ADDITIONAL DYNAMIC STABILITY SENSITIVITIES FOR THE DEVELOPMENT OF A REPLACEMENT FOR THE SCIT NOMOGRAM

by

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1. Introduction

This report is the continuation of dynamic stability sensitivity studies being conducted for the Southwest Transmission Expansion Plan (STEP) stakeholder group. The purpose of the studies is to aid the system operators in developing a replacement for the existing SCIT nomogram (Southern California Import Transmission versus East-of-the River Path Flow). The existing SCIT Nomogram will no longer be an adequate or appropriate operating guide once the planned STEP Short-term Upgrades are placed in service, which is currently planned for June of 2006.

Prior dynamic stability studies were conducted to determine the amount and location of dynamic voltage support devices that would be required to support the transfer levels identified in the production cost studies that were previously conducted for STEP. These studies were summarized in the report "Dynamic Stability Analysis for the Short-Term Upgrades of the STEP Project" which was issued in July 2004. In these studies, all major 500 kV transmission line outages were analyzed and the amount and location for required reactive support was identified. This report can be found on the California ISO website at the following link:

http://www1.caiso.com/docs/2004/07/07/2004070716074624407.pdf.

To select the amount of dynamic reactive support that would satisfy the majority of system conditions, sensitivity studies were performed. These studies also estimated the impact of different factors (inertia, generation availability, load levels, etc.) on the dynamic reactive support requirements. It is important to understand the relative significance of these various factors and their interaction in order to improve the design for dynamic voltage support and to develop improved tools for setting operating limits. The sensitivity studies were summarized in the report "Dynamic Stability Sensitivities for the STEP Short-Term Upgrades and the Development of a Replacement for the SCIT Nomogram" ("Dynamic Stability Sensitivities") issued in September 2004. This report can be found on the California ISO website at following link:

http://www1.caiso.com/docs/2004/09/22/2004092215552521819.pdf.

The present report is based on the continuation of these sensitivity studies. Although the "Dynamic Stability Sensitivities" report included detailed studies of many factors and analyzed their impacts, due to the complex interaction of these factors, some issues remained unclear. The sensitivity study results were discussed at a STEP Work Group meeting in November 2004 and that group developed recommendations for additional studies. This report summarizes these additional studies.

The analysis of dynamic stability system performance was needed not only to determine the required amount and location of the dynamic reactive support but also to develop a replacement for the existing SCIT nomogram. The nomogram's diagonal was developed based on dynamic stability performance. However, there are many changes and upgrades planned for the transmission system and the dynamic stability part of the nomogram will not be valid when these additions go into service. One of the goals of the studies described in this report was to determine which factors should be included in the new operating guides.

The system modeled in these studies includes the following upgrades:

1) Upgraded series capacitors on the following 500 kV lines: Hassayampa-North Gila-Imperial Valley, Palo Verde-Devers, Navajo-Crystal, Mead-Perkins, and Moenkopi-Eldorado;
2) Installation of a second 500/230 kV transformer bank at Devers Substation;
3) Dynamic reactive support (SVC) at the Devers 500 kV bus; and,
4) An upgrade of the 230 kV system west of Devers. These upgrades are expected to allow an increase in the EOR flow limit from the current 7550 MW to more than 9000 MW.

The previous studies showed that the most critical contingency for dynamic reactive support is a three-phase fault on the Hassayampa 500 kV bus cleared by opening the Hassayampa-North Gila 500 kV transmission line. This was the only outage considered in the "Dynamic Stability Sensitivities" report and in these studies.

In the studies described in the "Dynamic Stability Sensitivities" report, the impact of such variables as inertia in Southern California and Arizona, Southern California generation and load levels and bulk power transfers between Arizona, Nevada and California was studied. That study concluded that the main factors that have an impact on the required reactive support include:

1) The combined flow on the Palo Verde – Devers and Hassayampa - North Gila transmission lines (Palo Verde West flow).
2) Machine inertia on the sending end of the Palo Verde West transmission lines.
3) How far the flow on the Palo Verde West lines is transferred. Flow to Southern California from the North (North SCIT) served as an indicator for this factor.
4) The amount of real and reactive power reserves on the sending and receiving ends of the Palo Verde West transmission lines.

The "Dynamic Stability Sensitivities" study also established the required reactive support as a 600 MVAR Static VAR compensator (SVC) at the

Devers 500 kV bus. Later, this requirement was replaced with a 400 MVAR SVC at the Devers 500 kV bus, 2x150 MVAR shunt capacitors at the Valley 500 kV bus and 2x100 MVAR SVCs at the Valley 115 kV substation. The distribution of the additional reactive support will also improve voltage stability performance for contingencies other than the Hassayampa-North Gila outage.

The studies described in this report further investigated the impact of the different factors on dynamic stability performance and investigated the reasons for these impacts. The studies are intended to provide additional insight into how the system works in regard to dynamic stability performance and to facilitate the replacement of the SCIT Nomogram.

2. Study Conclusions

1. The impact of increased reactive support from the sending end of the Arizona-Southern California transfer path showed that additional MVAR injection on the sending end results in higher transient voltage in the Palo Verde area and thus, in higher transient voltage on the receiving end (Devers). The resulting decrease in the voltage dip is explained by the higher voltage and not by additional MVAR. Additional reactive support from the sending end replaces reactive output from the generators. Additional MVAR injection without any change in the scheduled voltage at the Palo Verde 500 kV bus did not improve, but exacerbated the voltage dip. The studies showed that impact of additional reactive support on the receiving end of the lines is significantly higher than impact of the reactive support on the sending end.

2. Increasing generator inertia on the sending end results in lower voltage dips. With higher inertia, the generator angle and real power output of the generators is higher, and reactive output is lower. This higher angle results in higher real power and lower reactive power flow on the Palo Verde-Devers line and reduced transient voltage dips on the receiving end of the line.

3. The total real and reactive power reserve from generation on the sending end has an impact on dynamic stability performance. Flows from the sending end (Palo Verde and Hassayampa) in both west and east directions can be indicators for the generation reserve. With a fixed number of generating units on the sending end, the higher the flows, the lower the reactive reserve.

4. Machine inertia on the receiving end does not have an impact on the transient voltage dip.

5. Reactive support at the receiving end has a significant impact. The location of this reactive support is important. Voltage support from the Pastoria plant provides little benefit and voltage support from the Mountainview plant provides a substantial benefit.

6. With high real power output of the generators at the receiving end, reactive reserve is lower, and the voltage dip is higher.

7. The impact of increased Southern California load on dynamic stability performance depends on the location of the resources used to supply this increase in load.

8. The previous studies described in the "Dynamic Stability Sensitivities" report showed that imports to Southern California from the North (North SCIT) have an impact on dynamic stability performance. With the Palo Verde West and Palo Verde East flows held constant, higher North SCIT flows improved system performance (lower voltage dip). This was believed to be due to the fact that the transfers from Arizona are traveling a shorter distance with the higher North SCIT flow.

   However, these studies showed that the dynamic stability performance depended on how the change in the North SCIT flow was modeled. The critical factor appears to be the reactive power flow on North SCIT rather than the real power flow. With higher reactive power flows on North SCIT, the system dynamic performance was worse. Additional reactive power flow into Southern California indicates lower reactive power reserves in Southern California.

SCIT Nomogram Replacement Recommendations

From all the studies that have been conducted, it is clear that the existing SCIT nomogram will no longer be an appropriate operating guide after the addition of the STEP short-term upgrades, which is currently scheduled for the spring of 2006. While the individual SCIT and EOR limits will need to be retained, the SCIT nomogram should be retired. In its place a new operating guide (nomogram or table) will need to be developed that is focused on the voltage dip at Devers. The primary factor in this new operating guide will need to be the flow on the Palo Verde West Path (Hassayampa-North Gila and Palo Verde-Devers). Based on the studies performed for this report, the maximum capability of the Palo Verde West path will be approximately 3600 MW. Many factors will impact this capability.

The factors that were determined to have the most substantial impact on the transient voltage dip at Devers include:

- Flows on the Palo Verde West and Palo Verde East transmission lines
- Reactive power reserve in Southern California. This could be monitored through the voltage at critical buses.
- Machine inertia on the sending end of the Palo Verde West transmission lines. This could be monitored based on the amount and

type of generation units on-line at Palo Verde, Hassyampa and Gila River.

At a minimum, the above factors should be accounted for in the new operating guide. In addition to these factors, there are many other factors that impact the transient voltage dip, however, due to the number of these factors and the non-linearity of these factors, including all of these factors in the operating guide would be very complex and would not be practical. As a result, substantial simplifying assumptions will be necessary.

To simplify the operating guide, conservative assumptions could be used for other factors that are not as critical. For example, the studies used to develop the nomogram could assume that relatively few units would be on-line in Southern California, Nevada, and Eastern and Northern Arizona and that these units are operating at a high real power output. In addition, the load in Southern California, Arizona and Nevada could be modeled at a high level. A simple operational guide would be a table with the Palo Verde West flow limit versus the number of generating units on-line at the Palo Verde, Hassayampa and Gila River plants.

3. Study Assumptions and Methodology

The power flow base case used in the studies was the case developed by Southern California Edison (SCE), which was used previously to confirm the 600 MVAR dynamic reactive support requirement. This case includes the following assumptions:

East of River flow	8064 MW.
Combined flow on the Palo Verde-Devers and Hassayampa-North Gila lines (Palo Verde West)	3520 MW
Southern California imports (SCIT)	15836 MW
Northern portion of SCIT	11932 MW
Southern California inertia	85542 MWsec

The new Mountain View generation project was modeled with four units generating a total of 500 MW. The Palo Verde power plant was modeled with all three units generating. Two Palo Verde generators were modeled as being upgraded and generating 1403 MW (Unit #1) and 1400 MW (Unit #2), the third unit was modeled generating 1352 MW. Imperial Valley generation was modeled at 330 MW (two units).

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

	Load	Generation (incl. pumps)	Losses	Import
SCE	16417	8439	444	8422
SDG&E	3150	1220	89	2019
LADWP	4203	2828	360	1735
IID	361	538	32	-145
Arizona	9858	15827	376	-5593
Nevada	3586	2795	36	827
CFE	1301	1437	24	-112
Total Southwest	38876	33084	1361	7153

The following generation dispatch was assumed in the Hassayampa area.

Arlington	3 units, 450 MW, 450 MVAR max (all on-line, Pmax 700 MW)
Harquahala	not dispatched (maximum 6 units, 1128 MW, 609 MVAR)
Mesquite	6 units, 830 MW, 860 MVAR max (all on-line, Pmax 1382 MW)
Red Hawk	3 units, 300 MW, 350 MVAR max (max 6 units, 984 MW, 700 MVAR)
Gila River	2 units, 420 MW, 270 MVAR max (max 12 units, 2428 MW, 1520 MVAR)

Total: 14 units, 2000 MW, 1930 MVAR max. Maximum amount of generation at Hassayampa and Gila River is 33 units, 6622 MW, 4139 MVAR.

Total inertia of the on-line generation at Hassayampa and Gila River was modeled at 19164 MWsec. The maximum inertia with all the units on-line is 42861 MWsec. If the Palo Verde units are included, the total inertia on the sending end of the southern EOR lines was 37082 MWsec and the maximum inertia with all units on-line would be 60779 MWsec.

At the time the studies were performed, splitting the reactive support between the Devers and Valley substations was not yet recommended, therefore, one 600 MVAR SVC was modeled at the Devers 500 kV bus.

The base case provided by SCE modeled the phase shifters at Perkins and Liberty as being in operation. Usually, these phase shifters are bypassed, except for several hours a year when they are used to relieve the loading on transmission lines comprising the northern and southern section of the EOR Path. The studies were performed with these phase shifters in operation, as well as with the phase shifters bypassed. The base case with the phase shifters bypassed was modified so that the Palo Verde West flow would be at its limit for the case studied.

It should be noted that the base cases represented very stressed conditions because there were relatively few generation units at Hassyampa and Gila River modeled, and at the same time the flow on the Palo Verde West transmission lines was high. The case also had high SCIT and high Southern California Edison load.

The base case described above was used as a starting point in developing other cases with different flows on the major transmission paths, different loads, and different generation dispatches. The purpose of the studies was to better understand impact of different factors on the dynamic stability performance and the goal was to determine how the new nomogram should be developed rather than developing the nomogram itself. Therefore, the exact assumptions used in the base case were not that essential. What was important that the power flow cases used for the studies were highly stressed, and the system was close to transient voltage dip limits.

The study methodology was to vary different factors to determine what impact these factors have on the dynamic stability performance. The Hassayampa-North Gila outage following a four-cycle three-phase fault on the Hassayampa 500 kV bus was studied, since it was determined to be the most critical outage and was the driving outage behind the dynamic reactive support requirement. The factors that were considered in these studies include machine inertia in Arizona and Southern California, Southern California load and generation, and the flows on major paths. The previous studies showed that the paths flows that impact the dynamic stability performance and could be the factors in the new nomogram are Palo Verde West (the combined flow on the Palo Verde - Devers and Hassayampa - North Gila 500 kV lines), Palo Verde East (the combined flow on the Palo Verde-West Wing, Palo Verde-Rudd and Jojoba-Kyrene 500 kV lines) and North SCIT (which includes all the SCIT flows minus the flows from Palo Verde and Imperial Valley). Therefore, these flows were monitored in the studies.

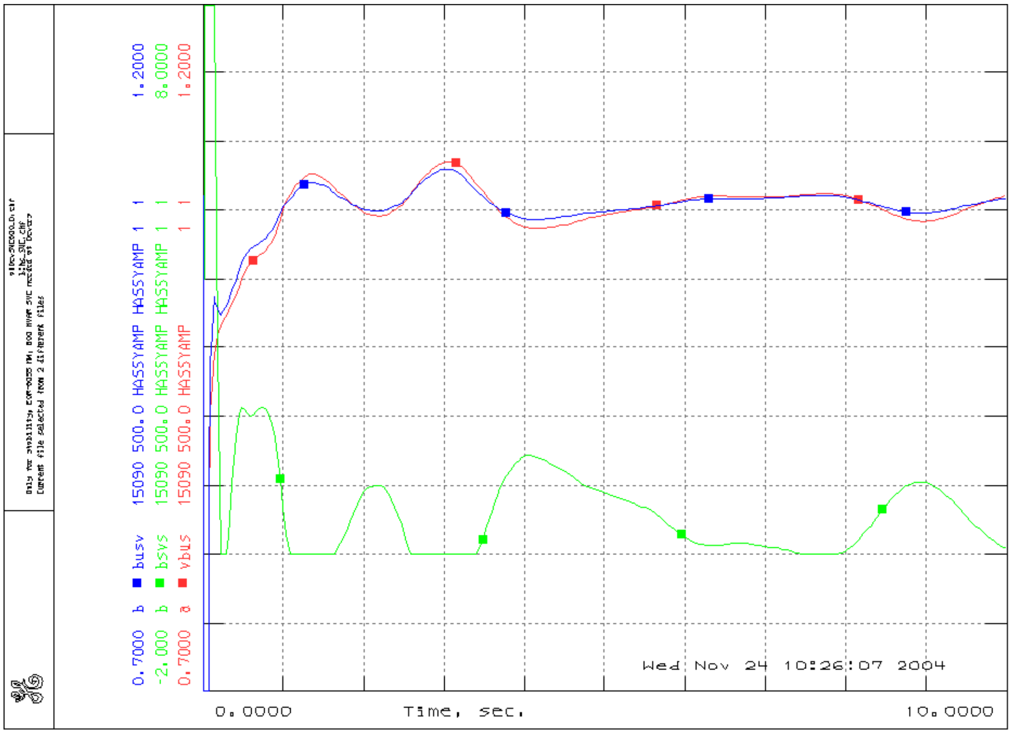
The studies also examined the impact of additional reactive support on the sending and on the receiving ends of the transfer path from Arizona to Southern California and the impact of different load and generation dispatches in Arizona and Nevada. The study results are summarized in the following sections of the report.

4. Study Results. Impact of Reactive Support from the Sending End

To investigate the impact of reactive support of the generation at Hassayampa, a 1000 MVAR fictitious SVC was modeled at the Hassyampa 500 kV bus. The results of these studies are presented in the following plots.

Comparison plots: curves a – base case, b- same case with the Hassayampa SVC

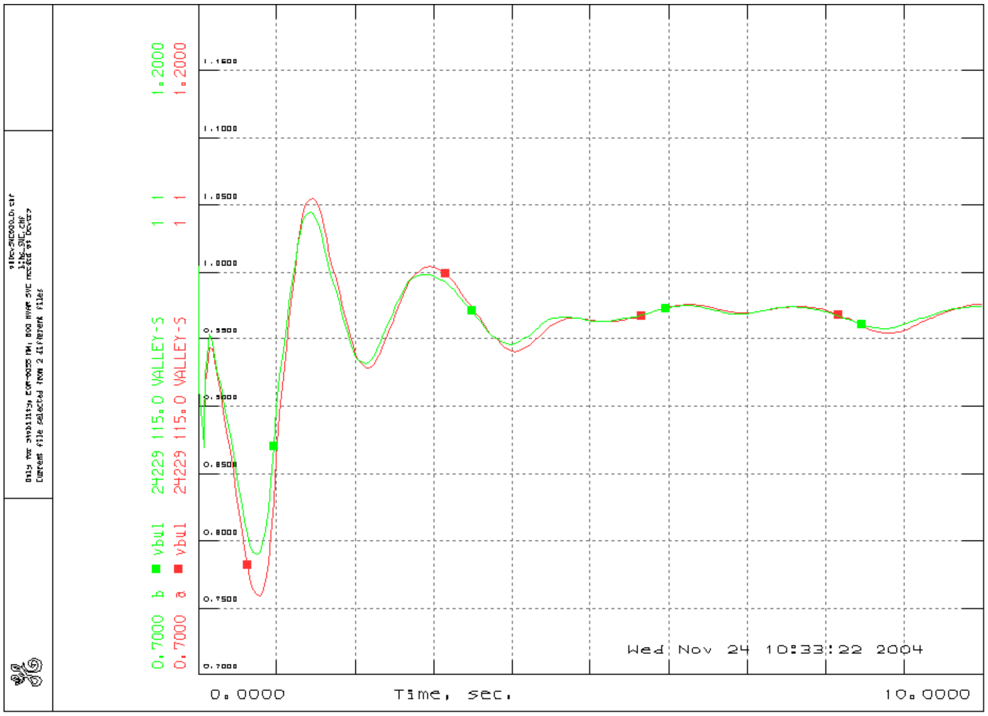
Voltage at Hassyampa and reactive output from Hassayampa SVC



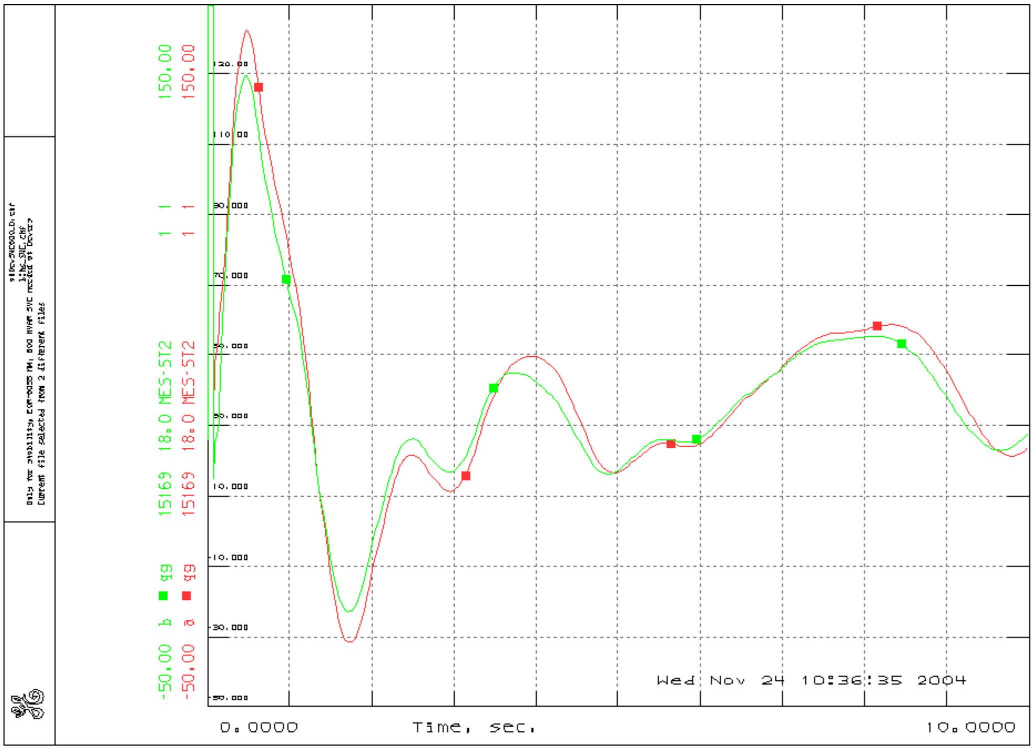
As can be seen from the plot, at the time of the highest voltage dip (approx. 0.77 sec), voltage at Hassayampa was slightly higher with the SVC. The SVC supplied around 200 MVAR. Voltage at the Palo Verde 500 kV bus and thus, at the Hassayampa 500 kV bus, which is close to Palo Verde, is regulated by the Palo Verde generators. Under steady-state conditions it was modeled to be held at 1.06 (530 kV).

As the following plots show, voltage dip at Valley was 4% lower with the SVC, reactive output from the generators at Hassayampa and Palo Verde was also slightly lower with the SVC.

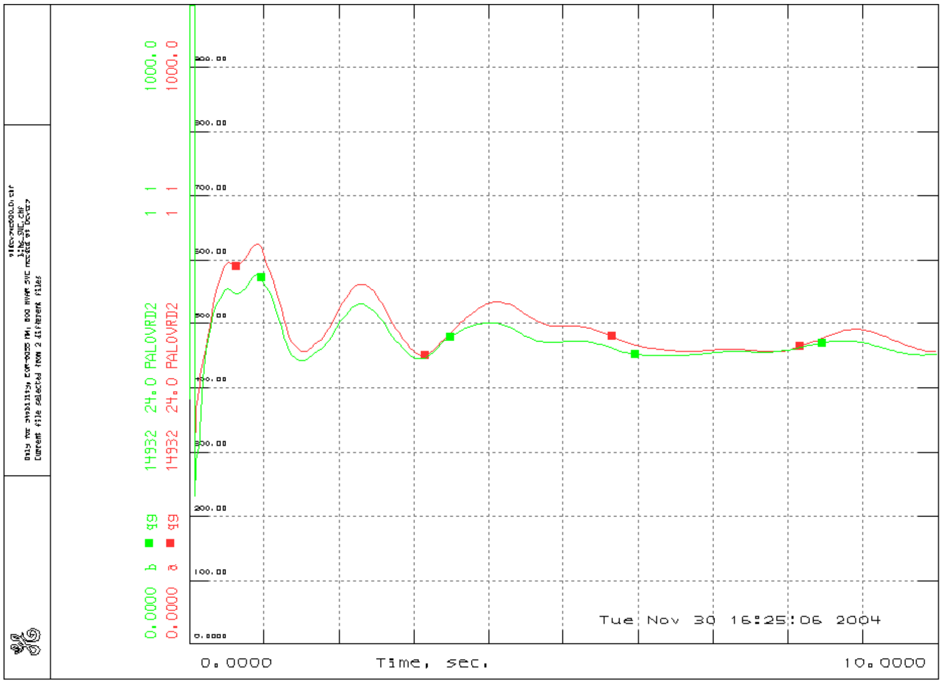
Voltage at the Valley 115 kV bus



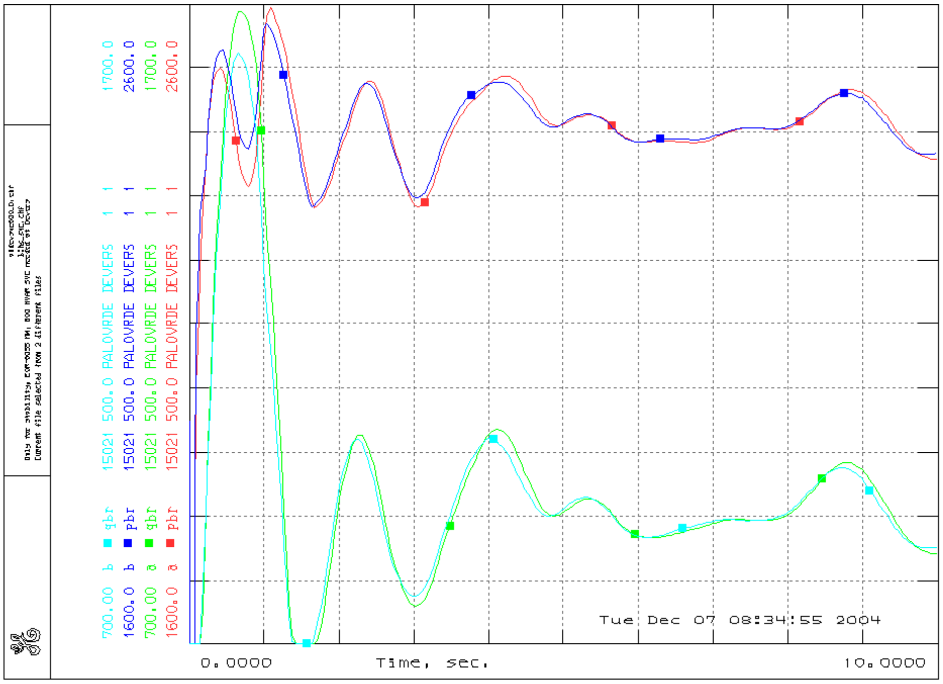
Reactive output from Mesquite generator (voltage was the same for both runs)



Reactive output from Palo Verde generator # 2



Flow on the Palo Verde-Devers 500 kV line (a – no SVC, b-with SVC)



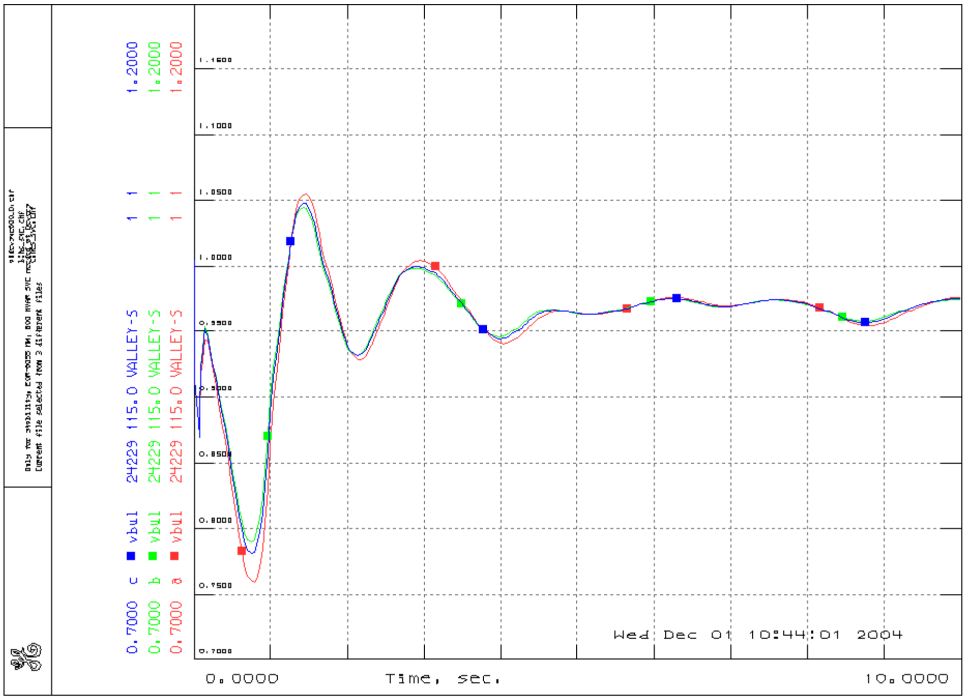
The reactive power flow on Palo Verde-Devers line at the time of the highest voltage dip was lower with the SVC and the real power flow was higher.

Reactive output from the SVC at Hassayampa replaced reactive power output from the generators at Hassayampa and Palo Verde. At the same time, it provided for higher transient voltages in the Palo Verde-Hassayampa area and higher transient voltage at Devers. Due to the higher voltage at Devers, there was lower reactive power flow on the Palo Verde-Devers line and a lower voltage dip. This way, the SVC at the sending end helped to maintain higher voltage and thus lower voltage dip.

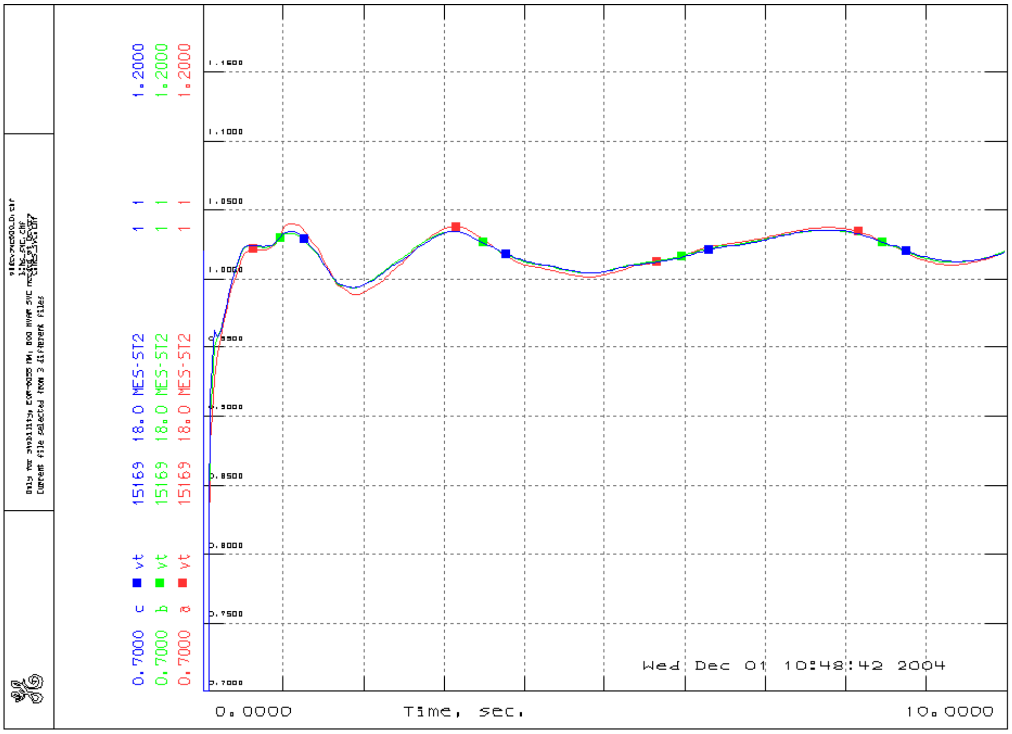
Another test had the same size SVC installed at the Mesquite 230 kV bus.

The following plots compare results of the base case (curves ‘a’), the case with a 1000 MVAR SVC at Hassayampa 500 kV bus (curves ‘b’) and the case with a 1000 MVAR SVC at Mesquite 230 kV bus (curves ‘c’).

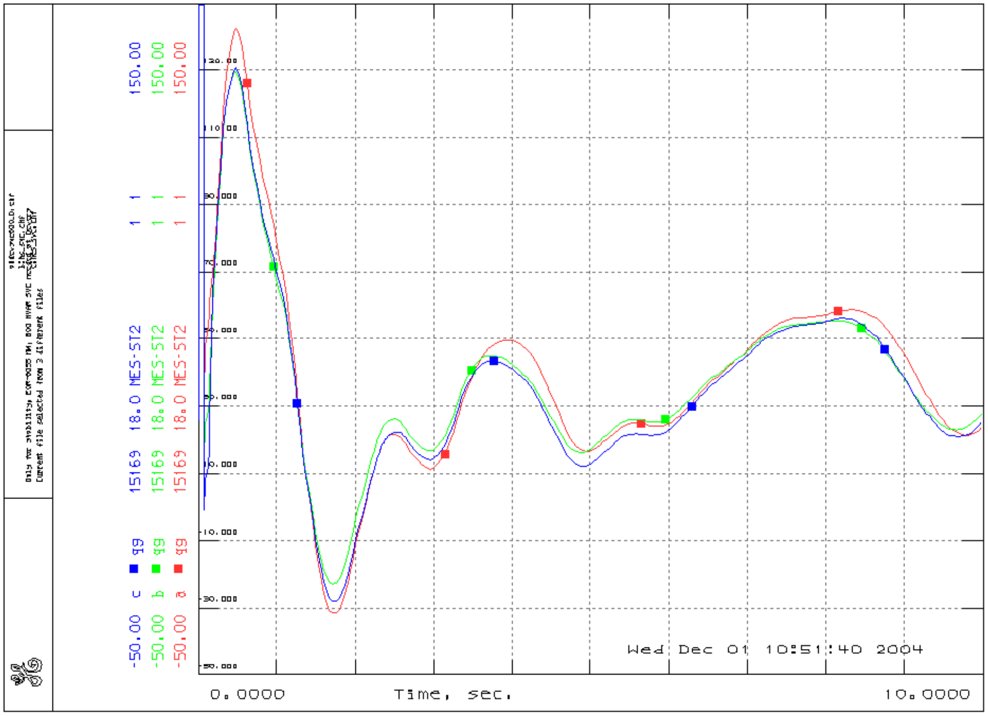
Voltage at the Valley 115 kV bus



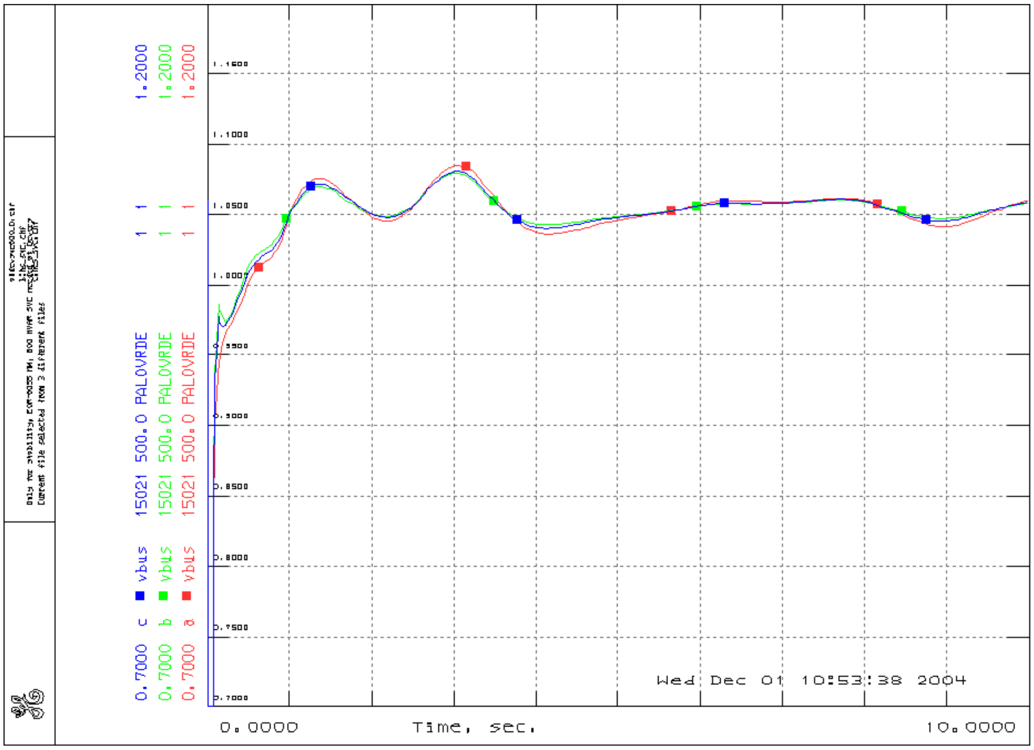
Voltage at the Mesquite steam generator



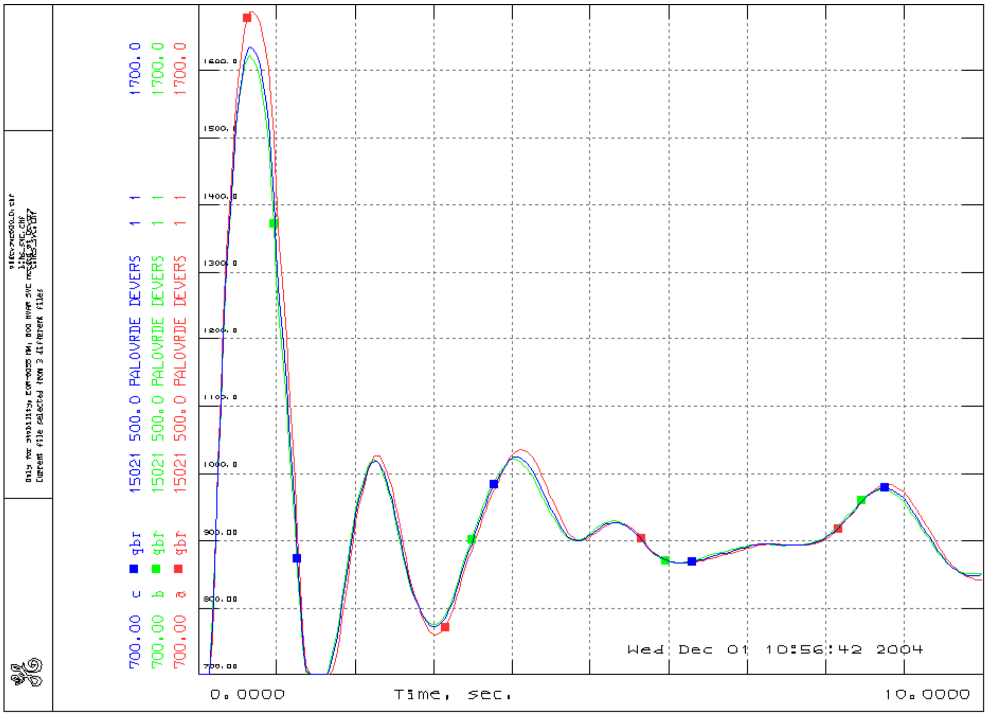
Reactive output from the Mesquite generator



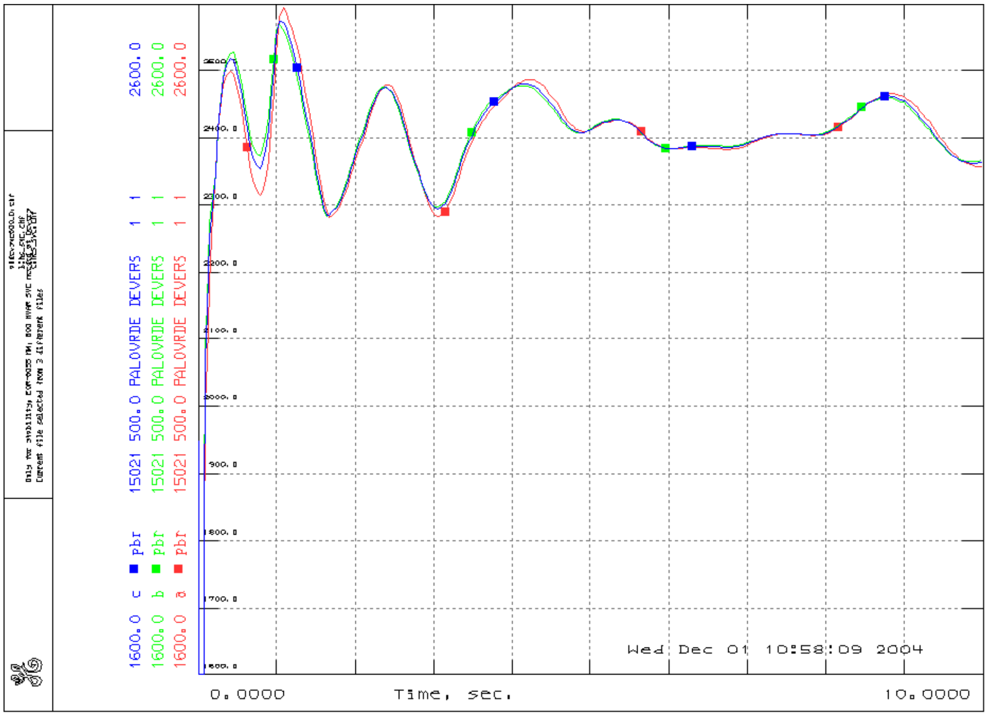
Voltage at the Palo Verde 500 kV bus (a – no additional reactive support, b- SVC at Hassayampa, c- SVC at Mesquite)



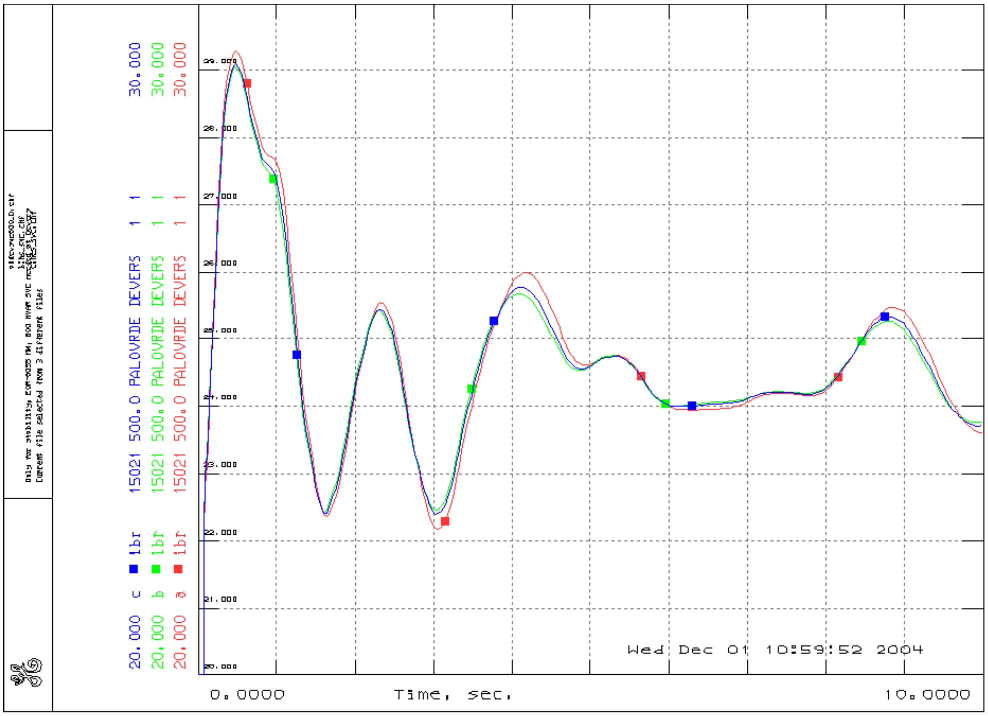
Reactive power flow on the Palo Verde-Devers line



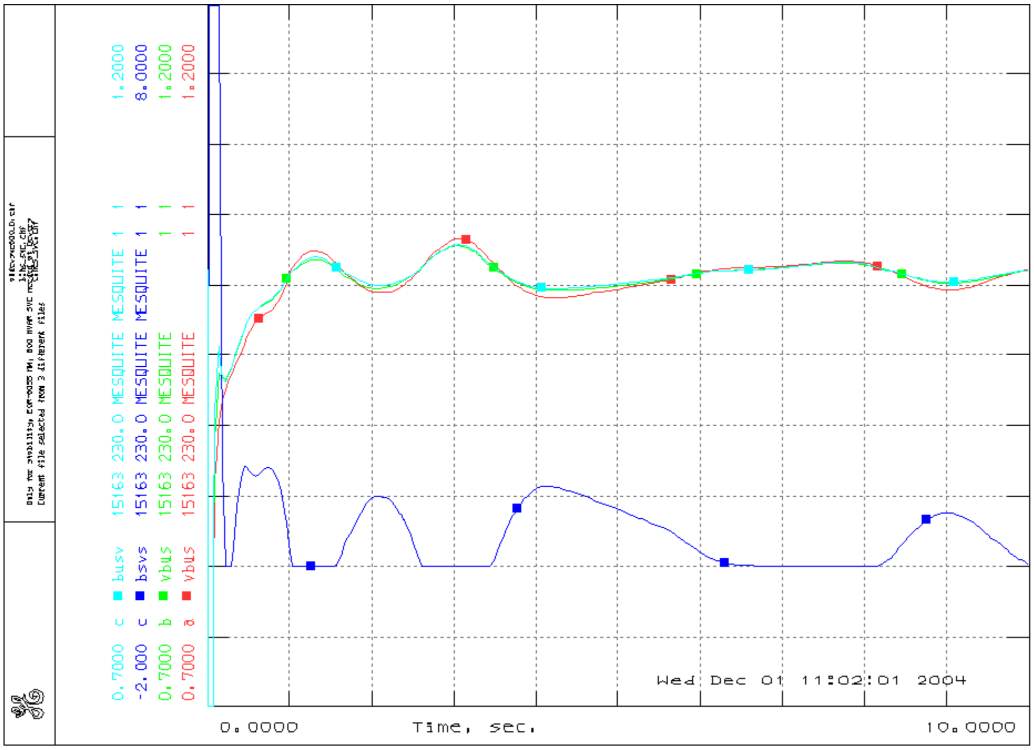
Real power flow on the Palo Verde-Devers line
(a – no additional reactive support, b- SVC at Hassayampa, c- SVC at Mesquite)



Current on the Palo Verde-Devers line



Voltage on the Mesquite 230 kV bus and the SVC output



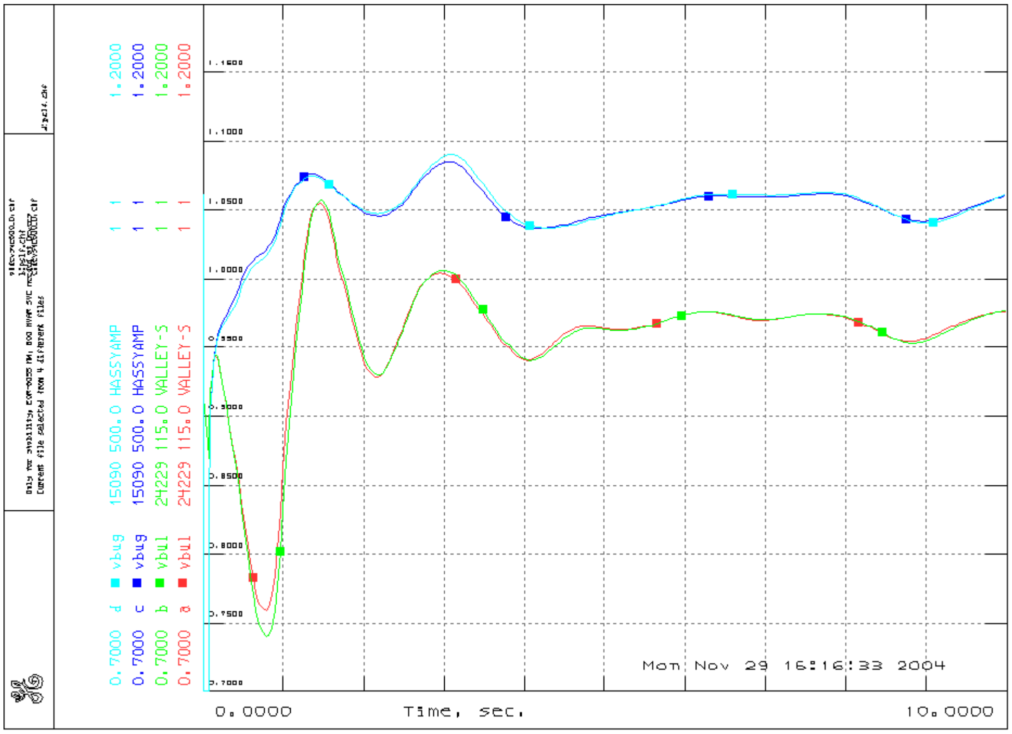
Conclusion:

Additional reactive support on the sending end has some positive impact on the voltage dip because it raises the voltage on the sending end. The closer the fictitious SVC is to the Palo Verde 500 kV bus, the higher the impact. Adding a SVC on the sending end reduces reactive power flow on the Palo Verde-Devers line. Reactive power from the SVC is replaced by the reduction of reactive power output from the Palo Verde and Hassayampa generators and higher reactive flow from Palo Verde to the east.

In the next test, additional reactive support on the sending end was not modeled as a fictitious SVC, but as increased reactive output from the generators at Hassayampa. To increase the reactive output from these generators, their scheduled voltage was increased from 1.02 per unit in the base case to 1.06 per unit. In the power flow cases, all generators at Hassayampa are modeled as regulating voltage on their terminals.

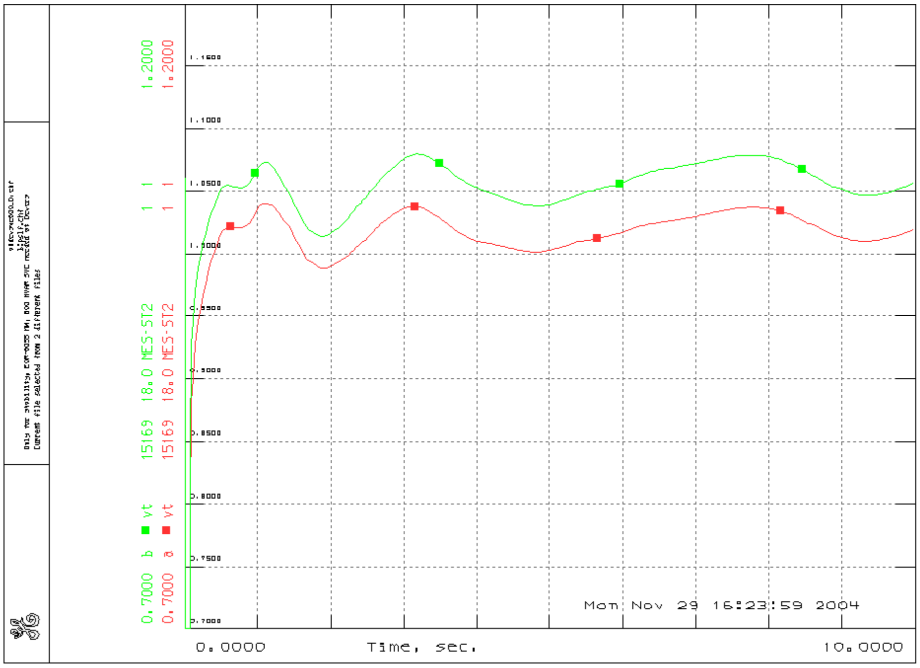
On the following plots, curves ‘a’ and ‘c’ represent the base case, curves ‘b’ and ‘d’ represent the case with the higher scheduled voltages.

Voltage at the Valley 115 kV and Hassayampa 500 kV buses

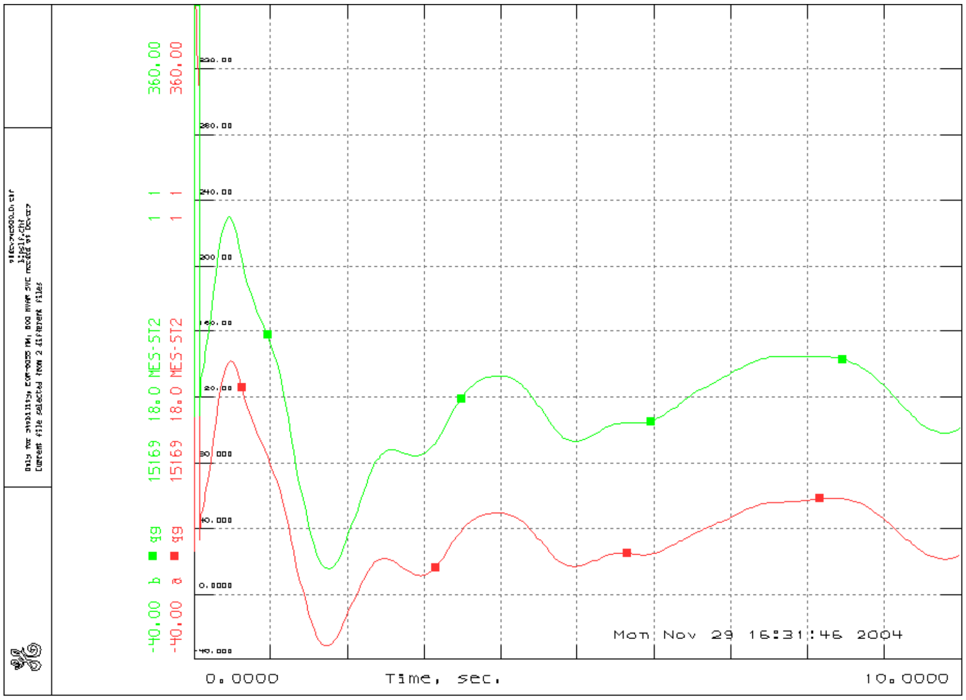


Voltage at the Hassayampa 500 kV bus is the same in both cases because the Hassyampa 500 kV bus is close to Palo Verde, and the Palo Verde 500 kV bus voltage is regulated by the Palo Verde generators. Higher scheduled voltage on the Hassayampa generators worsens voltage dip because the higher reactive power output from the Hassayampa generators leads to a lower reactive output from the Palo Verde generators. The lower reactive output from the Palo Verde generators, and the associated lower internal generator voltage, worsens the voltage dip.

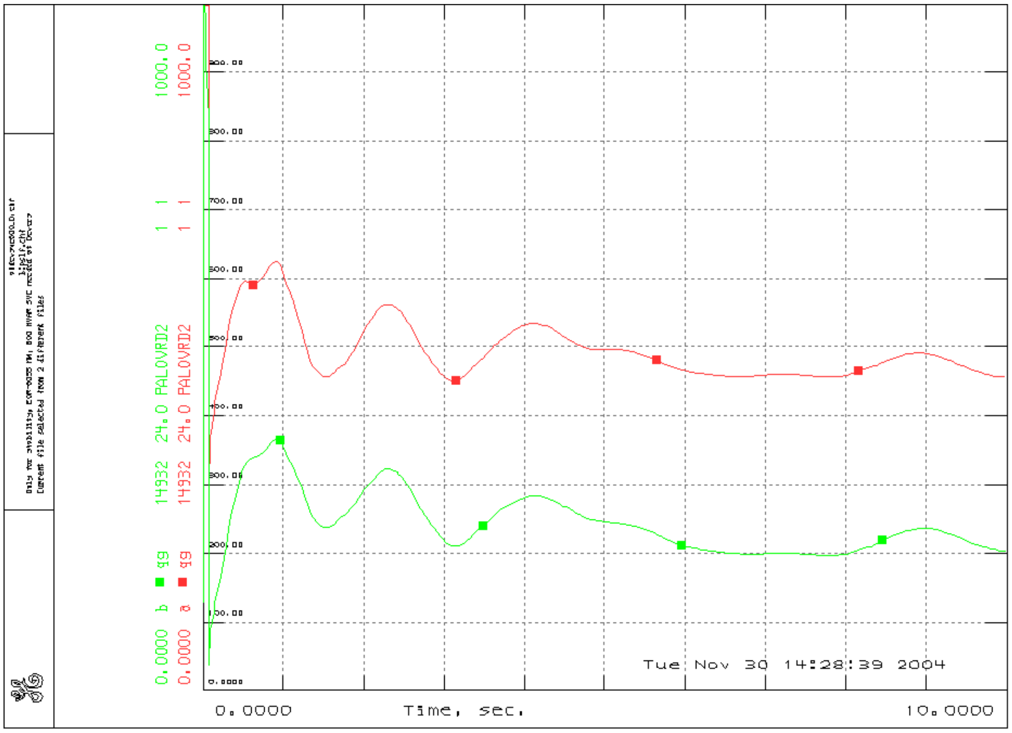
Voltage at Mesquite steam generator (a-base case, b- higher scheduled voltage)



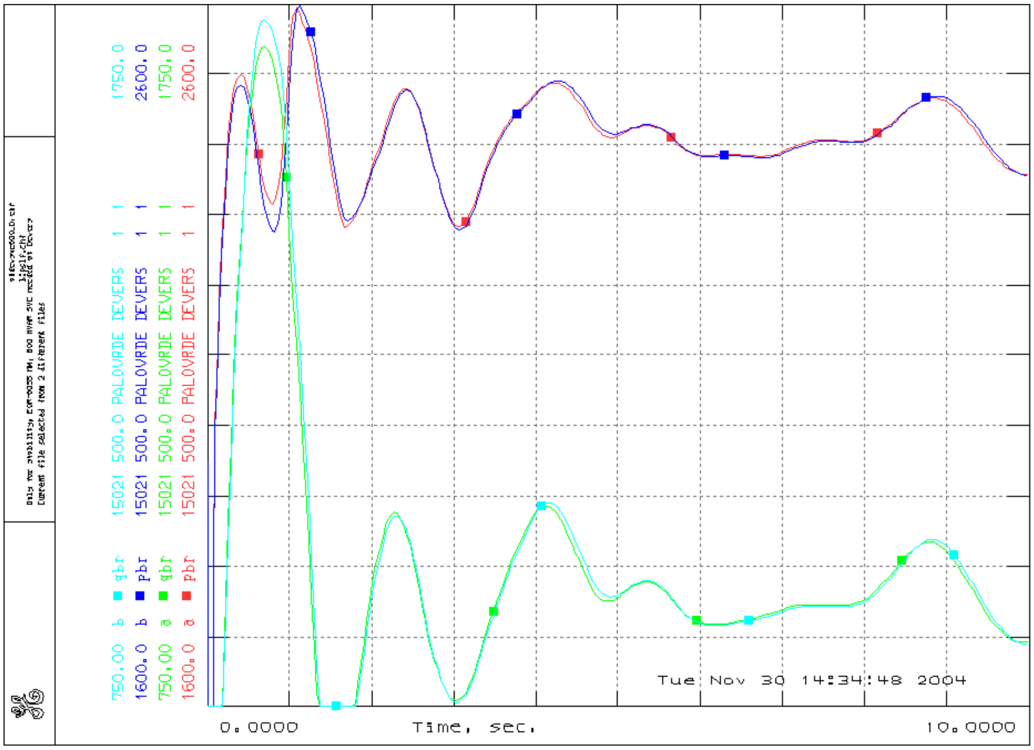
Reactive output from Mesquite generator (real power output was the same)



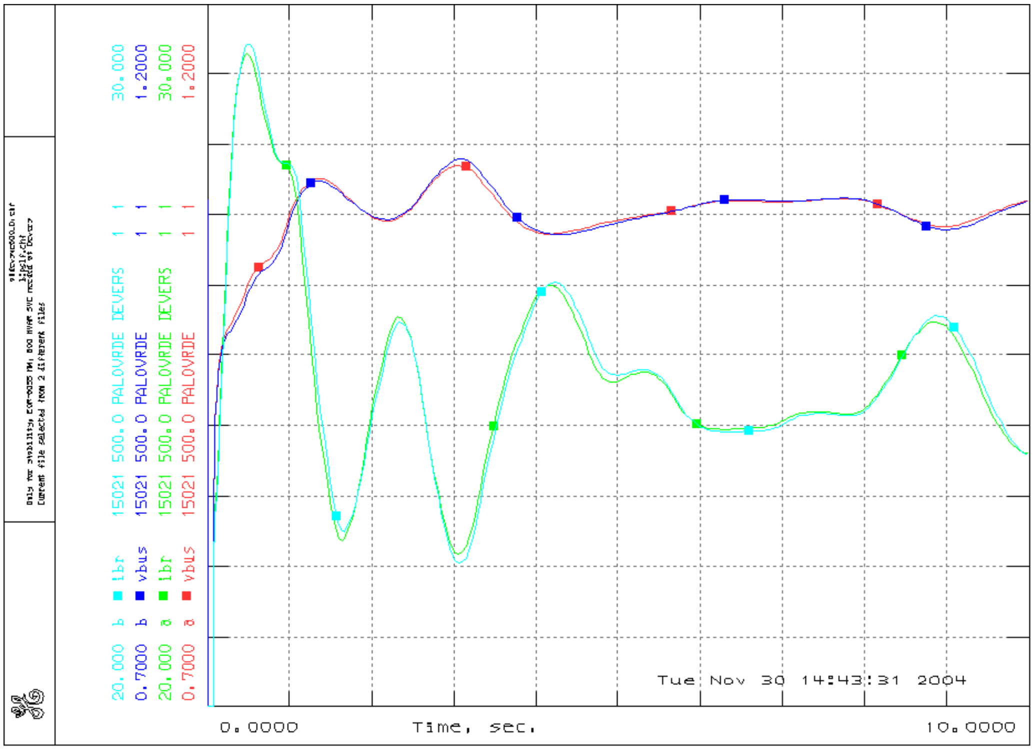
Reactive output from the Palo Verde generator # 2



Real and reactive power flow on the Palo Verde-Devers line



Current on the Palo Verde-Devers line and voltage on Palo Verde



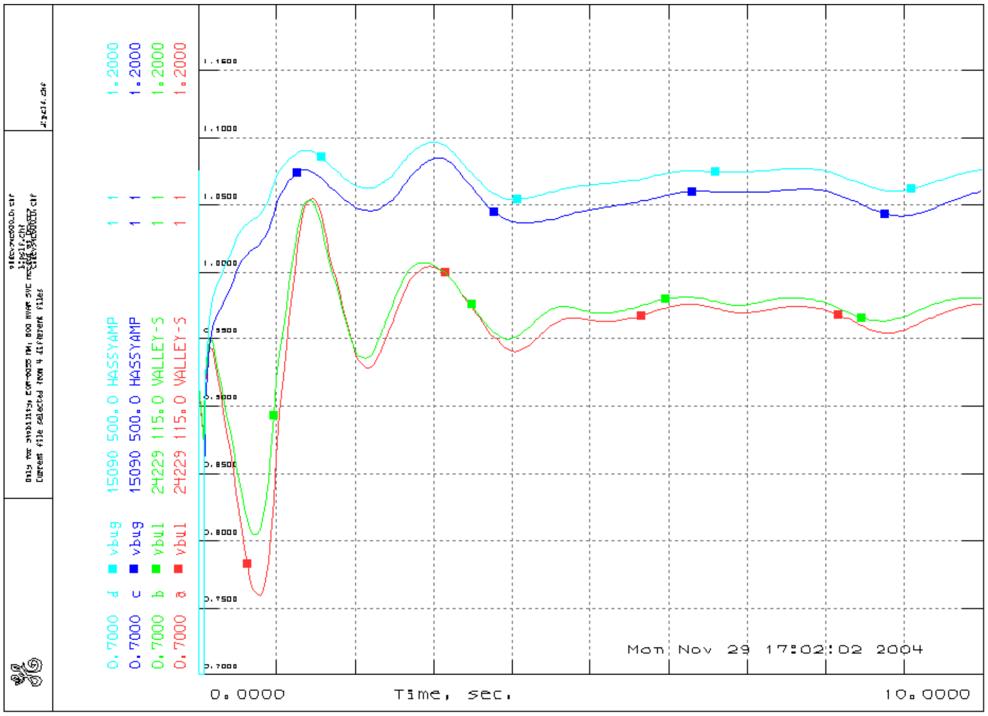
The following table compares the base case and the case with higher scheduled voltage at Hassayampa at the time of the highest voltage dip.

Transmission facility	Base case		Higher Hass vlt		Voltage		
	Real power, MW	Reactive power, MVAR	Real power, MW	Reactive power, MVAR		base	Hi Hs
Power plants at Hassayampa	1398	588	1371	1238	Hassayampa	510	508
Hass.-PaloVerde	1024	725	999	1453	Palo Verde	510	508
Hass.-Jojoba	374	-137	372	-215	Jojoba	512	512
Jojoba-Kyrene	548	-51	553	-48	Kyrene	512	512
PV power plant	3738	1115	3696	395	Devers	394	385
Paloverde-Devers	2316	1676	2277	1713	Westwing	496	495
PV-Westwing+Rudd	2446	164	2418	135	Rudd	518	517
Total output of PV and Hass. plants, SVC	**5136**	**1703**	**5067**	**1633**			
PV east flow	**2994**	**113**	**2971**	**87**			

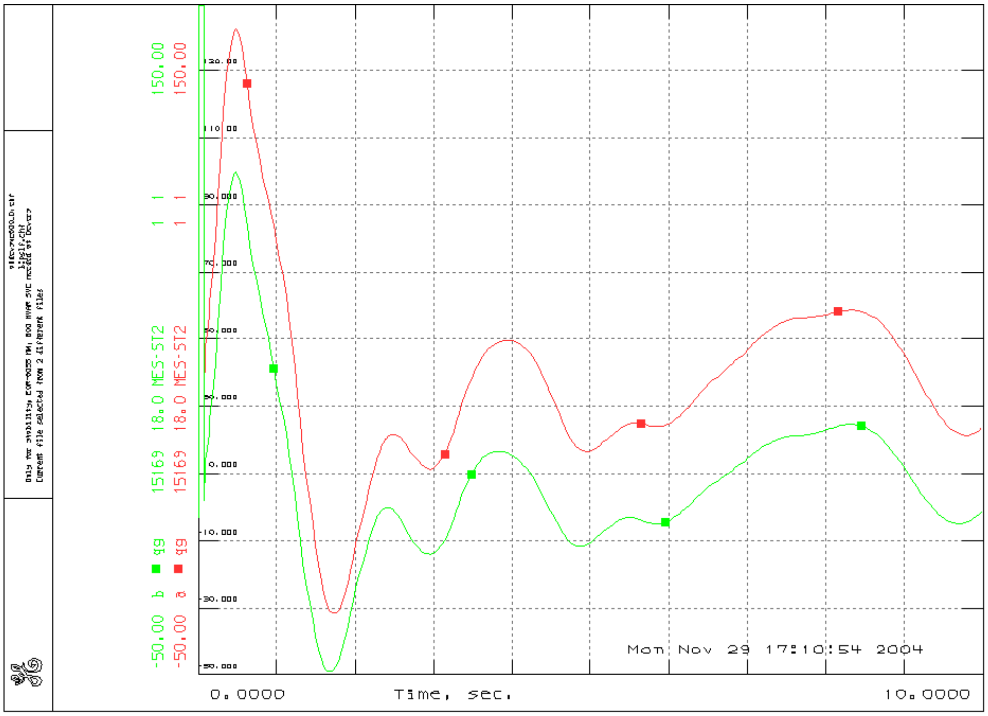
Higher scheduled voltages at the power plants at Hassayampa caused higher reactive output from these plants and lower reactive output from the Palo Verde units. With higher reactive output from the Hassayampa generators, the reactive power flow on the Palo Verde-Devers line was higher and real power flow lower. The voltage dip on the receiving end of the line was higher with the higher scheduled voltages at the Hassayampa plants. Since the Palo Verde 500 kV bus voltage remained the same in both cases (it is regulated by the Palo Verde generators), reactive support from the Hassayampa generators did not help to reduce the voltage dip.

The next test examined the impact of increasing the scheduled voltage at the Palo Verde 500 kV bus from 530 kV to 540 kV. In the following comparison plots, curves 'a' and 'c' are for the base case with the 530 kV scheduled voltage at the Palo Verde bus, curves 'b' and 'd' are for the case with the higher voltage (540 kV). As seen from the plots, higher scheduled voltage at Palo Verde helps to reduce the voltage dip.

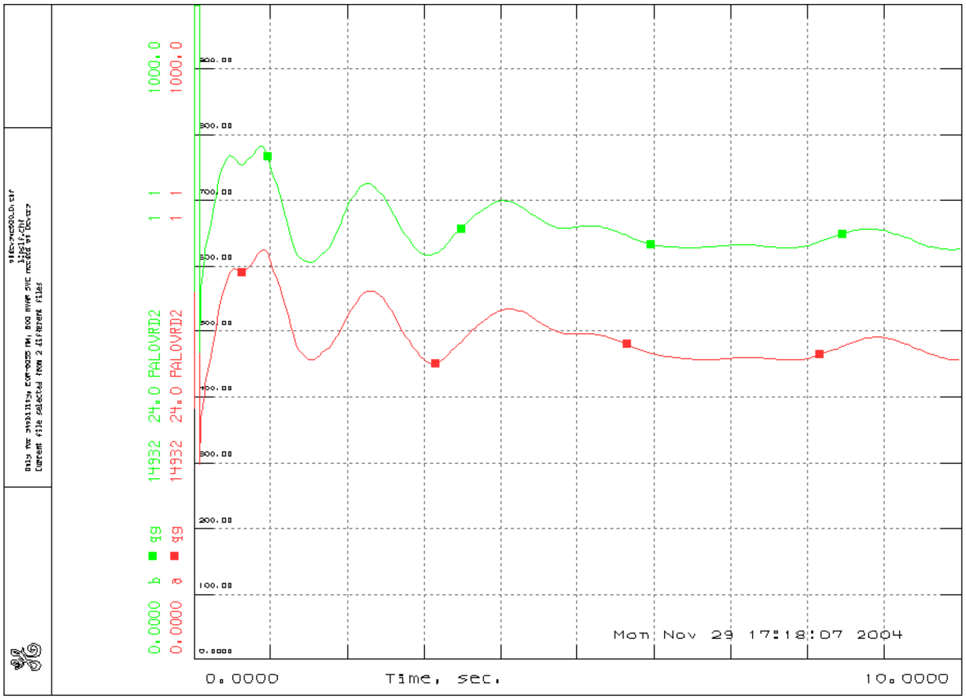
Voltage at the Valley 115 kV and Hassayampa 500 kV buses



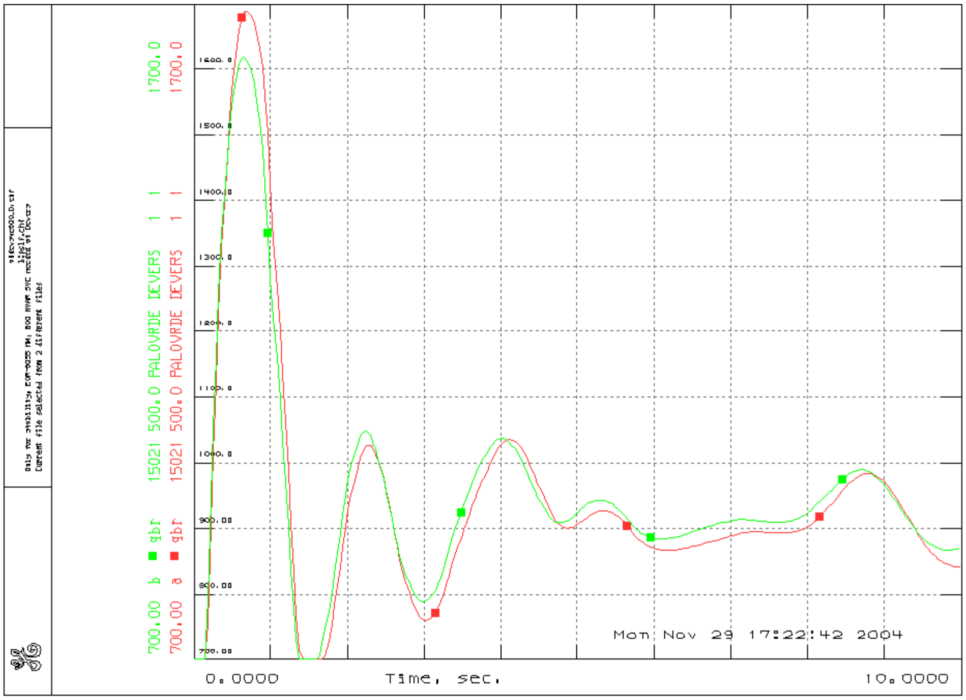
Reactive output from Mesquite generator



Reactive output from Palo Verde generator # 2



Reactive power flow on Palo Verde-Devers line



In the case with higher scheduled voltage at Palo Verde, the reactive output of the Palo Verde generators was higher and the reactive output of Hassayampa generators was lower. Higher transient voltage at Palo Verde caused higher transient voltage at Devers and thus reduced the reactive losses on the Palo Verde – Devers line and lowered the voltage dip. Even if the reactive power output from the Palo Verde generators was higher than in the case with lower scheduled voltage, more reactive power went to the east of Palo Verde than to the west (Devers).

The following tables compare transient power flows and voltages for the cases with and without the SVC and the case with higher scheduled voltage at Palo Verde at the time of the highest voltage dip.

Transmission facility	No SVC		SVC		Palo Verde Vsched 1.08	
	Real power, MW	Reactive power, MVAR	Real power, MW	Reactive power, MVAR	Real power, MW	Reactive power, MVAR
Power plants at Hassayampa	1398	588	1403	491	1400	284
SVC				224		
Hass.-PaloVerde	1024	725	1034	824	1044	345
Hass.-Jojoba	374	-137	370	-109	356	-60
Jojoba-Kyrene	548	-51	545	-34	530	-8
PV power plant	3738	1115	3803	970	3827	1559
Paloverde-Devers	2316	1676	2374	1596	2421	1593
PV-Westwing+Rudd	2446	164	2463	201	2450	314
Total output of PV and Hass. plants, SVC	**5136**	**1703**	**5206**	**1685**	**5227**	**1843**
PV east flow	**2994**	**113**	**3008**	**167**	**2980**	**306**

Voltage (kV) at selected buses at the time of highest voltage dip

	No SVC	SVC	PV Vlt = 1.08
Hassayampa	510	515	521
Palo Verde	510	514	520
Jojoba	512	515	521
Kyrene	512	515	518
Devers	394	402	417
Westwing	496	500	505
Rudd	518	523	528

Conclusions:

The main factor for transient voltage dip at Devers is the ability of the system to hold the scheduled voltage at Palo Verde. As long as the scheduled voltage is held, additional reactive support provides little benefit. Performance was better if the Palo Verde generators rather than the Hassayampa generators provided the reactive support, presumably because the Palo Verde generators are electrically closer to the 500 kV bus. Transient voltage dip performance can be improved by raising the scheduled voltage at Palo Verde.

5. Study results. Impact of the Machine Inertia of Generators in Arizona

The impact of generator inertia was studied by changing the inertia constants of the machines. Although changing the inertia constants makes the dynamic data and thus the study results to be hypothetical rather than real, it was done to eliminate the impact of factors other than the generators' inertia. The same power flow case was utilized in all stability runs. Thus, all the other variables such as on-line generation, generation dispatch, substation load, and transmission facility loading were excluded. The goal of this study was to better understand the inertia impact and to investigate what effect the changes in inertia have.

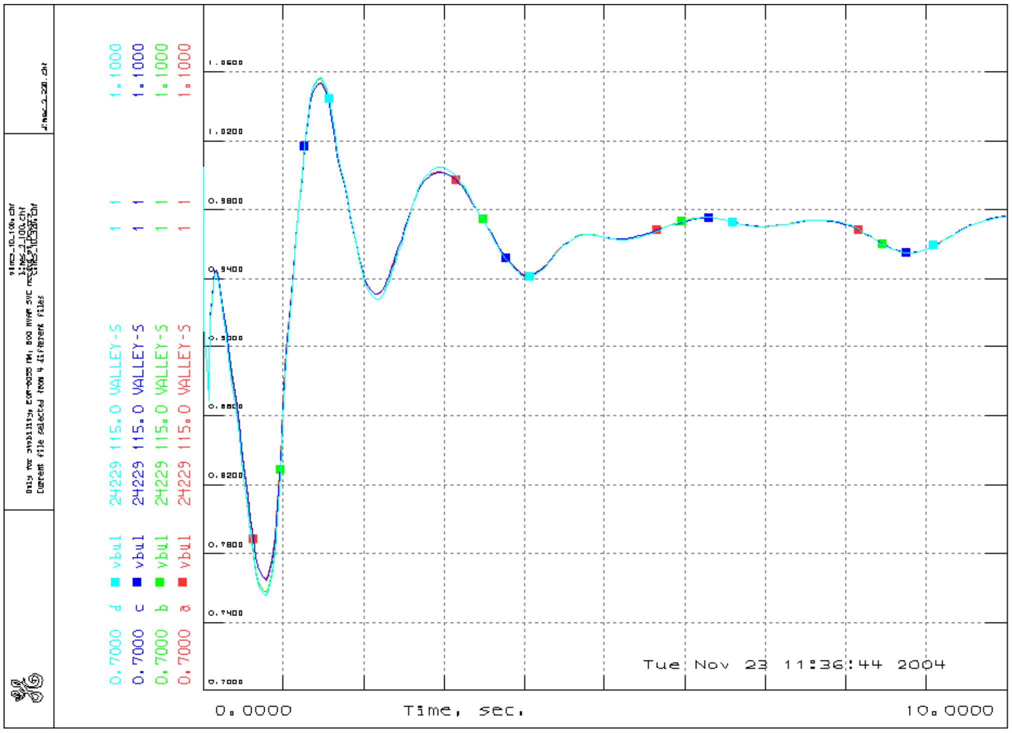
The following plots compare dynamic stability performance with the Hassayampa-North Gila outage for four cases. The difference in the cases was the inertia constant of the Mesquite steam turbine generator and the output from this generator. A 600 MVAR SVC was modeled at the Devers 500 kV bus.

The first two cases had the Mesquite steam turbine generator at 100 MW (P max = 321 MW). The first case had the inertia constant modeled as 2 MWsec/MVA, and the second one as 10 MWsec/MVA (the base case has the inertia constant of this machine modeled at 4.609 MWsec/MVA). The same studies were repeated with the Mesquite steam turbine generator at 320 MW (power was decreased by 220 MW at the Mesquite gas turbine generators # 1 and # 2 by 75 MW each, and at the Gila gas turbine generator # 2 by 70 MW). Changes in the generator's output were modeled to evaluate the impact of the generator's reactive reserve.

On the following comparison plots,

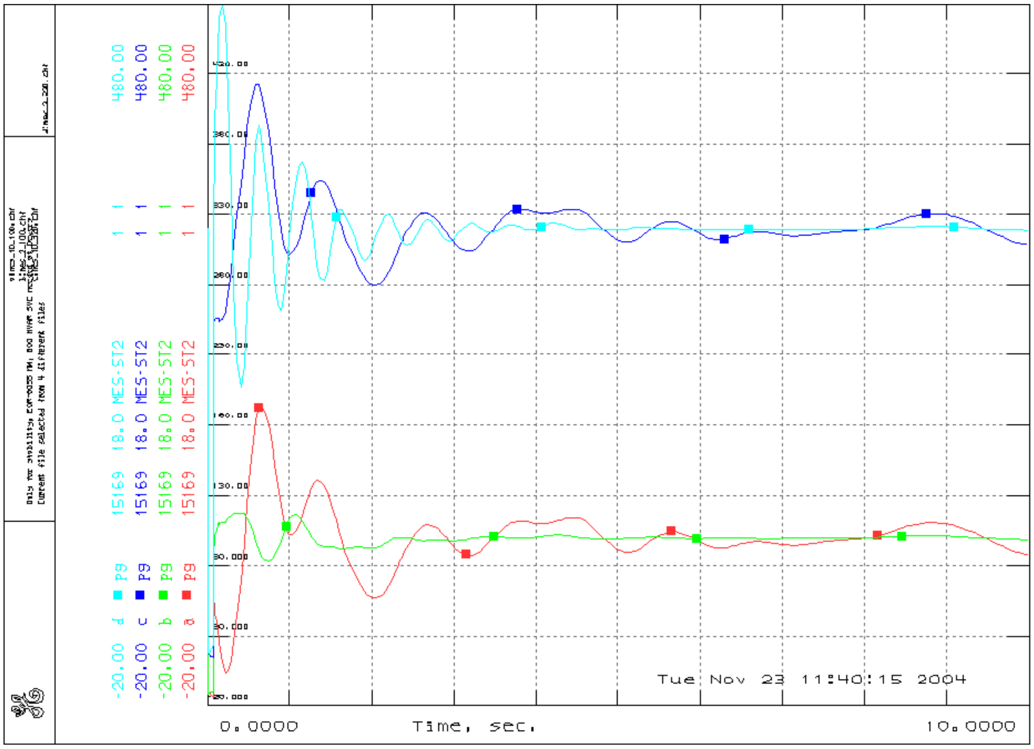
Curves 'a'	Mesquite inertia constant 10, output 100 MW
Curves 'b'	Mesquite inertia constant 2, output 100 MW
Curves 'c'	Mesquite inertia constant 10, output 320 MW
Curves 'd'	Mesquite inertia constant 2, output 320 MW

Voltage at the Valley 115 kV load bus
a - H=10, P= 100 b - H= 2, P= 100 c - H=10, P= 320 d - H= 2, P = 320

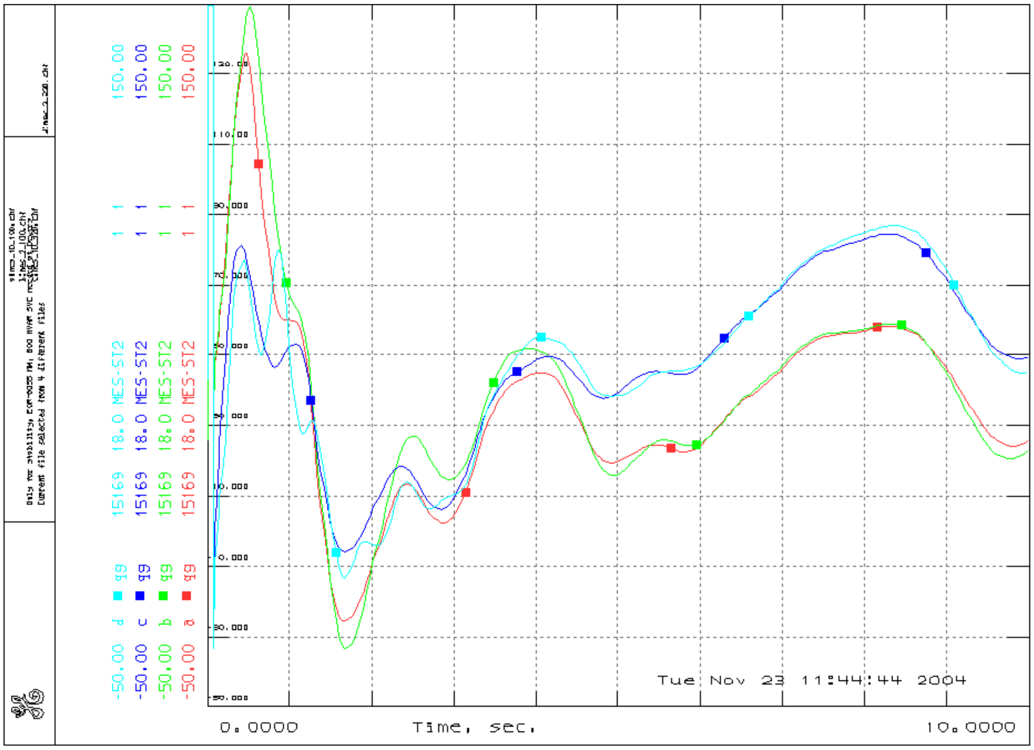


As can be seen from the plot, there was lower voltage dip with higher inertia. The voltage dip did not depend on the generator output.

Real power output of Mesquite generator

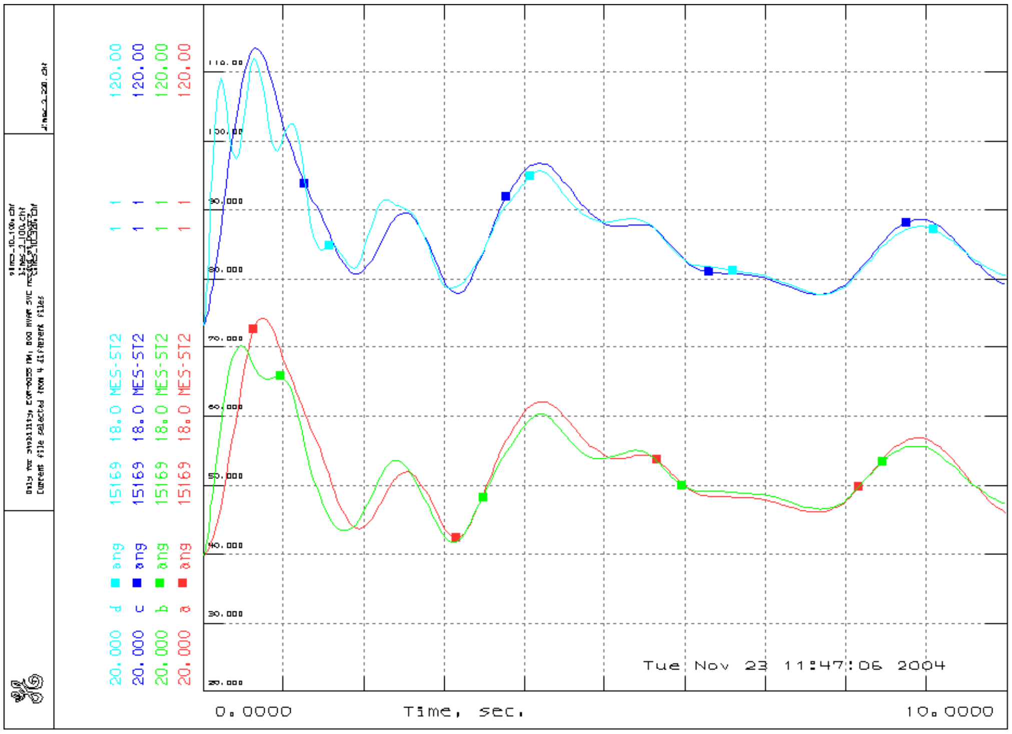


Reactive power output of Mesquite generator
a- H=10, P= 100 b - H= 2, P= 100 c - H=10, P= 320 d - H= 2, P = 320



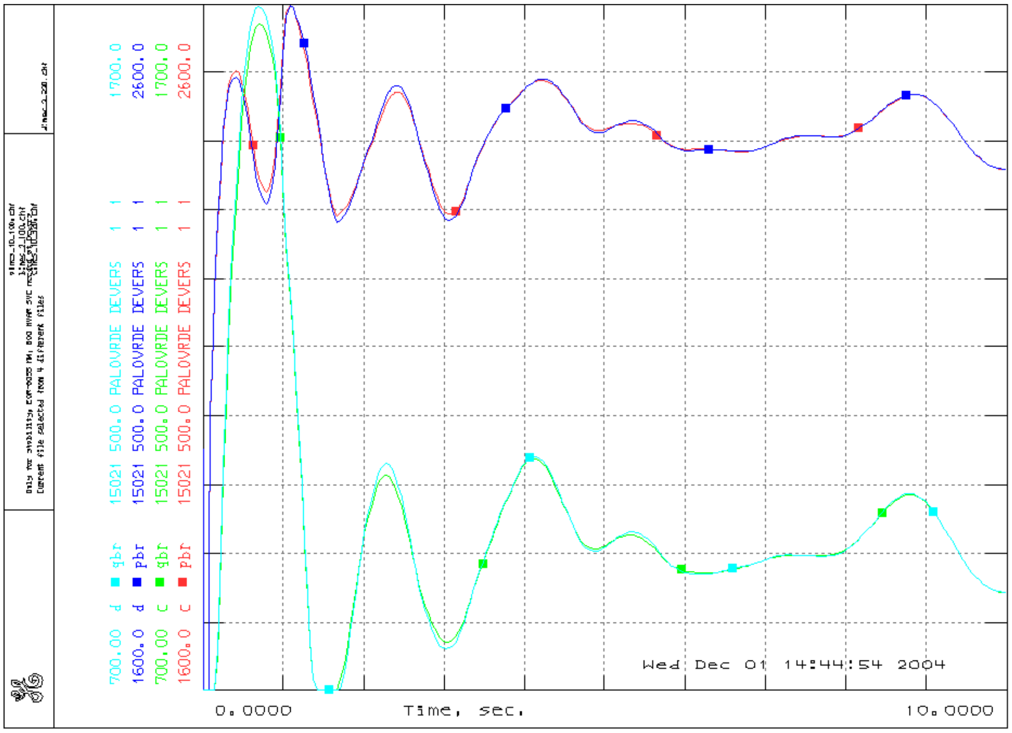
The reactive output from the generator was lower with higher inertia and was also lower with higher real power output (lower reactive reserve with higher real power output).

The angle of the Mesquite generator was higher with higher inertia and with higher real power output.



The voltage on the Palo Verde 500 kV bus was the same for all the simulations.

With higher inertia, real power flow on the Palo Verde-Devers line was higher and reactive power flow was lower at the time of the highest voltage dip.



The current on the Palo Verde-Devers line was the same for the two cases with different inertia.

The following table compares the cases with high and low inertia at the time of the highest voltage dip.

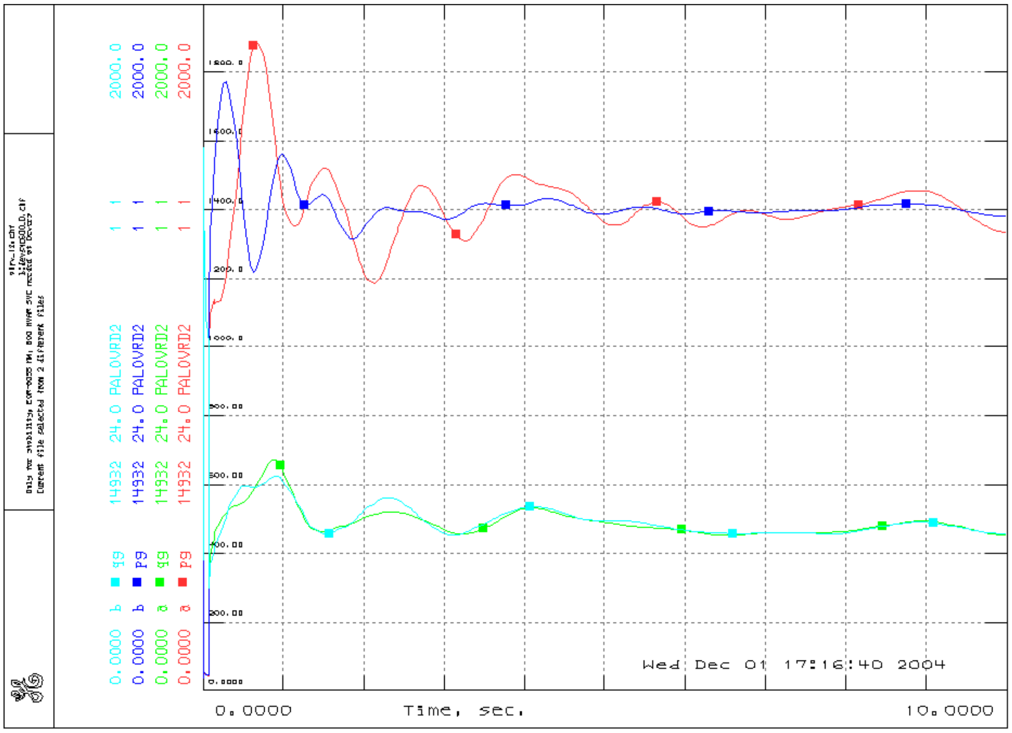
Transmission facility	Mes ST1 H= 10		Mes ST1 H=2		Voltage magn/angle		
	Real power, MW	Reactive power, MVAR	Real power, MW	Reactive power, MVAR		H=10	H=2
Power plants at Hassayampa	1452	554	1364	583	Hassayampa	510 /84.6	510 /85.4
Hass.-Palo Verde	1057	693	986	719	Palo Verde	510 /84.6	510 /85.4
Hass.-Jojoba	395	-139	377	-136	Jojoba	513 /83.6	513 /84.5
Jojoba-Kyrene	562	-50	549	-48	Kyrene	512 /80.1	512 /81.0
PV power plant	3761	1117	3756	1118	Devers	397 /30.4	393 /31.1
Palo Verde-Devers	2327	1653	2311	1672	Westwing	497 /79.8	497 /80.7

Transmission facility	Mes ST1 H= 10		Mes ST1 H=2		Voltage magn/angle		
	Real power, MW	Reactive power, MVAR	Real power, MW	Reactive power, MVAR		H=10	H=2
PV-Westwing + Rudd	2491	158	2432	167	Rudd	519 /81.8	519 /82.6
Total output of PV and Hass. plants	**5213**	**1671**	**5120**	**1701**			
PV east flow	**3053**	**108**	**2981**	**119**			

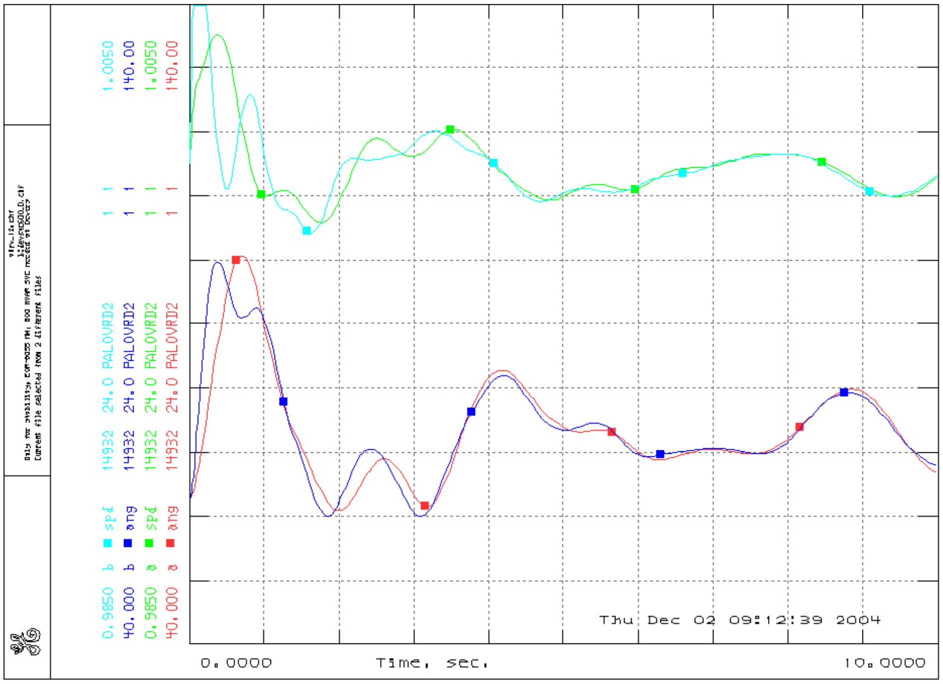
To confirm the results, the same test was performed with change of inertia on Palo Verde unit # 2. In the base case, the inertia constants of the Palo Verde generators are 3.831 MWsec/MVA. The test case modeled inertia constant of the unit #2 at 12 MWsec/MVA.

On the following plots, curves ‘a’ – high inertia, ‘b’ –low inertia

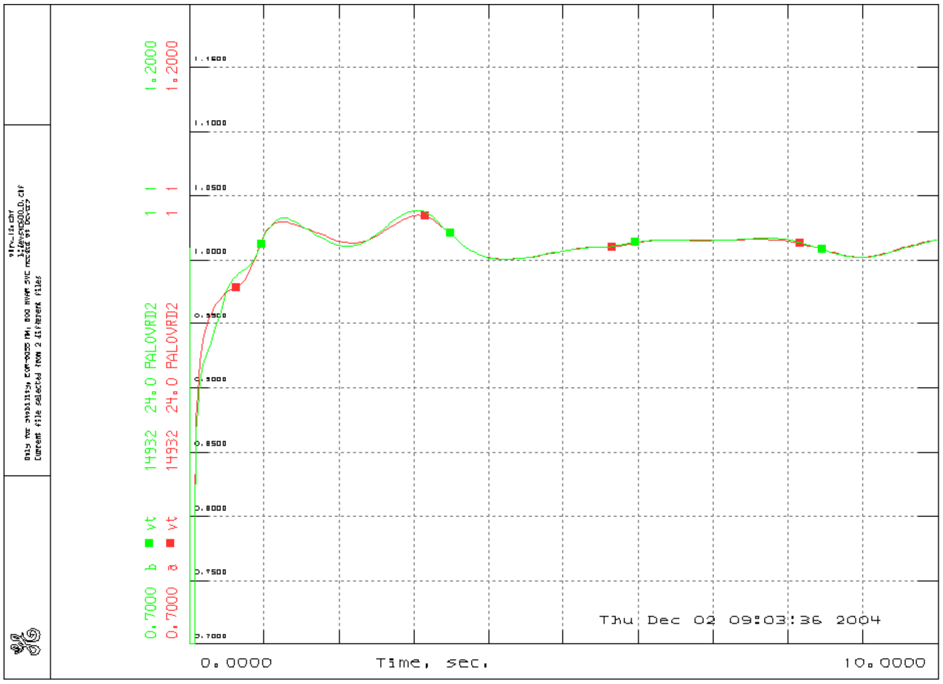
Real and reactive power output from the Palo Verde generator



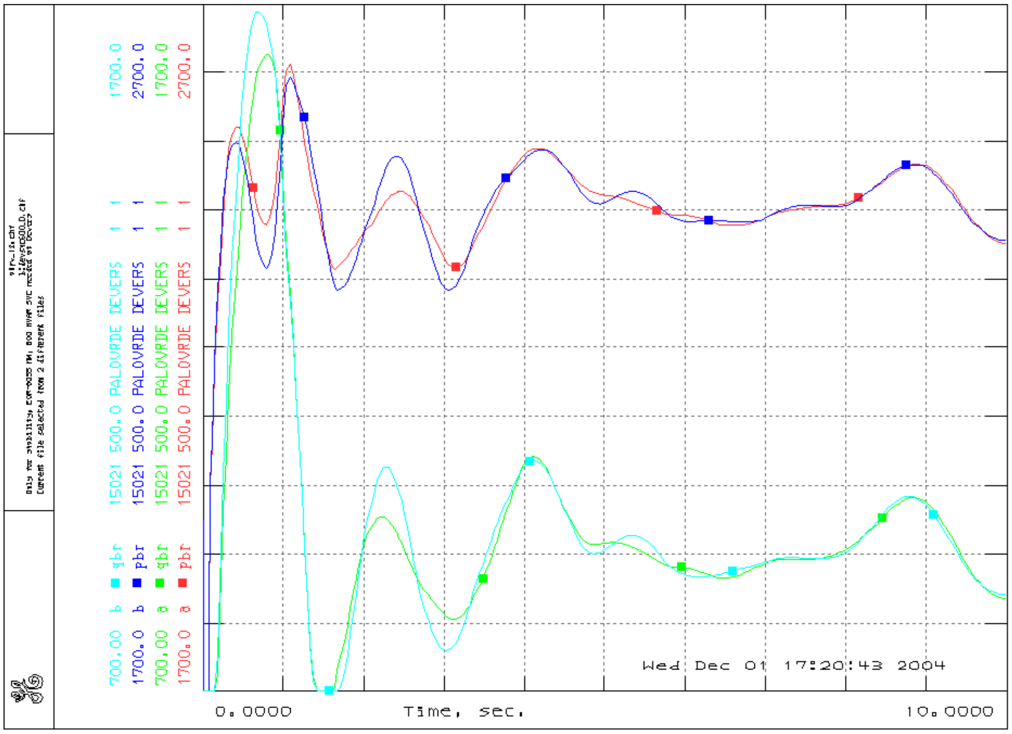
Angle and speed of the Palo Verde generator
a-high inertia, b- low inertia. At the time of the highest voltage dip, the angle of unit # 2 was higher with the higher inertia of this unit.



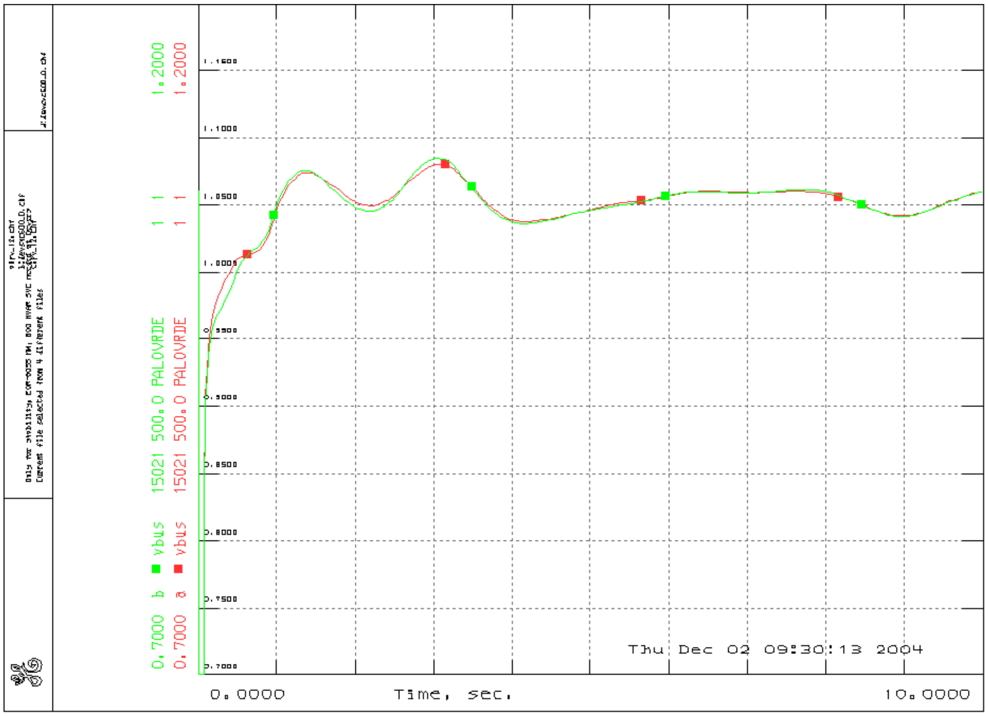
Voltage on the Palo Verde generator.



Real and reactive power flow on the Palo Verde-Devers line. With higher inertia, the real power flow was higher and the reactive power flow was lower.



The current on the Palo Verde-Devers line was the same for both simulations at the time of the highest voltage dip.
The voltage at the Palo Verde 500 kV bus was the same for both cases.



The following table compares the cases with high and low inertia at the time of the highest voltage dip (0.775 sec)

Transmission facility	High PV inertia		Low PV inertia		Voltage magn/angle		
	Real power, MW	Reactive power, MVAR	Real power, MW	Reactive power, MVAR		H=12	H= 3.8
Power plants at Hassayampa	1350	629	1351	590	Hassayampa	510 /82.5	510 /85.4
Hass.-Palo Verde	845	787	965	728	Palo Verde	510 /82.4	510 /85.3
Hass.-Jojoba	505	-159	387	-138	Jojoba	513 /81.2	513 /84.4
Jojoba-Kyrene	650	-66	557	-49	Kyrene	512 /77.1	512 /80.9
PV power plant	4388	969	3810	1106	Devers	405 /27.7	394 /31.1
Palo Verde-Devers (PV end)	**2378**	**1626**	**2314**	**1670**	Westwing	497 /76.8	497 /80.6
Palo Verde-Devers (Dev end)	-2197	+702	-2137	+603	Rudd	519 /79.3	519 /82.6
Palo Verde-Devers loss	181	2328	177	2273			
PV-Westwing + Rudd	2856	132	2460	165			
Total output of PV and Hass. plants	**5738**	**1598**	**5161**	**1696**			
PV east flow	**3506**	**66**	**3017**	**116**			

Conclusions:

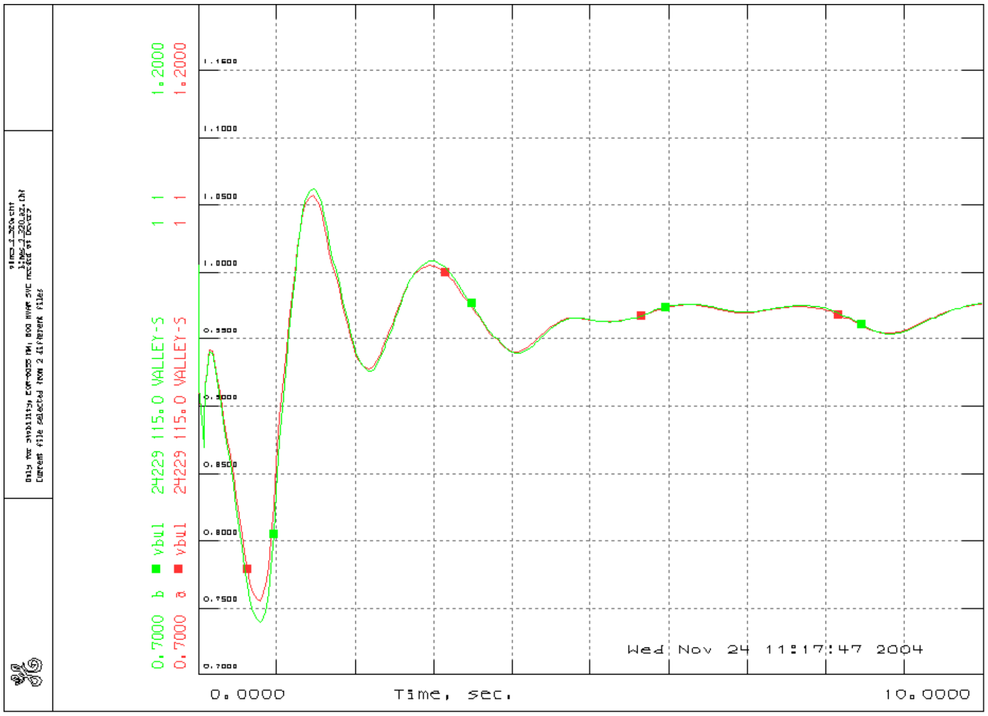
Higher inertia on the machines on the sending end results in a lower voltage dip. At the time of the highest voltage dip, with higher inertia, the generator angle and real power output are higher and the reactive power output is lower. With higher inertia on the sending end, more real power and less reactive power flows on the Palo Verde-Devers line, and the voltage on the receiving end is higher.

6. Study results. Impact of Reactive Reserve from Generators in Arizona

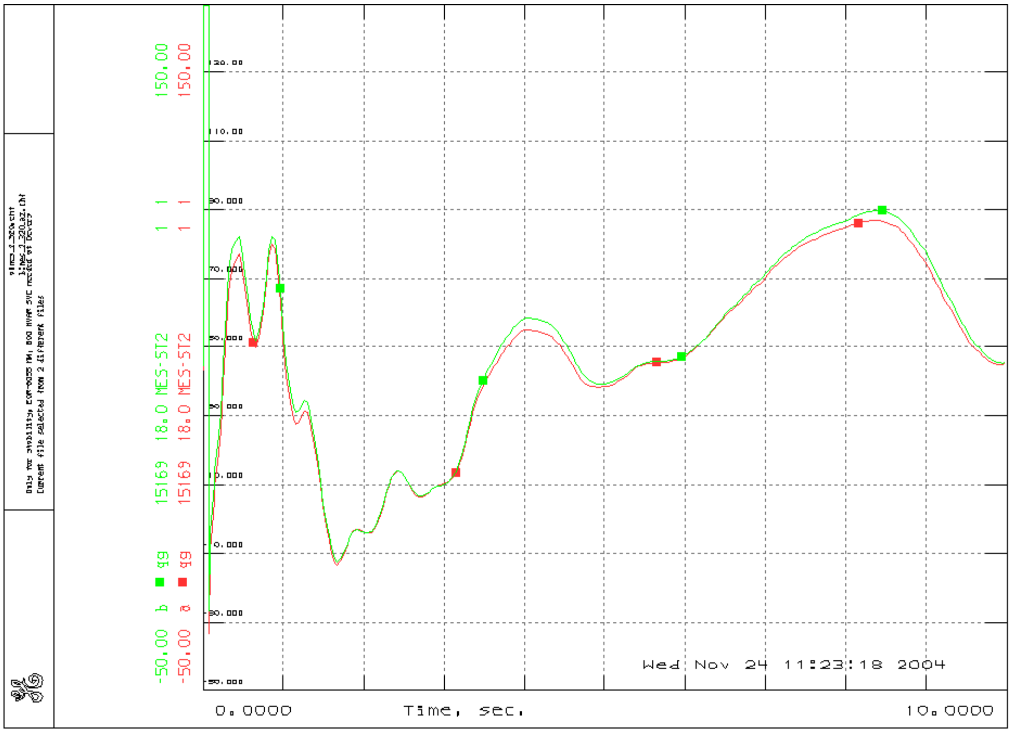
When an increase in the level of real power generation at the Mesquite steam turbine was modeled as being compensated by a decrease in other generation at Hassayampa, the resulting reduction in reactive support from this machine was compensated by increased reactive support from the other machines at Hassayampa. This way, the total reactive support from Hassayampa remained the same. To better separate the impact of inertia and reactive support, another study was performed. The Mesquite steam turbine generation was increased from 100 MW to 320 MW and compensated not at Hassayampa as in the previous studies, but in east Arizona (the generation at each of the Santan units #1-4 was reduced from 80 MW to 25 MW). The Mesquite machine inertia constant was modeled at 2 MWsec/MVA to examine the case with low inertia. The study results were compared with the case with 320 MW Mesquite steam turbine generation compensated by a decrease in generation at Hassayampa and the same inertia constant. It should be noted, that when Mesquite generation was modeled as being replaced at Santan, the Palo Verde West flow increased from 3520 MW to 3527 MW. To bring this flow back to 3520 MW, as in the base case, Santan generation was further reduced (by another 20 MW). The case with higher Mesquite and lower Santan generation had 200 MW higher Palo Verde East flow.

Results with the Mesquite inertia at 2 MWsec/MVA and 320 MW output with different modeling of the Santan generation are provided in the following plots. Curves ‘a’ show the case with increase in Mesquite generation compensated at Hassayampa, curves ‘b’ – compensated at Santan.

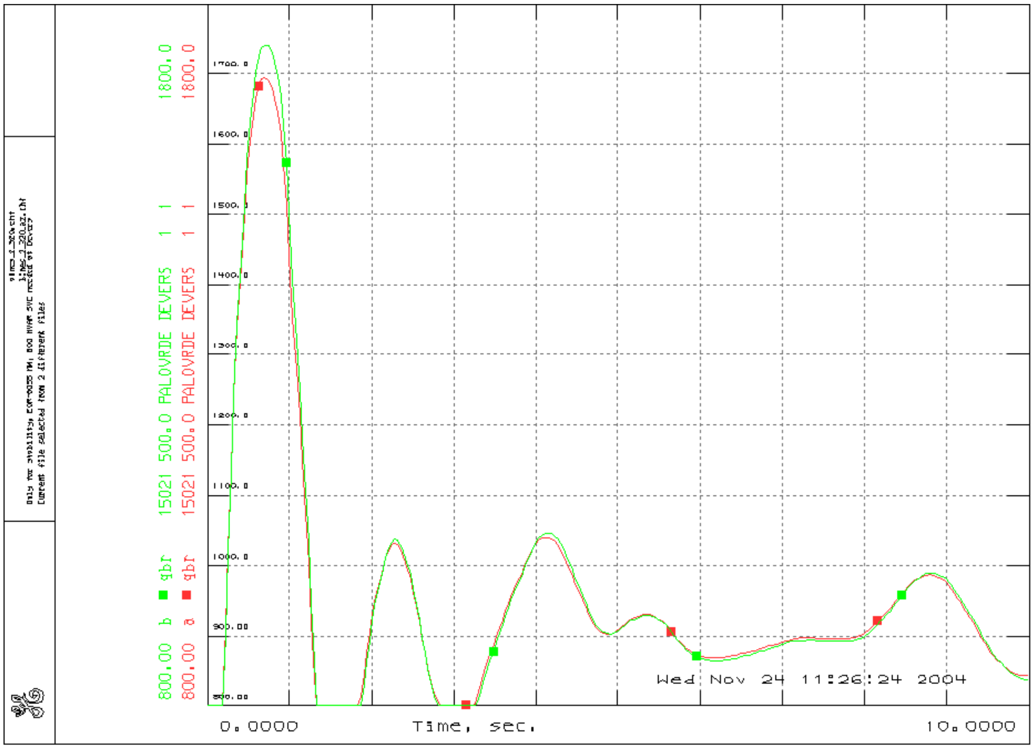
Voltage at Valley, higher dip with compensation at Santan (higher PV east flow)



The reactive output of the Mesquite generator was the same for both cases.



Reactive power flow on Palo Verde-Devers, higher with compensation at Santan



Conclusion:

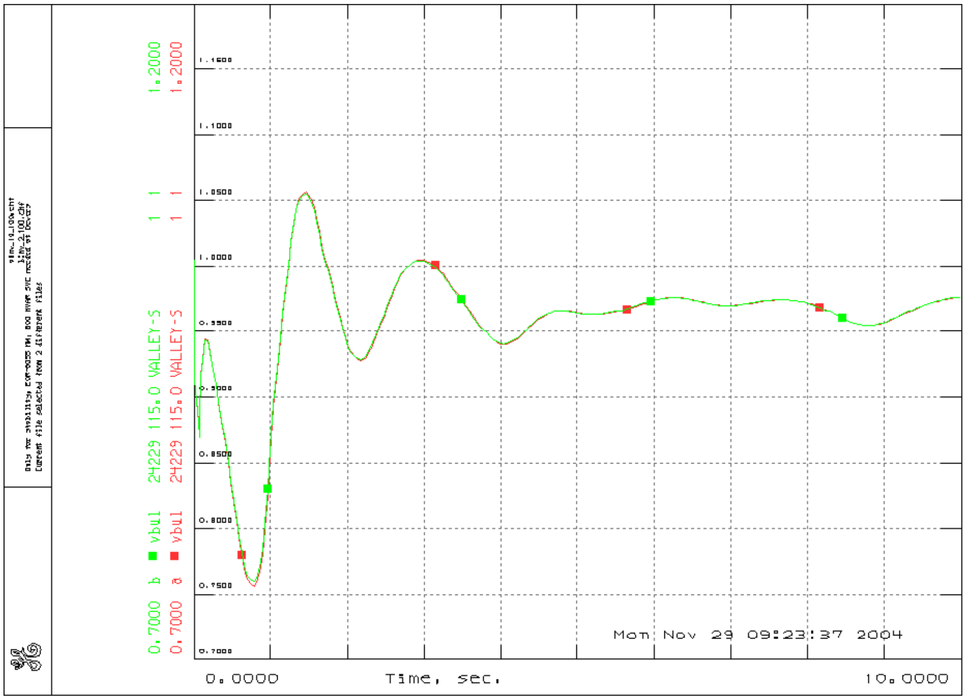
The total reactive reserve from the generation on the sending end may have an impact on dynamic stability performance, however it is not possible to separate the impact of the reactive reserve and the Palo Verde West and Palo Verde East flows. With a constant number of generating units on-line at Palo Verde and Hassayampa, the higher the Palo Verde West and Palo Verde East flows, the lower the reactive reserve.

7. Study results. Impact of the Machine Inertia and Reactive Support on the Receiving End

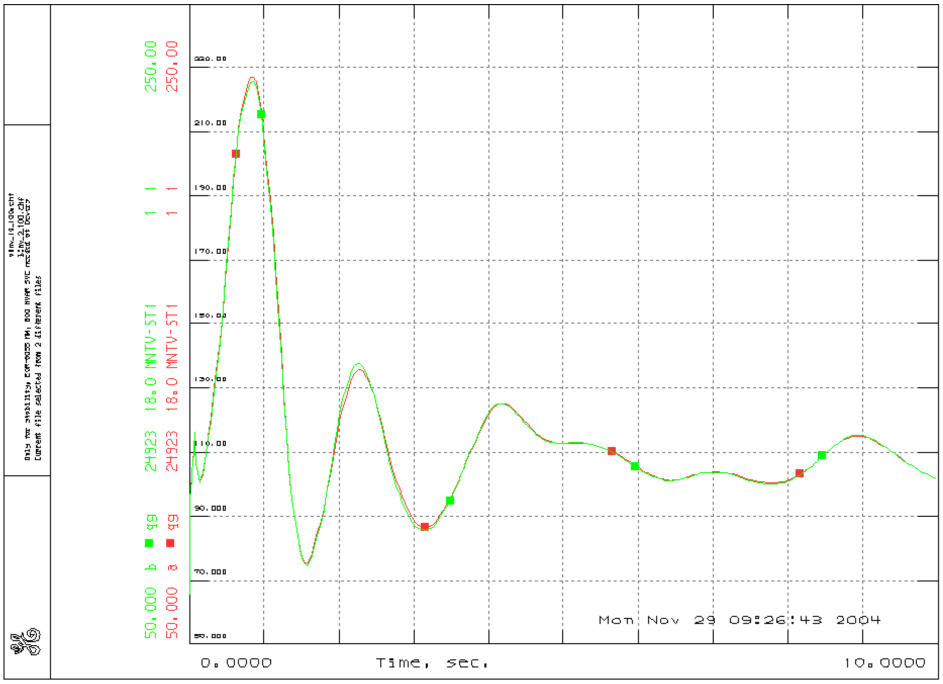
Dynamic simulations of the Hassayampa-North Gila outage were performed using different inertia constants for Mountain View generation. In the base case the steam unit inertia constant was 3.65 MWsec/MVA, and the output was 100 MW. In the test runs, the inertia of the Mountain View steam unit was modeled at 10 MWsec/MVA and at 2 MWsec/MVA.

On the following plots, curve ‘a’ – H = 10, curve ‘b’ – H = 2.

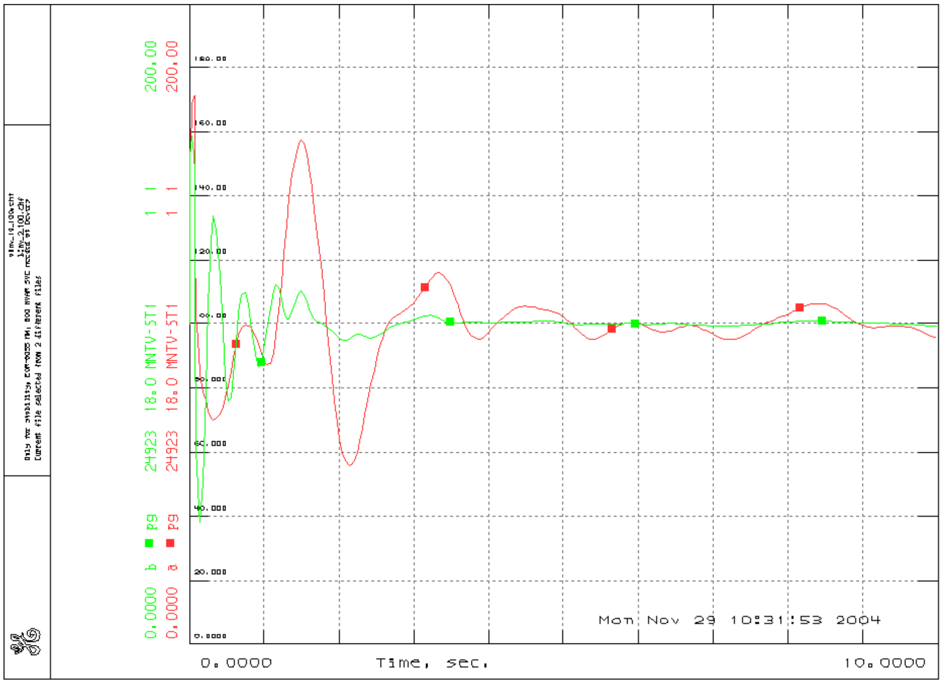
The Valley 115 kV bus voltage was not impacted by the changes in inertia.



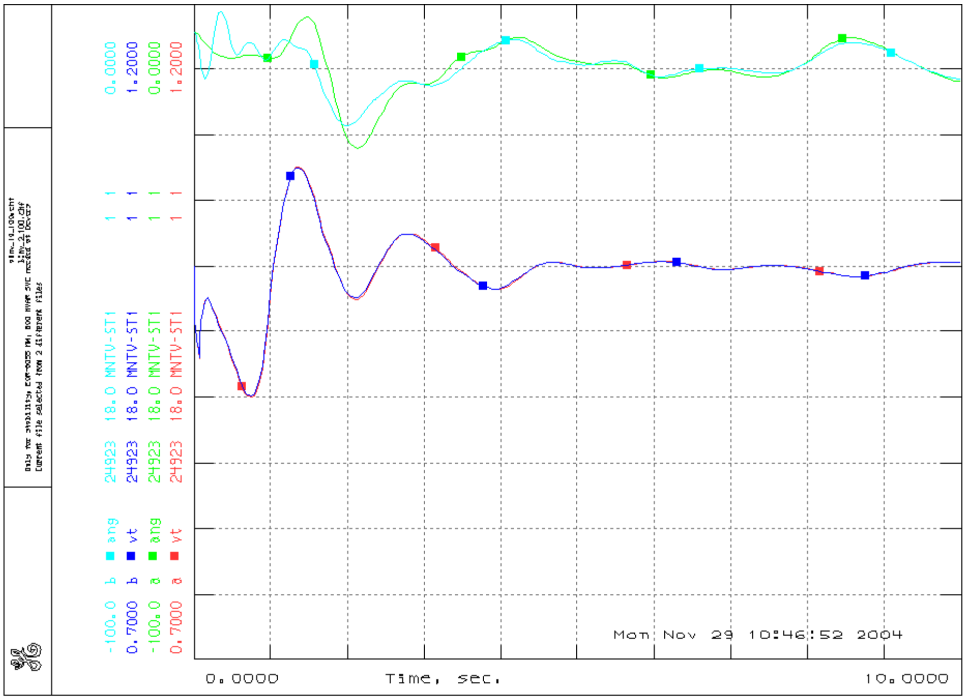
The reactive output of the Mountain View steam generator was not impacted by the change in inertia.



At the time of highest voltage dip, the real power output from the Mountain View steam generator was higher with lower inertia.



The voltage at the Mountain View steam generator was not impacted by the change in inertia. At the time of the highest voltage dip, the generator angle was higher with lower inertia.

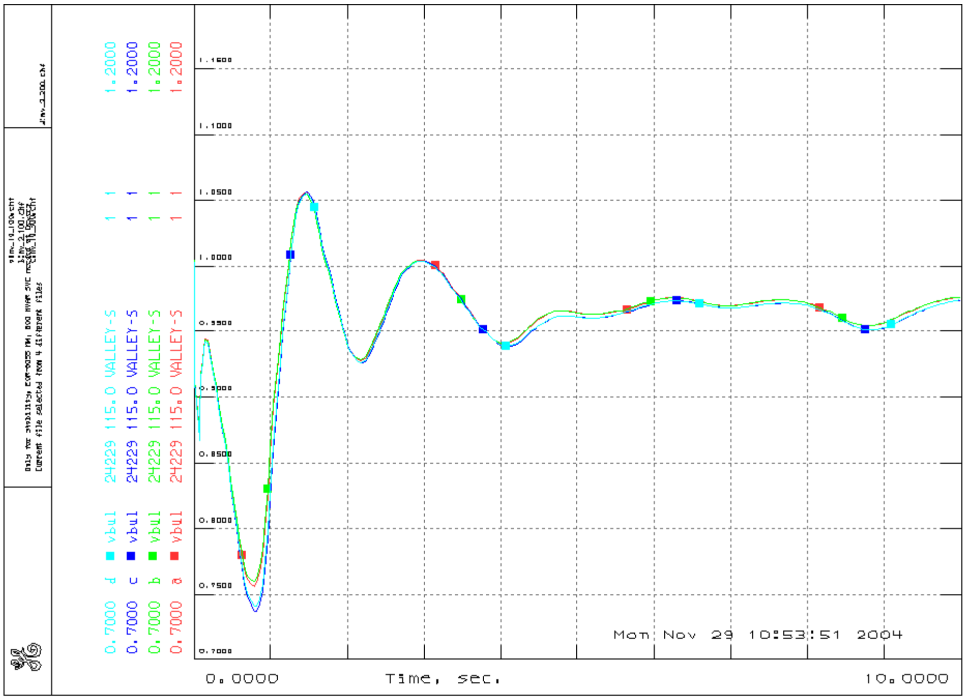


The impact of the real power reserve on the sending end was studied by modeling the Mountain View steam turbine generating 300 MW compared with 100 MW in the base case. Additional generation at Mountain View was modeled by reducing generation at Alamitos.

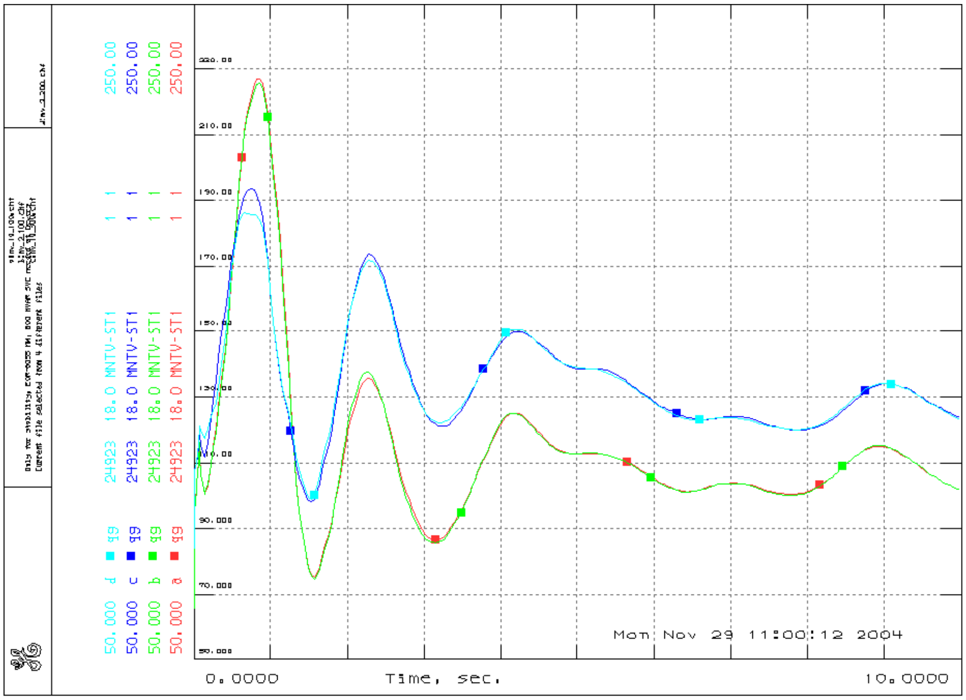
On the following plots,

Curve ‘a’	Mountain View inertia constant 10, output 100 MW
Curve ‘b’	Mountain View inertia constant 2, output 100 MW
Curve ‘c’	Mountain View inertia constant 10, output 300 MW
Curve ‘d’	Mountain View inertia constant 2, output 300 MW

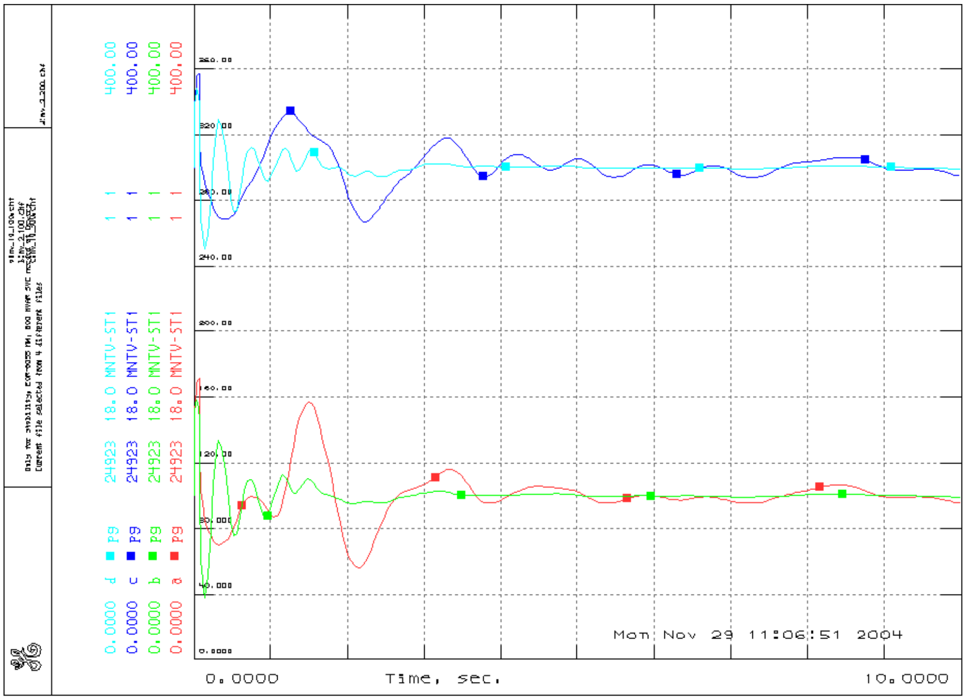
The Valley 115 kV bus voltage was not impacted by the change in inertia. With lower real power output from the Mountain View generator, the voltage dip was lower.



Reactive power output from Mountain View
a- H=10, P=100, b- H= 2, P=100, c- H=10, P=300, d- H=2, P=300
With lower real power output, it was no inertia impact. With high real power output, it was less reactive output with low inertia at the time of the highest voltage dip. With lower real power output, reactive power output was higher regardless of machine inertia.



Real power output from Mountain View
a- H=10, P=100, b- H= 2, P=100, c- H=10, P=300, d- H=2, P=300



At the time of the largest voltage dip, the simulation with higher real power output from Mountain View increased the transient voltage dip. The cases with different inertias did not change the voltage dip.

The following table compares the base case and the case with the Mountain View generation increased 200 MW and compensated at Alamitos. Alamitos and West Phoenix generation was adjusted so that North SCIT, Palo Verde West and Palo Verde East flows were the same.

Case	Base case t=0	Higher Mnt View gen t=0
Palo Verde West, MW	**3520**	**3520**
Palo Verde West, MVAR	693	698
North SCIT, MW	**11932**	**11932**
North SCIT, MVAR	320	375
Palo Verde East, MW	**2218**	**2218**
Palo Verde East, MVAR	-13	-10
MVAR from SCE gen	2277	2359
MVAR from NV gen	750	763
Voltage on Devers	510	509
Voltage on Vincent	527	526

Case	Base case t=0	Higher Mnt View gen t=0
Highest vlt dip	Valley 115	Valley 115
% vlt dip	24.5%	26.7%

At the time of the highest voltage dip (0.775 sec)

Transmission facility	Base case		Higher Mtn View gen		Voltage magn/ang		
	Real power, MW	Reactive power, MVAR	Real power, MW	Reactive power, MVAR		base	Hi Mt Vw
Power plants at Hassayampa	1351	590	1330	608	Hassayampa	510 /85.4	510 /87.4
Hass.-PaloVerde	965	728	930	750	Palo Verde	510 /85.3	510 /87.3
Hass.-Jojoba	387	-138	400	-143	Jojoba	512 /84.4	513 /86.3
Jojoba-Kyrene	557	-49	567	-52	Kyrene	512 /80.9	513 /82.8
PV power plant	3810	1106	3785	1130	Devers	394 /31.1	384 /33.2
Paloverde-Devers	**2314**	**1670**	**2257**	**1705**	Westwing	497 /80.6	496 /82.6
PV-Westwing+Rudd	2460	165	2458	177	Rudd	519 /82.6	519 /84.5
Total output of PV and Hass. plants	**5161**	**1696**	**5115**	**1738**			
PV east flow	**3017**	**116**	**3025**	**125**			

Conclusions

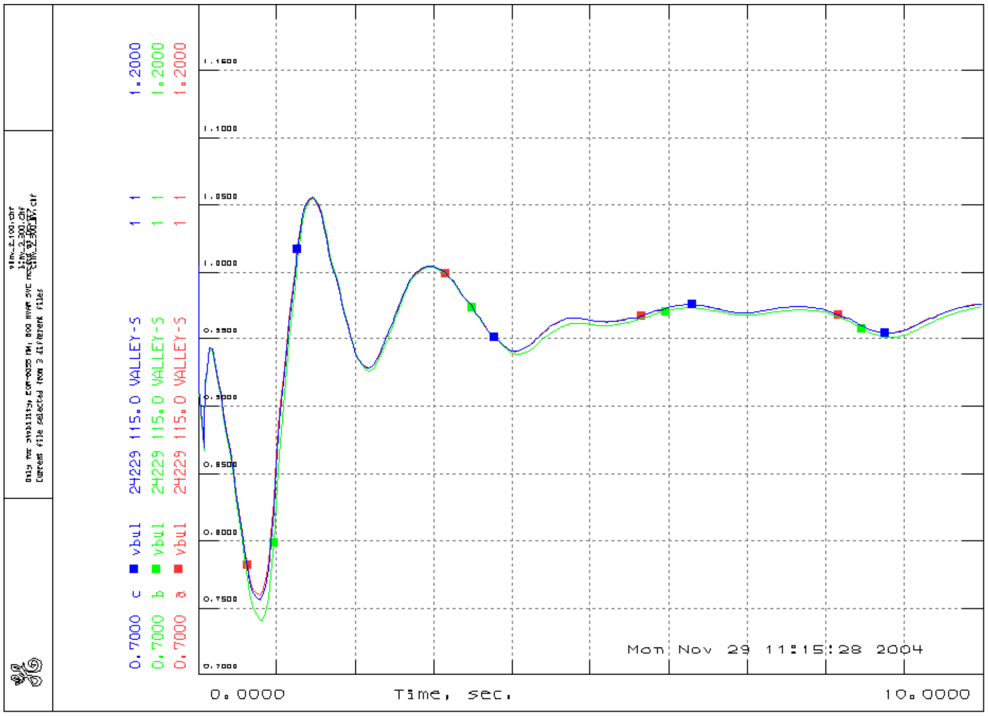
Inertia on the receiving end does not impact the voltage dip. The voltage dip was higher with higher Mountain View generation (with the same number of units on-line) due to lower reactive output and thus, lower voltage on the Mountain View bus.

However, in this test, the increase in the Mountain View generation was replaced by a decrease in generation at Alamitos, which changed flows and voltages in SCE. This change may impact the results.

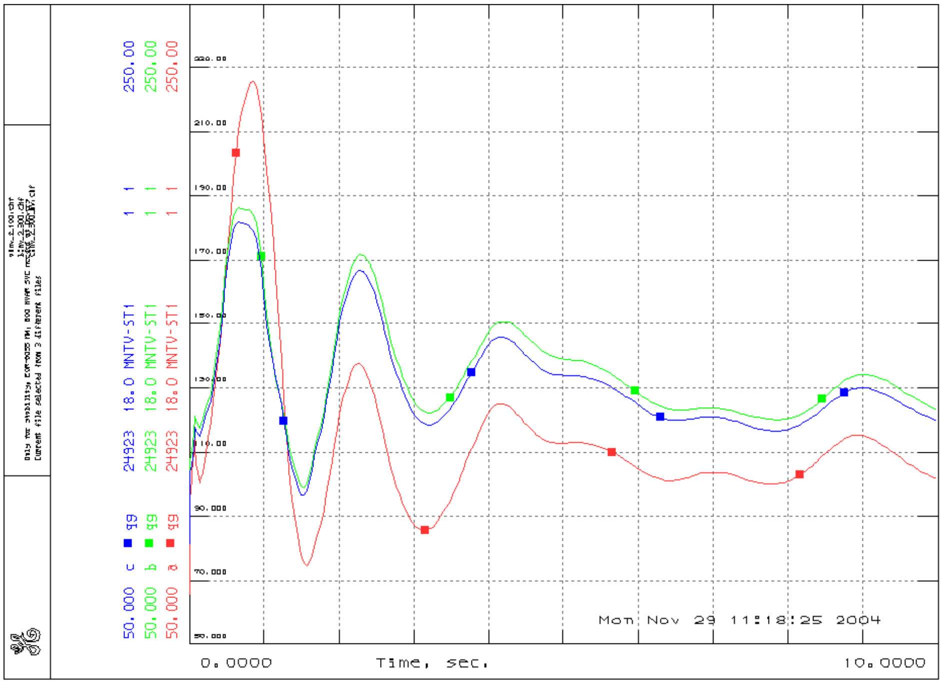
The following plots compare cases with the Mountain View steam generator output increased from 100 MW in the base case to 300 MW in the test case. This increase in generation was compensated at Alamitos in one case and at the other Mountain View units in another case. The inertia constant was modeled at 2 MWsec/MVA.

Curve ‘a’- Mountain View at 100 MW, curve ‘b’- 300 MW compensated at Alamitos, curve ‘c’- 300 MW replaced at other Mountain View units.

The voltage dip was unchanged when an increase in generation from the Mountain View steam turbine generator (100 MW to 300 MW) was replaced by generation from other Mountain View units. The voltage dip was increased when the increase in Mountain View generation was compensated by a decrease in Alamitos generation.

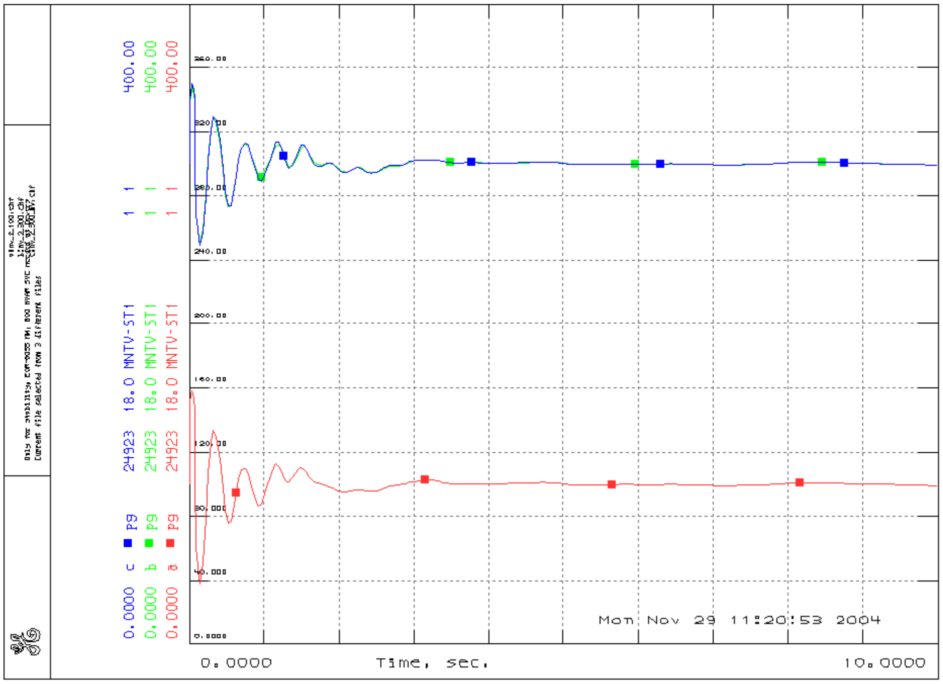


Reactive output from Mountain View steam generator
a-Mountain View at 100 MW, b- 300 MW replaced at Alamitos, c- 300 MW replaced at other Mountain View units.

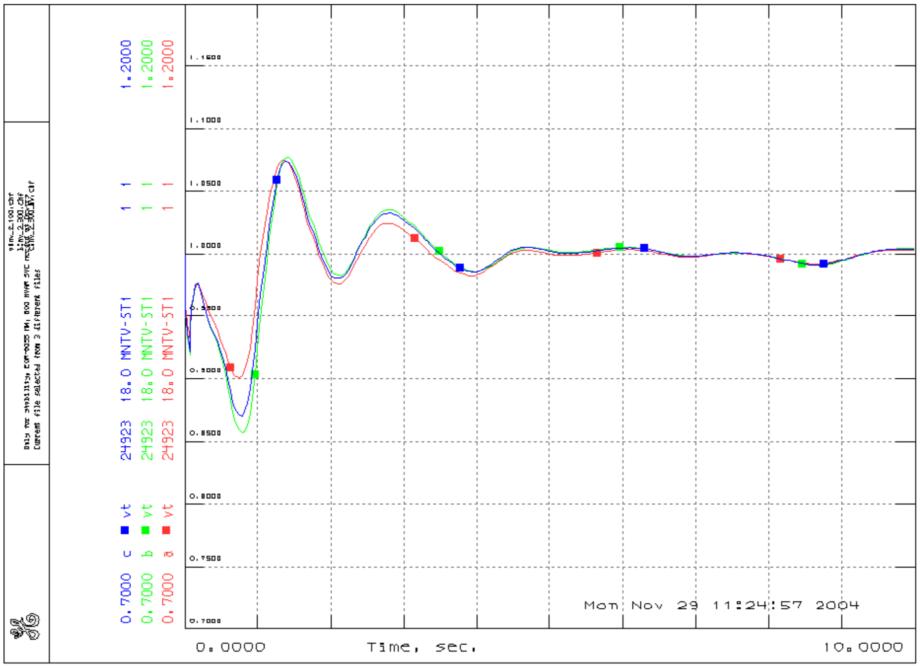


With lower real power output of the generator, the reactive output was higher. Reactive output was slightly lower when an increase in the steam turbine generation was compensated by a decrease in output at the other Mountain View units.

Real power output from Mountain View

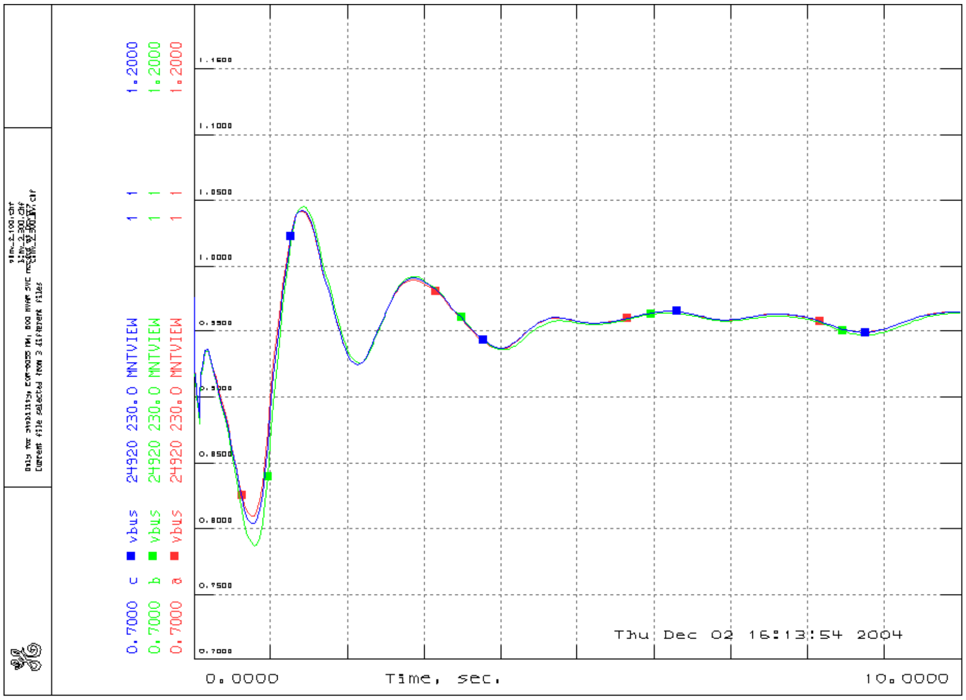


Voltage at Mountain View steam generator. ‘a’-output at 100 MW, ‘b’- 300 MW replaced at Alamitos, ‘c’- 300 MW replaced at other Mountain View units.



On the generator terminals, the transient voltage was higher for lower real power output. The voltage was lower when the increase in the Mountain View generation was compensated at Alamitos.

The next plot shows the voltage at the Mountain View 230 kV bus. When the increase in Mountain View generation was compensated at Alamitos, transient voltage was lower due to lower reactive reserve at Mountain View



With an increase in Mountain View steam generator output that was compensated by a decrease in output from other Mountain View units, the reactive reserve from total Mountain View was approximately the same and the voltage dip was the same. When the increase in the Mountain View generation was compensated by decrease of the generation at Alamitos, the Mountain View plant did not have sufficient reactive power reserve to hold the voltage at the same level as with the lower real power output. Therefore, the voltage dip was worse even if the Palo Verde West flow was slightly lower (3514 MW versus 3520 MW in the base case).

Conclusion

Reactive support from the receiving end has an impact on the voltage dip, but inertia does not. Reactive power reserve from the generators on the receiving end also has impact on the voltage dip. The system dynamic stability performance is very sensitive to the location of the reactive support.

8. Study results. Impact of the Southern California Load

Power flow cases for this study were developed starting with high SCE load. Change in load was compensated by generation in PG&E and the Northwest (Coulee and Pittsburg). Hassayampa generation was adjusted to maintain the same Palo Verde West flow. The amount of generation units in Arizona and Southern California was held the same in all the cases to eliminate the impact of inertia. In the base case SCE load was 16417 MW and – 815 (negative) MVAR. Palo Verde West flow was 3520 MW and 693 MVAR, Palo Verde East flow was 2218 MW and –13 (negative) MVAR, North SCIT 11932 MW and 320 MVAR. The highest voltage dip was at the Valley 115 kV bus - 24.5%. Mechanically switched capacitors and static VAR devices (SVD) in SCE were modeled as automatically regulating voltage, so in the cases with higher load there was more reactive support from these devices than in the cases with lower load.

The results of this study are summarized in the following tables.

SCE load/Flows	18059-j897	17517-j870	16991-j844	16481-j819	15905-j790
Palo Verde West, MW	3520	3520	3520	3520	3520
P. Verde West, MVAR	856	837	818	789	818
North SCIT, MW	13566	13023	12499	11993	11433
North SCIT, MVAR	602	489	414	202	182
Palo Verde East, MW	2045	2104	2162	2250	2368
P. Verde East, MVAR	18	11	7	-16	-35
Voltage on Devers	489	491	492	493	494
Voltage on Vincent	520	523	525	527	529
Highest vlt dip	Padua 66	Valley115	Valley 115	Valley 115	Valley 115
% vlt dip	35.1	30.6	28.0	25.5	26.9

SCE load/Flows	15348-j762	Same w/out Diablo1, hi Pts&Coule	14811-j736	14292-j710	13792-j685
Palo Verde West, MW	3520	3520	3520	3520	3520
P Verde West, MVAR	791	791	800	783	775
North SCIT, MW	10893	10893	10378	9881	9407
North SCIT, MVAR	144	180	300	267	248
Palo Verde East, MW	2493	2431	2548	2626	2730
P Verde East, MVAR	-59	-48	-62	-81	-90
Voltage on Devers	497	497	496	498	499
Voltage on Vincent	531	535	534	534	532
Highest vlt dip	Valley 115	Valley 115	Valley 115	Valley 115	Valley 115
% vlt dip	26.0	25.5	26.8	26.8	27.1

As can be seen from the tables, there was less transient voltage dip with higher Southern California load. However, after a certain load level was reached, the voltage dip started to increase with a decrease in load. This inconsistency can be explained by the fact that flows on the other major paths (Palo Verde East and North SCIT) were not held constant; therefore, there were other factors that impacted the voltage dip. With the decrease in load and the Palo Verde West flow held constant, the Palo Verde East flow increased and the North SCIT flow decreased, since no other generation or load, except for the generation at Hassayampa was changed.

This test was performed for the case with the phase shifters at Perkins and Liberty in operation. The same test, but with these phase shifters bypassed showed similar results, even if the Palo Verde West flows were higher and the Palo Verde East flows lower. These results are summarized in the following table.

SCE load/Flows	18059-j897	17517-j870	16991-j844	16481-j819	15905-j790	15348-j762
P. Verde West, MW	3663	3663	3663	3663	3663	3663
P.VerdeWest, MVAR	952	946	935	899	937	912
North SCIT, MW	13437	12896	12373	11867	11310	10769
North SCIT, MVAR	458	399	335	131	242	115
P. Verde East, MW	1860	1950	2030	2163	2337	2481
P Verde East, MVAR	-182	-181	-179	-203	-214	-232
Voltage on Devers	487	488	489	493	490	492
Voltage on Vincent	520	523	525	530	530	532
Highest vlt dip	Valley115	Valley115	Valley 115	Valley 115	Valley 115	Valley 115
% vlt dip	28.4	27.7	26.6	24.6	27.6	27.2

The same test was repeated with both Palo Verde West and Palo Verde East flows held constant by adjusting generation at Hassayampa (a small decrease) and load in Arizona and Nevada (decreased with decrease in load). The SCE load decrease was modeled as being compensated by a decrease in Coulee and Pittsburg generation. The results are provided in the following tables.

SCE load/Flows	18059-j897	17517-j870	16991-j844	16481-j819	15905-j790
Palo Verde West, MW	3520	3520	3520	3520	3520
P. Verde West, MVAR	856	842	824	839	811
North SCIT, MW	13566	13020	12494	11992	11420
North SCIT, MVAR	602	495	401	390	239
Palo Verde East, MW	2045	2045	2045	2045	2045
P. Verde East, MVAR	18	3	-17	-48	-103
Voltage on Devers	489	491	493	494	495

SCE load/Flows	18059-j897	17517-j870	16991-j844	16481-j819	15905-j790
Voltage on Vincent	520	523	526	528	531
Highest vlt dip	Padua 66	Valley 115	Valley 115	Valley 115	Valley 115
% vlt dip	35.1	29.3	26.4	26.4	23.6

SCE load/Flows	15348-j762	Same w/out	14811-j736	14292-j710	13792-j685
Palo Verde West, MW	3520	3520	3520	3520	3520
P. Verde West, MVAR	815	800	837	827	819
North SCIT, MW	10880	10879	10366	9869	9393
North SCIT, MVAR	229	253	352	369	356
Palo Verde East, MW	2045	2045	2045	2045	2045
P. Verde East, MVAR	-142	-133	-148	-172	-203
Voltage on Devers	494	496	492	493	494
Voltage on Vincent	530	535	532	531	530
Highest vlt dip	Valley 115	Dome tap 161	Valley 115	Valley 115	Valley 115
% vlt dip	23.4	22.9	23.9	23.3	23.0

As can be seen from the tables, the voltage dip decreases with a decrease in Southern California load if the flows on the Palo Verde West and Palo Verde East paths are held constant. It should be noted that in this test, the Palo Verde West and Palo Verde East flows were held constant by adjusting load in Arizona and Nevada. The same test was performed, but instead of decreasing Arizona and Nevada load with a decrease in the Southern California load, the Palo Verde flows were held constant by adjusting (increasing) generation at Harry Allen. Additional generation was modeled in the starting case (six Duke units and four Calpine units) to allow for higher range of the change in load.
The results are summarized in the following tables.

SCE load/Flows	18059-j897	17517-j870	16991-j844	16481-j819	15905-j790
Palo Verde West, MW	3520	3520	3520	3520	3520
P.Verde West, MVAR	857	849	843	856	856
North SCIT, MW	13566	13024	12508	12020	11476
North SCIT, MVAR	602	645	760	937	1151
Palo Verde East, MW	2045	2045	2045	2045	2045
P. Verde East, MVAR	15	17	10	19	24
Voltage on Devers	489	490	491	490	490
Voltage on Vincent	520	524	525	523	520
Highest vlt dip	Dome tap161	Dome tap 161	Dome tap 161	Valley 115	Wlmt 138

SCE load/Flows	18059-j897	17517-j870	16991-j844	16481-j819	15905-j790
% vlt dip	22.4	22.7	23.4	27.3	49.2

SCE load/Flows	15348-j762	Same w/out Diablo1, hi Pts&Coulee
Palo Verde West, MW	3520	3520
P. Verde West, MVAR	864	837
North SCIT, MW	10962	10955
North SCIT, MVAR	1326	1315
Palo Verde East, MW	2045	2045
P. Verde East, MVAR	32	27
Voltage on Devers	489	492
Voltage on Vincent	515	523
Highest vlt dip	unstable	unstable
% vlt dip		

As can be seen from the tables, in this case, the result was the opposite. With a decrease in the Southern California load and the Palo Verde West and East flows held constant, the voltage dip increased with a decrease in load when the flows were held constant by increasing Nevada generation.

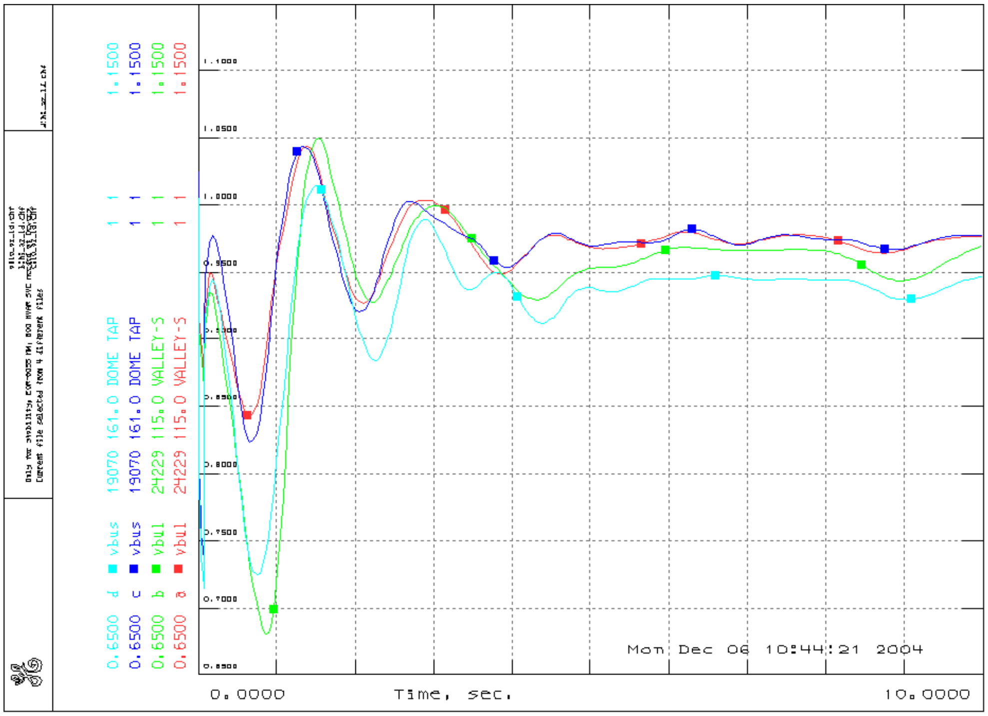
The next test confirmed that the system dynamic stability performance could be different even when the amount of generation units on-line and major path flows were the same. In addition to the base case, three cases with the same Palo Verde West, Palo Verde East and North SCIT flows were studied. SCE load was modeled the same as in the base case: 16417 MW and -815 MVAR. The first sensitivity case had 10% lower load in Arizona compensated by a decrease in generation at Glen Canyon, Alamitos and Hassayampa to hold the flows constant. The second case also had 10% lower Arizona load, but in this case, the decrease in load was compensated by a decrease in generation in Nevada and Phoenix, as well as at Hassayampa and Alamitos. The third case had 9% higher load in Arizona than in the base case, and this increase in load was compensated by an increase in generation in Phoenix, Glen Canyon, at Hassayampa and Alamitos.

The following table compares the results of this study for the case with the Perkins and Liberty phase shifters in operation.

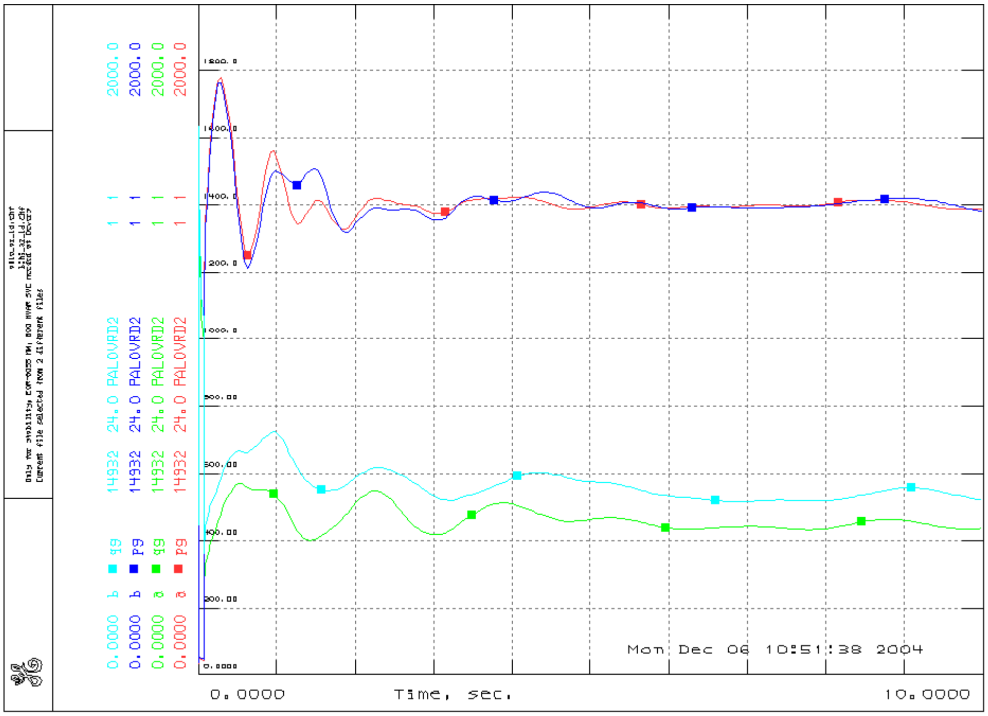
Case	Base case	Lower AZ load (10%), Glencyn gen, adj. Hass and Alam gen	Lower AZ load (10%), NV and Phx gen, adj. Hass and Alam gen	Hi AZ load (9%), Glencyn, Phx gen, adj Hass and Alam
Palo Verde West, MW	**3520**	**3520**	**3520**	**3520**
Palo Verde West, MVAR	693	772	727	729
North SCIT, MW	**11932**	**11932**	**11932**	**11932**
North SCIT, MVAR	320	277	-251	479
Palo Verde East, MW	**2218**	**2218**	**2218**	**2218**
Palo Verde East, MVAR	-13	-252	-122	136
Voltage on Devers	510	500	505	506
Voltage on Vincent	527	527	530	525
Highest vlt dip	Valley 115	Dometap 161	Dometap 161	Valley 115
% vlt dip	24.5%	22.9%	19.6%	31.8%
Volt dip on Valley 115	24.5%	21.5%	<20%	31.8%

The last two cases are illustrated on the following plots. These were the cases with the lowest and with the highest voltage dip.

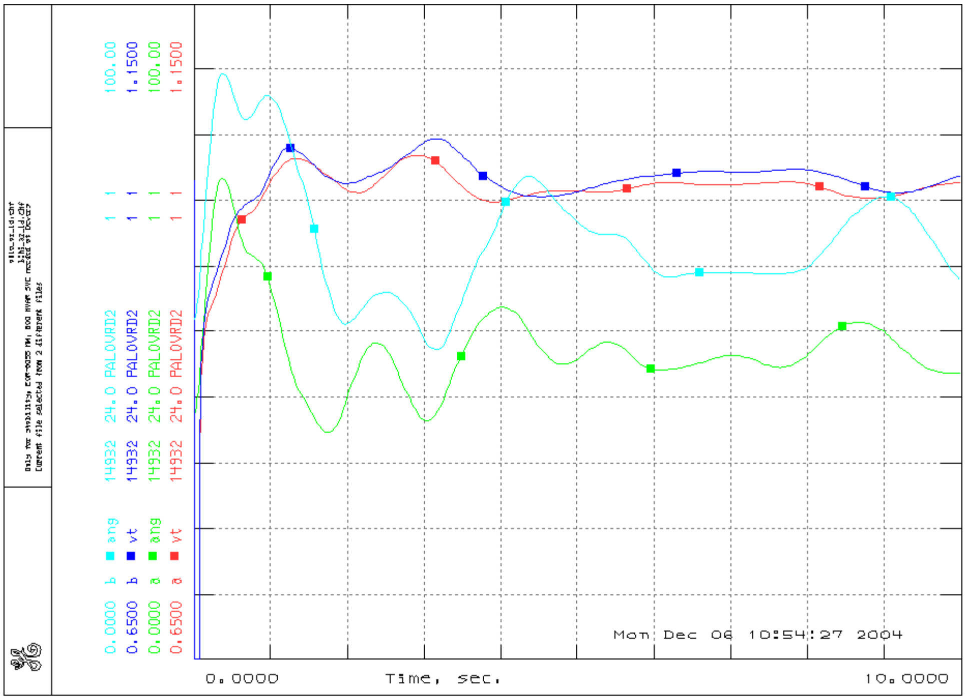
Voltage on the Valley 115 kV and Dometap 161 kV buses
Curves, ‘a’ and ‘c’ – low Arizona load, ‘b’ and ‘d’ – high Arizona load



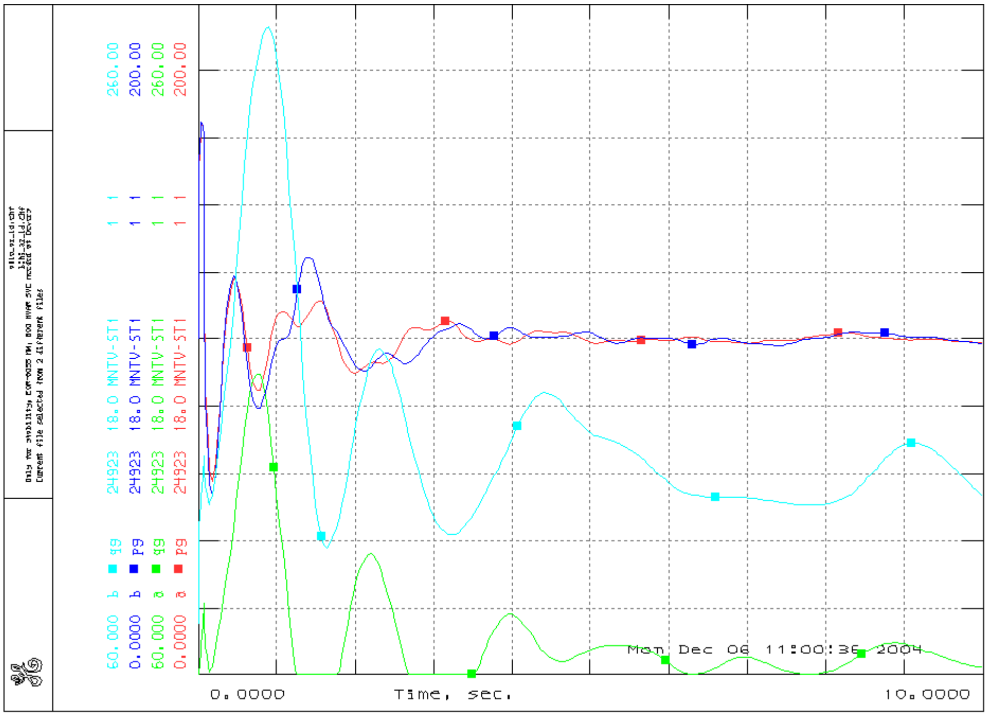
Real and reactive power output from the Palo Verde generator # 2
Curves ‘a’ - low Arizona load, ‘b’ – high Arizona load



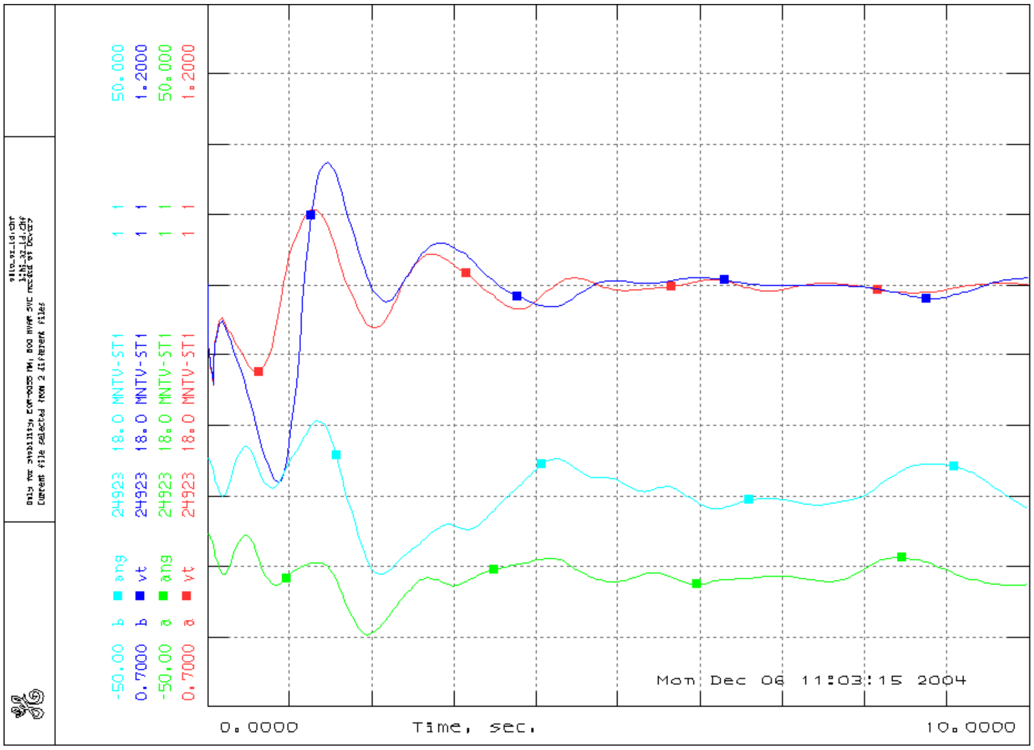
Voltage and angle of the Palo Verde generator



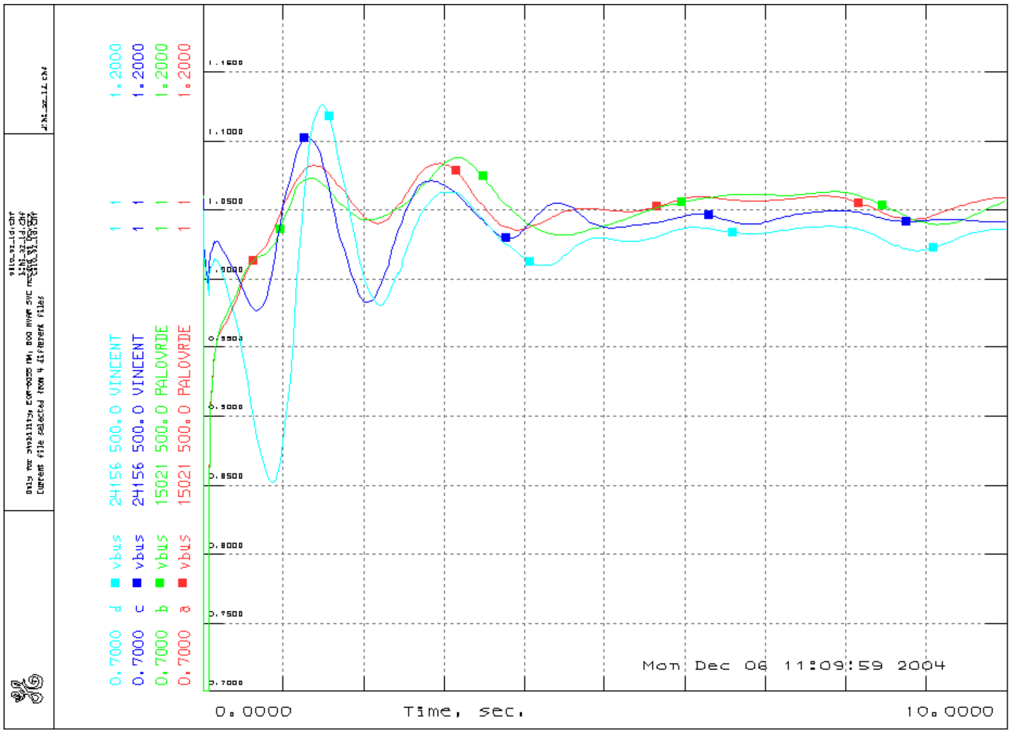
Real and reactive power output from the Mountain View generator
Curves ‘a’ - low Arizona load, ‘b’ – high Arizona load



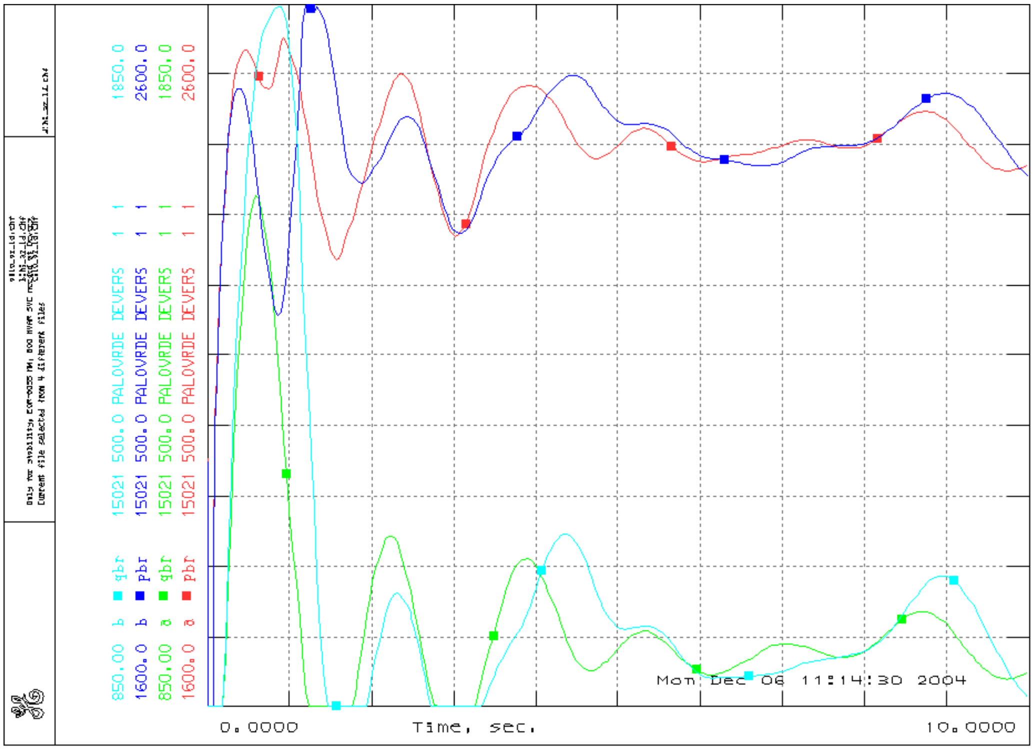
Voltage and angle of the Mountain View generator



Voltage on the Palo Verde and Vincent 500 kV buses
Curves, ‘a’ and ‘c’ – low Arizona load, ‘b’ and ‘d’ – high Arizona load



Real and reactive flow on the Palo Verde-Devers line, ‘a’ –low AZ load, ‘b’- high load



Results of the same test, but for the case with the Perkins and Liberty phase shifters bypassed are in the following table.

Case	Base case	Lower AZ load (10%), Glencyn gen, adj. Hass and Alam gen	Lower AZ load (10%), NV and Phx gen, adj. Hass and Alam gen	Hi AZ load (9%), Glencyn, Est AZ gen, adj Hass and Alamt
Palo Verde West, MW	**3663**	**3663**	**3663**	**3663**
Palo Verde West, MVAR	793	792	857	791
North SCIT, MW	**11806**	**11806**	**11806**	**11806**
North SCIT, MVAR	242	206	179	264
Palo Verde East, MW	**2107**	**2107**	**2107**	**2107**
Palo Verde East, MVAR	-199	-419	-248	-3
Voltage on Devers	507	507	499	507
Voltage on Vincent	527	528	528	527
Highest vlt dip	Domtap161	Dometap 161	Dometap 161	Valley 115
% vlt dip	24.2%	22.9%	23.4%	25.5%
Volt dip on Valley 115	22.6%	20.2%	21.6%	25.5%

As can be seen from the study results, machine inertia on the sending end and flows on the major paths are not the only factors that impact the system dynamic stability performance. The voltage dip may be different with the same Palo Verde East, Palo Verde West and North SCIT flows and the same amount of units on-line when the generation dispatch and load levels in Southern California, Arizona and Nevada are different. It appeared that the voltage dip was worse when the system has lower reactive reserves (higher load and higher generation). As the comparison tables show, the voltage dip was higher when the reactive power flow into Southern California from the north was higher. Although in the cases with and without the Perkins and Liberty phase shifters in operation, flows were different, the impact of the factors studied on the dynamic stability performance was the same.

Conclusion:

Dynamic stability performance with the Hassayampa-North Gila outage depends more on the North SCIT reactive power flow than it does on the North SCIT real power flow. Additional reactive power flow into Southern California indicates lower reactive power reserve in Southern California. Therefore, the transient voltage dip was higher with higher reactive power flow into Southern California.

9. Study Results. Impact of On-line Generation Units in Southern California and Nevada

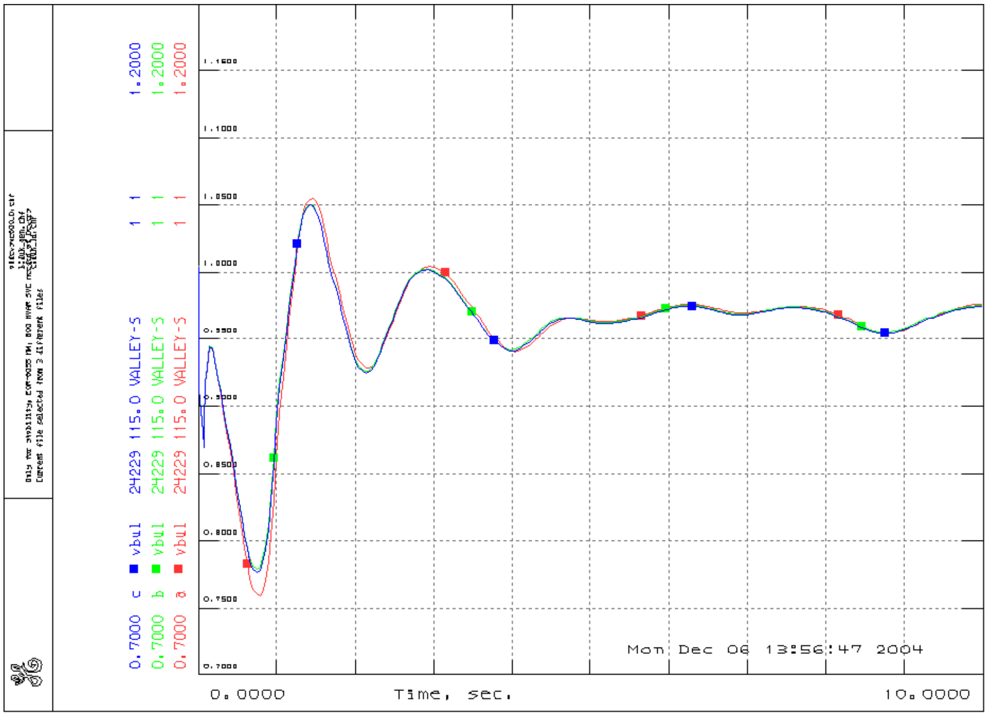
To investigate the impact of on-line generation units, the base case was compared with the case without three Mountain View generation units (base case generation from these units was 400 MW). The decrease in generation from Mountain View was compensated either by increasing generation from other Southern California units (Alamitos, Huntington Beach) or by decreasing load. To hold Palo Verde West and Palo Verde East flows constant, generation was adjusted at the West Phoenix and Arlington power plants. The same test was performed with the addition of three Duke units at Harry Allen. Generation from these units was compensated either by decreasing generation or increasing load in Nevada.

The results of these studies are summarized in the following table.

As can be seen from the table, the results were different depending on the amount of generation units on-line. It appeared that not only reactive support from Mountain View improved the system dynamic stability performance, but also reactive support from the Harry Allen plants. The voltage dip was also slightly different depending on whether the change in generation was modeled as compensated by the change in load or by the change in other generation.

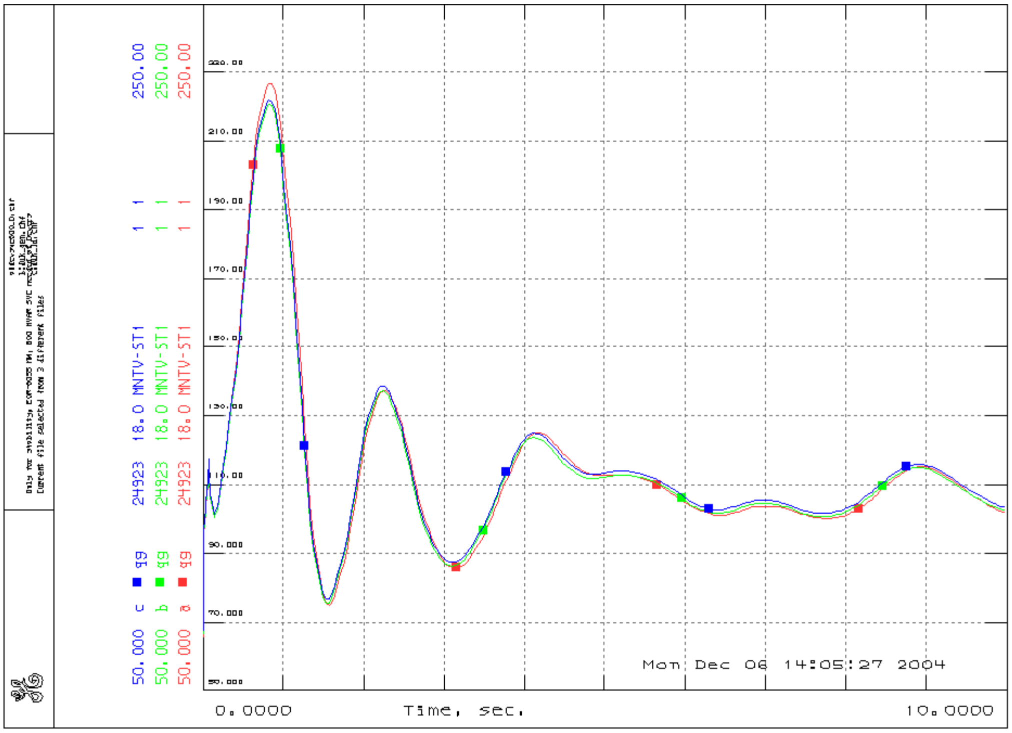
Case/Flows	Base case	Without 3 Mtn View units compensated by gen	Without 3 Mtn View units compensated by load	With 3 Duke units compensated by gen	With 3 Duke units compensated by load
Palo Verde West, MW	**3520**	**3520**	**3520**	**3520**	**3520**
Palo Verde West, MVAR	693	777	710	695	697
North SCIT, MW	**11932**	**11932**	**11932**	**11932**	**11932**
North SCIT, MVAR	320	393	361	388	380
Palo Verde East, MW	**2218**	**2218**	**2218**	**2218**	**2218**
Palo Verde East, MVAR	-13	-11	-16	-3	6
MVAR from SCE gen	2277	2155	2114	2303	2331
MVAR from NV gen	750	743	742	740	868
Voltage on Devers	510	499	507	509	509
Voltage on Vincent	527	527	527	526	526
Highest vlt dip	Valley 115	Padua 66	Padua 66	Dometap 161	Dometap 161
% vlt dip	24.5%	30.8%	29.9%	23.0%	23.3%
Volt dip on Valley 115	24.5%	30.3%	29.5%	21.8%	22.0%

The following plots compare cases with and without Duke generation.
a – base case, b- additional Duke units compensated by decrease of generation in Nevada, c- additional Duke units compensated by increase in load in Nevada.
Voltage on the Valley 115 kV bus

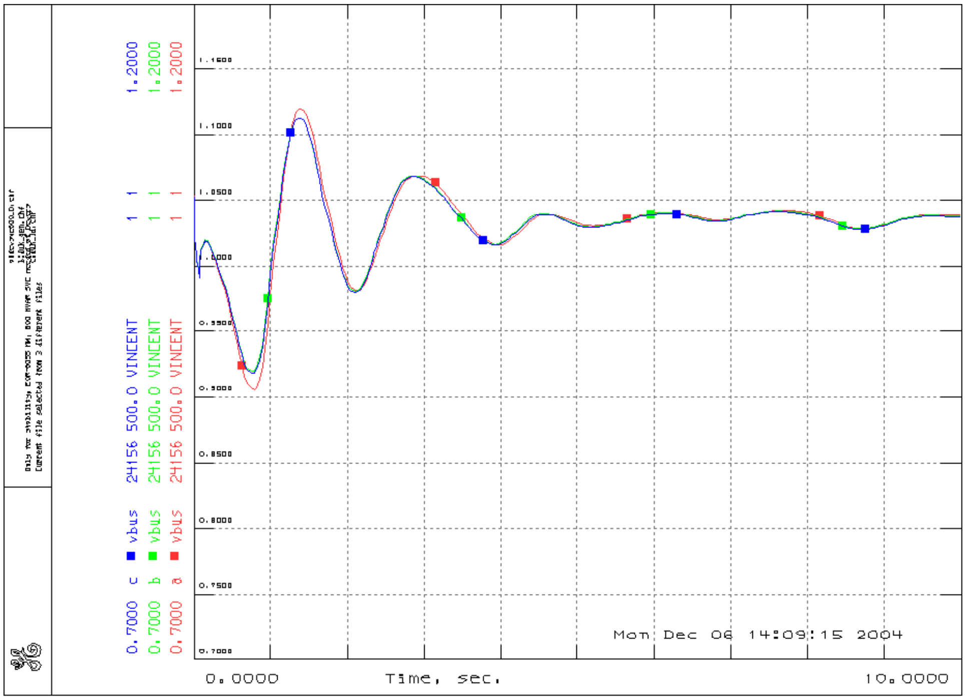


Real and reactive power output from Palo Verde generators was the same for all simulations.

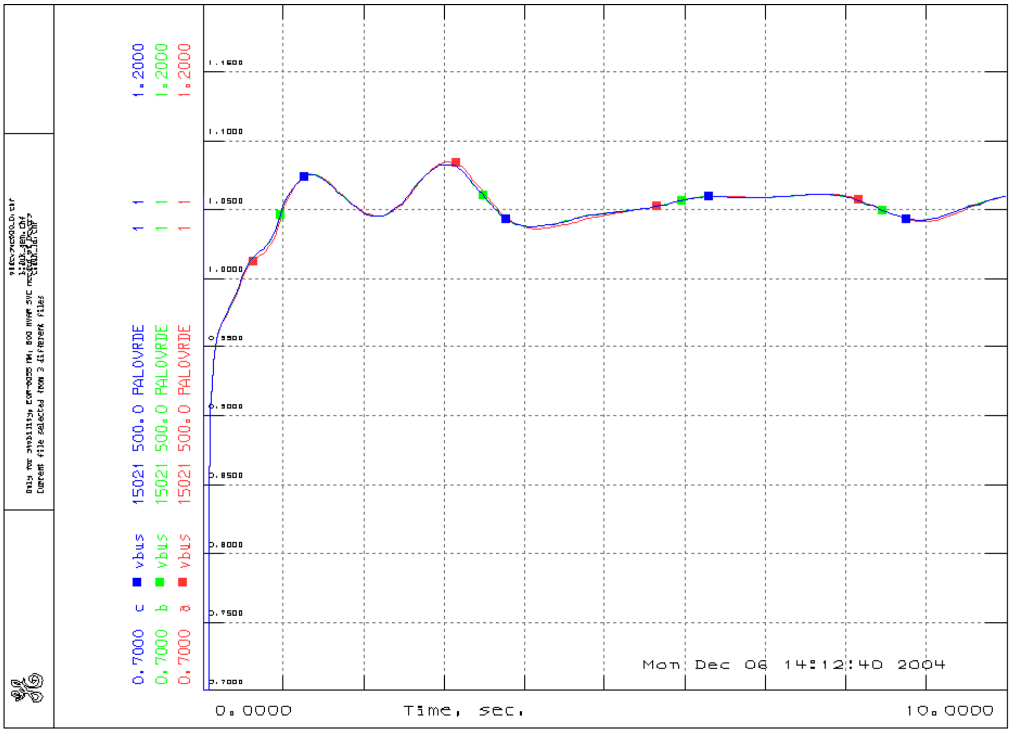
Reactive power output from Mountain View generator, higher w/out Duke units.



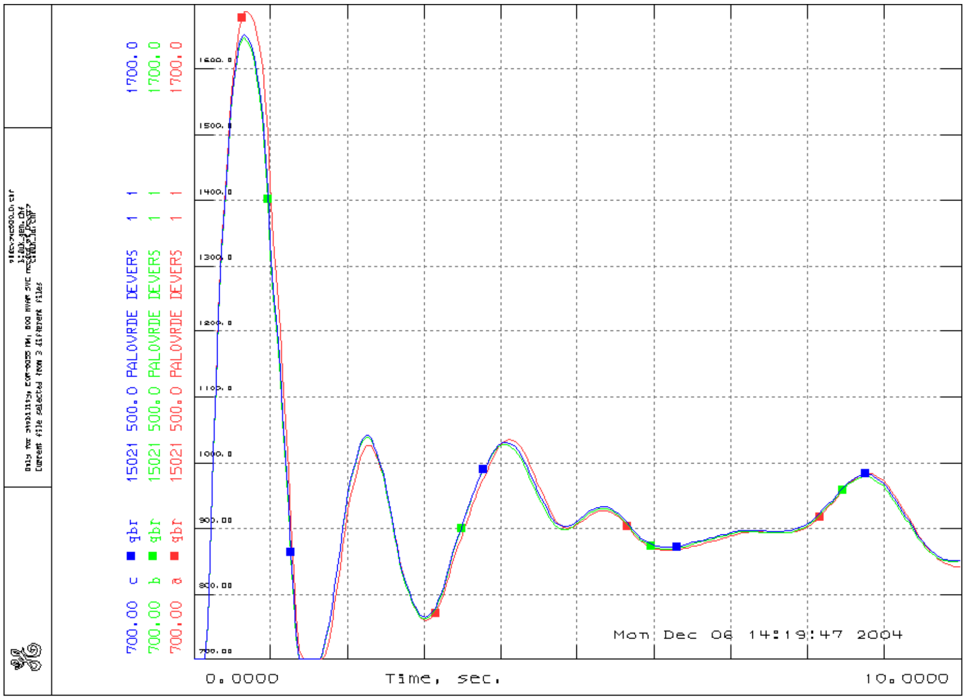
Voltage on the Vincent 500 kV bus, lower w/out Duke units



Voltage on Palo Verde 500 kV, no impact of Duke units



Reactive power flow on the Palo Verde-Devers line, higher w/out Duke units



Conclusion: Reactive support from the generation units in Nevada also has an impact on the dynamic stability performance.

10. Considerations for Development of the new Arizona-Southern California Transfer Nomogram

From all the studies that have been conducted, it is clear that the existing SCIT nomogram will no longer be an appropriate operating guide after the addition of the STEP short-term upgrades, which is currently scheduled for the spring of 2006. While the individual SCIT and EOR limits will need to be retained, the SCIT nomogram should be retired. In its place a new operating guide (nomogram or table) will need to be developed that is focused on the voltage dip at Devers. The primary factor in this new operating guide will need to be the flow on the Palo Verde West Path (Hassayampa-North Gila and Palo Verde-Devers). Based on the studies performed for this report, the maximum capability of the Palo Verde West path will be approximately 3600 MW. Many factors will impact this capability. The factors that were determined to have the most substantial impact on the transient voltage dip at Devers include:

- Flows on the Palo Verde West and Palo Verde East transmission lines
- Reactive power reserve in Southern California. This could be monitored through the voltage at critical buses.
- Machine inertia on the sending end of the Palo Verde West transmission lines. This could be monitored based on the amount and type of generation units on-line at Palo Verde, Hassyampa and Gila River.

At a minimum, the above factors should be accounted for in the new operating guide. In addition to these factors, there are many other factors that impact the transient voltage dip, however, due to the number of these factors and the non-linearity of these factors, including all of these factors in the operating guide would be very complex and would not be practical. As a result, substantial simplifying assumptions will be necessary. To simplify the operating guide, conservative assumptions could be used for other factors that are not as critical. For example, the studies used to develop the nomogram could assume that relatively few units would be on-line in Southern California, Nevada, and Eastern and Northern Arizona and that these units are operating at a high real power output. In addition, the load in Southern California, Arizona and Nevada could be modeled at a high level.