayampa-North Gila-Imperial Valley, Palo Verde-Devers, Navajo-Crystal and Moenkopi-Eldorado 500 kV transmission lines, installation of the second 500/230 kV transformer bank at the Devers Substation and the upgrade of the 230 kV system west of Devers. The second 500/230 kV transformer on the Miguel Substation and series capacitors upgrade on the Imperial Valley-Miguel 500 kV transmission line were also modeled as a part of the SDG&E upgrades. These upgrades are expected to allow increase in the EOR flow limit from the current 7550 MW to 8055 MW. The James Hsu Option, in addition to the short-term upgrades, proposes to bypass the Perkins phase shifter, increase thermal capability of the Perkins-Mead series capacitors and increase the percentage of series compensation on the McCullough-Victorville 500 kV lines from 35% to 70%.

For the short-term upgrades, a summer peak case with high Southern California Imports (SCIT) was studied, as well as an off-peak case with high EOR flow. For the James Hsu Option, an off-peak case with high EOR flow was studied. The dynamic stability analysis for the peak case included simulations of all single 500 kV transmission line outages in the Southwest and outages of major generation (Palo Verde and San Onofre). The off-peak and James Hsu Option analysis included studies of the Palo Verde-Devers and Hassayampa-North Gila 500 kV single-line outages, since these outages were the most critical in identification of the required reactive support.

Previous dynamic stability studies conducted for STEP have indicated a wide variety of dynamic reactive support requirements. This wide range was primarily due to the wide range of assumptions used in the studies. Critical assumptions include the location and amount of new and retired generation, the generation dispatch and resulting transfer levels. To evaluate the impact of these and other factors, the present analysis also included numerous sensitivity studies. The effect of such factors as Southern California import levels, inertia of the generating units on-line, distribution of flow between southern and northern EOR transmission lines, voltage support from the on-line generation and load modeling assumptions was studied.

1.2. Summary of the Study Results

Major results of the dynamic stability analysis are summarized below.

- For the summer peak case for all the contingencies studied, the system dynamic performance was stable, well damped and within the planning criteria. The only exception was an outage of the Imperial Valley-Miguel 500 kV transmission line with cross-tripping of the Imperial Valley-La Rosita 230 kV line as part of the remedial action scheme (RAS). Tripping of the Imperial Valley-La Rosita line with an outage of the Imperial Valley-Miguel line caused local violations of the WECC transient frequency standard in the Cerro Prieto area in the Comision Federal de Electricidad (CFE) system in Mexico. These violations are expected to occur when load in the CFE system is high. They do not impact the rest of the WECC transmission system.

- The Palo Verde-Devers 500 kV line outage with a three-phase fault on the sending end of the line may cause local frequency violations on three geothermal generation buses in the Imperial Irrigation District (IID) when these units generate at full output and the EOR flow is high. These violations do not impact any other areas.

- The Hassayampa-North Gila 500 kV line outage with a three-phase fault on the sending end of the line may cause voltage violations under off-peak conditions with high EOR flow. The violations are expected to occur in the Devers-Mirage and Valley areas of the Southern California Edison (SCE) system. To mitigate these violations, the installation of additional dynamic reactive support is required.

- The upgrades recommended in the James Hsu Option allow for the increase in EOR flow to 8750 MW without installation of additional dynamic reactive support. However, without an increase in series compensation on the McCullough-Victorville 500 kV transmission lines, which allows the shifting of more flow to the northern EOR transmission lines, additional dynamic reactive support will be required. Additional reactive support will be also required with lower Arizona inertia (fewer units on-line) or higher Southern California load.

- The identified voltage criteria violations under off-peak conditions with high EOR flow can be mitigated by the installation of a minimum of a 200 MVAR Static Compensator (STATCOM) or a 240 MVAR Static VAR Compensator (SVC) on the Devers 500 kV bus, or the installation of additional 20-ohm Thyristor Controlled Series Capacitor (TCSC) on the Palo Verde-Devers 500 kV transmission line.

- It appears that the installation of a TCSC is more effective than installation of the same size STATCOM, and a STATCOM is more effective than the same size SVC.

- The study results and the recommended amount of additional dynamic reactive support are very sensitive to the type of load in Southern California. If the proportion or amount of induction motor load is higher than 20% as assumed in the studies, significantly more reactive support may be required.

- The study results, and the required amount of reactive support, are sensitive to the value and distribution of load in Southern California. With higher load and with more load concentrated in the Devers and Valley areas, the required amount of reactive support will be higher.

- Reactive support from the on-line generation in Southern California has a significant impact on the system dynamic stability performance. In particular, if the Mountain View Generation Project is not in service, the installation of a 200 MVAR STATCOM or a 20 ohm TCSC will not be sufficient to mitigate the criteria violations. At a minimum, a 30-ohm TCSC or a 330 MVAR STATCOM will be required in this case.

- The impact of reactive support from on-line generation depends on the location of this generation. The closer a generator is to the Devers or Valley areas, the higher is its impact. In particular, the Mountain View and Alamitos plants have higher impact than the Palomar and Otay Mesa plants, and the Pastoria plant did not have any impact on the amount of required reactive support.

- The inertia of the Southern California generators did not impact the system dynamic stability performance. However, the location and amount of reactive support from the on-line generators in this area had a significant impact.

- The inertia of the generators on the sending end of the southern EOR lines (at Palo Verde, Hassayampa and Gila River), as well as inertia of other Arizona generators has a significant impact on system stability. If all the existing generation units in this area were on-line, no additional reactive support would be required for the EOR flow level studied.

- The distribution of flow between the southern EOR lines (Palo Verde-Devers and Hassayampa-North Gila) and the rest of the EOR has a significant impact on system dynamic stability performance. This distribution depends on the generation dispatch between Nevada and Arizona. With higher flow on the southern lines, more dynamic reactive support will be required. With the recommended 200 MVAR dynamic reactive support, the combined flow on the Southern EOR lines should be limited depending on the inertia of the generators in Arizona (from 3440 MW with low Arizona inertia to 3520 MW with high Arizona inertia).

- The location of the TCSC on the Palo Verde-Devers 500 kV line does not impact the dynamic stability performance as long as the size of the TCSC is the same.

- Simultaneous high EOR flow and high SCIT may require higher dynamic reactive support than identified in the studies. The studies showed that with higher SCIT due to fewer generation units on-line in Southern California, the required dynamic reactive support might be as high as 800 MVAR (two STATCOMs, 400 MVAR each on the Devers and Valley 500 kV buses).

1.2. Recommendations

- To provide dynamic reactive support for the short-term upgrades of the STEP Project, it is recommended to install at minimum a 200 MVAR STATCOM at the Devers 500 kV Substation. Even if the studies showed that installation of a TCSC would be more effective in mitigation of voltage criteria violations with the Hassayampa-North Gila 500 kV line outage, contrary to the TCSC, a STATCOM may provide reactive support under conditions other than this outage.

- Since the system dynamic stability performance depends on the combined flow on the southern EOR lines and on the inertia of the on-line generators in Arizona, it is recommended to monitor the Arizona inertia and flow on these lines. The flow on the southern EOR lines should not exceed the limit for the certain system conditions (for example, 3440 MW for 86,000 MWsec inertia of Arizona generation, or 3520 MW for 95,000 MWsec inertia).

- It is recommended to revise the EOR/SCIT nomogram so that it would better represent the present system conditions. Since the studies showed that Southern California inertia does not impact the dynamic stability performance, it should not be included in the nomogram. It is recommended that instead of the EOR/SCIT values, the nomogram should include flow on the southern and northern EOR lines separately. The nomogram should also include inertia of the on-line generation units in Arizona. In addition, the nomogram should consider the location and amount of reactive support from the on-line generation in Southern California.

- It is recommended to revise the RAS for the Imperial Valley-Miguel 500 kV transmission line outage so that it would not include tripping of the Imperial Valley-La Rosita 230 kV line. Additional generation tripping may be considered instead. If the RAS for this outage is not revised, CFE may experience violations of the WECC transient frequency criteria in the Cerro Prieto area.

- It should be taken into account that the recommended amount of dynamic reactive support was determined based on a snapshot from the economic studies. As it is shown in this report, with simultaneously high SCIT and EOR flow, or higher combined flow on the Hassayampa-North Gila and Palo Verde-Devers lines, and low inertia in Arizona, the amount of required reactive support might be higher.

- Since the required reactive support depends on the study assumptions and the present study showed that depending on the assumptions, it might vary from 0 to 800 MVAR, it is recommended for the STEP stakeholders to evaluate what amount of additional dynamic reactive support is reasonable. A new EOR/SCIT nomogram should then be developed based on the approved amount of dynamic reactive support.

The following sections of the report describe the study assumptions, study methodology and results of the technical studies in more detail.

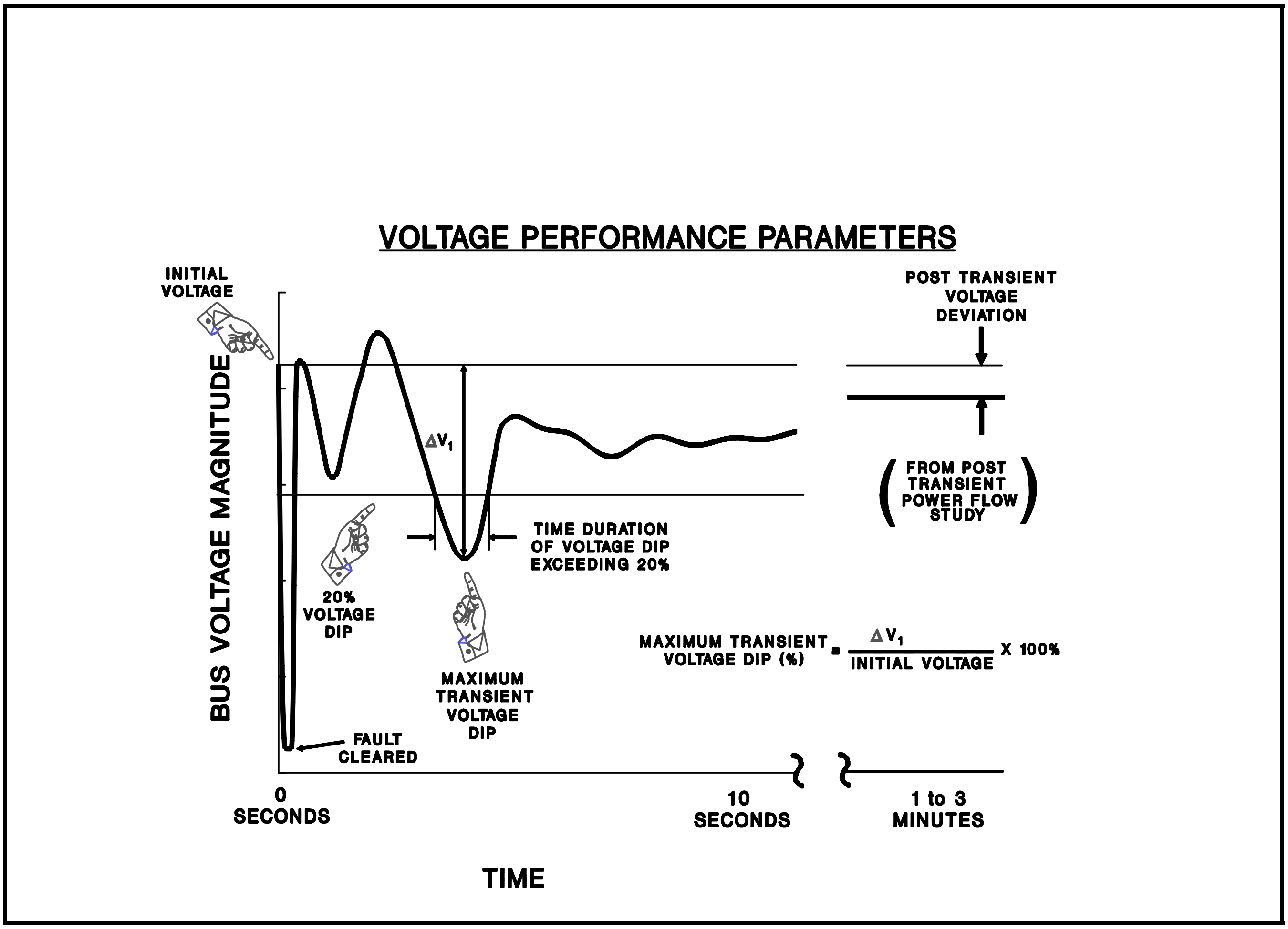
2. STUDY METHODOLOGY

Dynamic stability studies were performed to determine if the system performance satisfies the NERC/WECC criteria. Transient stability performance criteria are included in the WECC Standards. They are briefly summarized in the following table.

WECC DISTURBANCE-PERFORMANCE TABLE OF ALLOWABLE EFFECTS ON OTHER SYSTEMS

NERC and WECC Categories	Outage Frequency Associated with the Performance Category (outage/year)	Transient Voltage Dip Standard	Minimum Transient Frequency Standard	Post Transient Voltage Deviation Standard (See Note 2)
A	Not Applicable	Nothing in addition to NERC		
B	≥ 0.33	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.	Not below **59.6** Hz for 6 cycles or more at a load bus.	Not to exceed **5%** at any bus.
C	0.033 – 0.33	Not to exceed **30%** at any bus. Not to exceed **20% for more than 40 cycles** at load buses.	Not below **59.0** Hz for 6 cycles or more at a load bus.	Not to exceed **10%** at any bus.
D	< 0.033	Nothing in addition to NERC		

The voltage performance criteria are illustrated in the following plot.



The base cases used in the study were developed from snapshots from the STEP production cost studies. One case modeled the hour during the summer peak period when SCIT is at its highest level. The second case modeled the hour during the off-peak season when the sum of the flows on the Palo Verde-Devers and Hassayampa-North Gila lines were the highest and SCIT was at a moderate level for the season being studied.

For the peak case, all 500 kV outages in the Southwest were studied, as well as an outage of two Palo Verde units and an outage of two San Onofre units.

Dynamic stability studies previously performed by the Cal-ISO showed that for the off-peak cases with high EOR flow, the most critical outages were the Palo Verde-Devers and Hassayampa-North Gila 500 kV transmission line outages. These outages were studied for the off-peak case and for the James Hsu Option. In addition, the Imperial Valley-Miguel 500 kV line outage was studied for all the cases because frequency criteria violations were identified with this outage under peak load conditions.

Each contingency was modeled as a four-cycle, three-phase fault on the sending end of the transmission line cleared by opening of the line. The system performance during single outages was compared with the standards for the

Category B contingencies, and the performance during double outages was compared with the standards for the Category C contingencies.

The system dynamic stability performance was studied using the GE PSLF computer program and a computer routine developed by the Cal-ISO, which runs dynamic simulations according to the list of contingencies using files with switching sequences for these contingencies. The program analyzed the output for each contingency, determined and listed the critical buses with the highest voltage dip and lowest frequency, compared the system performance with the WECC criteria and listed all voltage and frequency criteria violations if any. The program output showed voltage criteria violations at the load and generation buses with the voltage dip higher than 25%, all other buses with the voltage dip higher than 30%, and duration of the voltage dip higher than 20% for more than 20 cycles at load buses. The program output also showed frequency criteria violations at the load and generation buses with the frequency lower than 59.6 Hz for longer than 6 cycles.

3. STUDY ASSUMPTIONS

In all the cases, Palo Verde-Devers 500 kV transmission line was modeled as consisting of five sections with series capacitors installed approximately 60 miles from the substations. This modeling represents the actual configuration of this transmission line. Governors on the load-based generators were modeled as being blocked. No additional reactive support was modeled in the base cases.

According to WECC recommendation, all loads larger than 5 MW were modeled as consisting of 20% induction motors with typical parameters across the WECC system.

3.1. Peak Case

The initial case was developed from the Heavy Summer 2005 WECC base case. The case modeled high Southern California Imports (SCIT); the SCIT was at 15960 MW. The East-of-River (EOR) flow was modeled at 7142 MW, Southern California inertia at 114346 MWsec. California-Oregon Intertie (COI) flow was modeled at 4020 MW. The case had the following load and generation assumptions in the Southwest (all numbers are in MW):

	Load	Generation	Losses	Import
SCE	20501	11940	429	8990
SDG&E	4550	2434	132	2248
LADWP	5944	3819	426	2551
IID	651	769	38	-80
Arizona	13515	19237	348	-5374
Nevada	5370	4171	68	1267
CFE	1871	1907	26	-10
Total Southwest	52402	44277	1467	9592

The following generation dispatch was assumed in the Hassayampa area.

Arlington 3 units, 600 MW, 450 MVAR max
Harquahala 2 units, 376 MW, 203 MVAR max
Mesquite 4 units, 588 MW, 545 MVAR max
Red Hawk 6 units, 964 MW, 692 MVAR max
Gila River 11 units, 1482 MW, 1183 MVAR max
Total: 26 units, 4010 MW.

Generation at Imperial Valley was modeled at 840 MW. One La Rosita unit was modeled connected to the La Rosita 230 kV bus, and not to the Imperial Valley bus.

3.2. Off- Peak Case

This study case was developed from the economic studies. The original case was the 2004-05 Heavy Winter WECC case, updated and modified by the CAISO to represent stressed EOR conditions. The study modeled an off-peak case with East of River flow at 8075 MW. It had high flows on the Palo Verde-Devers and Hassayampa-North Gila lines (3418 MW combined) and the most critical, but realistic generation dispatch. Southern California imports (SCIT) were modeled at 12245 MW, Southern California inertia at 81099 MWsec. New SCE Mountain View generation project was modeled at 1000 MW. Two Palo Verde generators were modeled as upgraded to 1473 MW each.

The case had the following load and generation assumptions in the Southwest (all numbers are in MW):

	Load	Generation	Losses	Import
SCE	13651	7061	368	6958
SDG&E	3118	1814	100	1404
LADWP	4112	2257	272	2127
IID	585	791	37	-169
Arizona	9048	16978	300	-7630
Nevada	3001	3165	38	-126
CFE	1543	1703	36	-124
Total Southwest	35058	33769	1151	2440

The following generation dispatch was assumed in the Hassayampa area.

Arlington 3 units, 600 MW, 450 MVAR max (all units on-line)
Harquahala 2 units, 275 MW, 203 MVAR max (out of 6 units, 609 MVAR max)
Mesquite 3 units, 660 MW, 430 MVAR max (out of 6 units, 860 MVAR max)
Red Hawk 6 units, 920 MW, 692 MVAR max (all units on-line)
Gila River 6 units, 1040 MW, 666 MVAR max (out of 12 units, 1332 MVAR)
Total: 20 units, 3495 MW, 2441 MVAR max, unavailable MVAR 1502.

Total inertia of the on-line generation at Hassayampa and Gila River was 26437 MWsec, maximal inertia if all the units are on-line is 42861 MWsec. If the Palo Verde units are included, total inertia on the sending end of the southern EOR lines was 44355 MWsec, maximal inertia is 60779 MWsec.

Generation assumptions at the Imperial Valley were 760 MW of generation from the Imperial Valley and one La Rosita unit. Intergen generation was not dispatched.

Phase shifters at Perkins and Liberty were modeled as blocked.

3.3. Case with 8750 EOR Flow

This case was developed to study the so-called James Hsu Option. James Hsu, from the Salt River Project, suggested studying an option of upgrades to increase EOR flow limit up to 8750 MW without additional new transmission facilities. The additional upgrades (over the short-term STEP upgrades) included 1) bypassing the Perkins phase shifter, 2) increasing thermal capability of the Perkins-Mead 500 kV line series capacitors and 3) increasing percentage of compensation in the McCullough-Victorville 500 kV transmission lines from 35% to 70%.

The case studied was developed by James Hsu. This case included the upgrades described above. The EOR flow was modeled at 8750 MW, total flow on the Southern EOR lines (Palo Verde-Devers and Hassayampa-North Gila) was 3451 MW. Southern California imports (SCIT) were modeled at 11477 MW, Southern California inertia at 89450 MWsec. The new SCE Mountain View generation project was modeled at 950 MW. Two Palo Verde generators were modeled as upgraded to 1473 MW each.

The case modeled a phase shifter on the El Centro-Imperial Valley 230 kV line, which held zero MW flow on this line and on the El Centro 230/161 kV transformer. This phase shifter was proposed as one of the options to mitigate the El Centro transformer congestion, however it is not clear at this time whether this project is going to be constructed.

The following load and generation assumptions in the Southwest were used (all numbers are in MW):

	Load	Generation	Losses	Import
SCE	13317	8305	324	5336
SDG&E	3150	1172	82	2060
LADWP	4202	2403	277	2076
IID	352	893	34	-507
Arizona	9958	18590	282	-8350
Nevada	3586	3166	41	461
CFE	1315	1351	24	-12
Total Southwest	35880	35880	1064	1064

The following generation dispatch was assumed in the Hassayampa area.

Arlington 3 units, 600 MW, 450 MVAR max (all units on-line)
Harquahala 6 units, 975 MW, 609 MVAR max (all units on-line)
Mesquite 6 units, 1110 MW, 860 MVAR max (all units on-line)
Red Hawk 6 units, 896 MW, 692 MVAR max (all units on-line)
Gila River 11 units, 1246 MW, 1360 MVAR max (one unit off-line)

Total: 32 units, 4827 MW, 3971 MVAR max. Total inertia of the Hassayampa and Gila River generation was 41511 MWsec, which is substantially higher than in the off-peak case with 8075 MW EOR flow (26437 MWsec).

Generation assumptions at the Imperial Valley were 50 MW of generation from the Imperial Valley. Intergen generation was not dispatched, La Rosita unit No.1 was modeled connected to the CFE's La Rosita Substation.

4. STUDY RESULTS. SUMMER PEAK CASE

All 500 kV outages in the Southwest were studied. No Additional Reactive Support was modeled. The following table summarizes the study results.

Outage	**Fault location**	**System performance**	**Largest Voltage Dip**		**Lowest Frequency**	
			Bus	**%dip**	**Bus**	**Frq, Hz**
Devers-Valley	Devers	stable, no violations	Valley 115	5.2	IndWells115	59.688
Eldorado-McCullough	Eldorado	stable, no violations	Needls 69	9.0	Padua 66	59.659
Eldorado-Mohave	Eldorado	stable, no violations	Needls 69	10.5	Padua 66	59.659
Eldorado-Moenkopi	Eldorado	stable, no violations	Needls 69	9.5	Padua 66	59.659
Imperial Valley-North Gila	North Gila	stable, no violations	Devers 500	9.2	CPUU3 13.8	59.681
Imperial Valley-Miguel, trip Imp.Vly generation as RAS	Imp. Valley	stable, **frequency violations**	Pendetn 69	8.6	CPTU3 13.8	59.568
Intermntain-Adelanto DC	none	stable, no violations	Tw cities 69	10.2	Blndl1 12.5	59.723
Lugo-Eldorado, Lugo-Mohave double outage	Lugo	stable, no violations	Padua 66	32.9 ♦	Padua 66	59.093
Lugo-Eldorado	Lugo	stable, no violations	Padua 66	30.3 ♦	Padua 66	59.093
Lugo-Mohave	Lugo	stable, no violations	Padua 66	28.5♦	Padua 66	59.102
Lugo-Miraloma # 2	Lugo	stable, no violations	Padua 66	31.7♦	Padua 66	59.093
Lugo-Miraloma # 3	Lugo	stable, no violations	Padua 66	31.5♦	Padua 66	59.093
Lugo-Miraloma double	Lugo	stable, no violations	Padua 66	41.2♦	Padua 66	59.093
Lugo-Victorville	Victorville	stable, no violations	Padua 66	14.3	Padua 66	59.412
Lugo-Vincent double	Lugo	stable, no violations	Padua 66	31.9♦	Padua 66	59.083

♦ In this case, high voltage dip indicates slower voltage recovery after the fault, which is not a violation

♦ In this case, high voltage dip indicates slower voltage recovery after the fault, which is not a violation

Outage	Fault location	System performance	Largest Voltage Dip		Lowest Frequency	
			Bus	%dip	Bus	Frq, Hz
Adelanto-Victorville	Adelanto	stable, no violations	Sylmar 230	12.7	Padua 66	59.484
Adelanto-Toluca	Adelanto	stable, no violations	Toluca 500	16.2	Padua 66	59.484
Adelanto-Rinaldi # 2	Adelanto	stable, no violations	Rinaldi 500	14.6	Padua 66	59.484
Adelanto-Market Place	Adelanto	stable, no violations	Sylmar 230	13.3	Padua 66	59.486
Midway-Vincent double	Vincent	stable, no violations	Wilsona 66	18.1	Wilsona 66	59.248
Mc Cullough-Victorville	Mc Cullough	stable, no violations	Needls 69	10.0	Padua 66	59.639
Two Palo Verde generators,	none	stable, no violations	PetrsnFlt 230	20.1	RBW lake25	59.640
Bi-pole Pacific DC Intertie	none	stable, no violations	Newell 69	7.8	BSPHYD26 2	59.692
Paloverde-Devers	Palo Verde	stable, no violations	N.Gila 500	12.6	Schrader 69	59.663
Serrano-Miraloma	Serrano	stable, no violations	Padua 66	13.9	Padua 66	59.465
Serrano-Valley	Valley	stable, 1 frq violation	Valley 115	13.1	Valley 115	57.715
Lugo-Serrano	Serrano	stable, no violations	Padua 66	15.7	Padua 66	59.465
Two San Onofre generators	none	stable, no violations	PTRSNFLT230	9.5	RBWLak 25	59.785
Hassayampa-North Gila	Hassayampa	stable, no violations	Dometap 161	18.2	Schrader 69	59.662
Perkins-Westwing double	Westwing	stable, no violations	Devers 500	7.2	Newm413.8	59.766
Paloverde-Westwing double	Palo Verde	stable, no violations	Devers 500	18.1	Schrader 69	59.663
Paloverde-Westwing	Palo Verde	stable, no violations	Ploverde500	13.2	Schrader 69	59.663
Navajo-Crystal	Navajo	stable, no violations	Needls 69	9.0	Padua 66	59.659

As can be seen from the table, the only outage, which caused criteria violations was the Imperial Valley-Miguel 500 kV line outage with Imperial Valley generation (837 MW) and Imperial Valley-La Rosita 230 kV line tripped by the remedial actions scheme (RAS). The frequency violations were in the Chapultepes and Cerro Prieto areas in CFE as shown in the tables and the plot below.

HIGHEST VOLTAGE DIP

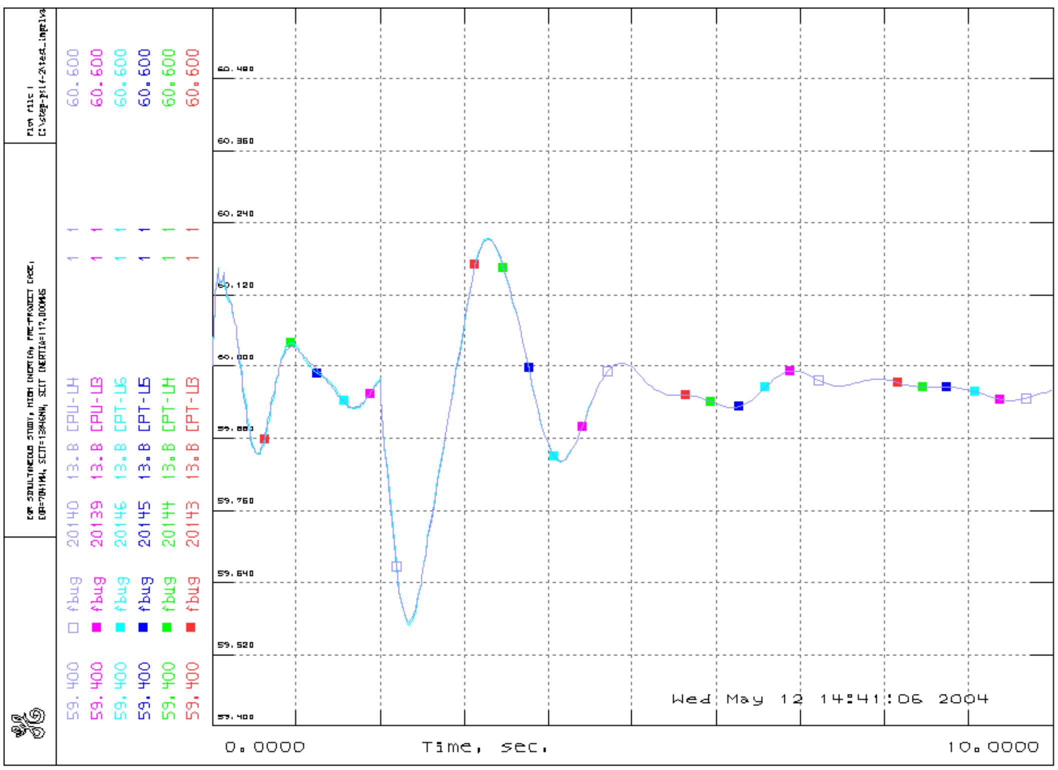
AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
22	PENDLETN	69	vbul		0.985	0.9	8.6	2.829
22	IV-GEN	230	vbus		0.994	0.051	94.9	0.7
24	SANTIAGO	66	vbug		1.021	0.939	8	2.904

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.592	2.342
20	CPT-161	161	fbus		59.59	2.342
20	CPT-U3	13.8	fbug		59.568	2.342

FREQUENCY LESS THAN 59.6

AREA	BUS NAME	BUS KV	TYPE		Cycles	From	To
20	CPD-U1	13.8	fbug		9	2.304	2.454
20	CPD-U2	13.8	fbug		9	2.304	2.454
20	CPT-U1	13.8	fbug		9	2.304	2.454
20	CPT-U2	13.8	fbug		9	2.304	2.454
20	CPT-U3	13.8	fbug		11.2	2.267	2.454
20	CPT-U4	13.8	fbug		11.2	2.267	2.454
20	CPT-U5	13.8	fbug		11.2	2.267	2.454
20	CPT-U6	13.8	fbug		11.2	2.267	2.454
20	CPU-161	161	fbul		6.7	2.304	2.417
20	CPU-U1	13.8	fbug		11.2	2.267	2.454
20	CPU-U2	13.8	fbug		11.2	2.267	2.454
20	CPU-U3	13.8	fbug		11.2	2.267	2.454
20	CPU-U4	13.8	fbug		11.2	2.267	2.454
20	CPU-U5	13.8	fbug		6.7	2.304	2.417



The frequency violations were due to the trip of the Imperial Valley-La Rosita 230 kV line as part of the RAS for this outage. The studies showed that frequency violations might occur with the Imperial Valley-Miguel 500 kV line outage and opening of the Imperial Valley-La Rosita 230 kV line even without a fault. Therefore, the timing of opening of the Imperial Valley-La Rosita line does not impact the violations.

Without tripping of the Imperial Valley-La Rosita line, there were no violations as shown in the following table with the dynamic simulation results.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
62	PTRSNFLT	230	vbul		0.876	0.828	5.4	2.5
22	IV-GEN	230	vbus		0.994	0.051	94.9	0.7
22	BOULEVRD	69	vbug		0.95	0.909	4.3	0.213

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
54	RBW LAK9	25	fbul		59.853	4.525
54	791S701T	138	fbus		59.853	4.525
22	RAMCO_OY	13.8	fbug		59.763	0.175

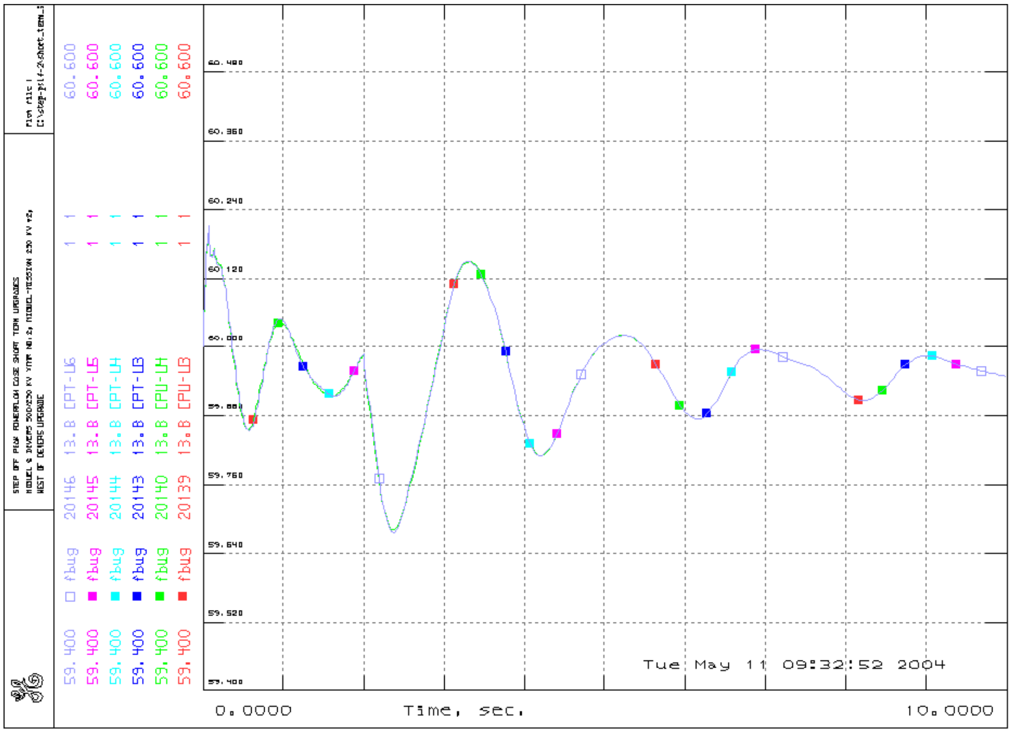
Dynamic simulation of the Imperial Valley-Miguel outage for the off-peak case did not indicate any criteria violations, as shown in the tables and on the plot below.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul		0.98	0.878	10.4	3.017
22	INTB	230	vbus		1.004	0	100	0.55
24	DEVERS	500	vbug		1.025	0.912	11.1	3.017

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.692	2.379
20	CPT-161	161	fbus		59.691	2.379
20	CPT-U3	13.8	fbug		59.676	2.379



Connection of the La Rosita generation unit to the Imperial Valley 230 kV bus in the peak case instead of connection to the La Rosita bus did not mitigate the frequency violations in this case. Tripping one La Rosita unit with this outage will mitigate overload on the La Rosita-Rumorosa 230 kV line and allow to avoid tripping the Imperial Valley-La Rosita line. This way, the frequency violations will be avoided.

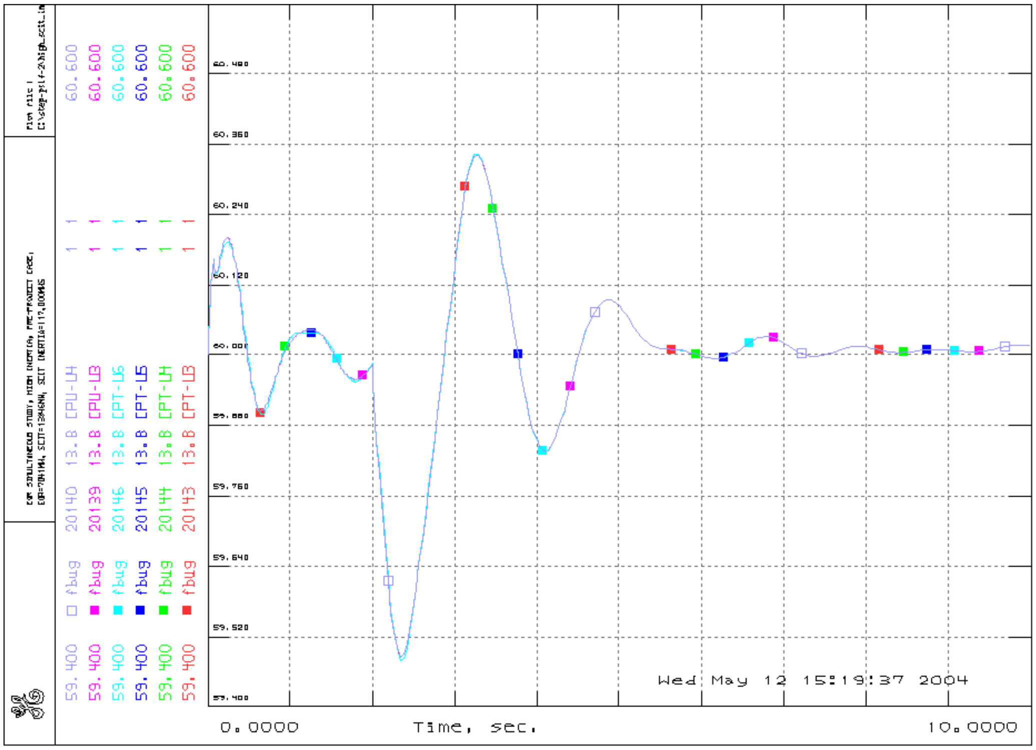
The case with lower Imperial Valley generation (generation at Imperial Valley was modeled 150 MW lower and at Hassayampa 150 MW higher) showed the same frequency violations. Not tripping Imperial Valley generation with the Imperial Valley-Miguel outage did not mitigate the frequency violations, but exacerbates the system performance, as shown in the following table and the plot. All frequency violations are not listed due to too many violations not only in the Cerro Prieto and Chapultepes areas, but also in Mexicali and Wisteria.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
8	LAQUINTA	92	vbul		0.993	0.853	14.1	2.867
8	SHIELDS	92	vbus		1.002	0.865	13.6	2.867
24	CAPWIND	115	vbug		0.999	0.88	12	2.904

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.507	2.342
20	CPT-161	161	fbus		59.506	2.342
20	CPT-U3	13.8	fbug		59.48	2.342



The observed frequency violations are explained by the fact that with opening of both the Imperial Valley-Miguel and Imperial Valley-La Rosita transmission lines, all CFE system will be connected to the WECC system by only one transmission line from Tijuana. With high CFE load, it may cause unacceptable frequency dip. The peak case modeled the CFE load at 1871 MW and the off-peak case modeled the CFE load at 1543 MW. Simulation of the Imperial Valley-Miguel outage with higher load in the off-peak case showed the same frequency violations, and the simulation of the peak case with lower CFE load did not show the violations.

It may be recommended not to open the Imperial Valley-La Rosita 230 kV line with the Imperial Valley-Miguel outage under peak load conditions, but rather trip some of the La Rosita generation.

5. STUDY RESULTS. OFF-PEAK CASE

5.1. Palo Verde-Devers outage

The dynamic simulation results are in the following tables.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
26	WLMNTNLD	138	vbul		1.033	0.794	23.2	0.7
26	HARB	138	vbus		1.034	0.794	23.2	0.7
26	ADELSVC	500	vbug		1.05	0.815	22.5	0.663

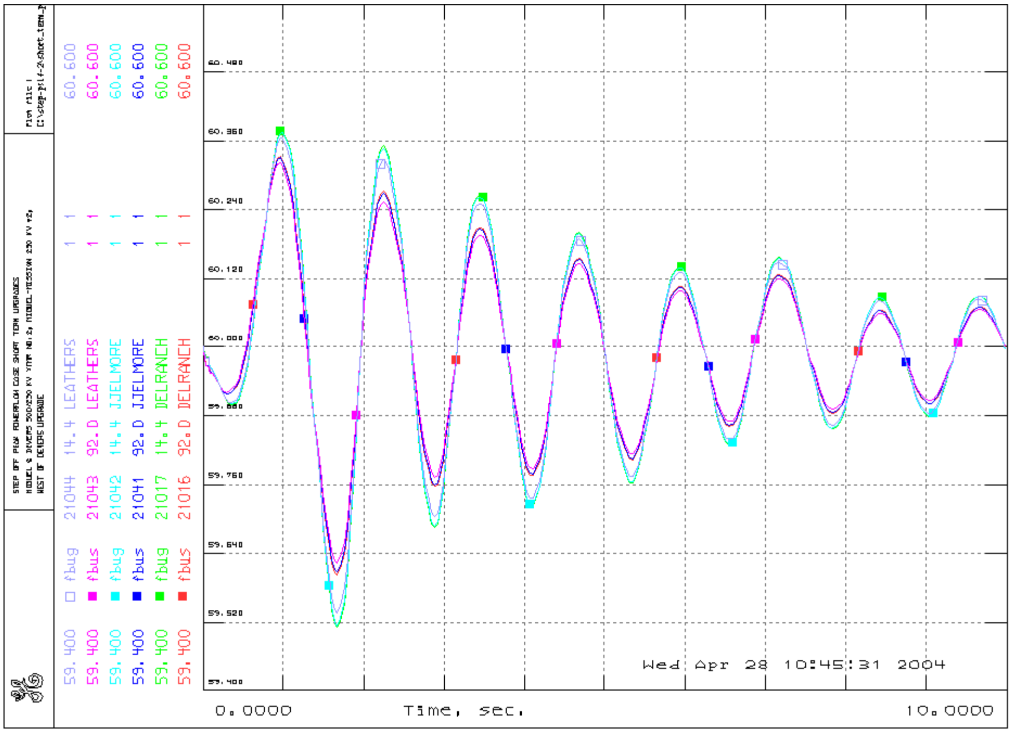
LOWEST FREQUENCY

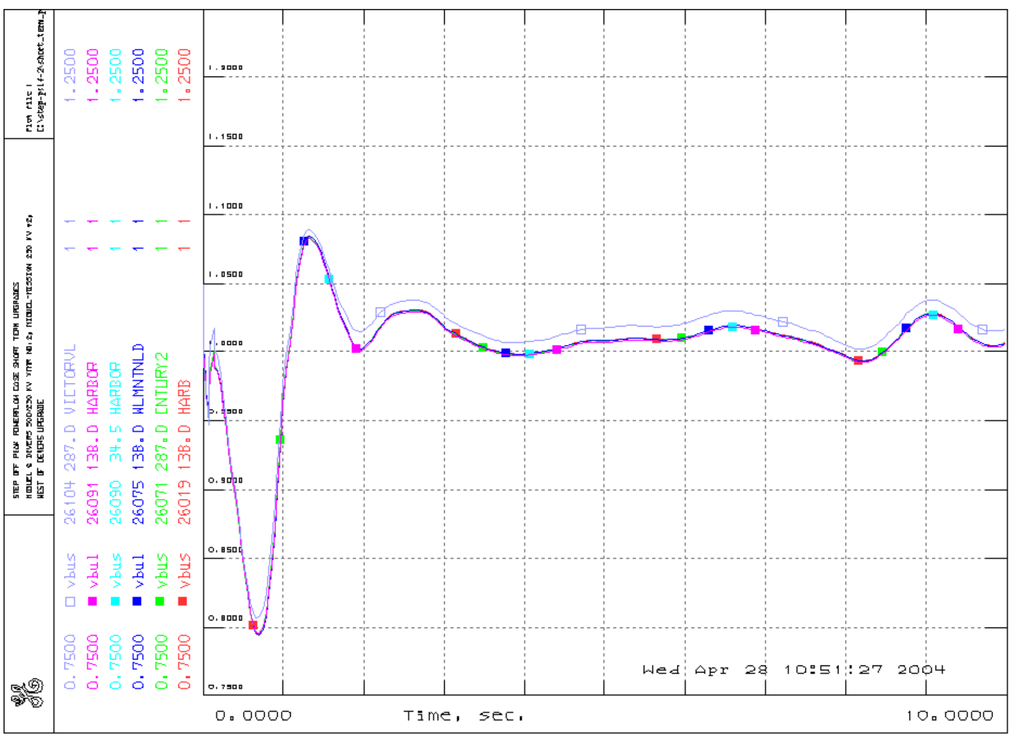
AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
54	AURORA 8	69	fbul		59.69	3.737
21	DELRANCH	92	fbus		59.602	1.675
21	DELRANCH	14.4	fbug		59.509	1.675

FREQUENCY LESS THAN 59.6

AREA	BUS NAME	BUS KV	TYPE		Cycles	From	To
21	DELRANCH	14.4	fbug		13.5	1.563	1.788
21	JJELMORE	14.4	fbug		13.5	1.563	1.788
21	LEATHERS	14.4	fbug		13.5	1.563	1.788

As can be seen from the tables, the Palo Verde-Devers outage caused frequency violations on three generator buses in the Midway area of the Imperial Irrigation District (IID). These violations were caused mainly by high inertia of these generators, they were local, and the frequency recovered. The plots of lowest frequency, highest voltage dip and some 500 kV line flows are shown below.


59.400 □ fbus 21044 14.4 LEATHERS 1 1 60.600
59.400 ■ fbus 21043 92.0 LEATHERS 1 1 60.600
59.400 ■ fbus 21042 14.4 JJELMORE 1 1 60.600
59.400 ■ fbus 21041 92.0 JJELMORE 1 1 60.600
59.400 ■ fbus 21017 14.4 DELRANCH 1 1 60.600
59.400 ■ fbus 21016 92.0 DELRANCH 1 1 60.600
60.480
60.360
60.240
60.120
60.000
59.880
59.760
59.640
59.520
59.400
Wed Apr 28 10:45:31 2004
0.0000
Time, sec.
10.0000


0.7500 □ vbus 26104 287.0 VICTORVL 1 1 1.2500
0.7500 ■ vbus 26091 138.0 HARBOR 1 1 1.2500
0.7500 ■ vbus 26090 34.5 HARBOR 1 1 1.2500
0.7500 ■ vbus 26075 138.0 WLMNTNLD 1 1 1.2500
0.7500 ■ vbus 26071 287.0 CNTURY2 1 1 1.2500
0.7500 ■ vbus 26019 138.0 HARB 1 1 1.2500
1.2000
1.1500
1.1000
1.0500
1.0000
0.9500
0.9000
0.8500
0.8000
0.7500
Wed Apr 28 10:51:27 2004
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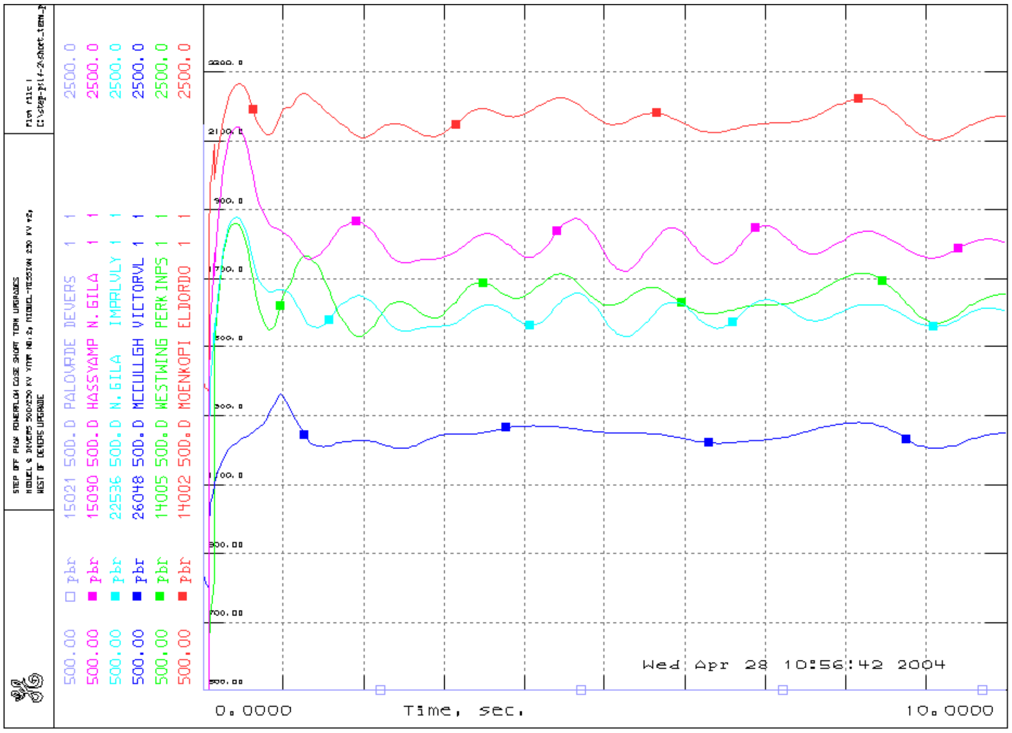
Time, sec.
10.0000



5.2. Hassayampa-North Gila outage

The dynamic simulation results are in the following tables.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul	1.004	0.748	25.4	0.738
24	VALLEYSC	500	vbus	1.04	0.784	24.6	0.738
24	DEVERS	500	vbug	1.025	0.751	26.8	0.7

VOLTAGE CRITERIA VIOLATIONS

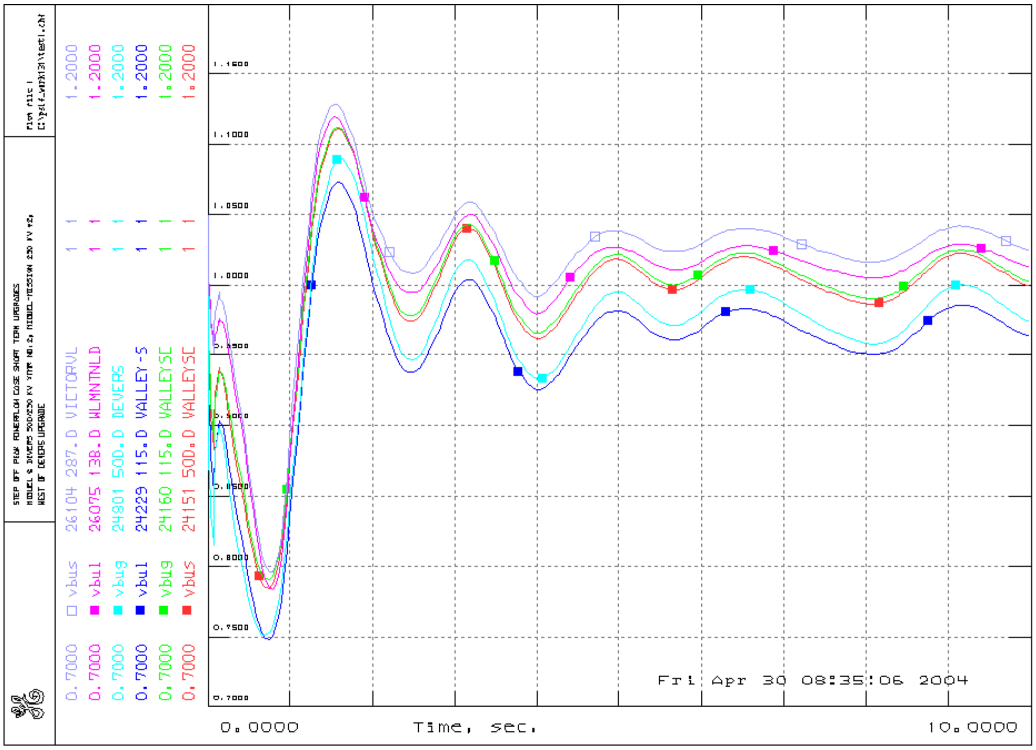
AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEYSC	115	vbug	1.041				24.7	0.513	0.925
24	VALLEY-S	115	vbul	1.004	0.748	25.4	0.74	29.2	0.475	0.963
24	YUCCA	115	vbul	0.99				27	0.475	0.925
24	HI DESER	115	vbul	0.98				29.2	0.475	0.963
24	BANNING	115	vbul	0.981				27	0.475	0.925
24	GARNET	115	vbug	1.001				27	0.475	0.925
24	SANTA RO	115	vbul	1.011				27	0.475	0.925
24	EISENHOW	115	vbul	1.003				24.7	0.513	0.925
24	FARREL	115	vbul	1				27	0.475	0.925
24	CONCHO	115	vbul	1.008				27	0.475	0.925
24	THORNHIL	115	vbul	1.005				24.7	0.513	0.925
24	TAMARISK	115	vbul	1.014				24.7	0.513	0.925
24	INDIAN W	115	vbul	1.008				27	0.475	0.925
24	CARODEAN	115	vbul	0.988				27	0.475	0.925

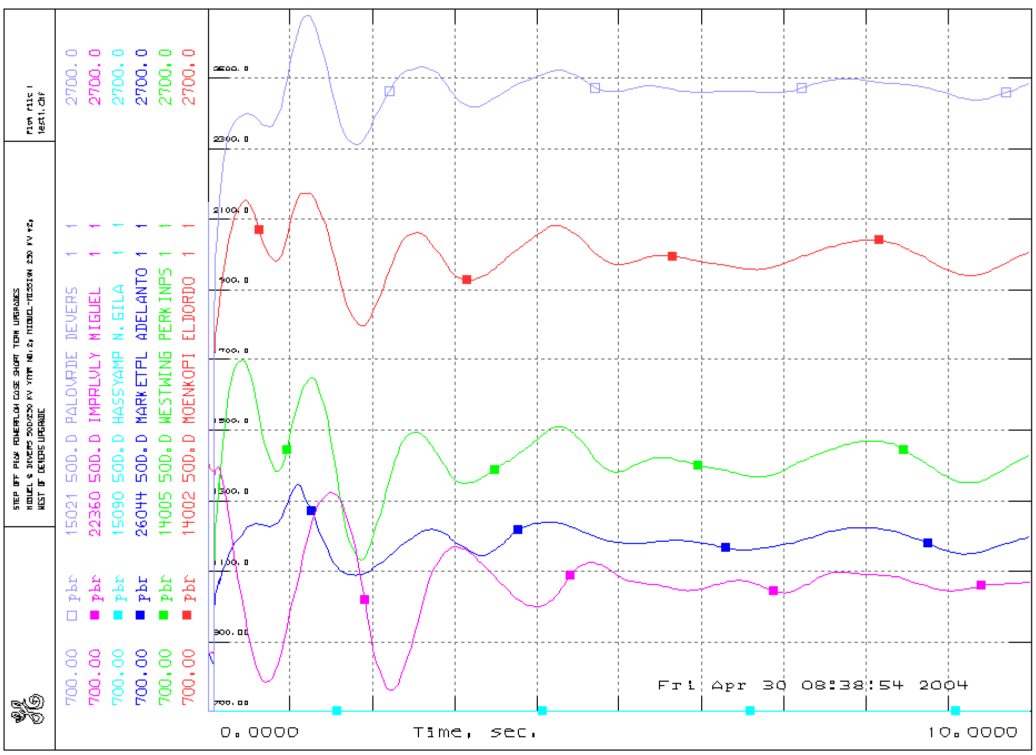
24	INDIGO	115	vbug	1.001				27	0.475	0.925
24	TERAWND	115	vbug	1				27	0.475	0.925
24	CAPWIND	115	vbug	1.003				27	0.475	0.925
24	BUCKWND	115	vbug	1				27	0.475	0.925
24	ALTWIND	115	vbug	1				27	0.475	0.925
24	RENWIND	115	vbug	1.002				27	0.475	0.925
24	TRANWND	115	vbug	1.002				27	0.475	0.925
24	SEAWIND	115	vbug	0.998				27	0.475	0.925
24	PANAERO	115	vbug	0.998				27	0.475	0.925
24	VENWIND	115	vbug	1				27	0.475	0.925
24	SANWIND	115	vbug	1				27	0.475	0.925
26	HALLDALE	138	vbul	1.034				20.2	0.588	0.925
26	WLMNTNLD	138	vbul	1.033				22.5	0.588	0.963
26	HARBOR	138	vbul	1.032				22.5	0.588	0.963
24	WINTEC6	115	vbug	1				27	0.475	0.925
24	SEAWEST	115	vbug	1				27	0.475	0.925
24	ALTAMSA4	115	vbug	0.998				27	0.475	0.925

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
54	AURORA 8	69	fbul	59.672	3.737
54	SYNC_D08	69	fbus	59.675	3.737
54	SYNC_G19	13.2	fbug	59.655	3.775

As can be seen from the tables, with the Hassayampa-North Gila outage one violation was observed in the voltage dip magnitude, and multiple violations were observed in the duration of the voltage dip. All violations were in the SCE area. The following plots illustrate the highest and longest voltage dips and 500 kV transmission line flows.


vbus 26104 287.0 VICTORVL
vbul 26075 138.0 WLMNTNLD
vbug 24801 500.0 DEVERS
vbul 24229 115.0 VALLEY-S
vbug 24160 115.0 VALLEYSC
vbus 24151 500.0 VALLEYSC
Fri Apr 30 08:35:06 2004
0.0000
Time, sec.
10.0000


pbr 15021 500.0 PALOVRDE DEVERS
pbr 22360 500.0 IMPRLVLY MIGUEL
pbr 15090 500.0 HASSYAMP N.GILA
pbr 26044 500.0 MARKETPL ADELANTO
pbr 14005 500.0 WESTWING PERKINPS
pbr 14002 500.0 MOENKOPI ELDORDO
Fri Apr 30 08:38:54 2004
0.0000
Time, sec.
10.0000

6. STUDY RESULTS. JAMES HSU OPTION

6.1. Base Case

Three most critical single contingencies were studied: Imperial Valley-Miguel with cross-tripping of the La Rosita-Imperial Valley 230 kV line and Imperial Valley generation tripping, Palo Verde-Devers and Hassayampa-North Gila 500 kV line outages. The system performance was stable with no criteria violations for all these outages. The following tables summarize results of the dynamic stability simulations.

Imperial Valley-Miguel outage

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
20	CTA-69	69	vbul		1.007	0.915	9.1	0.413
99	IV-GEN	230	vbus		1.009	0.05	95	0.638
24	CAPWIND	115	vbug		1.001	0.928	7.3	2.904

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.645	2.342
20	CPT-161	161	fbus		59.644	2.342
20	CPT-U3	13.8	fbug		59.623	2.342

Palo Verde-Devers outage

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
18	NEEDLES	69	vbul		0.971	0.842	13.2	0.55
22	N.GILA	500	vbus		1.064	0.911	14.4	0.325
26	MKTPSVC	500	vbug		1.073	0.943	12.2	0.513

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
14	BAGDAD	115	fbul		59.728	0.042
8	DELRAN	92	fbus		59.675	1.6
8	DELRANCH	14.4	fbug		59.608	1.6

Hassayampa-North Gila outage

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul		0.978	0.792	19.1	0.588
24	DEVERS	500	vbus		1.035	0.812	21.5	0.588
24	VALLEYSC	115	vbug		1.001	0.805	19.6	0.588

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.659	0.363
20	CPT-161	161	fbus		59.658	0.363
20	CPD-U1	13.8	fbug		59.628	0.325

6.2. Sensitivity Study

This study was performed to determine why the James Hsu Option of the upgrades does not require installation of additional reactive support. The Hassayampa-North Gila outage was studied, since it was the most critical outage.

A sensitivity case was developed with lower inertia in the Hassayampa-Gila River area. Load in the Arizona and Nevada areas was reduced to the levels modeled in the off-peak case, and the generation at Hassayampa and Gila River was also reduced. In addition, contrary to the off-peak case, the James Hsu Option base case modeled high SCE generation with old inefficient units (Huntington Beach, Mandalay Bay, Redondo Beach, Ormond) in service. The sensitivity case modeled one Huntington Beach unit off. The following table compares assumptions in the James Hsu Option base case, the sensitivity case and the off-peak case without James Hsu Option upgrades.

	Base case James Hsu option	Sensitivity case James Hsu option	Off-peak case w/out James Hsu upgrades
Arizona load, MW	9958	9048	9048
Nevada load, MW	3586	3001	3001
EOR Flow, MW	8750	8238	8075
Paloverde-Devers and Hassayampa-N.Gila flow, MW	3451	3258	3418
Hassayampa and Gila River generation			
Amount of units	32	20	20
MW output	4827	3368	3495
Total inertia, MWSec	41511	26437	26437

The dynamic simulation of the Hassayampa-North Gila outage in the sensitivity case did not show any criteria violations even if the inertia at Hassayampa was the same as in the off-peak case and the EOR flow was higher than in the off-peak case. It can be explained by lower flow on the Palo Verde-Devers and Hassayampa-North Gila lines. Due to an increase in series compensation on the McCullough-Victorville 500 kV lines in the James Hsu Option, a large portion of the EOR flow was diverted to the northern lines, and the combined flow on the southern (Palo Verde-Devers and Hassayampa-North Gila) lines was 160 MW lower than in the off-peak case with lower EOR flow.

Another sensitivity case modeled higher flow on the Southern EOR lines. The higher flow was achieved by reducing generation from the Mountain View power plant, even if amount of the generating units was the same as in the other cases to provide reactive support. This reduction of generation was compensated by increasing generation at Hassayampa, however, without increasing the amount of units on-line. This sensitivity case modeled EOR flow at 8576 MW and the Southern EOR lines combined flow at 3454 MW.

The stability simulation of this sensitivity case showed only one slight voltage violation at the Valley 115 kV load bus for the Hassayampa-North Gila outage (duration of voltage dip higher than 20% for 21 cycles). This better than expected system performance can be explained by lower load in the SCE area modeled in the James Hsu case, and thus a lower amount of induction motors, which contribute to the voltage dip. Load in the Devers-Valley area in this case was modeled 440 MW lower than in the off-peak case.

Another sensitivity study was performed for the base off-peak case with the increase in series compensation on the McCullough-Victorville lines. This additional compensation allowed to reduce flow on the Palo Verde-Devers and Hassayampa-North Gila lines from 3418 to 3301 MW. Simulation of the Hassayampa-North Gila outage for this case without additional reactive support did not identify any criteria violations as shown in the table below.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.012	0.805	20.5	0.625
24	VALLEYSC	500	vbus		1.049	0.84	19.9	0.625
24	DEVERS	500	vbug		1.035	0.801	22.6	0.588

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.684	1.825
20	CPD-230	230	fbus		59.682	1.825
20	CPD-U1	13.8	fbug		59.665	1.825

A modification of the James Hsu option was also studied. This modification did not include an increase in the series compensation on the McCullough-Victorville 500 kV lines. The case had 3553 MW combined flow on the Southern EOR lines versus 3451 MW flow on these lines with additional series compensation, EOR flow was 8746 MW. However, dynamic simulation of the Hassayampa-North Gila outage for this case did not identify any criteria violations as shown in the table below.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul		0.972	0.761	21.7	0.663
24	DEVERS	500	vbus		1.027	0.78	24.1	0.625
24	VALLEYSC	115	vbug		0.995	0.771	22.4	0.663

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.645	0.363
20	CPT-161	161	fbus		59.644	0.363
20	CPD-U1	13.8	fbug		59.614	0.325

This case had high inertia in the Hassayampa-Gila River area – 41511 MWsec. With lower inertia, additional reactive support will be required. A dynamic simulation of the Hassayampa-North Gila outage with 26437 MWsec inertia (20 generation units on-line, the same as in the off-peak base case) showed voltage violations without additional reactive support. In this case, EOR flow was 8729 MW, combined flow on the southern EOR lines was 3503 MW. The results of this simulation are shown in the following table.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul	0.988	0.734	25.7	0.663
24	DEVERS	500	vbus	1.035	0.741	28.4	0.663
24	VALLEYSC	115	vbug	0.999	0.731	26.9	0.663

VOLTAGE CRITERIA VIOLATIONS

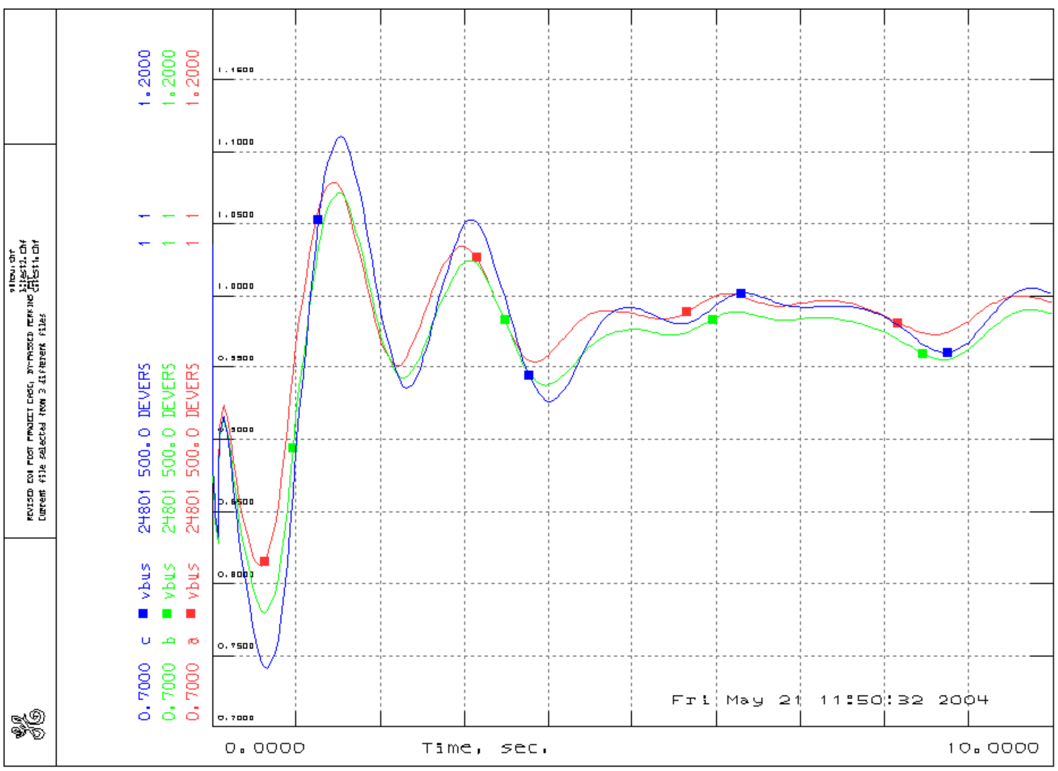
AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	ALTWIND	115	vbug	1.007				27	0.438	0.888
24	BANNING	115	vbul	0.987	0.737	25.3	0.66	27	0.438	0.888
24	BUCKWND	115	vbug	1.007				27	0.438	0.888
24	CAPWIND	115	vbug	1.01	0.758	25	0.66	27	0.438	0.888
24	CARODEAN	115	vbul	0.996	0.744	25.3	0.66	27	0.438	0.888
24	CONCHO	115	vbul	1.017	0.759	25.4	0.66	27	0.438	0.888
24	EISENHOW	115	vbul	1.011	0.758	25.1	0.66	27	0.438	0.888
24	FARREL	115	vbul	1.007	0.755	25.1	0.66	27	0.438	0.888
24	GARNET	115	vbug	1.008				27	0.438	0.888
24	HI DESER	115	vbul	0.988	0.734	25.7	0.66	27	0.438	0.888
24	INDIAN W	115	vbul	1.017	0.759	25.4	0.66	27	0.438	0.888
24	PANAERO	115	vbug	1.002				24.7	0.475	0.888
24	RENWIND	115	vbug	1.009				27	0.438	0.888
24	SANTA RO	115	vbul	1.02	0.762	25.3	0.66	27	0.438	0.888
24	SANWIND	115	vbug	1.006				27	0.438	0.888
24	SEAWIND	115	vbug	1.002				24.7	0.475	0.888
24	TAMARISK	115	vbul	1.023				24.7	0.475	0.888
24	TERAWND	115	vbug	1.007				27	0.438	0.888
24	THORNHIL	115	vbul	1.013	0.759	25	0.66	27	0.438	0.888
24	TRANWND	115	vbug	1.009				27	0.438	0.888
24	VALLEYSC	115	vbug	0.999	0.731	26.9	0.66	29.2	0.438	0.925
24	VENWIND	115	vbug	1.006				27	0.438	0.888
24	YUCCA	115	vbul	0.997	0.746	25.2	0.66	27	0.438	0.888
24	INDIGO	115	vbug	1.008				27	0.438	0.888

24	WINTEC6	115	vbug	1.007				27	0.438	0.888
24	SEAWEST	115	vbug	1.007				27	0.438	0.888
24	ALTAMSA4	115	vbug	1.002				24.7	0.475	0.888
24	VALLEY-S	115	vbul	1.004	0.749	25.4	0.66	24.7	0.475	0.888

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
20	PAR-230	230	fbul	59.63	1.825
20	CPD-230	230	fbus	59.628	1.825
20	CPD-U1	13.8	fbug	59.61	1.825

The following plot compares voltage on the Devers 500 kV bus for the base case James Hsu Option, the same case without increase in series compensation, and the case without increase in series compensation and lower inertia at the sending end of the southern EOR lines. Curve “a” is the base case, “b” is the base case without additional series compensation, “c” is the case without additional compensation and lower inertia.



From this sensitivity study, it can be concluded that increase in the amount of series compensation on the northern EOR transmission lines improves the system dynamic stability performance due to the shift of the EOR flow from the southern to the northern lines. The amount of required dynamic reactive support and whether the dynamic reactive support is required significantly depends on the inertia on the sending end of the southern EOR lines and on the load assumptions in Southern California.

7. VOLTAGE VIOLATIONS MITIGATION FOR THE OFF-PEAK CASE

The measures that were studied to mitigate the observed voltage violations with the Hassayampa-North Gila 500 kV transmission line outage are described below. Since the Hassayampa-North Gila outage appeared to be the most critical, only this outage was considered to determine the amount and locations of required reactive support.

7.1. Installation of a Static Synchronous Compensator (STATCOM) at the Devers 500 kV bus.

It was assumed that STATCOM's scheduled voltage is the same as the voltage at the Devers 500 kV bus under normal conditions. This way, the STATCOM does not supply or absorb reactive power under normal conditions.

200 MVAR STATCOM

With this size STATCOM, no criteria violations were observed. Maximal voltage dip was reduced by 4.5%. The dynamic simulation results are in the following table.

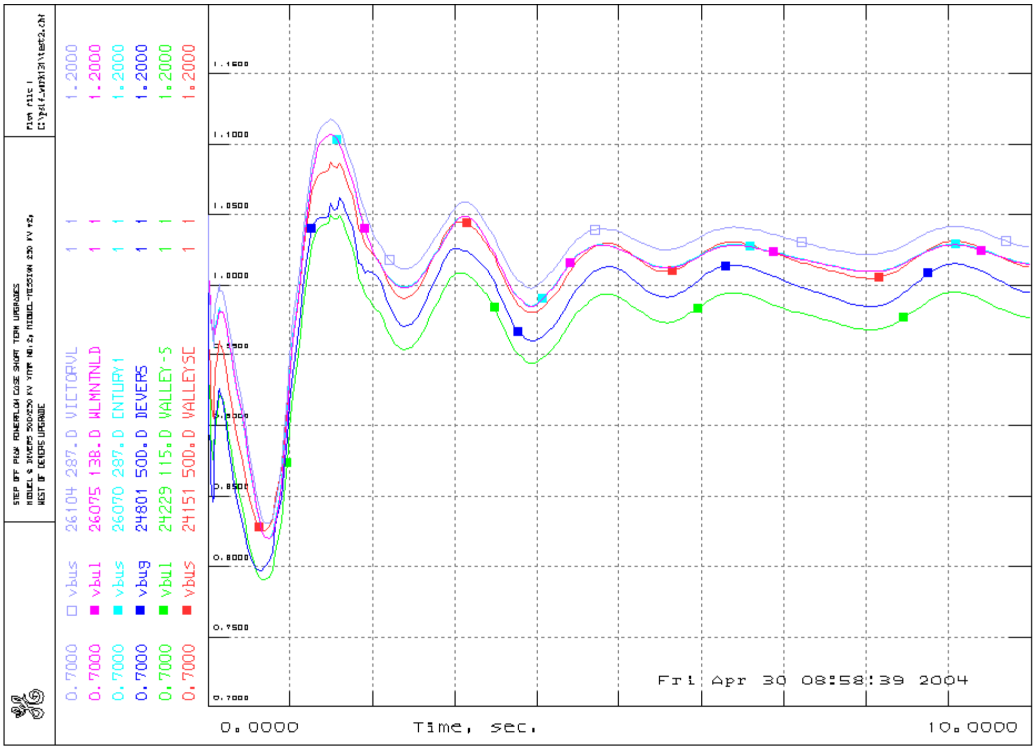
HIGHEST VOLTAGE DIP

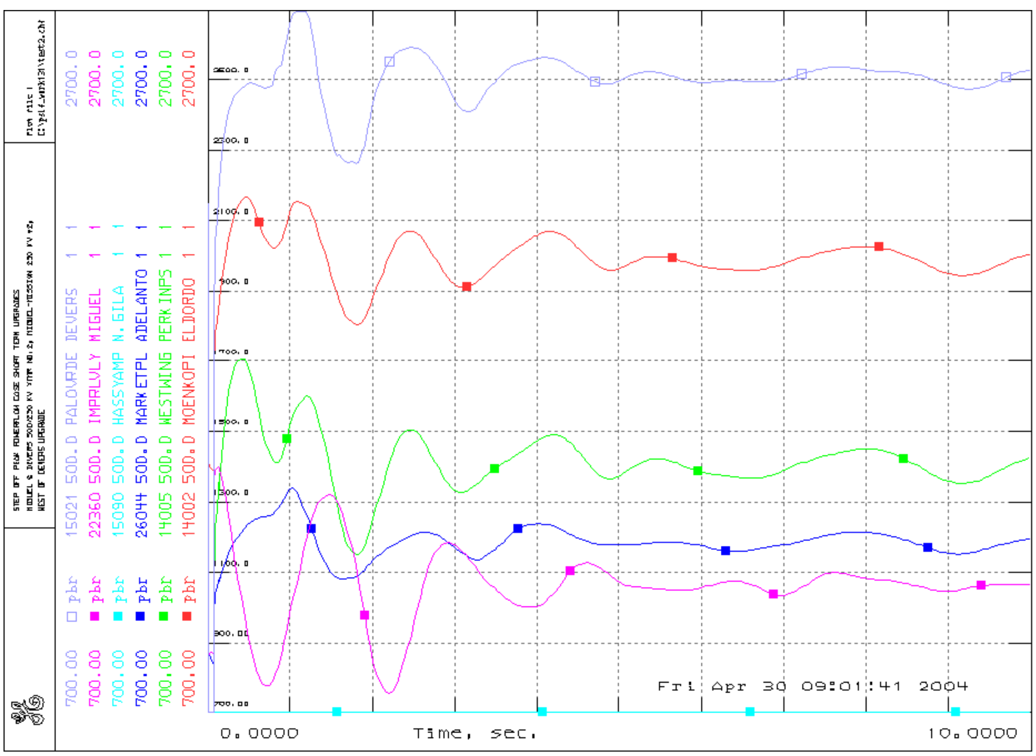
AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.79	21.3	0.7
26	VICTORVL	287	vbus		1.049	0.831	20.8	0.738
24	DEVERS	500	vbug		1.025	0.797	22.3	0.625

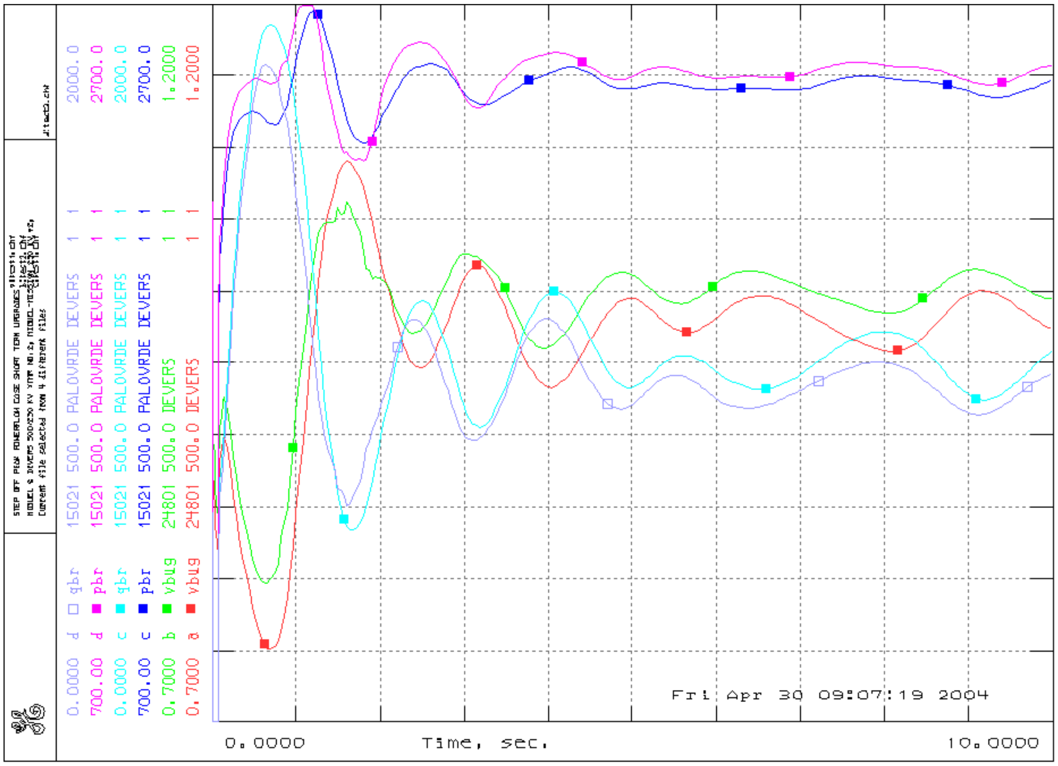
LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	PAR-230	230	fbul		59.695	1.863
20	CPD-230	230	fbus		59.693	1.863
20	CPD-U1	13.8	fbug		59.676	1.863

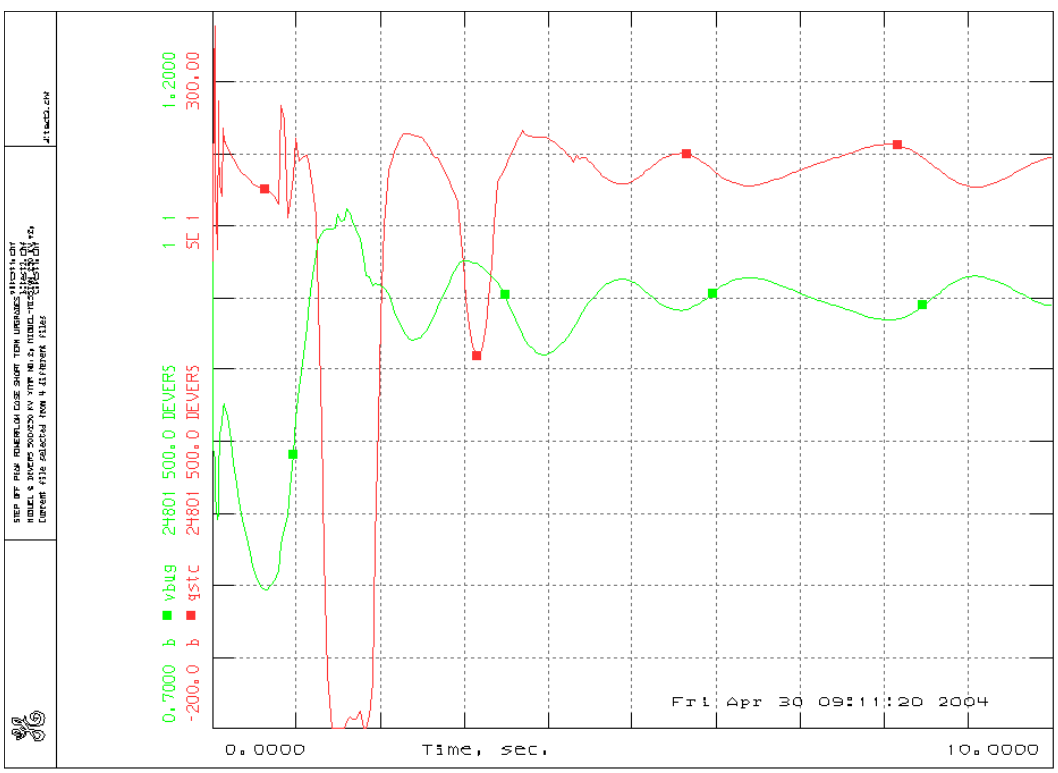
The following plots show the results of this simulation and comparison between the original case and the case with STATCOM. The first plot illustrates voltage dips, second – flow on 500 kV lines and the third plot compares voltage dip at the Devers 500 kV bus and real and reactive power flow on the Palo Verde-Devers line with and without STATCOM. On this plot, curves "a" and "c" – no STATCOM, curves "b" and "d" – with STATCOM.


0.7000 vbus 26104 287.0 VICTORVL 1 1 1.2000
0.7000 vbul 26075 138.0 WLMNTNLD 1 1 1.2000
0.7000 vbus 26070 287.0 CENTURY1 1 1 1.2000
0.7000 vbug 24801 500.0 DEVERS 1 1 1.2000
0.7000 vbul 24229 115.0 VALLEY-5 1 1 1.2000
0.7000 vbus 24151 500.0 VALLEYSC 1 1 1.2000
Fri Apr 30 08:58:39 2004
0.0000
Time, sec.
10.0000


700.00 pbr 15021 500.0 PALOVRDE DEVERS 1 2700.0
700.00 pbr 22360 500.0 IMPRLVLY MIGUEL 1 1 2700.0
700.00 pbr 15090 500.0 HASSYAMP N.GILA 1 1 2700.0
700.00 pbr 26044 500.0 MARKETPL ADELANTO 1 2700.0
700.00 pbr 14005 500.0 WESTWING PERKINPS 1 1 2700.0
700.00 pbr 14002 500.0 MOENKOPI ELDORDO 1 1 2700.0
Fri Apr 30 09:01:41 2004
0.0000
Time, sec.
10.0000



The following plot shows the STATCOM output and voltage. As can be seen from the plot, the STATCOM supplies around 200 MVAR at the time the voltage dip is the highest.



The study to determine the minimal size STATCOM to eliminate voltage violations showed that this STATCOM should be at least between 140 and 160 MVAR. As can be seen from the following tables, there were no violations with a 160 MVAR STATCOM and one voltage violation at the Valley 115 kV load bus with a 140 MVAR STATCOM.

140 MVAR STATCOM

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul	1.004	0.778	22.5	0.7
24	VALLEYSC	500	vbus	1.04	0.814	21.8	0.7
24	DEVERS	500	vbug	1.025	0.784	23.6	0.663

VOLTAGE CRITERIA VIOLATIONS

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEY-S	115	vbul	1.004				22.5	0.513	0.888

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
20	PAR-230	230	fbul	59.692	1.863
20	CPD-230	230	fbus	59.69	1.863
20	CPD-U1	13.8	fbug	59.674	1.863

160 MVAR STATCOM

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.782	22.1	0.7
26	VICTORVL	287	vbus		1.049	0.824	21.4	0.738
24	DEVERS	500	vbug		1.025	0.788	23.1	0.663

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	PAR-230	230	fbul		59.693	1.863
20	CPD-230	230	fbus		59.691	1.863
20	CPD-U1	13.8	fbug		59.675	1.863

The STATCOM model used in the studies utilized typical parameters of the device. These parameters may be optimized and tuned, so that a smaller size STATCOM would be also adequate. The STATCOM parameters and specifications may be determined in more detailed studies.

7.2. Installation of a Static VAR Compensator (SVC) at the Devers 500 kV bus

200 MVAR SVC

The studies showed that a 200 MVAR SVC appeared to be slightly less effective than the same size STATCOM. The highest voltage dip was approximately 1% higher with SVC than the same size STATCOM. However, this size SVC also eliminates voltage violations.

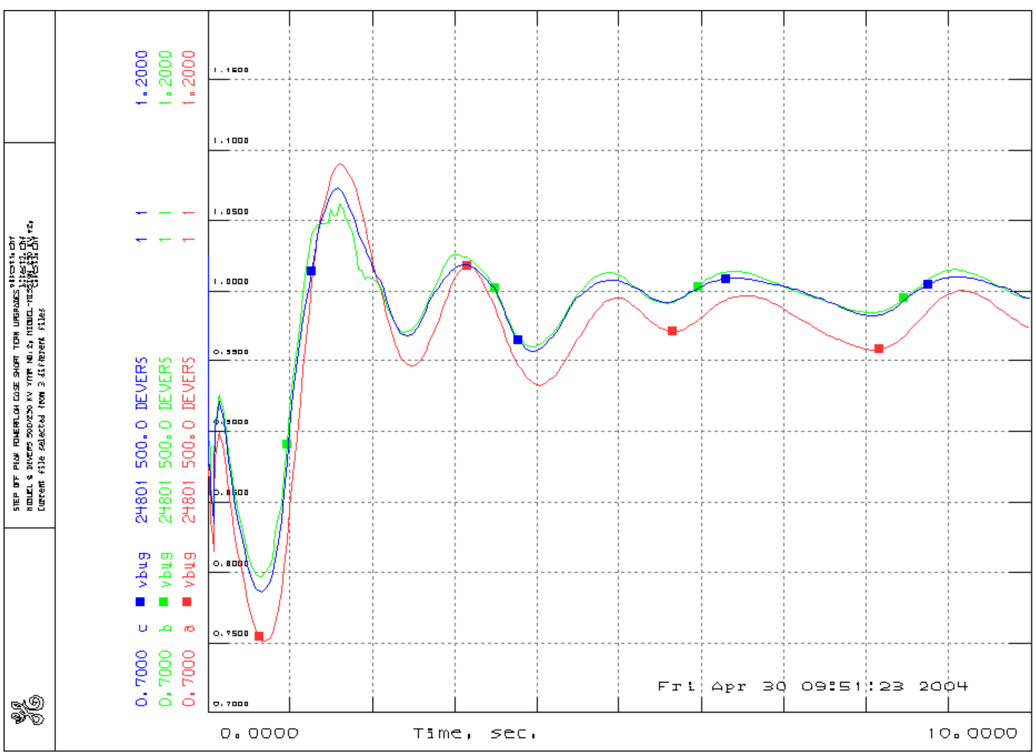
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.78	22.3	0.7
24	VALLEYSC	500	vbus		1.04	0.816	21.6	0.7
24	DEVERS	500	vbug		1.025	0.786	23.4	0.663

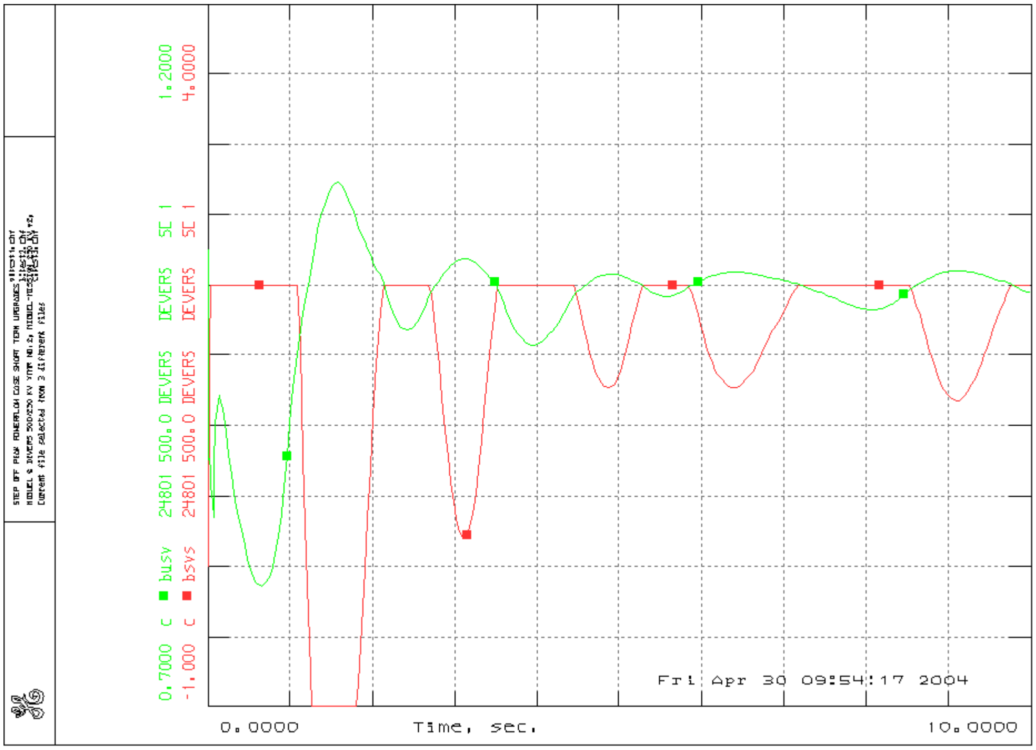
LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	PAR-230	230	fbul		59.694	1.863
20	CPD-230	230	fbus		59.692	1.863
20	CPD-U1	13.8	fbug		59.675	1.863

The following plot compares voltage dip with STATCOM, SVC and the original case without reactive support. Curve “a” – no reactive support, “b” – STATCOM, “c” – SVC.



The following plot shows the SVC output and voltage. As can be seen from the plot, SVC supplies 200 MVAR at the time of the highest voltage dip.



The study to determine the minimal size SVC to eliminate voltage violations showed that this SVC should be larger than 180 MVAR. Results of the simulation of the 180 MVAR SVC identified a voltage criteria violation on the Valley 115 kV load bus, as shown below.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul	1.004	0.777	22.6	0.7
24	VALLEYSC	500	vbus	1.04	0.813	21.9	0.7
24	DEVERS	500	vbug	1.025	0.782	23.7	0.663

VOLTAGE CRITERIA VIOLATIONS

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEY-S	115	vbul	1.004				22.5	0.513	0.888

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
20	PAR-230	230	fbul	59.693	1.863
20	CPD-230	230	fbus	59.691	1.863
20	CPD-U1	13.8	fbug	59.675	1.863

The study results for the STATCOM and SVC models showed that STATCOM is more effective. Installation of a 180 MVAR SVC appeared to be equivalent to a

140 MVAR STATCOM. To have some margin, it is recommended to install either 240 MVAR SVC or 200 MVAR STATCOM on the Devers 500 kV bus for the short-term upgrades of the STEP project.

7.3. Installation of a Thyristor-Controlled Series Capacitors (TCSC) on the Palo Verde-Devers 500 kV Transmission Line

In this simulation, the action of thyristor controlled series capacitor was modeled as increase in the series compensation at the Devers end of the Palo Verde-Devers 500 kV line at the time when the three-phase fault at Hassayampa was cleared. The series compensation was modeled as double compared to the compensation under normal conditions (increased from 28.3% to 56.5% of the line reactance). This is equivalent to 40-ohm decrease in the line reactance. The line was modeled as returned to its original reactance after 1 second.

Such increase in series compensation allowed the elimination of voltage violations and substantially decreased the voltage dip.

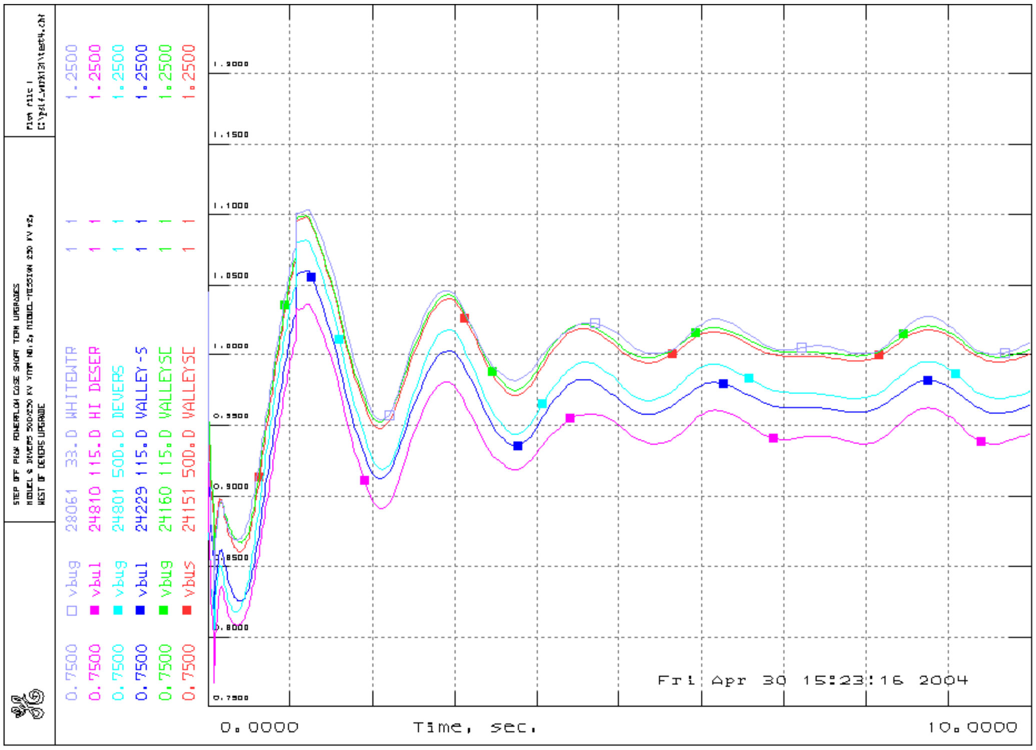
HIGHEST VOLTAGE DIP

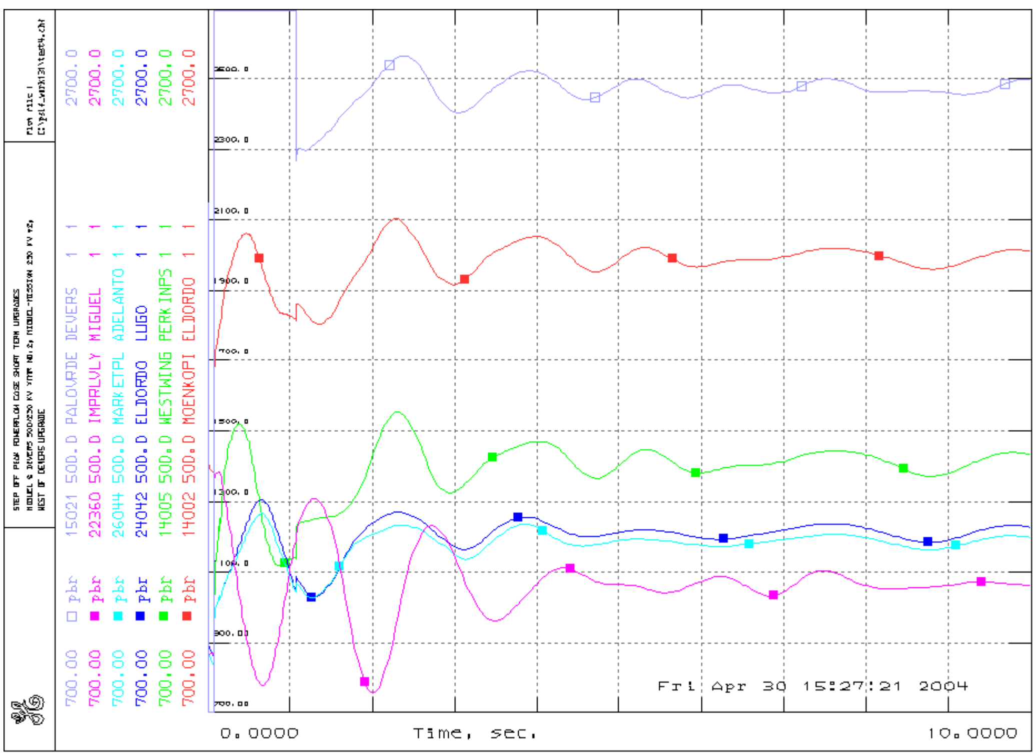
AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.825	17.8	0.388
24	TAP803	115	vbus		0.985	0.814	17.4	0.35
24	DEVERS	500	vbug		1.025	0.817	20.3	0.338

LOWEST FREQUENCY

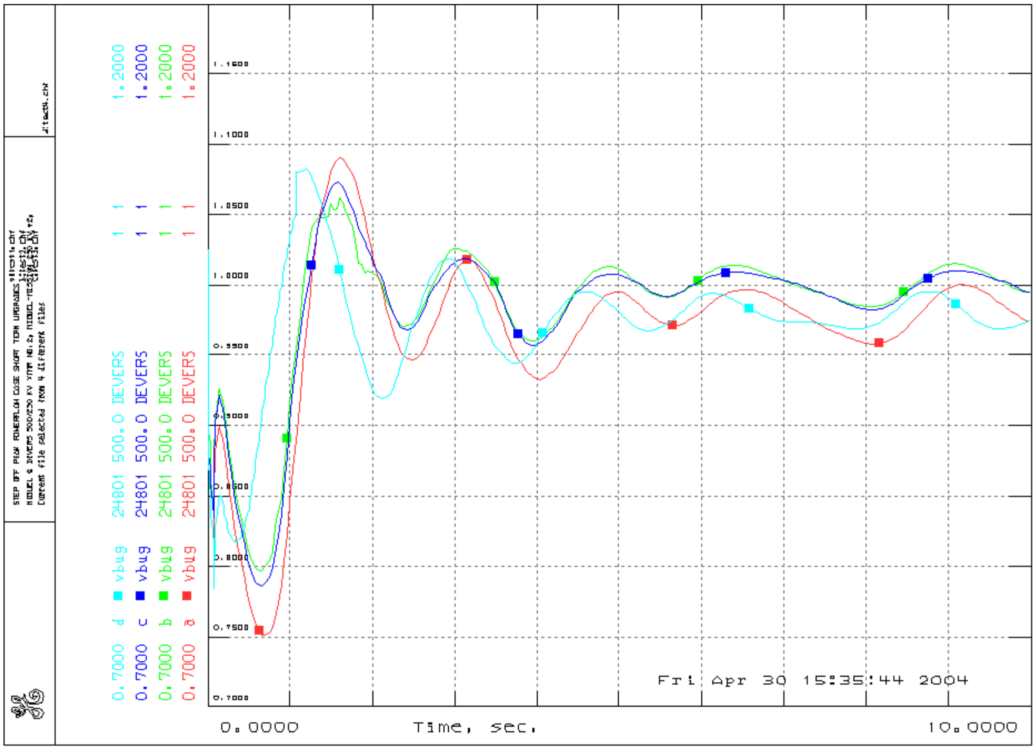
AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.7	1.671
20	CPT-161	161	fbus		59.7	1.671
20	CPD-U1	13.8	fbug		59.684	1.671

The plots illustrating the voltage dip and 500 kV line flows are shown below.





The following plot compares voltage dip at the Devers 500 kV bus with no additional compensation, 200 MVAR STATCOM, 200 MVAR SVC and 40 ohm TCSC. (Curve "a"- no compensation, "b"- STATCOM, "c"- SVC, "d"- TCSC)



To optimize the size of TCSC, the studies with different options of the TCSC were performed.

20 ohm TCSC. This series capacitor should be approximately equivalent to 200 MVAR shunt compensation, since it would generate 200 MVAR at the voltage of 500 kV. No criteria violations were observed.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.802	20.1	0.55
24	VALLEYSC	500	vbus		1.04	0.838	19.5	0.538
24	DEVERS	500	vbug		1.025	0.797	22.3	0.488

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.692	1.746
20	CPD-230	230	fbus		59.691	1.783
20	CPD-U1	13.8	fbug		59.674	1.783

10 ohm TCSC. One voltage violation was observed at the Valley 115 kV load bus.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul	1.004	0.78	22.3	0.638
24	VALLEYSC	500	vbus	1.04	0.816	21.6	0.638
24	DEVERS	500	vbug	1.025	0.779	24.1	0.575

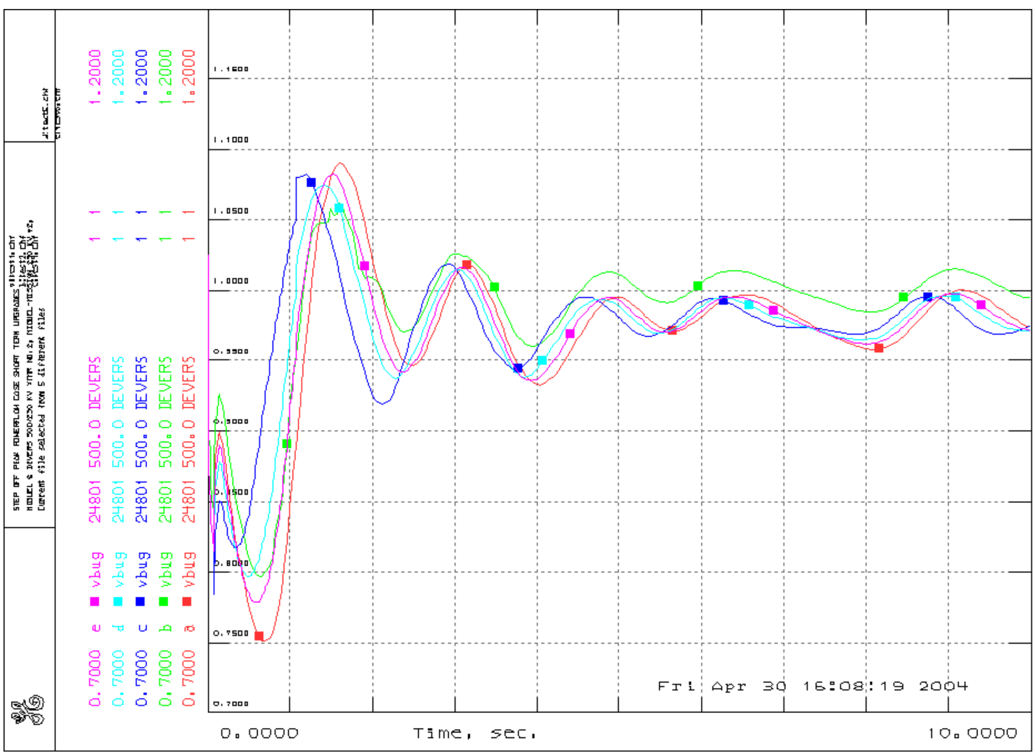
VOLTAGE CRITERIA VIOLATIONS

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEY-S	115	vbul	1.004				20.2	0.463	0.8

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
20	CPU-161	161	fbul	59.689	1.821
20	CPD-230	230	fbus	59.687	1.821
20	CPD-U1	13.8	fbug	59.67	1.821

The following plot compares voltage dip at the Devers 500 kV bus without additional compensation, with 200 MVAR STATCOM and with three options of TCSC. Curve “a” – no additional compensation, “b”- STATCOM, “c”- 40 ohm TCSC, “d” – 20 ohm TCSC, “e” – 10 ohm TCSC. As can be seen from the plot, a 20 ohm TCSC appeared to be equivalent to a 200 MVAR STATCOM.



If the TCSC option is selected, in order to have some margin, it can be recommended to install a 20 ohm TCSC in addition to the existing series capacitors on the Palo Verde-Devers 500 kV line. The TCSC can be installed in addition to the existing series capacitors close to the Devers end of the line. This addition will increase series compensation by another 14%. The TCSC should be set so that it will be turned on only during excessive voltage swings.

Insertion of a 20 ohm TCSC was also modeled as inserted at 8 cycles and removed at 50 cycles after the fault. It also eliminated the voltage violations, but the voltage dip was higher.

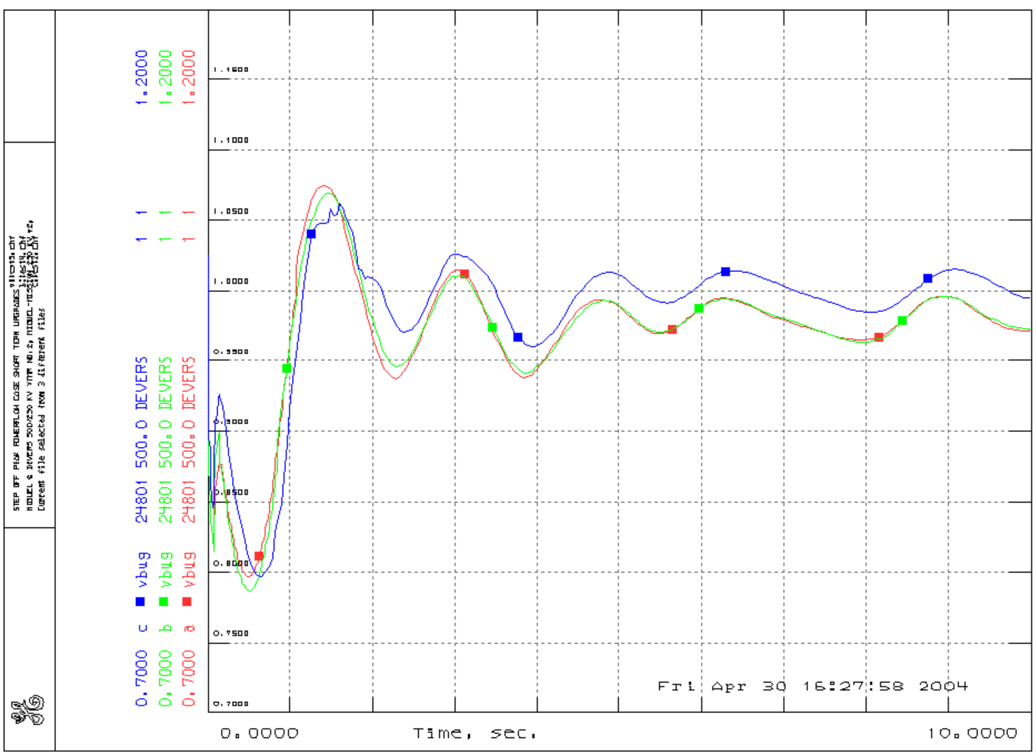
HIGHEST VOLTAGE DIP

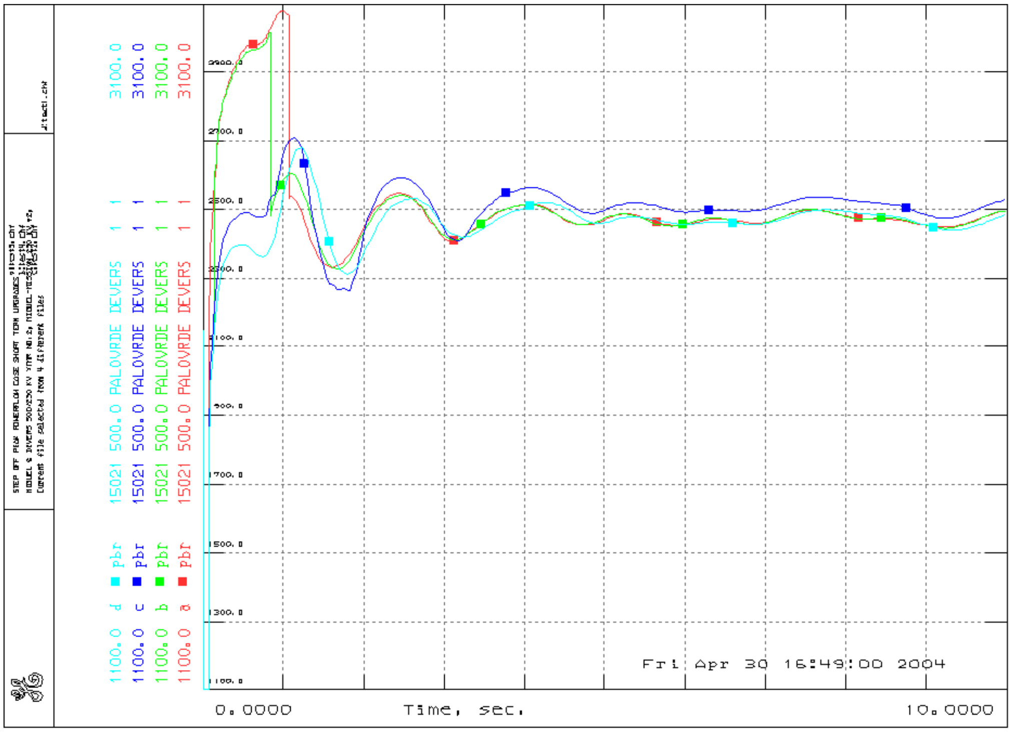
AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.791	21.2	0.563
24	VALLEYSC	500	vbus		1.04	0.827	20.5	0.55
24	DEVERS	500	vbug		1.025	0.786	23.3	0.5

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.707	1.775
20	CPD-230	230	fbus		59.705	1.775
20	CPD-U1	13.8	fbug		59.689	1.775

The following plots compare the Devers 500 kV bus voltage and Palo Verde-Devers real and reactive power flows with a 20 ohm TCSC inserted at 4 cycles and removed at 64 cycles (curve "a"), the same TCSC inserted at 8 cycles and removed at 50 cycles (curve "b") and a 200 MVAR STATCOM (curve "c"). The plots with the Palo Verde-Devers flows also include the case without additional compensation (curve "d"). As can be seen from the plot, later insertion and earlier removal of the TCSC leads to a higher voltage dip.




Fri Apr 30 16:49:00 2004
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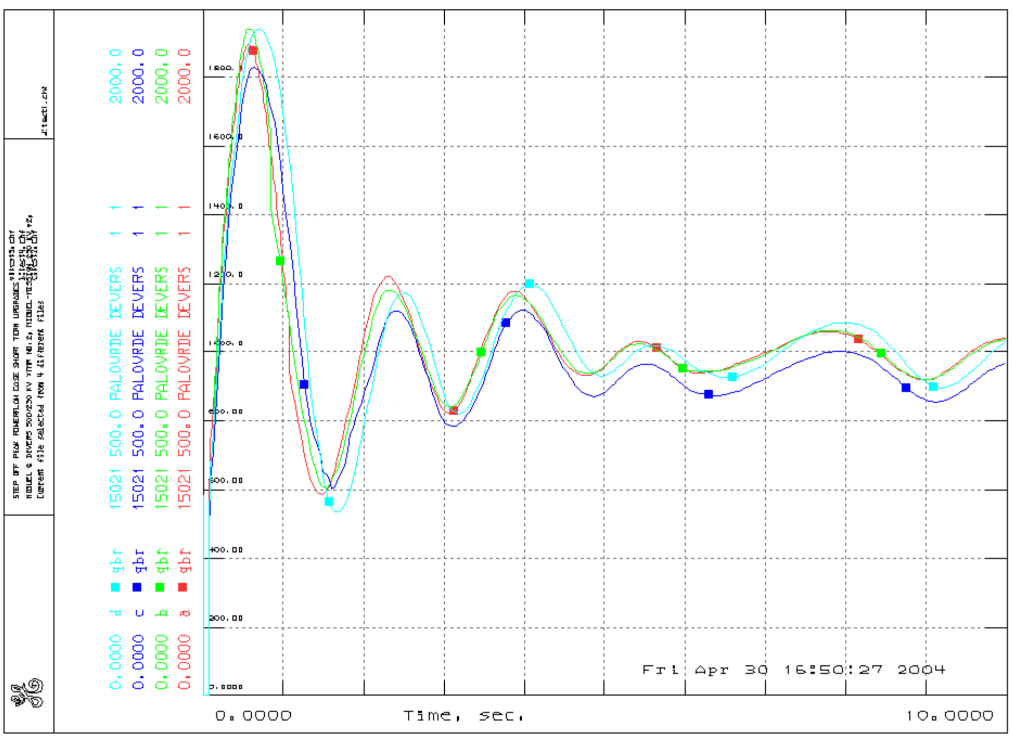
Fri Apr 30 16:50:27 2004
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Time, sec.
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8. SENSITIVITY STUDIES OF THE OFF-PEAK CASE

8.1. Higher Percentage of Induction Motor Load in the Desert Areas

In this sensitivity study, the load models were changed from the default 20% of load higher than 5 MW modeled as induction motors to 50% of load higher than 5 MW in the desert areas of SCE and in Arizona modeled as induction motors. Parameters of the induction motors were modeled as typical, the same as in the default model. The higher percentage of induction motor modeling was based on the fact that in the valley and desert areas, a large portion of load is air conditioners, which are induction motors. The previous analysis made by different utilities showed that during summer peak in the valley and desert areas air conditioners may comprise up to 80% of load. Since the study case was not the peak case, this percentage might be lower. Therefore, 50% of induction motor load appeared to be a reasonable assumption.

This study was performed also to investigate impact of the load modeling on the study results. Hassayampa- North Gila 500 kV line outage was studied with a 200 MVAR STATCOM at Devers. The study results showed multiple voltage violations. The following tables show the highest voltage dip and lowest frequency. There were too many voltage violations, so they are not listed.

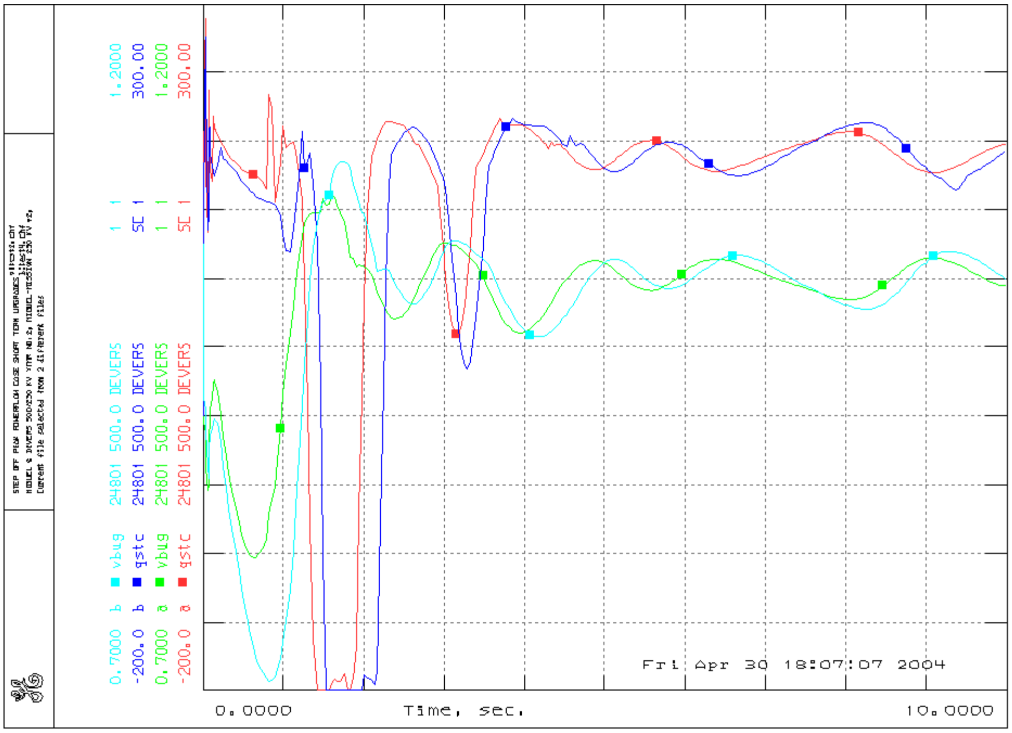
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.67	33.3	0.888
26	HARB	138	vbus		1.034	0.696	32.6	0.888
24	VALLEYSC	115	vbug		1.041	0.715	31.4	0.888

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
14	SCHRADER	69	fbul		59.584	0.067
14	KYRENEST	69	fbus		59.63	0.067
54	SYNC_G19	13.2	fbug		59.613	3.925

The following plot compares voltages at the Devers 500 kV bus and STATCOM's reactive power output with different modeling of induction motor load. Curves "a" – 20% of load modeled as induction motors, curves "b" – 50% of load modeled as induction motors in the desert and valley areas, and 20% in the rest of the system.



The same sensitivity study was performed with a 20 Ohm TCSC. This simulation also showed substantially higher voltage dip and multiple voltage violations with the 50% of load in the valley and desert areas of SCE and in Arizona modeled as induction motors (too many violations to list). However, the results were better than with a 200 MVAR STATCOM as shown in the following tables.

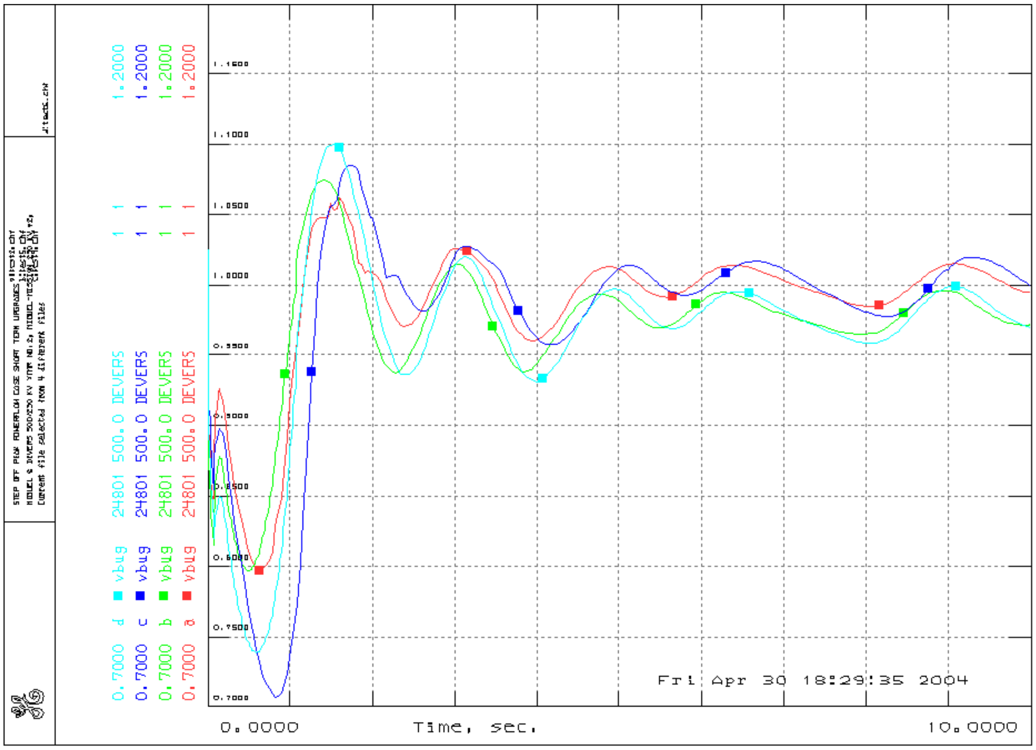
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul		0.98	0.708	27.7	0.663
24	TAP803	115	vbus		0.985	0.717	27.2	0.663
24	DEVERS	500	vbug		1.025	0.739	27.9	0.588

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
14	SCHRADER	69	fbul		59.584	0.067
14	KYRENEST	69	fbus		59.63	0.067
14	KYRENE 1	12.5	fbug		59.63	0.067

The following plot shows voltage at Devers with a 200 MVAR STATCOM or 20 Ohm TCSC and 20% and 50% of induction motor load (curve “a”- STATCOM and 20% induction motor load, “b”- TCSC and 20% induction motor load, “c”- STATCOM and 50% induction motor load, “d”- TCSC and 50% induction motor load).



It may be concluded that accurate load modeling is essential for the dynamic stability studies. Also, with higher percentage of induction motor load, the TCSC shows better dynamic stability performance than STATCOM.

Stability simulations with larger TCSC showed that even a 40-ohm TCSC did not eliminate the violations. The following table shows the study results with 40-ohm TCSC.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul	0.98	0.752	23.3	0.425
24	TAP803	115	vbus	0.985	0.76	22.9	0.425
24	DEVERS	500	vbug	1.025	0.774	24.6	0.388

VOLTAGE CRITERIA VIOLATIONS

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEY-S	115	vbul	1.004				21	0.275	0.625
24	YUCCA	115	vbul	0.99				20.2	0.25	0.588
24	HI DESER	115	vbul	0.98				22.5	0.238	0.613
24	BANNING	115	vbul	0.981				21	0.25	0.6
24	SANTA RO	115	vbul	1.011				20.2	0.263	0.6
24	CONCHO	115	vbul	1.008				21	0.25	0.6
24	INDIAN W	115	vbul	1.008				21	0.25	0.6
24	CARODEAN	115	vbul	0.988				20.2	0.25	0.588

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
14	SCHRADER	69	fbul	59.584	0.067
14	KYRENEST	69	fbus	59.63	0.067
14	KYRENE 1	12.5	fbug	59.63	0.067

If a STATCOM option of dynamic reactive support is selected, with this amount of induction motor load, at least 600 MVAR of dynamic reactive support might be required. The results are shown for dynamic stability simulation with a 600 MVAR STATCOM at the Devers 500 kV bus.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
26	WLMNTNLD	138	vbul		1.033	0.815	21.2	0.738
26	VICTORVL	287	vbus		1.049	0.827	21.2	0.738
26	ADELSVC	500	vbug		1.05	0.833	20.7	0.738

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
14	SCHRADER	69	fbul		59.583	0.067
14	KYRENEST	69	fbus		59.629	0.067
14	KYRENE 1	12.5	fbug		59.629	0.067

8.2. No Mountain View Generation Project

This sensitivity study was performed in the assumption that the Mountain View Generation Project is not built. The Mountain View generation was modeled as replaced by other generation plants in SCE (Alamitos 3 – 315 MW, Alamitos 6 385 MW, Huntington Beach 2 – 200 MW, Redondo Beach 7 - 100 MW). Southern California inertia in this case was 81179 MWsec, which is slightly higher than in the base case (81099 MWsec)

Without additional reactive support, multiple voltage criteria violations were observed (too many to list, therefore only the highest voltage dips and the lowest frequencies are shown).

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul	0.973	0.662	32	0.775
24	TAP803	115	vbus	0.979	0.669	31.7	0.775
24	DEVERS	500	vbug	1.016	0.687	32.4	0.775

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
54	AURORA 8	69	fbul	59.629	3.812
54	SYNC_D08	69	fbus	59.632	3.812
54	SYNC_G19	13.2	fbug	59.609	3.85

Contrary to the base off-peak case, addition of a 200 MVAR STATCOM did not eliminate the violations, as shown in the tables below.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul	0.973	0.723	25.7	0.738
24	TAP803	115	vbus	0.979	0.73	25.4	0.738
24	DEVERS	500	vbug	1.016	0.749	26.3	0.7

VOLTAGE CRITERIA VIOLATIONS

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEYSC	115	vbug	1.039				22.5	0.513	0.888
24	VALLEY-S	115	vbul	1.001				24.7	0.513	0.925
24	YUCCA	115	vbul	0.983	0.736	25.1	0.74	27	0.475	0.925
24	HI DESER	115	vbul	0.973	0.723	25.7	0.74	27	0.475	0.925
24	BANNING	115	vbul	0.975	0.728	25.3	0.74	27	0.475	0.925
24	GARNET	115	vbug	0.995				27	0.475	0.925
24	SANTA RO	115	vbul	1.004	0.752	25.1	0.74	27	0.475	0.925
24	EISENHOW	115	vbul	0.996				27	0.475	0.925
24	FARREL	115	vbul	0.994				27	0.475	0.925
24	CONCHO	115	vbul	1.001	0.749	25.2	0.74	27	0.475	0.925
24	THORNHIL	115	vbul	0.998				27	0.475	0.925
24	TAMARISK	115	vbul	1.007				24.7	0.513	0.925
24	INDIAN W	115	vbul	1.001	0.748	25.2	0.74	27	0.475	0.925
24	CARODEAN	115	vbul	0.982	0.734	25.2	0.74	27	0.475	0.925
24	INDIGO	115	vbug	0.995				27	0.475	0.925
24	TERAWND	115	vbug	0.994				27	0.475	0.925
24	CAPWIND	115	vbug	0.996				27	0.475	0.925
24	BUCKWND	115	vbug	0.994				27	0.475	0.925
24	ALTWIND	115	vbug	0.994				27	0.475	0.925
24	RENWIND	115	vbug	0.996				27	0.475	0.925
24	TRANWND	115	vbug	0.996				27	0.475	0.925
24	SEAWIND	115	vbug	0.992				27	0.475	0.925
24	PANAERO	115	vbug	0.992				27	0.475	0.925
24	VENWIND	115	vbug	0.994				27	0.475	0.925
24	SANWIND	115	vbug	0.993				27	0.475	0.925
24	WINTEC6	115	vbug	0.994				27	0.475	0.925
24	SEAWEST	115	vbug	0.994				27	0.475	0.925
24	ALTAMSA4	115	vbug	0.992				27	0.475	0.925

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
54	AURORA 8	69	fbul	59.69	3.737
54	SYNC_D08	69	fbus	59.693	3.737
54	SYNC_G19	13.2	fbug	59.673	3.737

The simulation with a 20 ohm TCSC also showed voltage criteria violations, however, fewer violations than with a 200 MVAR STATCOM as shown below.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul	0.973	0.742	23.8	0.575
24	TAP803	115	vbus	0.979	0.748	23.6	0.575
24	DEVERS	500	vbug	1.016	0.76	25.2	0.525

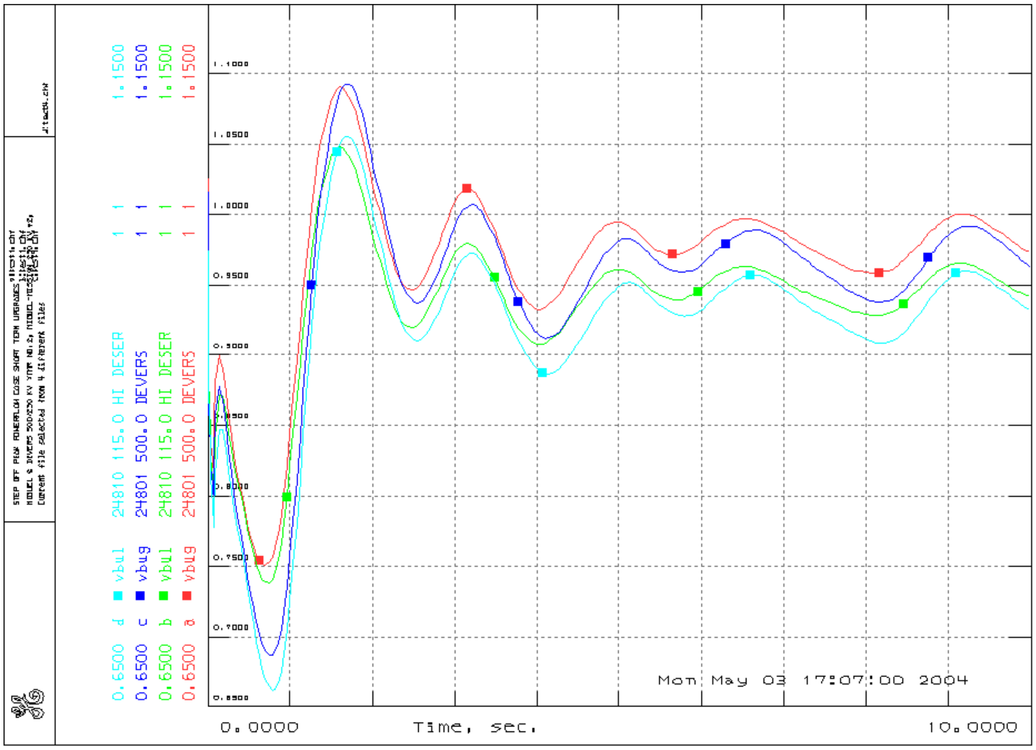
VOLTAGE CRITERIA VIOLATIONS

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEY-S	115	vbul	1.001				20.2	0.413	0.75
24	YUCCA	115	vbul	0.983				24.7	0.363	0.775
24	HI DESER	115	vbul	0.973				26.2	0.35	0.788
24	BANNING	115	vbul	0.975				25.5	0.35	0.775
24	GARNET	115	vbug	0.995				23.2	0.375	0.763
24	SANTA RO	115	vbul	1.004				24	0.375	0.775
24	EISENHOW	115	vbul	0.996				23.2	0.375	0.763
24	FARREL	115	vbul	0.994				23.2	0.375	0.763
24	CONCHO	115	vbul	1.001				24.7	0.363	0.775
24	THORNHIL	115	vbul	0.998				22.5	0.388	0.763
24	TAMARISK	115	vbul	1.007				21	0.4	0.75
24	INDIAN W	115	vbul	1.001				24.7	0.363	0.775
24	CARODEAN	115	vbul	0.982				24.7	0.363	0.775
24	INDIGO	115	vbug	0.995				23.2	0.375	0.763
24	TERAWND	115	vbug	0.994				23.2	0.375	0.763
24	CAPWIND	115	vbug	0.996				23.2	0.375	0.763
24	BUCKWND	115	vbug	0.994				23.2	0.375	0.763
24	ALTWIND	115	vbug	0.994				23.2	0.375	0.763
24	RENWIND	115	vbug	0.996				23.2	0.375	0.763
24	TRANWND	115	vbug	0.996				23.2	0.375	0.763
24	SEAWIND	115	vbug	0.992				23.2	0.375	0.763
24	PANAERO	115	vbug	0.992				23.2	0.375	0.763
24	VENWIND	115	vbug	0.994				23.2	0.375	0.763
24	SANWIND	115	vbug	0.993				23.2	0.375	0.763
24	WINTEC6	115	vbug	0.994				23.2	0.375	0.763
24	SEAWEST	115	vbug	0.994				23.2	0.375	0.763
24	ALTAMSA4	115	vbug	0.992				23.2	0.375	0.763

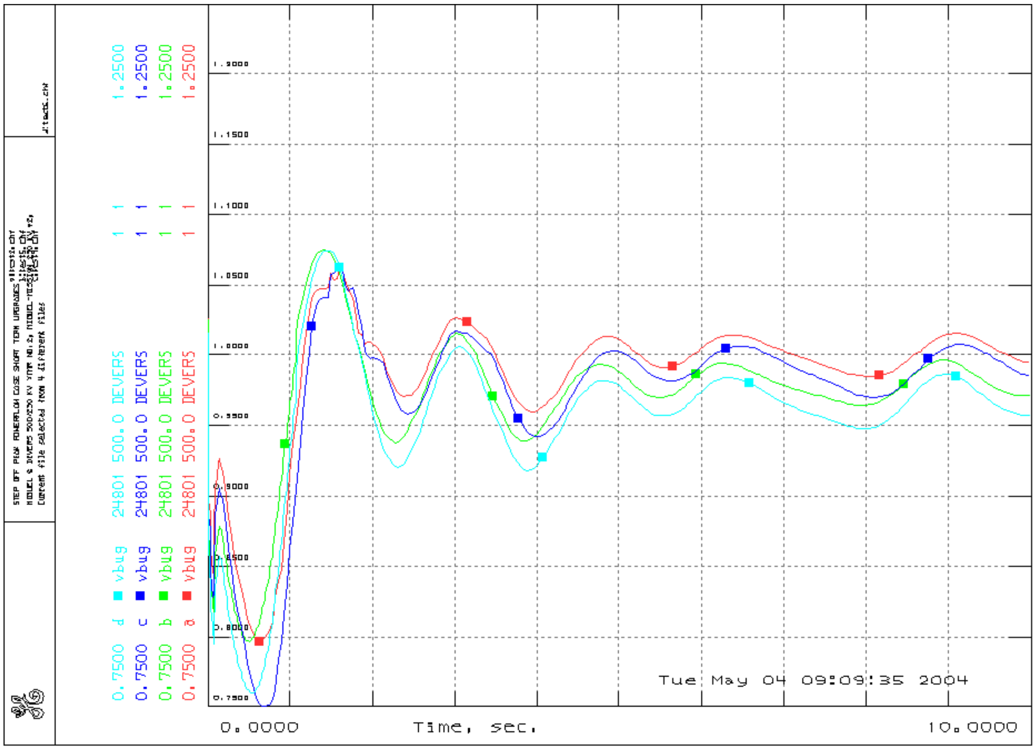
LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
20	CPU-161	161	fbul	59.691	1.783
20	CPD-230	230	fbus	59.69	1.783
20	CPD-U1	13.8	fbug	59.674	1.783

As can be seen from the study results, there was substantially higher voltage dip without the Mountain View generation. The following plot compares voltages on the Devers 500 kV and High Desert 115 kV buses without additional reactive support in the base case and the case without Mountain View generation ("a" and "b" the case with Mountain View, "c" and "d" – without Mountain View).



The following plot compares voltage at the Devers 500 kV bus. Curve "a" - 200 MVAR STATCOM with the Mountain View project, "b" - 20 ohm TCSC with Mountain View Project, "c" – 200 MVAR STATCOM without Mountain View, "d" – 20 ohm TCSC without Mountain View.



It can be concluded that in the case without the Mountain View Project, a 20 Ohm TCSC appeared to be more effective than a 200 MVAR STATCOM. Also, as can be seen from the study results, the total Southern California inertia did not have any impact on the system dynamic stability performance.

A simulation with a larger TCSC showed that a 30 Ohm TCSC would eliminate voltage violations in this case. The following table shows the results of this study.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	HI DESER	115	vbul		0.973	0.763	21.6	0.475
24	TAP803	115	vbus		0.979	0.769	21.4	0.475
24	DEVERS	500	vbug		1.016	0.779	23.3	0.438

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.693	1.708
20	CPT-161	161	fbus		59.692	1.708
20	CPD-U1	13.8	fbug		59.676	1.746

The study of the Hassayampa-North Gila outage with a 300 MVAR STATCOM showed slight voltage violations without the Mountain View Project, duration of the voltage dip higher than 20% was up to 22 cycles in the High Desert area. 330 MVAR STATCOM eliminated these violations.

8.3. Different Inertia at Hassayampa and Gila River.

Higher inertia

This case modeled all generation units at Hassayampa and Gila River being on-line, total generation approximately the same as in the original case, but each unit generating less. This case had the following assumptions regarding Hassayampa and Gila River generation:

Arlington	3 units, 303 MW, 450 MVAR max
Harquahala	6 units, 638 MW, 609 MVAR max
Mesquite	6 units, 640 MW, 860 MVAR max
Red Hawk	6 units, 640 MW, 692 MVAR max
Gila River	12 units, 1280 MW, 1332 MVAR max

Total: 33 units, 3501 MW, 3943 MVAR max. Total inertia was 42861 MWsec. (The original case modeled 20 units and 26437 MWsec inertia).

The East of River flow and the flow on the Palo Verde-Devers and Hassayampa-North Gila 500 kV lines was approximately the same as in the original case (EOR flow 8077 MW, versus 8075 MW in the original case), and total flow on the two transmission lines 3418 MW (same as in the original case). No additional reactive support was modeled.

The dynamic stability simulation of the Hassayampa-North Gila outage showed no criteria violations and voltage dip significantly lower than in the original case as shown in the following table.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.849	15.4	0.625
24	VALLEYSC	500	vbus		1.04	0.884	15	0.625
24	DEVERS	500	vbug		1.025	0.851	17	0.588

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
24	INDIAN W	115	fbul		59.748	0.054
24	TAP805	115	fbus		59.749	0.054
24	ESRP P1	6.9	fbug		59.708	0.067

Lower inertia

The case with lower inertia at Hassayampa and Gila River modeled slightly lower EOR flow (8056 MW versus 8075 MW in the base case) and slightly lower flow on the Palo Verde-Devers and Hassayampa-North Gila lines (total 3409 MW versus 3418 MW in the base case). It had two fewer generation units at Hassayampa compared to the base case: one less unit at Mesquite and one less unit at Red Hawk. Total inertia at Hassayampa and Gila River was 24274 MWsec versus 26437 MWsec in the base case. The base case modeled stressed conditions, therefore it was not possible to model high EOR flow with significantly lower inertia at Hassayampa. Nevertheless, even with lower EOR and Palo Verde-Devers and Hassayampa-North Gila flows, the voltage violations were more severe than in the original case.

Without additional reactive support, there were many voltage violations with the Hassayampa-North Gila outage. The following table shows the highest voltage dip and the lowest frequency, there were too many voltage violations to list.

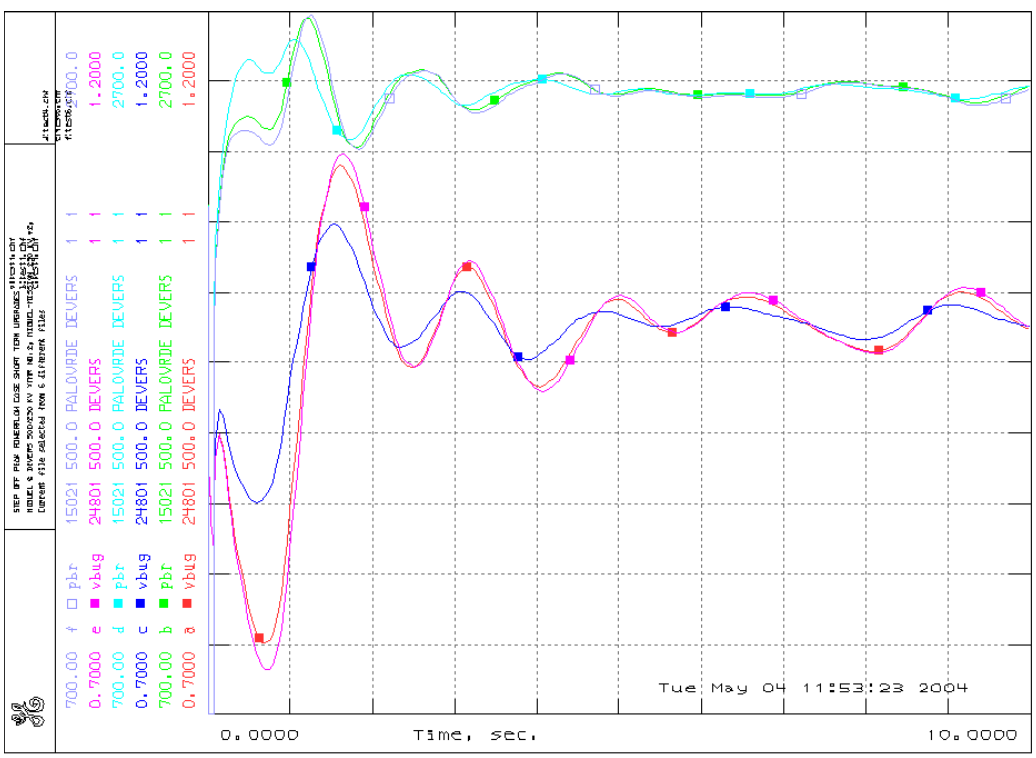
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul	1.004	0.729	27.4	0.738
26	HARB	138	vbus	1.034	0.758	26.7	0.813
24	DEVERS	500	vbug	1.026	0.732	28.6	0.7

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
54	AURORA 8	69	fbul	59.642	3.775
54	SYNC_D08	69	fbus	59.645	3.775
54	SYNC_G19	13.2	fbug	59.623	3.812

The following plot shows flow on the Palo Verde-Devers line and voltage at the Devers 500 kV bus. Curves “a” and “b” – base case, “c” and “d” – the case with higher inertia, and “e” and “f” – the case with lower inertia.



The simulation of the low inertia case with a 200 MVAR STATCON showed that the addition of a 200 MVAR STATCOM was not sufficient to eliminate the violations. There was one voltage violation at the Valley 115 kV load bus as shown below.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul	1.004	0.775	22.8	0.7
26	VICTORVL	287	vbus	1.05	0.813	22.6	0.738
24	DEVERS	500	vbug	1.026	0.782	23.7	0.663

VOLTAGE CRITERIA VIOLATIONS

AREA	BUS NAME	BUS KV	TYPE	Initial	MaxDip	Prct	@time	Cycles	From	To
24	VALLEY-S	115	vbul	1.004				22.5	0.513	0.888

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE	MaxDip	@time
20	PAR-230	230	fbul	59.681	1.863
20	CPD-230	230	fbus	59.679	1.863
20	CPD-U1	13.8	fbug	59.662	1.863

The same low inertia case did not show any criteria violations when a 20 Ohm TCSC was added on the Palo Verde-Devers 500 kV line.

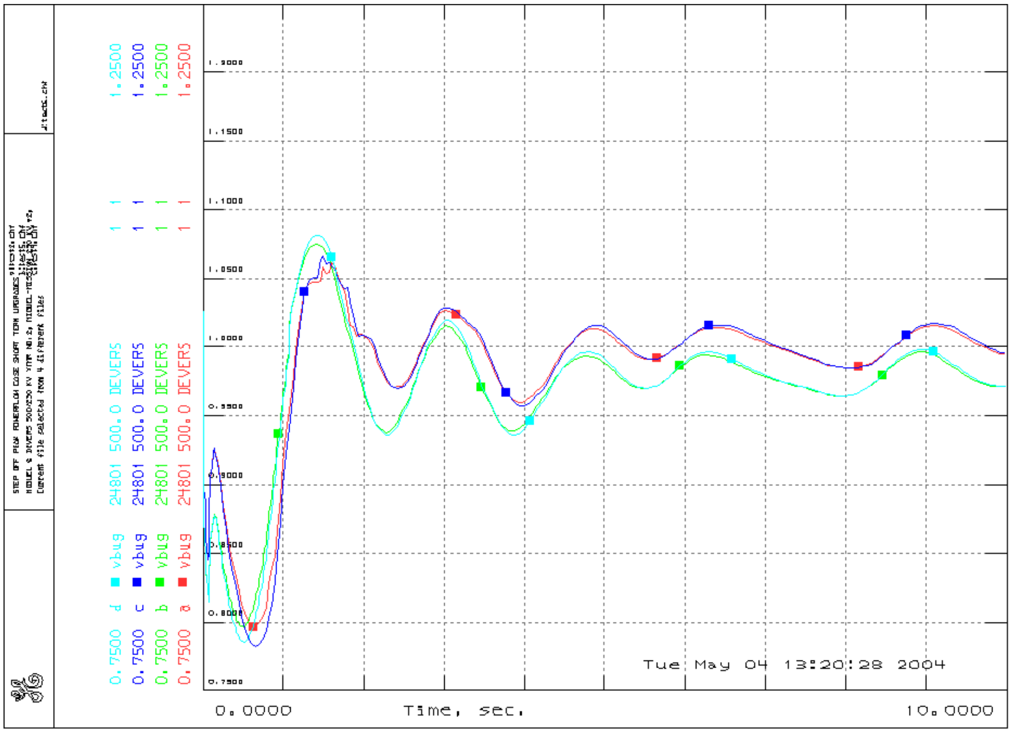
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.791	21.2	0.563
24	VALLEYSC	500	vbus		1.041	0.827	20.6	0.563
24	DEVERS	500	vbug		1.026	0.785	23.5	0.5

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.678	1.783
20	CPD-230	230	fbus		59.677	1.783
20	CPD-U1	13.8	fbug		59.659	1.783

The following plot shows voltage at the Devers 500 kV bus with addition of a 200 MVAR STATCOM or a 20 Ohm TCSC. On this plot, curve “a” – STATCOM in the base case, “b”- TCSC in the base case, “c” – STATCOM in the low inertia case, “d” –TCSC in the low inertia case.



As all the previous sensitivity studies, this study showed that a 20 Ohm TCSC is more effective than a 200 MVAR STATCOM.

8.4. Different Locations of the Thyristor-Controlled Series Capacitors

When the Thyristor-Controlled Series Capacitor (TCSC) was studied, it was assumed that it would be installed at the same location the existing series capacitors are located at approximately 60 miles from the Devers substation. Sensitivities studies were performed to determine an optimal location of a 20 Ohm TCSC. The Hassayampa-North Gila outage was studied.

20 Ohm TCSC in addition to the existing series capacitors 60 miles from Palo Verde

This study showed that installing a TCSC at this location also eliminates criteria violations with the Hassayampa-North Gila outage. The voltage dip was only slightly (less than 1%) higher than if the TCSC was installed 60 miles from the Devers Substation.

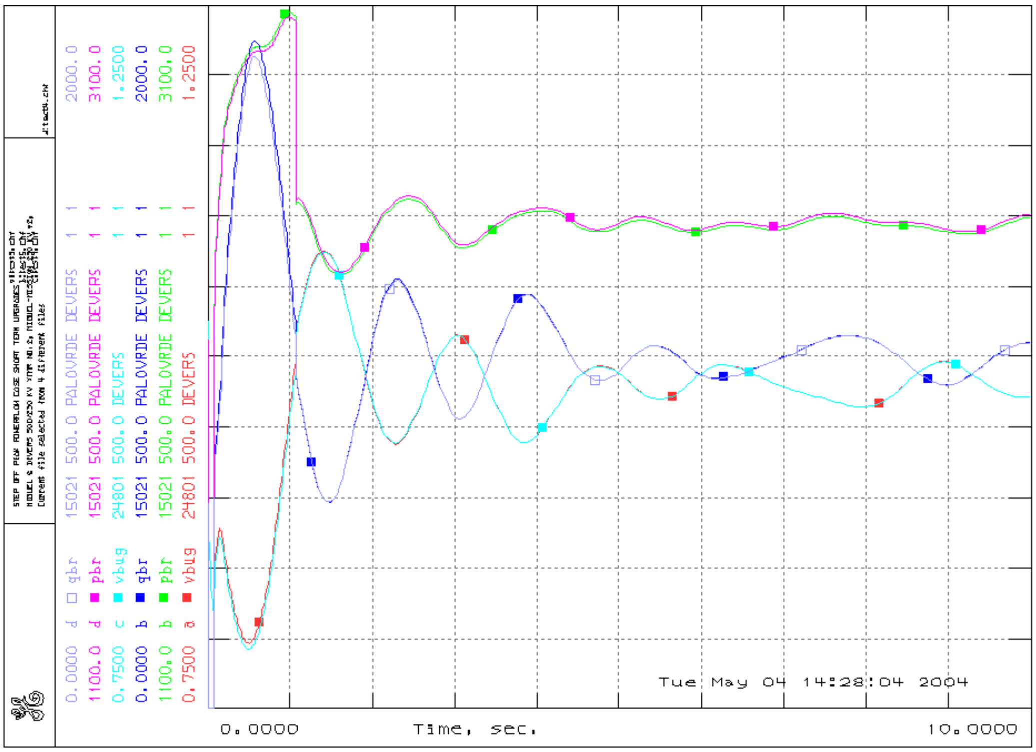
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.799	20.4	0.55
24	VALLEYSC	500	vbus		1.04	0.834	19.8	0.538
24	DEVERS	500	vbug		1.025	0.792	22.8	0.488

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.693	1.783
20	CPD-230	230	fbus		59.692	1.783
20	CPD-U1	13.8	fbug		59.675	1.783

The following plot compares voltage at the Devers 500 kV bus and flow on the Palo Verde-Devers line for these two TCSC locations (curves “a” and “b” – TCSC is 60 miles from Devers, curves “c” and “d” – TCSC is 60 miles from Palo Verde).



20 Ohm TCSC on the Palo Verde-Devers line at Devers Substation

This TCSC location also eliminated all criteria violations with the Hassayampa-North Gila outage. There was almost no difference in the voltage dip compared to other locations (voltage dip was 0.1% lower than with the TCSC installation with the existing series capacitors 60 miles from Devers).

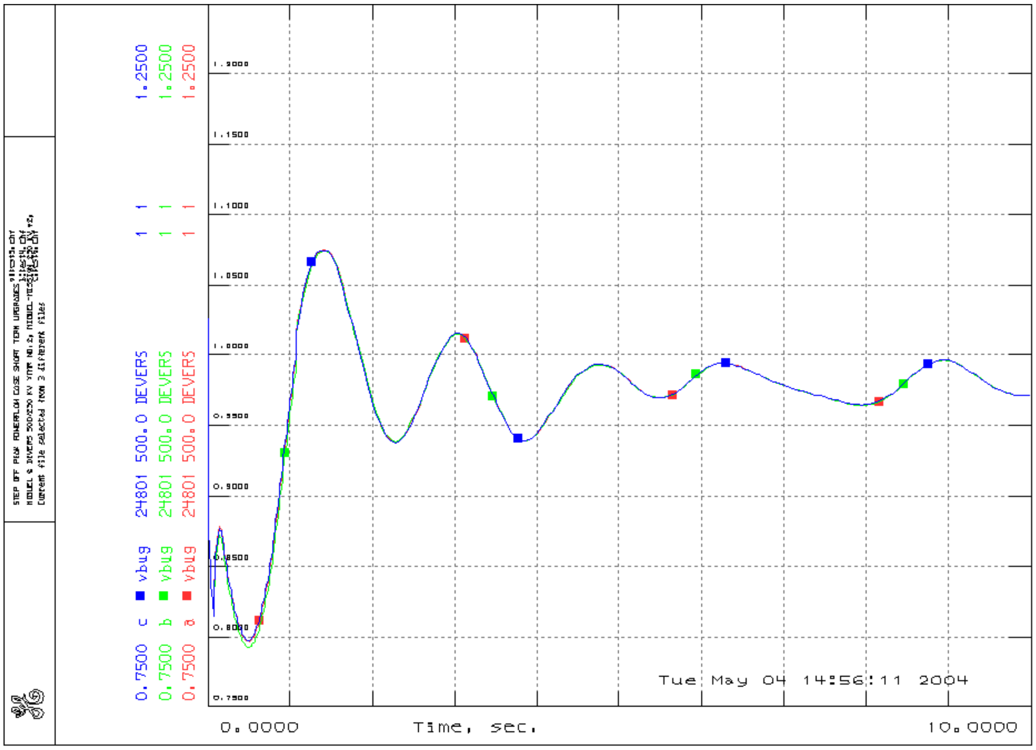
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
24	VALLEY-S	115	vbul		1.004	0.803	20	0.55
24	VALLEYSC	500	vbus		1.04	0.838	19.4	0.538
24	DEVERS	500	vbug		1.025	0.798	22.2	0.488

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.692	1.75
20	CPD-230	230	fbus		59.691	1.75
20	CPD-U1	13.8	fbug		59.674	1.75

The following plot compares voltage at the Devers 500 kV bus with a 20 Ohm TCSC at “a” – 60 miles from Devers, “b” – 60 miles from Palo Verde, “c” – at the Devers end.



8.5. Higher SCIT

This study modeled the off-peak case with the same EOR flow, but higher SCIT level. To achieve the higher SCIT, generation in Southern California was reduced. This generation decrease was compensated by increase of generation in the Northwest and PG&E. It appeared that increase in SCIT also causes increase in the EOR flow, EOR flow was decreased to match the level in the off-peak case by decreasing generation at Hassayampa. The case modeled the same amount of units at Hassayampa and Gila River as the base off-peak case, so that inertia on the sending end of the Palo Verde-Devers and Hassayampa-North Gila lines remained the same.

The sensitivity case modeled SCIT at 14459 MW and EOR at 8063 MW. These values were, respectively, 12245 MW and 8075 MW in the base case. The generators modeled to be off line in the sensitivity case compared to the base case included one San Onofre unit, one Alamitos and one El Segundo unit. Southern California inertia in the sensitivity case was 67207 MWsec, compared to 81099 MWsec in the base case. Total flow on the southern EOR lines was 3737 MW in the sensitivity case versus 3418 MW in the base case.

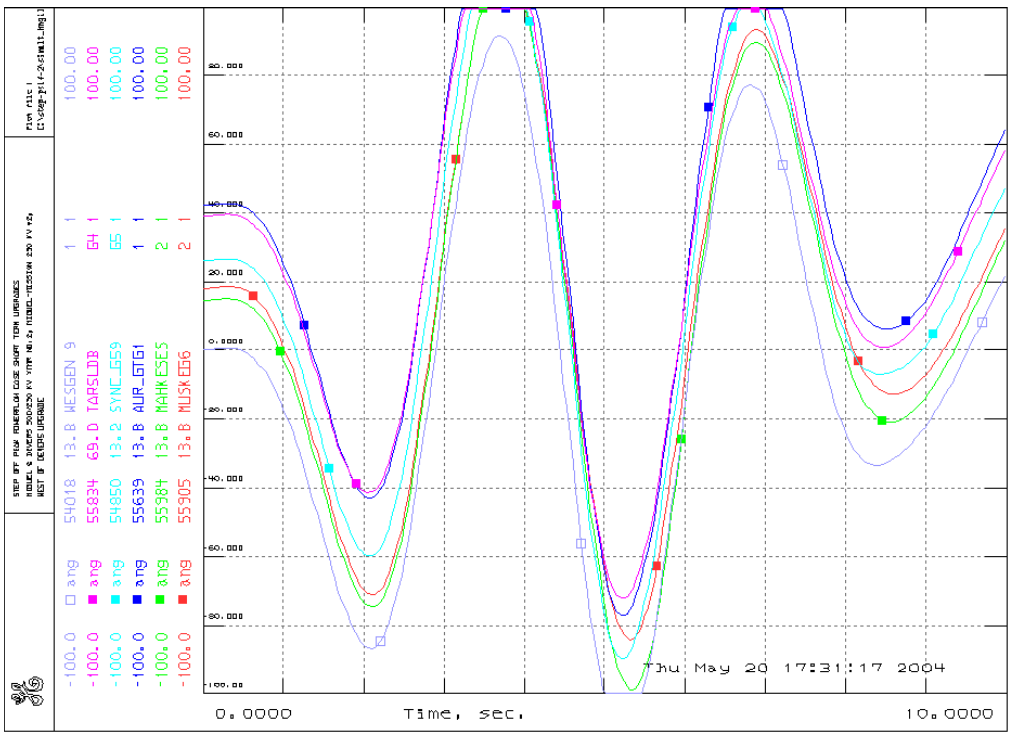
Dynamic simulation of the Hassayampa-North Gila outage showed multiple voltage and frequency criteria violations and under frequency load shedding. The buses with highest voltage dip and the lowest frequencies are shown in the table and the plots below. The first plot shows angles on the generator buses with the highest angle spread.

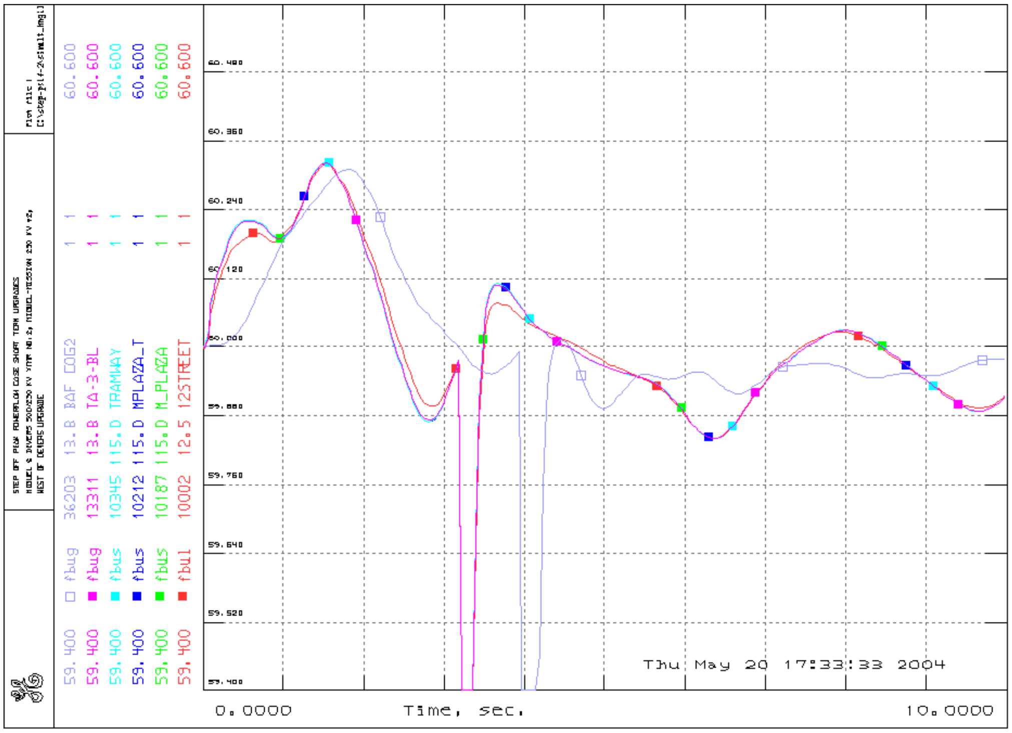
HIGHEST VOLTAGE DIP

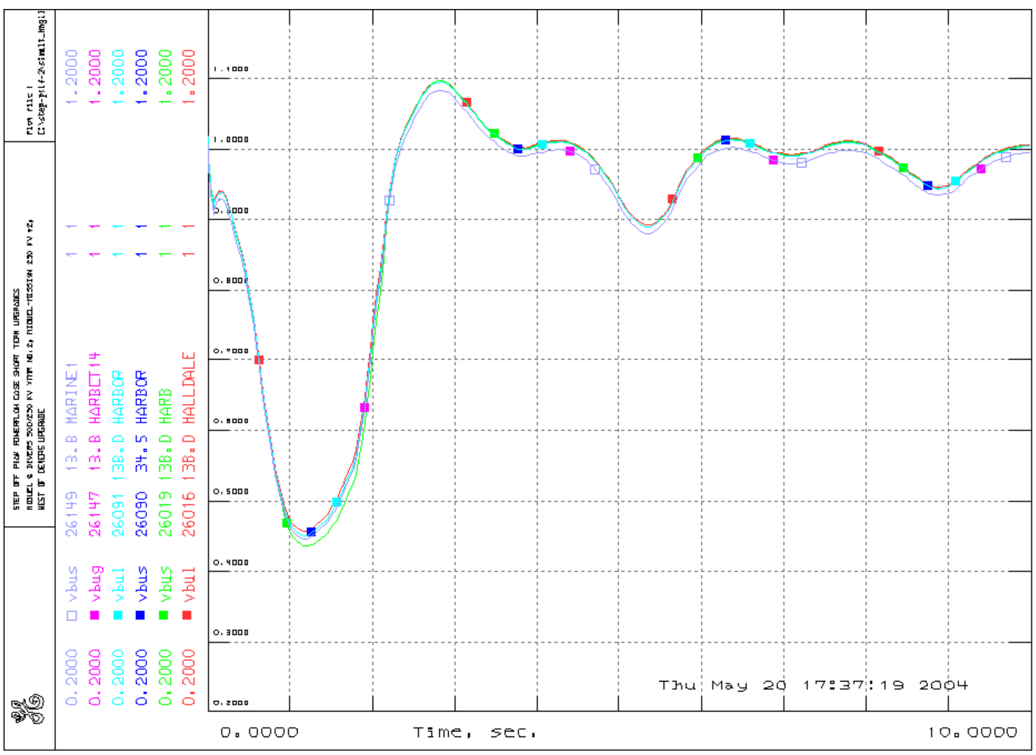
AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
26	WLMNTNLD	138	vbul		1.017	0.435	57.2	1.188
26	HARB	138	vbus		1.017	0.435	57.2	1.188
24	VALLEYSC	115	vbug		1.03	0.482	53.2	1.075

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
10	12STREET	12.5	fbul		39.992	3.212
10	TRAMWAY	115	fbus		39.999	3.212
30	BAF COG2	13.8	fbug		32.529	4







The studies showed that to bring the system performance to meet the criteria, at least 800 MVAR of additional dynamic reactive support needs to be installed. A 600 MVAR STATCOM at the Devers 500 kV bus eliminated frequency, but not voltage violations as shown in the table below. (There were too many violations to list, so only the highest voltage dips are shown).

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
26	WLMNTNLD	138	vbul		1.017	0.748	26.5	0.775
26	HARB	138	vbus		1.017	0.748	26.5	0.775
26	ADELSVC	500	vbug		1.04	0.781	24.9	0.775

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.649	0.363
20	CPT-161	161	fbus		59.649	0.363
20	CPT-U3	13.8	fbug		59.625	0.4

Two 400 MVAR STATCOMs, one at the Devers 500 kV bus and one at the Valley 500 kV bus mitigated the violations, as shown in the table below.

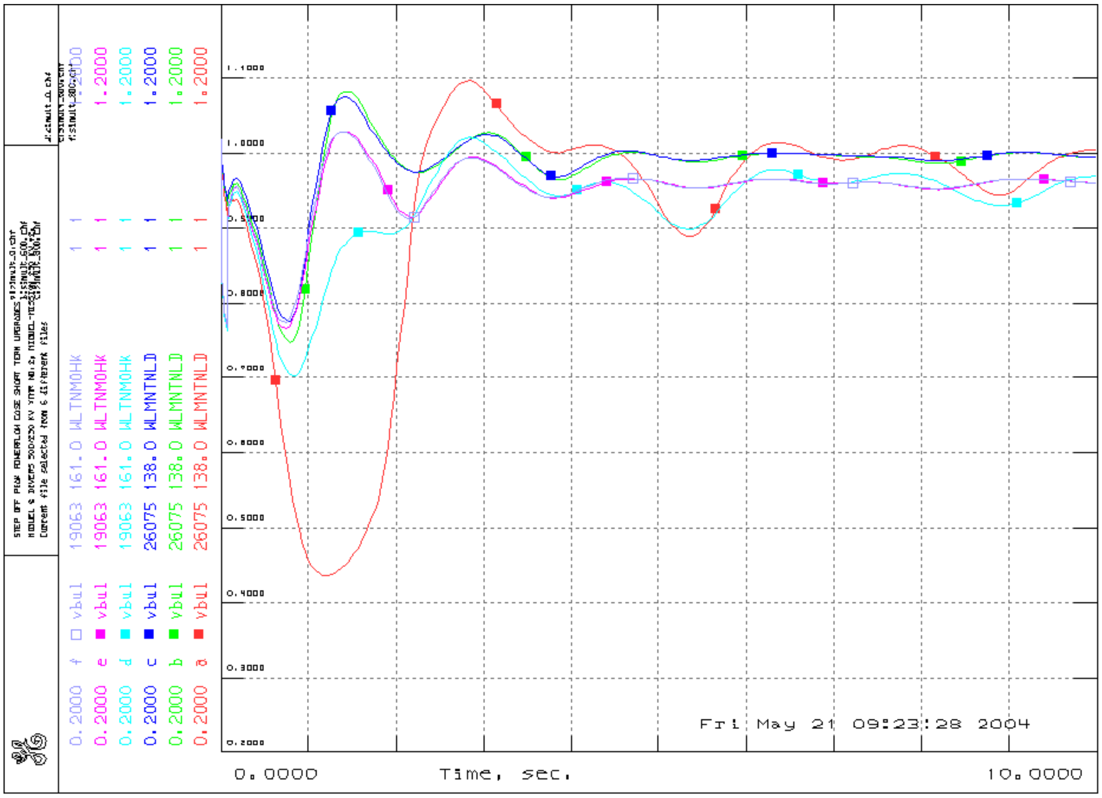
HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
14	WLTNMOHK	161	vbul		1.019	0.775	23.9	0.738
14	DOME TAP	161	vbus		1.021	0.773	24.3	0.738
26	ADELSVC	500	vbug		1.04	0.806	22.5	0.738

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.647	0.363
20	CPT-161	161	fbus		59.646	0.363
20	CPT-U3	13.8	fbug		59.622	0.4

The following plot shows voltage at the load buses in Southern California and Arizona with the highest voltage dip for the case without reactive support, with a 600 MVAR STATCOM at Devers and with 400 MVAR STATCOMs at Devers and Valley. Curves “a” and “d” are without reactive support, “b” and “e” with a 600 MVAR STATCOM at Devers, and “c” and “f” with two STATCOMs at Devers and Valley.



The sensitivity case modeled low inertia in the Hassayampa/Gila River area. The stability simulation of the same case, but with higher inertia, 30446 MWsec versus 26437 MWsec in the base case (by adding more generation units at Hassayampa with the same total generation) showed that addition of a 600 MVAR STATCOM at the Devers 500 kV bus was sufficient to eliminate the criteria violations.

The results of this simulation are in the following table.

HIGHEST VOLTAGE DIP

AREA	BUS NAME	BUS KV	TYPE		Initial	MaxDip	Prct	@time
14	WLTNMOHK	161	vbul		1.019	0.782	23.2	0.7
14	DOME TAP	161	vbus		1.021	0.782	23.5	0.7
24	VALLEYSC	500	vbug		1.029	0.811	21.2	0.738

LOWEST FREQUENCY

AREA	BUS NAME	BUS KV	TYPE		MaxDip	@time
20	CPU-161	161	fbul		59.65	0.363
20	CPT-161	161	fbus		59.649	0.363
20	CPT-U3	13.8	fbug		59.625	0.4

It can be concluded, that assumptions regarding generation units on-line in Southern California (and thus SCIT level and flow on the southern EOR lines) have significant impact on the amount of required reactive support.