DYNAMIC STABILITY SENSITIVITIES FOR THE STEP SHORT-TERM UPGRADES

AND

THE DEVELOPMENT OF A REPLACEMENT FOR THE SCIT NOMOGRAM

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1. Introduction

This report is the second part of the Southwest Transmission Expansion Plan (STEP) dynamic stability studies. The purpose of the first part of the dynamic stability studies 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. The studies were summarized in the report "Dynamic Stability Analysis for the Short-Term Upgrades of the Step Project" issued in July 2004. All major 500 kV transmission line outages were studied and the amount and location for the required reactive support was identified.

This report is a continuation of the dynamic stability studies. The purpose of these studies is to estimate the impact of different factors (inertia, generation availability, load levels, etc.) on the dynamic reactive support requirements. By understanding the relative importance of these various factors and their interaction, we can improve our design for dynamic voltage support and develop improved tools for setting operating limits.

The system modeled in these studies includes the following upgrades: 1) upgraded series capacitors on the Hassayampa-North Gila-Imperial Valley, Palo Verde-Devers, Navajo-Crystal and Moenkopi-Eldorado 500 kV transmission lines; 2) installation of a second 500/230 kV transformer bank at Devers Substation; 3) dynamic reactive support (Statcom or SVC) at the Devers 230 kV bus; and, 4) an upgrade of the 230 kV system west of Devers. These upgrades are expected to allow an increase in the East-of-River (EOR) flow limit from the current 7550 MW to 8055 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 this phase of the studies.

Sensitivity studies were performed to estimate the impact on the dynamic reactive support requirements for the following variables:

1) Inertia
    a. Hassayampa Inertia
    b. Other Arizona Inertia
    c. Southern California Inertia

2) Southern California Generation
    a. Unit outages
    b. Reduced unit output

3) Southern California load levels
    a. Load increase served by local generation

    b. Load increase served by imports
    c. Localized Devers and Valley load increase

4) Bulk Power Transfers
    a. Palo Verde to Southern California transfers (Southern EOR, or Palo Verde West)
    b. Las Vegas to Southern California transfers (Northern West-of-River (WOR))
    c. Northern California to Southern California transfers (Path 26)
    d. Pacific DC Intertie to Southern California transfers (Path 65)
    e. Arizona to Nevada transfers (Northern EOR)

The dynamic stability simulations conducted for these sensitivity studies were performed using an off-peak base case with high EOR flow (8075 MW). A conceptual nomogram for the Arizona-Southern California transfers for the dynamic stability studies was developed.

2. Study Conclusions

The main factors that impact the required reactive support at Devers include: 1) flow on the Palo Verde West transmission lines, 2) 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 and 4) the amount of real and reactive power reserves on the sending and receiving ends of the Palo Verde West transmission lines. Each of these major factors is summarized below:

1. **Path Flows:** The flow on the Palo Verde West transmission lines has a very significant impact on the required reactive support. Other path flows that impact the required reactive support include: Midway-Vincent (Path 26) and the Pacific DC Intertie, Northern West-of-River (Eldorado-Lugo, Mohave-Lugo, Marketplace-Adelanto, McCullough-Victorville, Victorville-Mead), Northern East-of-River (Navajo-Crystal, Eldorado-Moenkopi, Liberty-Peacock and Perkins-Mead), and Palo Verde East (Palo Verde-Westwing, Palo Verde-Rudd and Jojoba-Kyrene).

2. **Arizona Inertia:** The required dynamic reactive support depends substantially on the inertia on the sending end of the Palo Verde West (Palo Verde-Devers and Hassyampa-North Gila) transmission lines. The higher the inertia, the lower the required reactive support. The impact of the inertia from generation in the rest of Arizona is approximately half of the impact of the Palo Verde, Hassayampa and Gila River generation inertia. Southern California inertia has no impact on the dynamic voltage dip performance at Devers and on the required reactive support. It appears that this inertia should not be included in the Arizona-California transfer (Southern California Imports (SCIT)/East-of-River) nomogram for voltage dip concerns.

3. **Generation availability:** The studies indicate that the amount of Southern California generation on-line impacts the reactive support requirement. Units that are electrically close to Devers provide the greatest benefit. However, the results depend on how the sensitivity case is modeled. If the off-line generation is compensated by increasing generation to the north of Los Angeles instead of decreasing load, then the reactive support requirement would decrease rather than increase.

4. **Generation Real Power Output:** The impact of a reduction in the real power output from units in Southern California depends on the location of the units and how the decrease in generation is compensated. Generally, lower real power output from the units in southern California reduces the voltage dip at Devers.

5. **Load Levels:** Lower Southern California load results in higher reactive power support requirements (with the flows between Southern California and Arizona held constant). The amount of required reactive support depends significantly on how the change in load is compensated. For changes in the amount of local load at Valley and Devers, the impact was

no different than for an equivalent change across Southern California's entire load.

Based on these sensitivities, it is recommended that a new Arizona-Southern California transfer nomogram be developed that focuses on the voltage dip at Devers. Eventually this nomogram could replace the existing EOR/SCIT nomogram. To simplify the impact of different factors on the required dynamic reactive support, the dynamic stability portion of the Arizona-Southern California transfer nomogram could be developed using the following values: 1) combined flow on the Palo Verde-Devers and Hassayampa-North Gila 500 kV transmission lines (Palo Verde West flow), 2) machine inertia of the Palo Verde/Hassayampa/Gila River generators plus one-half of the inertia in the rest of Arizona, 3) flow to the Southern California from the North (to identify how far the power from Arizona is transferred), and 4) Palo Verde East flow (to identify the stress on the sending end of the system).

These studies indicate that the required dynamic reactive support at Devers depends on many factors and can vary from 0 to 600 MVAR. It is recommended that at least a 600 MVAR STATCOM or SVC be installed at the Devers 500 kV substation to satisfy the most conservative conditions.

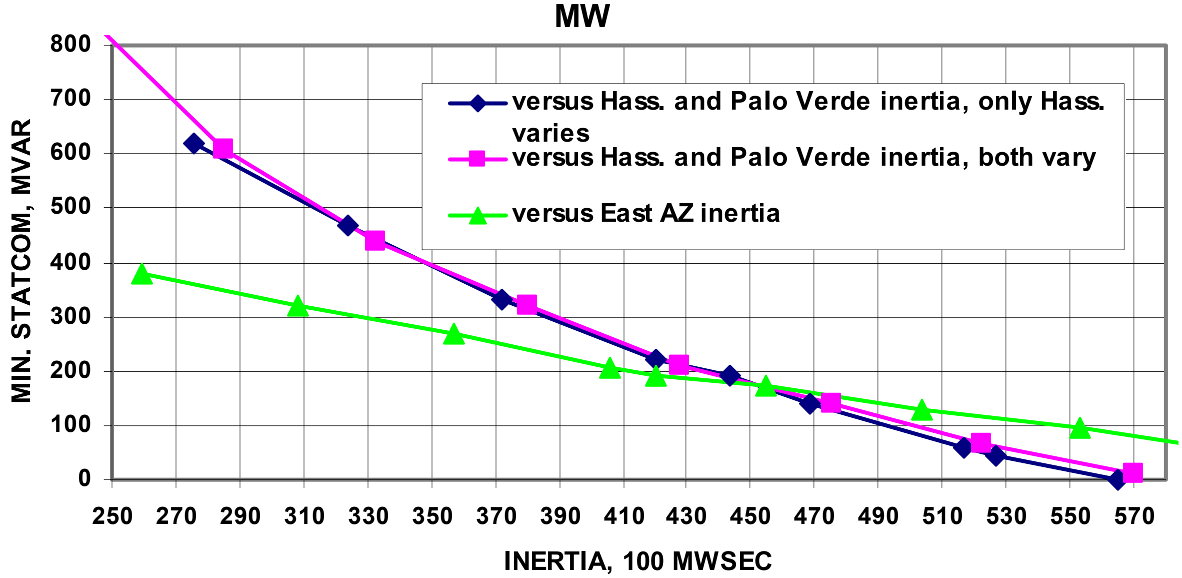
The study results are described and discussed in more detail in the following sections of the report.

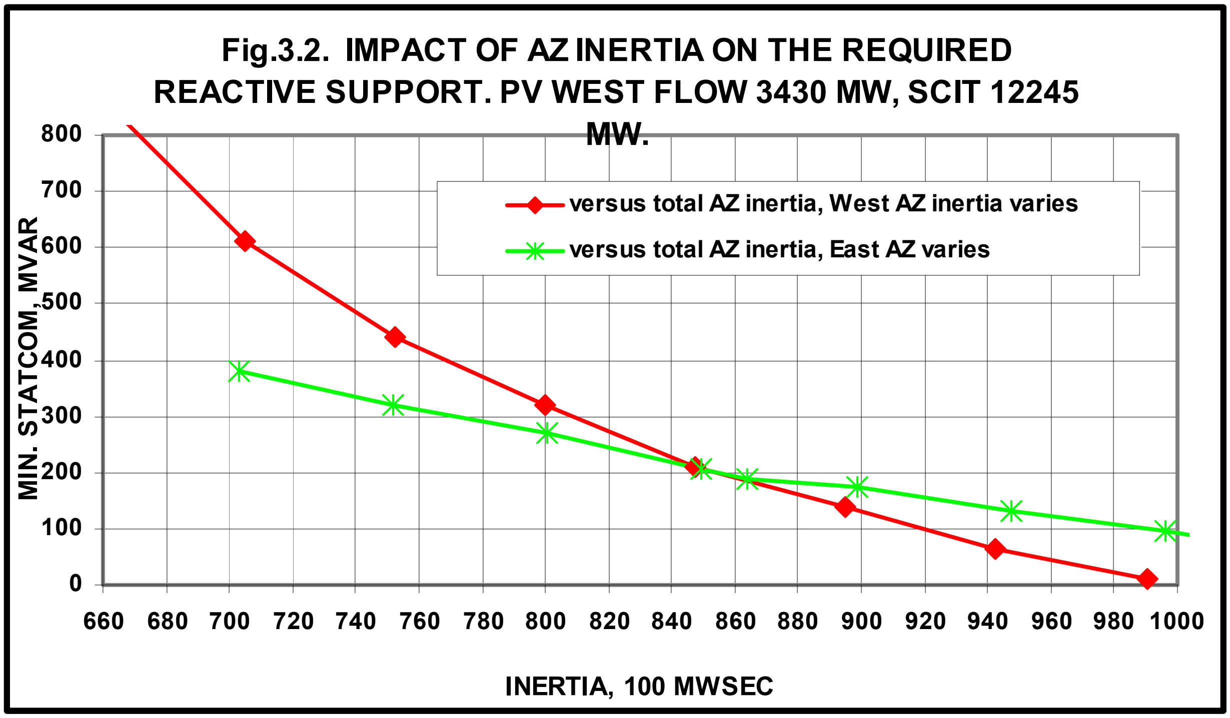
3. Study Results. Inertia Sensitivities

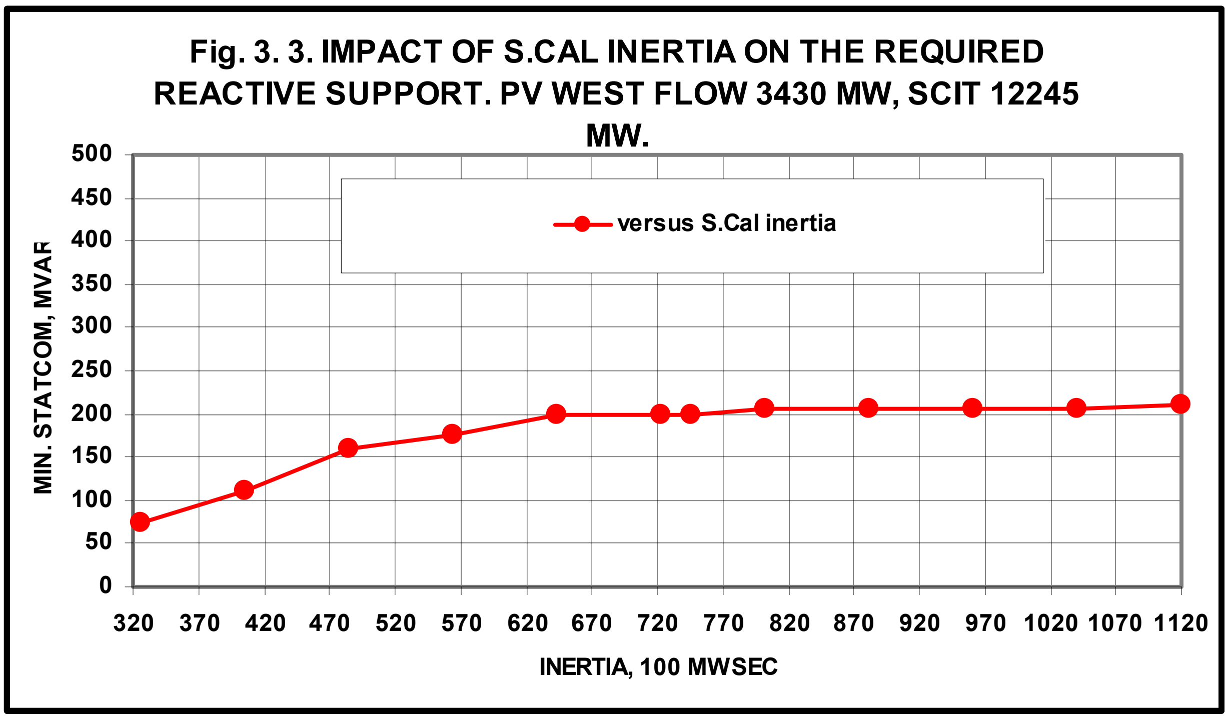
This study examined the impact of generator inertia on the required dynamic reactive support. The impact of the inertia of the Hassayampa and Palo Verde machines, of other machines in Arizona, and of machines in Southern California was studied. The base case with 8075 MW EOR flow, 3430 MW Palo Verde West (Palo Verde – Devers and Hassayampa-North Gila 500 kV lines) flow and 12245 MW Southern California Imports (SCIT) was used. To eliminate the impact of factors other than the generators' inertia, the study used hypothetical dynamic stability data for the machines. To vary inertia in the areas studied, different inertia coefficients for the generators were modeled. 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 required dynamic reactive support for different levels of inertia at Hassayampa, other plants in Arizona, and in southern California is shown in Figures 3.1, 3.2, and 3.3.

Fig.3.1. IMPACT OF ARIZONA INERTIA ON THE REQUIRED REACTIVE SUPPORT. PV WEST FLOW 3430 MW, SCIT 12245 MW





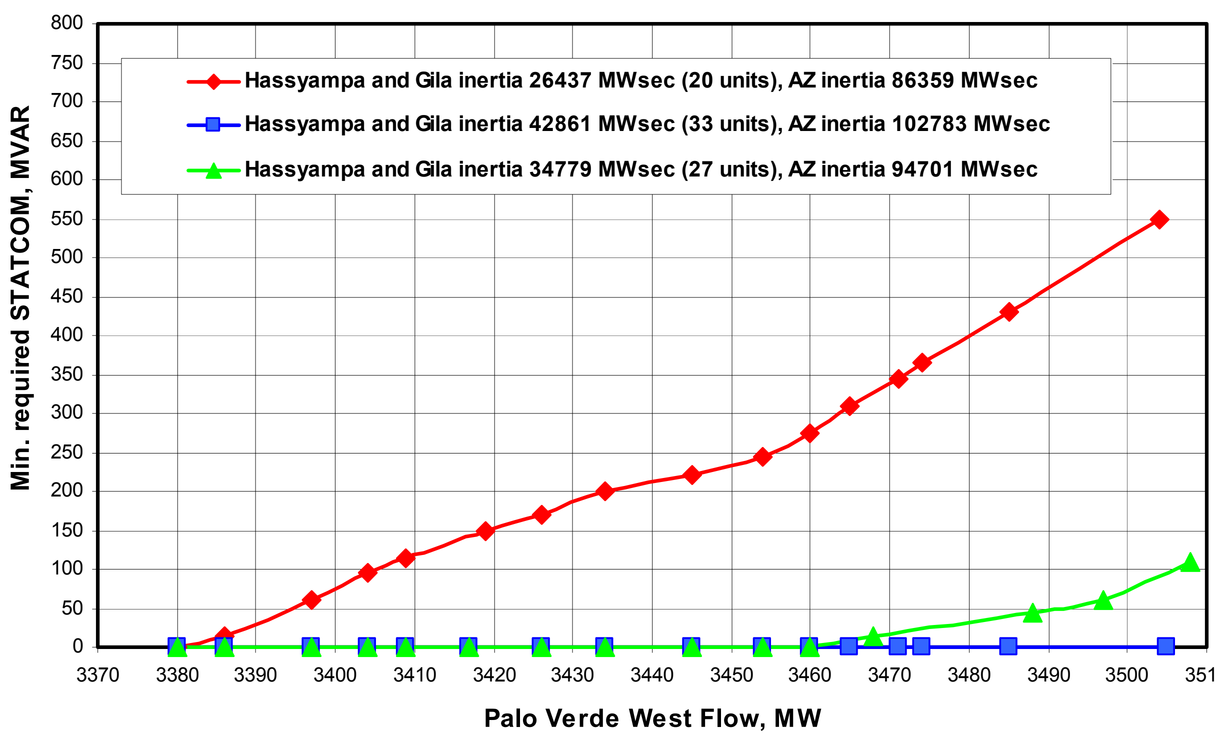


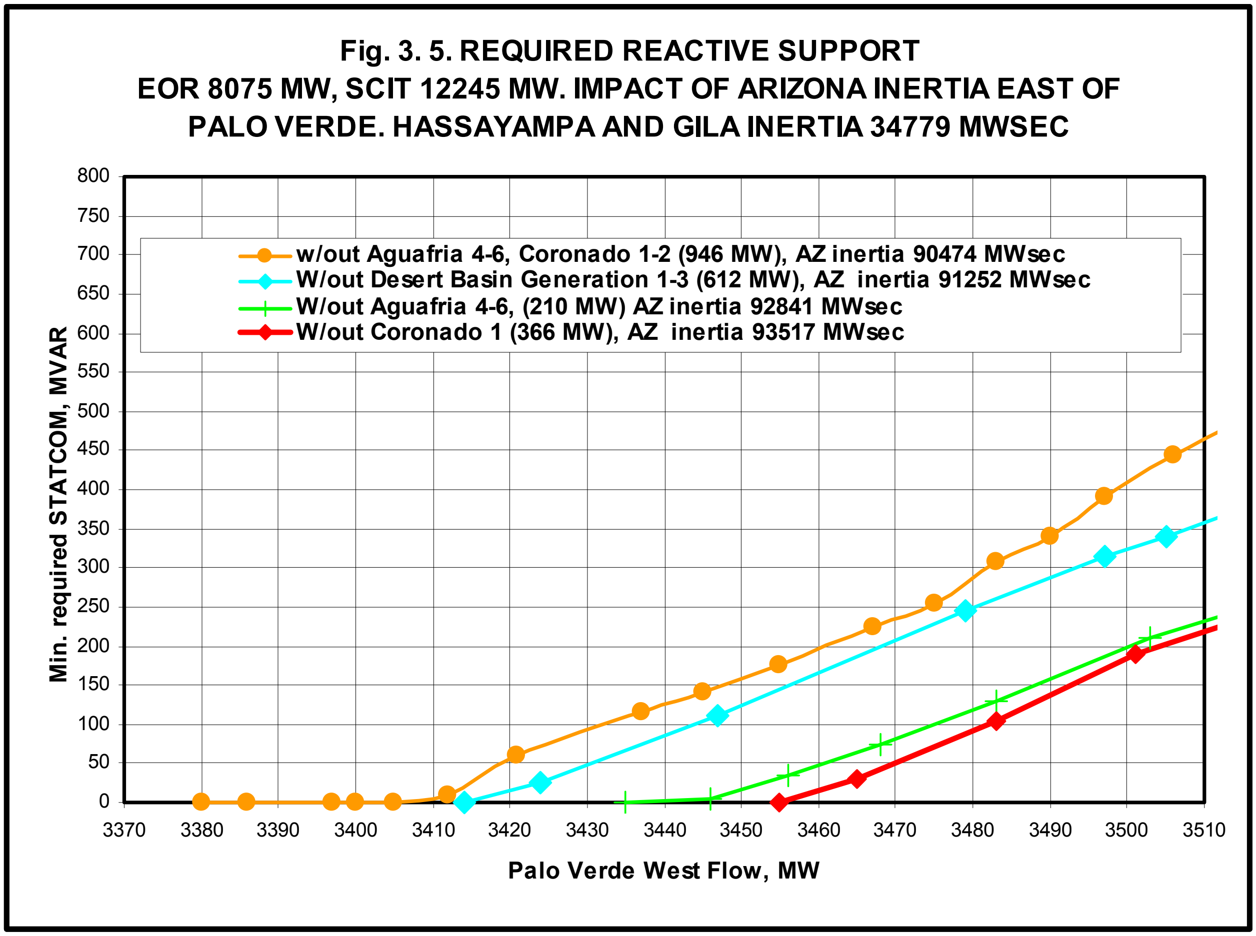
As can be seen from the plots, there is a strong correlation between the required amount of dynamic reactive support and the inertia on the sending end of the Palo Verde West lines (Palo Verde-Devers and Hassayampa-North Gila). The study also showed that dynamic stability performance is affected not only by inertia of the Palo Verde, Hassayampa and Gila River plants, but by the total inertia in Arizona. However, the impact of inertia east of Palo Verde is approximately half of the impact of inertia at Palo Verde and Hassayampa. The impact of the Palo Verde machines inertia is the same as impact of the inertia of the generation connected to Hassayampa. The studies showed linear dependency between the required reactive support and Arizona inertia, except for very low inertia levels, when the reactive support would be higher.

The study also clearly shows that the dynamic voltage support requirements at Devers are not affected by the amount of inertia in southern California, at least within the reasonable inertia levels.

To confirm the study conclusions, additional dynamic stability simulations of the Hassayampa-North Gila outage were performed without changing the inertia constants of the generators. Changes in the inertia levels were modeled by simulating different amounts of generation units on-line. The required amount of reactive support was plotted versus Palo Verde West flow. Southern California Imports (SCIT) and EOR flow were held constant by adjusting Southern California and Nevada generation. The study results are shown in Fig. 3.4 and 3.5. Fig. 3.4 shows the study results when only on-line generation at Hassayampa and Gila River was changed, Fig. 3.5 shows the results when the amount of on-line generation units at Hassayampa was held constant, but some units in Arizona east of Palo Verde were modeled off-line.

Fig.3.4. REQUIRED REACTIVE SUPPORT EOR 8075 MW, SCIT 12245 MW. IMPACT OF INERTIA AT HASSAYAMPA AND GILA RIVER



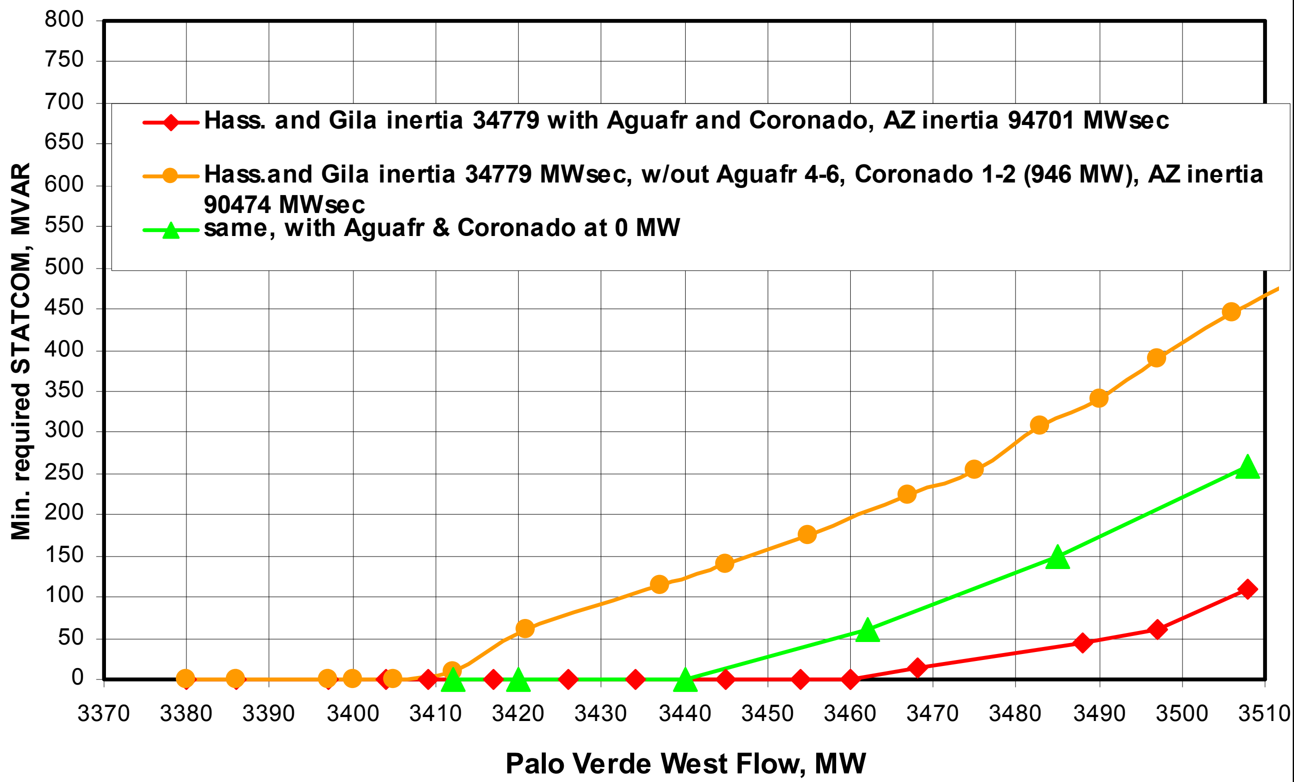


The study results showed that with 20 generation units on-line at Hassayampa and Gila River, no reactive support would be required if the flow on the Palo Verde West lines is less than 3380 MW. However, if the flow on these lines is 3520 MW, the reactive support requirement increases to 600 MVAR. The required reactive support would likely be higher with generation units in other areas in Arizona off-line. With 33 generation units at Hassayampa and Gila River on-line, reactive support will not be required even with a higher level of the Palo Verde West flow. The studies modeling Coronado and Aguafria generation off-line and replaced by other Arizona generation identify high reactive support requirements even with more generation units (and thus, higher inertia) at Hassayampa.

As can be seen from the plots, the results of the dynamic simulations with different amount of generation on-line were consistent with the study results where the area inertia was changed by varying the inertia coefficients of the machines.

The following plot shows the impact of inertia and real and reactive power output on the sending end. As can be seen from Fig.3.6, with the Coronado and Aguafria units on-line, but with zero active power generation, the reactive support requirements were lower than without these units, but higher than with these units supplying real power. This result shows high impact both of inertia and real and reactive output from the Arizona units. With zero real power output from the Arizona units, to maintain the same flow on the Palo Verde West lines as with these units providing real power, higher generation at Hassayampa is needed, which means that the system is more stressed, and thus, higher reactive support is required. With the units off-line, the impact of lower inertia is added to the impact of higher system stress, thus increasing the reactive support requirement.

Fig. 3. 6. REQUIRED REACTIVE SUPPORT
EOR 8075 MW, SCIT 12245 MW. IMPACT OF ARIZONA INERTIA AND REACTIVE SUPPORT



Conclusion:

Machine inertia on the sending end of the Palo Verde West lines has significant impact on the reactive support requirement. The higher the inertia, the lower the required reactive support. The impact of the inertia from generation in the rest of Arizona is approximately half of the impact of the Palo Verde, Hassayampa and Gila River generation inertia. Southern California inertia has no impact on the dynamic voltage dip performance.

4. Study Results. Southern California Generation Sensitivities

Two sensitivity studies were completed to investigate the effect of generation on the dynamic voltage support requirements. The first examines the effect of unit outages and the second examines a reduction in unit output where the units remain on-line supplying voltage support and contributing to system inertia. Different generation units were modeled off-line, one at a time. The generation from these plants was replaced by a decrease in Southern California load. Only the static part of the load was decreased (i.e., the amount of induction motor load remained the same). The SCIT, EOR, and Palo Verde West (Palo Verde-Devers and Hassayampa-North Gila) flows, as well as the amount of units on-line in the Hassayampa area, were held constant. For the sake of comparison, the size of the plants taken off-line was kept consistent (500-600 MW). The following plant outages were modeled:

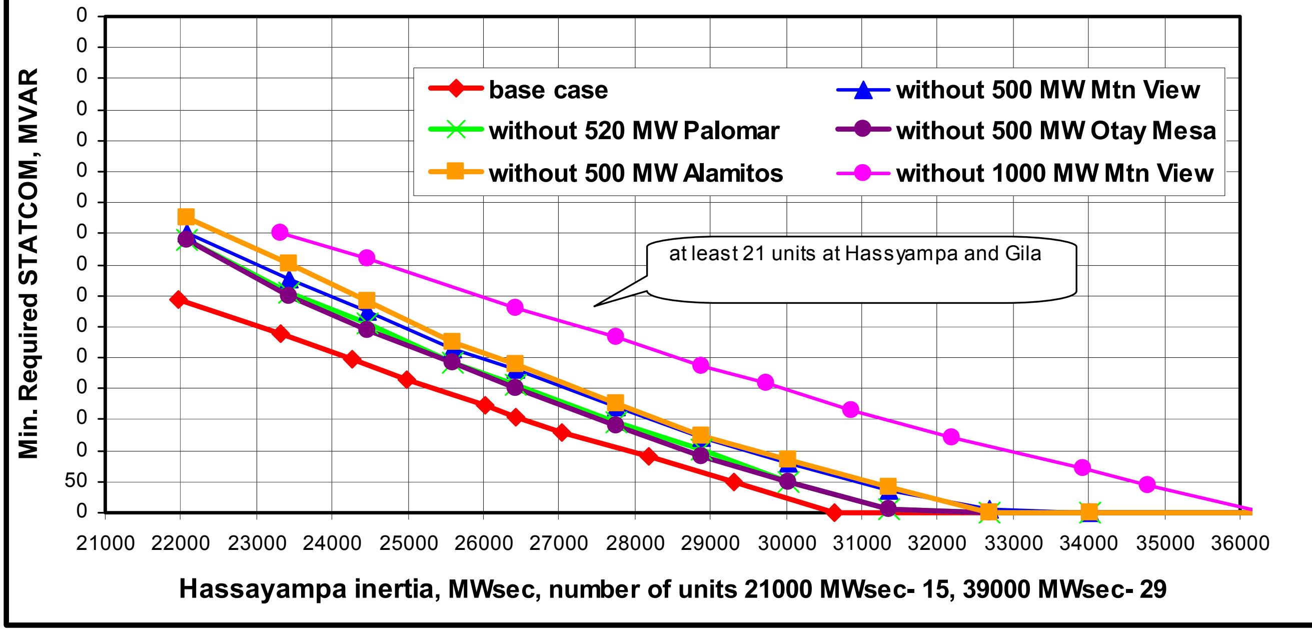
1) Mountain View (three of the 6 units modeled out; 500 MW)
2) Alamitos (two units; 600 MW)
3) Palomar (three units; 520 MW)
4) Otay Mesa (three units; 500 MW)

The dynamic simulation results indicate that the impact on dynamic stability performance was higher for the Mountain View and Alamitos plants than for the Otay Mesa and Palomar plants. Without either the Mountain View or Alamitos plants, the dynamic support requirement was approximately 85 MVAR higher. Without the entire 1000 MW Mountainview plant, the reactive support requirement increased linearly to 170 MVAR. The impact of the Palomar and Otay Mesa power plants were similar to each other. Without either one of these projects, the dynamic reactive support requirement would be 45 MVAR higher.

These results can be explained by the location of these power plants. The Mountain View project is the closest to the area of the highest voltage dip (Devers), and the reactive support from this plant helps to improve dynamic stability performance. Even though the Alamitos plant is farther from the Devers area, it is closer to the Valley 115 kV system, which is an area of high load. Therefore, the reactive support from this plant helps to alleviate the effects of the high load at Valley. The impact of the San Diego plants (Otay Mesa and Palomar) is lower than the Mountain View and Alamitos plants because they are located farther south from the area of the high load and high voltage dip.

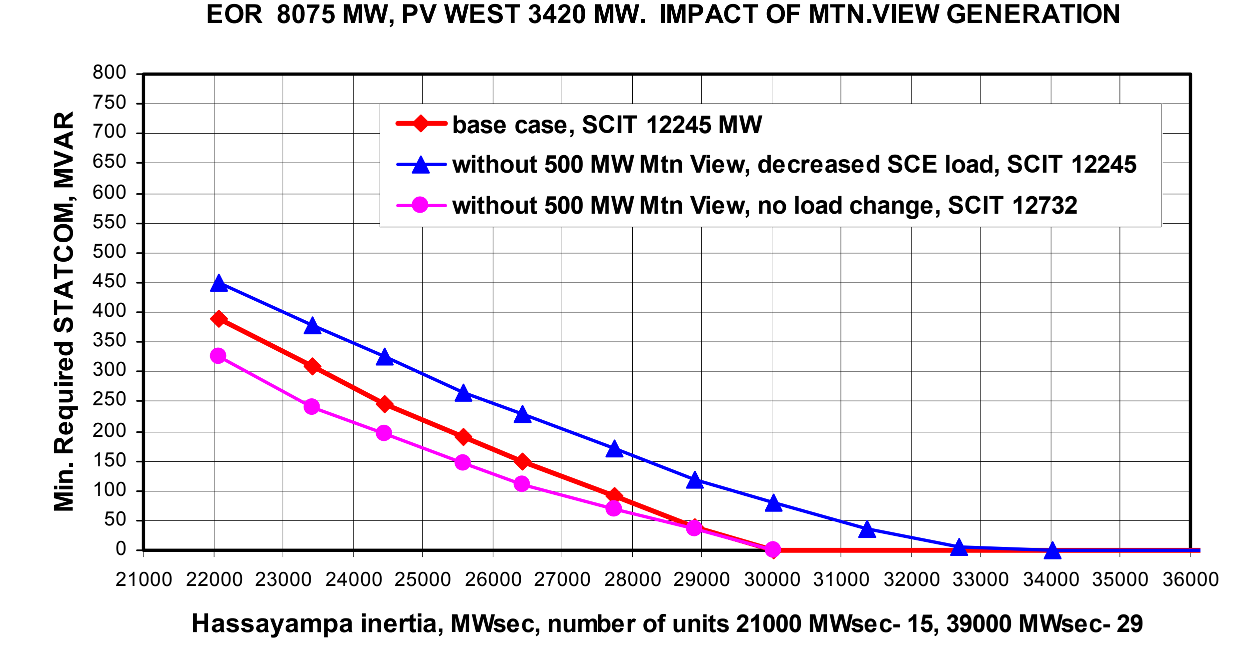
The results of these studies are summarized in Fig. 4.1.

Fig. 4.1. REQUIRED REACTIVE SUPPORT VS HASSAYAMPA INERTIA
EOR 8075 MW, PV WEST 3420 MW, SCIT 12245 MW.
IMPACT OF S.CAL GENERATION OUTAGES



As mentioned earlier, in these sensitivity studies, the generation from the units taken off-line was compensated by decreasing SCE load so that the SCIT and Palo Verde West flows could be held constant. This way, the study results were impacted not only by the units off-line but also by the decrease in load. To separate the effects of the generation taken off-line and the decrease in load, another study was performed. In this study, 500 MW of Mountain View generation was modeled as being off-line compensated by an increase in generation in the Northwest and Northern California. This way, the SCIT was increased to 12732 MW. Hassayampa and Nevada generation was adjusted to maintain 3420 MW flow on Palo Verde West and 8075 MW EOR. The study results are shown in Fig.4.2.

Fig. 4.2. REQUIRED REACTIVE SUPPORT VS HASSAYAMPA INERTIA
EOR 8075 MW, PV WEST 3420 MW. IMPACT OF MTN.VIEW GENERATION



As can be seen from the plot, with the same Southern California load, the case without three units at Mountain View shows better dynamic performance than the case with these units, especially with low inertia at Hassayampa. This can be explained by the fact that with the same load on the receiving end, higher generation on the sending end is needed to result in the same flow west of Palo Verde with Mountain View. Therefore, with the same Southern California load and the same Palo Verde West flow, the case with Mountain View generation is more stressed. It has higher Hassayampa generation and thus lower real and reactive power reserve on the sending end of the lines. The impact of the reduction in reactive reserve at Palo Verde appears to be higher than the impact of reduced reactive support from the Mountain View generation.

Additional sensitivity studies were conducted to examine a reduction in unit output without a unit outage. In these studies, the real power output of the southern California units was decreased but the units remained on line providing voltage support and contributing to system inertia. Palo Verde West and EOR flows were held constant (3420 MW and 8075 MW respectively). Inertia was also held constant, since all the cases had the same generation units on-line.

The results of this study are summarized below. The amount of generation from each power plant shown in the table was reduced by 500 MW. This reduction was compensated by either a 500 MW reduction in SCE load, or by an increase in generation in PG&E and the northwest. The table compares the effect of this generation reduction with the effect of taking the units off-line.

Table 4.1. Impact of reactive support from Southern California generation

Location of generation reduction	Minimum reactive support, MVAR	
	Real power reduced	Units off-line
Starting case	150	150
Mountain View compensated with NW and PG&E generation	0	110
Mountain View compensated with a decrease in SCE load	70	230
Pastoria compensated by an increase in NW and PG&E generation	180	170
Pastoria compensated by a decrease in SCE load	240	240
Alamitos compensated by an increase in NW and PG&E generation	110	170
Alamitos compensated by a decrease in SCE load	160	230
SCE generation decreased 500 MW proportionally, compensated by NW and PG&E generation	50	-
SCE generation decreased 500 MW proportionally, compensated by a 500 MW decrease in SCE load	100	-

As can be seen from the table, the reactive support from the on-line generation has an impact on dynamic stability performance, but this impact depends substantially on the generation location and can be positive or negative. One of the explanations for the lower reactive support requirement without active power generation is that to maintain the same flow on the Palo Verde West lines with lower generation on the receiving end, the generation on the sending end will be lower. This way the system is less stressed and has higher reactive reserves. With a decrease in load, the situation is the opposite: it requires higher generation at the sending end to maintain the same flow on the Palo Verde West lines. Also, without the active power output from the generation on the receiving end, the units provide more reactive support. As the study results show, the impact on reactive support from the outage of a Mountain View unit is higher than the impact of a decrease in load.

Reactive support from the Alamitos units has a lower impact than the Mountain View units and a lower impact than a decrease in load. Due to its location far to the northwest from the area with the high voltage dip, the impact of the Pastoria generation outage was substantially different than for a Mountain View or Alamitos outage. Since there was almost no difference in the required reactive support in the case with the Pastoria units off-line and in the case with these units on-line with reduced output, it can be concluded that reactive support from Pastoria does not impact the voltage dip for the Hassayampa-North Gila outage.

The study results also showed that factors other than Southern California generation outages have a major impact on voltage support requirements. Changes in the interchange between SCE and PG&E had a significant effect on the results. In addition, the changes in generation in Nevada and Arizona that were necessary to hold the East-of-River and Palo Verde West flows constant also had a significant effect on the results.

Conclusion:

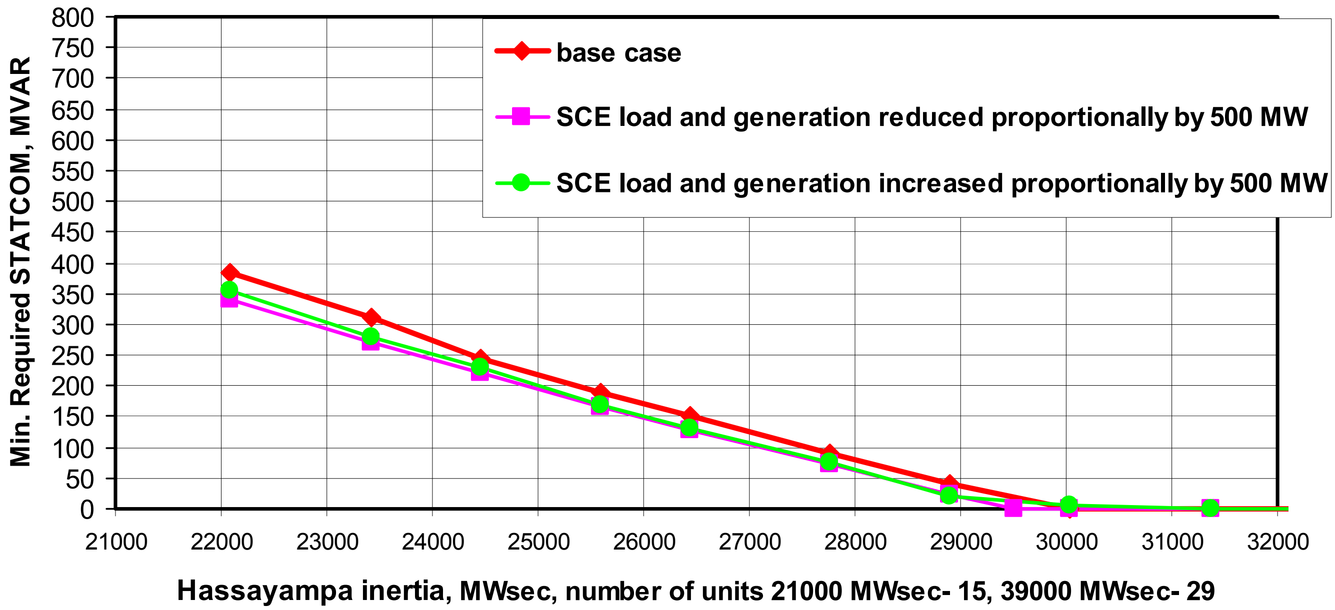
The amount of Southern California generation on-line impacts the reactive support requirement. Units that are electrically close to Devers provide the greatest benefit. However, the results depend on how the sensitivity case is modeled and on flows on the major paths to Southern California. If the off-line generation is compensated by increasing flow from the North instead of decreasing load, then the reactive support requirement would decrease rather than increase. The impact of a reduction in the real power output from units in Southern California depends on the location of the units and how the decrease in generation is compensated. Generally, lower real power output from the units in southern California reduces the voltage dip at Devers.

5. Study Results. Southern California Load Level Sensitivities

Two sensitivities investigated the effect of southern California load levels. The first sensitivity study examined the case where the difference in load is served by local generation. The second sensitivity study examined the case where the additional load is served by increased imports.

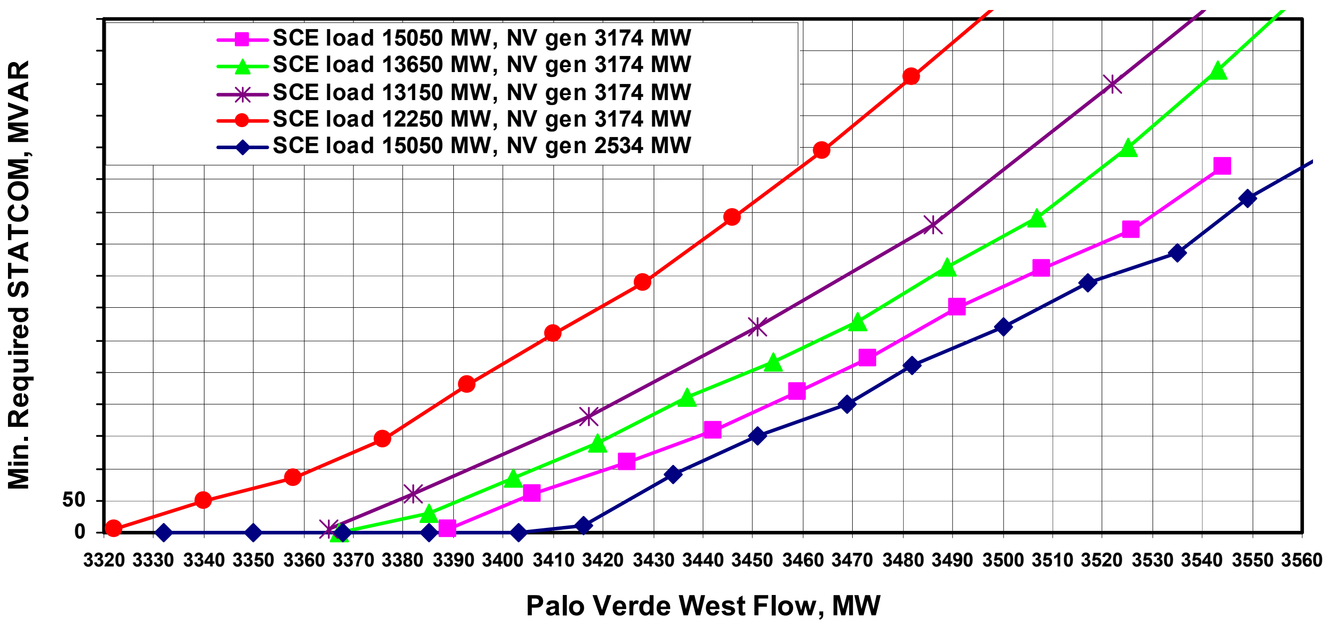
In the first sensitivity study, southern California load and generation were first reduced and then increased. Only the static part of the load was adjusted; the induction motor part remained the same as in the previous studies. The number of units on-line was held constant. The flows on SCIT, EOR, and Palo Verde West were held constant through adjustments in generation in Nevada and Arizona. The required reactive support was reduced slightly with the lower load level. This can be explained by the fact that the lower load required lower local reactive support. The reactive support from the plants remained the same even as the active power output of the plants was decreased. The required reactive support was also slightly lower with the higher SCE load. It can be explained by the fact that to hold the same Palo Verde West flow with the higher load, generation at Hassayampa needs to be reduced. Reducing generation in Arizona allowed for higher reserves in that area. The results of this study are shown in Fig. 5.1.

Fig.5.1. REQUIRED REACTIVE SUPPORT VS. HASSAYAMPA INERTIA. EOR FLOW (8075 MW), PV WEST (3420 MW) AND SCIT (12245 MW) HELD CONSTANT



The second sensitivity examined serving a southern California load increase through increased imports and a decrease in load through decreased imports. In the study cases, only generation at Hassayampa was varied and the flows on Palo Verde West, EOR, and SCIT were monitored. The studies showed that with the same generation from Hassayampa, the flow on the Palo Verde West lines increases with an increase in Southern California load, and since the Palo Verde West flow is higher, more reactive support will be required. If the flow on the Palo Verde West lines is held constant, higher Southern California load leads to a lower reactive support requirement. The following figure shows dependency of the required reactive support on the flow on the Palo Verde West lines for different Southern California load levels. Generation in Nevada was not varied, thus the Northern EOR flow was not held constant.

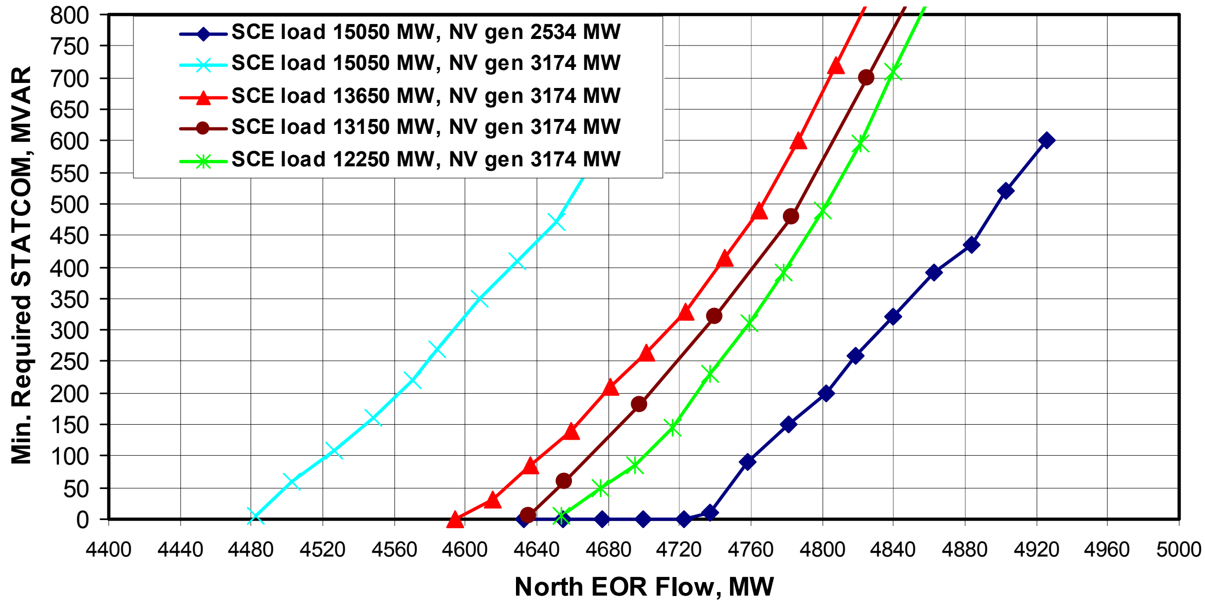
Fig. 5.2 REQUIRED REACTIVE SUPPORT VERSUS PALO VERDE WEST FLOW. ONLY HASSAYAMPA GENERATION VARIES, NEVADA GENERATION CONSTANT



As seen from Fig. 5.2, the required reactive support depends substantially on the Palo Verde West flow. However, with the same flow on the Palo Verde West lines, the lower the Southern California load, the higher the required reactive support. With lower Nevada generation, and thus higher North EOR flow, the required reactive support is slightly lower for the same load level.

Fig. 5.3 represents the same study results, but plotted versus North EOR flow.

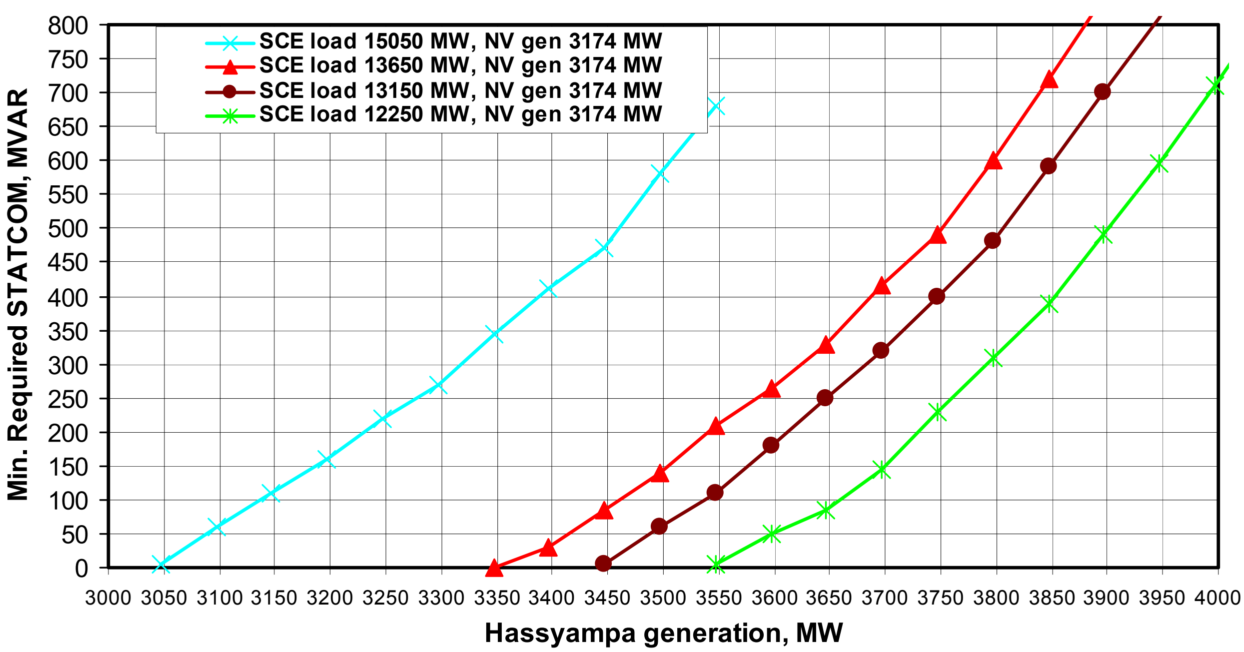
Fig. 5.3. REQUIRED REACTIVE SUPPORT VS NORTH EOR FLOW. ONLY HASSYAMPA GENERATION VARIES. NV GENERATION CONSTANT



As can be seen from Fig. 5.3, the higher the North EOR flow, the higher the required reactive support. With the same North EOR flow, the reactive support is higher for higher Southern California load. On the other hand, with the same North EOR flow and higher Southern California load, the flow on the Palo Verde West lines is higher, which is a reason for the higher reactive support requirement with the higher North EOR flow.

Fig. 5.4 illustrates Hassayampa generation in these stability runs.

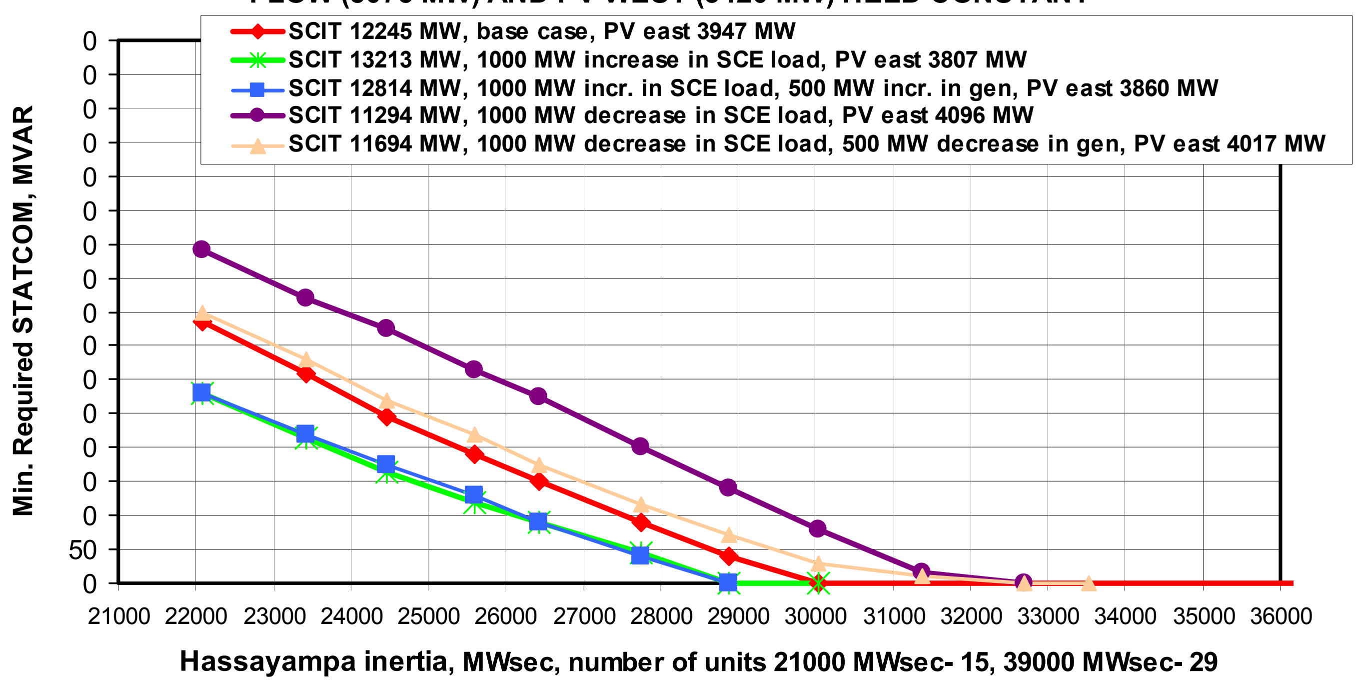
Fig. 5.4. REQUIRED REACTIVE SUPPORT. ONLY HASSAYAMPA GENERATION VARIES. NEVADA GENERATION CONSTANT



As can be seen from the plots, higher generation at Hassayampa leads to a higher reactive support requirement. With the same generation at Hassayampa, the required reactive support is higher with higher Southern California load. However, the Palo Verde West and North EOR flows were not held constant in this study. Therefore, with higher Hassayampa generation, flows on the EOR lines were higher, which explains the higher reactive support requirement.

In another sensitivity study, the Palo Verde West and North EOR flows were held constant by adjusting generation at Hassayampa and in Nevada. For each load level, SCIT also was held constant by adjusting SCE generation to compensate for the difference in losses. The following figure shows the required reactive support versus inertia at Hassayampa. Inertia at Hassayampa was varied by changing the amount of generating units on-line. The on-line generation units in the rest of Arizona, in Nevada and in Southern California were the same in all the simulations.

Fig.5.5. REQUIRED REACTIVE SUPPORT VS. HASSAYAMPA INERTIA. EOR FLOW (8075 MW) AND PV WEST (3420 MW) HELD CONSTANT



As can be seen from Fig.5.5, with the same Southern California generation, higher Southern California load led to a lower reactive support requirement with Palo Verde West and North EOR flows held constant. This result is consistent with the results of the previous sensitivity studies. However, the reactive support requirements with the change in load depends on how this change in load is compensated. Also, the study showed that even if the northern and southern (Palo Verde West) EOR flows are held constant, the required reactive support requirement is not correlated with SCIT. Apparently, there are factors other than SCIT that impact the need for reactive support. One of these factors is the flow on the Palo Verde East transmission lines (Palo Verde-Westwing, Palo Verde-

Rudd and Jojoba-Kyrene), which indicates how stressed the system is on the sending end. The higher this flow is, the higher the need for reactive support.

The studies of localized change in load included a load change at the Valley 115 kV bus and the Devers 115 kV system. Several stability simulations of the Hassayampa-North Gila outage were performed with different assumptions regarding total Southern California load and flows on Palo Verde West, Palo Verde East (Palo Verde-Westwing, Palo Verde-Rudd and Jojoba-Kyrene), and East-of-River. The results of these simulations are summarized in the following tables.

Table 5.1. Minimum required dynamic reactive support depending on the Valley-S 115 kV bus load					
SCE load MW	Valley-S load MW	PV west flow MW	PV east flow MW	EOR MW	Reactive support MVAR
Starting case					
13650	400	3418	3947	8075	150
Increase in load					
13650	420	3419	3946	8075	90
13650	520	3423	3941	8076	100
13650	520	3418	3947	8075	80
13650	600	3427	3937	8077	100
13650	600	3418	3947	8075	80
13670	420	3421	3944	8077	150
13690	440	3424	3941	8078	160
13690	440	3418	3947	8075	140
13750	500	3418	3947	8075	150
13850	600	3418	3947	8075	160
Decrease in load					
13650	380	3417	3950	8075	90
13650	300	3412	3953	8073	100
13650	300	3418	3947	8075	120
13650	200	3418	3947	8075	150
13630	380	3416	3949	8073	140
13630	380	3418	3947	8075	150
13550	300	3405	3960	8065	110
13550	300	3418	3947	8075	180
13450	200	3418	3947	8075	170
13350	100	3418	3947	8075	190

Table 5. 2. Minimum required dynamic reactive support depending on load in the Devers area					
SCE load MW	Devers 115 kV load	PV west flow MW	PV east flow MW	EOR MW	Reactive support MVAR
Starting case					
13650	535	3418	3947	8075	150
Increase in load					
13700	585	3425	3939	8079	160
13700	585	3418	3947	8075	130
13650	585	3418	3947	8075	130
13850	735	3418	3947	8075	90
13650	735	3418	3947	8075	110
Decrease in load					
13550	435	3401	3963	8065	140
13550	435	3418	3947	8075	210
13650	435	3418	3947	8075	200

A local increase in the Valley or Devers load without any other changes in load or generation causes an increase in the flow on the Palo Verde West lines, and therefore an increase in the reactive support requirement. However, if the Palo Verde West, Palo Verde East and EOR flows are held constant by adjusting generation in Nevada and Arizona, the required reactive support depends on how the increase in load is compensated. With total SCE load held constant, the reactive support requirement goes down. With the load in the rest of SCE the same as in the base case, the reactive support requirement goes slightly up if the Valley load increases and goes down if the Devers load increases. With a local decrease in load at Valley, the reactive support requirement also goes down if the rest of the SCE load is increased to compensate for the load decrease at Valley. Higher reactive support is only needed if Valley load decreases and the rest of the loads remain the same. With a decrease in the Devers area load, the reactive support requirement goes up regardless of how this load decrease is compensated.

It appears that the required dynamic reactive compensation depends on where is the system swing center is located. An increase in SCE load moves the swing center closer to the sending end of the Palo Verde West lines and thus decreases the reactive support requirement. A decrease in load causes the swing center to move westward, thus the power from the Arizona plants is transferred over a longer distance, which causes an increase in the reactive support requirement. The studies showed that with an increase in the Devers load, the load bus with the highest voltage dip moves from Valley to High Desert. With a decrease in load, the load bus with the highest voltage dip moves west from Valley to Wilmington in the Century City (LADWP) area.

Conclusion:

Lower Southern California load results in higher reactive power support requirements if the flows between Southern California and Arizona held constant. The amount of required reactive support depends significantly on how the change in load is compensated, thus on the flow on the major paths. For changes in the amount of local load at Valley and Devers, the impact was no different than for an equivalent change across Southern California's entire load.

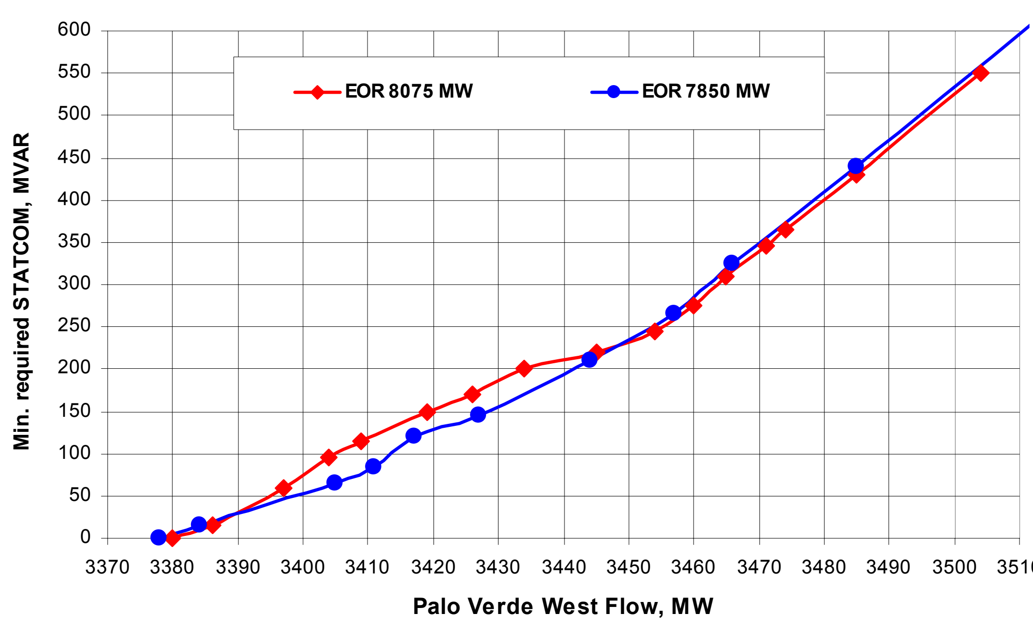
6. Study Results. Transfer Case Sensitivities

A variety of transfer case sensitivities were conducted to determine the critical factors associated with the dynamic voltage support requirement at Devers.

6.1. Palo Verde to Southern California Transfers (Palo Verde West) and Palo Verde to Arizona Transfers (Palo Verde East)

The flow on the two southern EOR, or Palo Verde West lines (Palo Verde-Devers and Hassayampa-North Gila), was varied while the total EOR flow, SCIT, and the amount of inertia were held constant. This was accomplished by re-dispatching generation in Nevada, Arizona and Southern California without changing the amount of units on-line. As can be seen from the plots, the dynamic voltage support requirement depends substantially on the flow on the Palo Verde West lines and does not depend on the total EOR flow.

Fig. 6.1. REQUIRED REACTIVE SUPPORT
SCIT 12245 MW, Hassyampa and Gila inertia 26437 MWsec (20 units), AZ inertia 86359 MWsec



The Palo Verde-Devers and Hassayampa-North Gila lines (Palo Verde West) are part of the East-of-River (EOR) path. In the next study, to investigate the impact of flow on northern and southern parts of EOR, the Palo Verde West flow and the flow on the Northern EOR lines (Navajo-Crystal, Eldorado-Moenkopi, Liberty-Peacock and Perkins-Mead) were monitored separately. The flow on the Palo Verde East lines (Palo Verde-Westwing, Palo Verde-Rudd and Jojoba-Kyrene) was also monitored.

Dynamic stability simulations of the Hassayampa-North Gila outage were performed with two of the flows (either Palo Verde East, Palo Verde West or Northern EOR) held constant and the third flow was varied. Only generation in Arizona and Nevada was varied, Southern California generation and load was held constant. Inertia at Hassayampa (amount of units on-line) was also held constant. The results of these studies are provided in the following plots.

Fig.6.2. REQUIRED REACTIVE SUPPORT VS. PALO VERDE WEST FLOW HASSAYAMPA INERTIA (26437 MWsec), NORTH EOR (4655 MW), SCE LOAD HELD CONSTANT. PV EAST FLOW CONSTANT FOR EACH CURVE

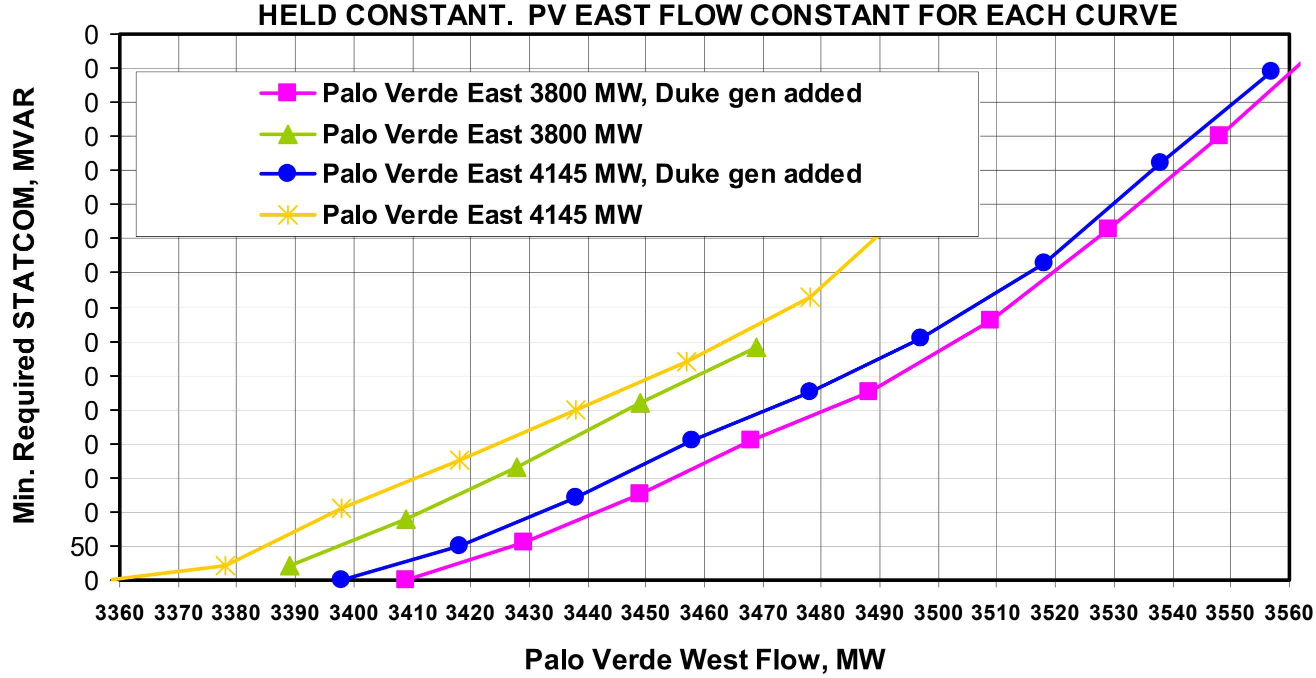


Fig. 6.2 shows that with the North EOR flow held constant, the impact of the Palo Verde East flow is substantially lower than the impact of the Palo Verde West flow. With the Palo Verde East flow held constant, each 1 MW increase in Palo Verde **West** transfer requires approximately 5 MVAR of additional reactive support. With the Palo Verde West flow held constant, each 1 MW increase in Palo Verde **East** transfer requires only 0.2 MVAR of additional reactive support.

The impact on the reactive support requirement from adding the Duke Power plant at Harry Allen was quite significant (up to a 150 MVAR decrease in reactive support requirement with three Duke units in service).

The next figure shows the impact of flows on the northern EOR system. As the northern EOR flow increases, the reactive support requirement decreases. This is contrary to the relationship between southern EOR flow and the reactive support requirement and provides additional evidence as to why total EOR flow is not a meaningful measure for identifying the voltage support requirements at Devers. The reactive support requirement may be the same for different levels of the EOR flow depending on how the EOR flow is distributed between the northern and southern lines.

Fig. 6.3 also corroborates the earlier finding that the addition of the Duke power plant at Harry Allen reduces the reactive support requirement at Devers by about 120-150 MVAR.

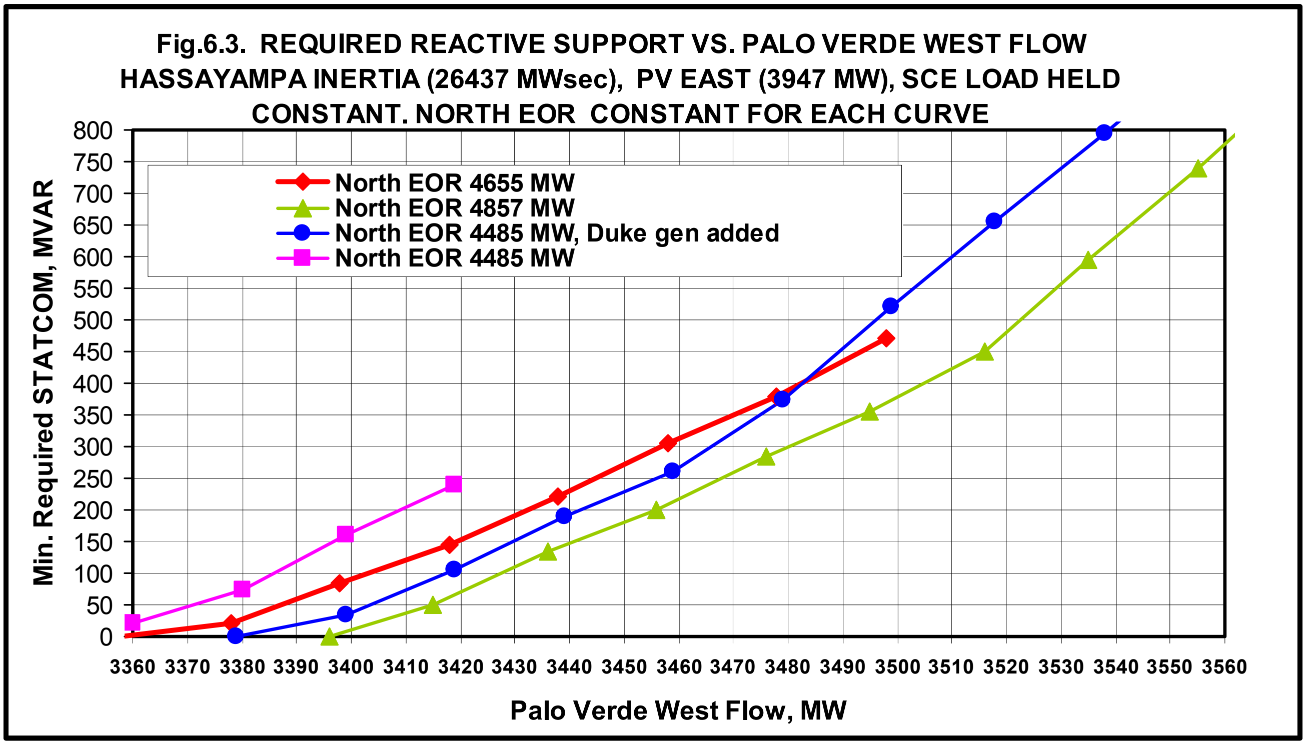
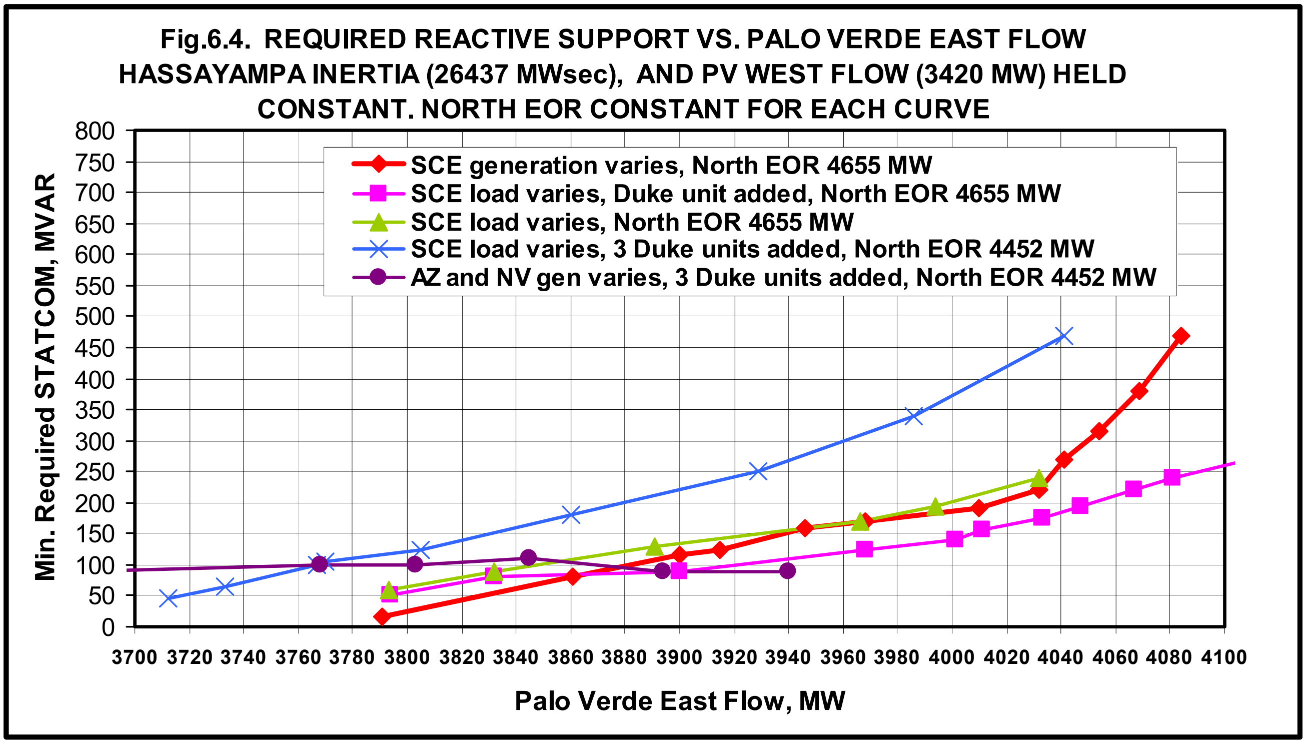


Fig. 6.4 shows the required reactive support versus Palo Verde East flow with the flows on northern EOR and southern EOR held constant. These flows were held constant to examine the impact of the Palo Verde East flow under different conditions, such as different Southern California load and generation dispatches.



As can be seen from the plots, the Palo Verde East flow has some impact, but it is much less than the impact of the Palo Verde West flow and it depends on the North EOR flow level. The required reactive support with the Duke power plant was higher with the same Palo Verde East flow because in these simulations the North EOR was lower, and to maintain the same Palo Verde East flow, the southern California load had to be lower than in the case without this plant.

6.2. Las Vegas to Southern California transfers (Northern WOR)

The northern West of River (WOR) lines include Eldorado-Lugo, Mohave-Lugo, Marketplace-Adelanto, Mc Cullough-Victorville 500 kV lines, as well as 230 kV lines between Eldorado and Lugo and a 287 KV line between Victorville and Mead.

The impact of this flow on the required dynamic reactive support was studied by varying generation in Southern California, Arizona and Nevada. The amount or location of the on-line units was not changed so that inertia would be constant. Only the amount of generation from the units was varied. The results indicate that the reactive support requirement depends on the generation dispatch and on which flows are held constant while varying the Northern WOR flow.

The results of these studies are provided in the following plots.

Fig. 6.5 shows the required reactive support when the Palo Verde West and North EOR flows were held constant. Flows on the North WOR were varied by changing generation in Southern California and adjusting generation at Hassayampa and Nevada so that the flows on Palo Verde West and North EOR would be constant.

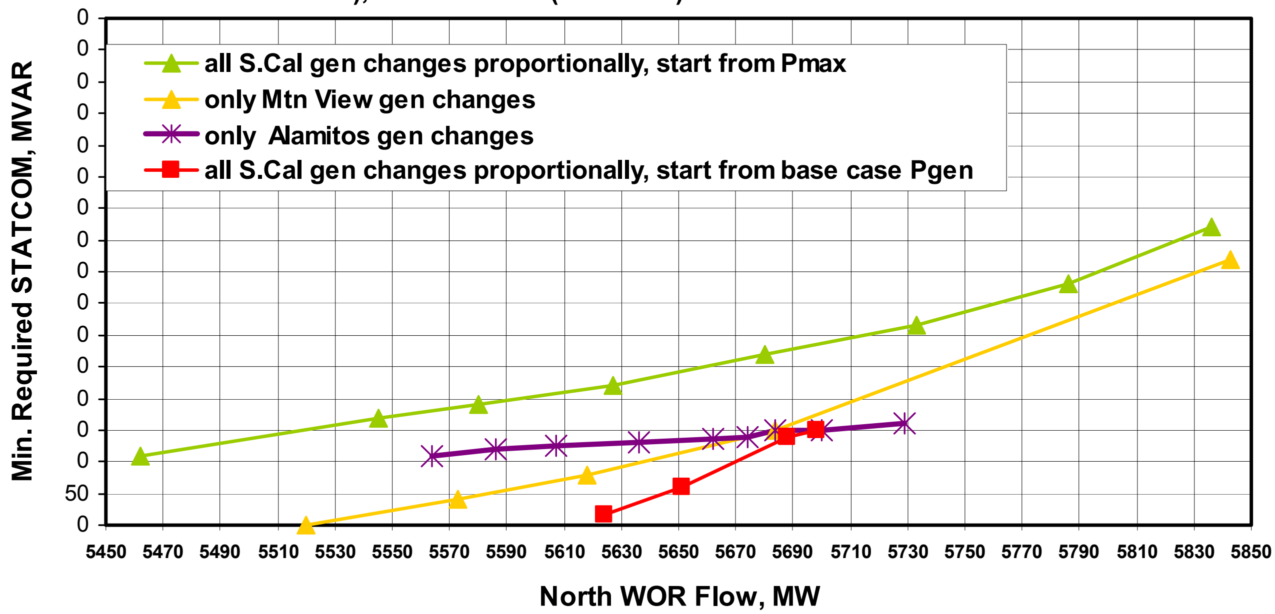
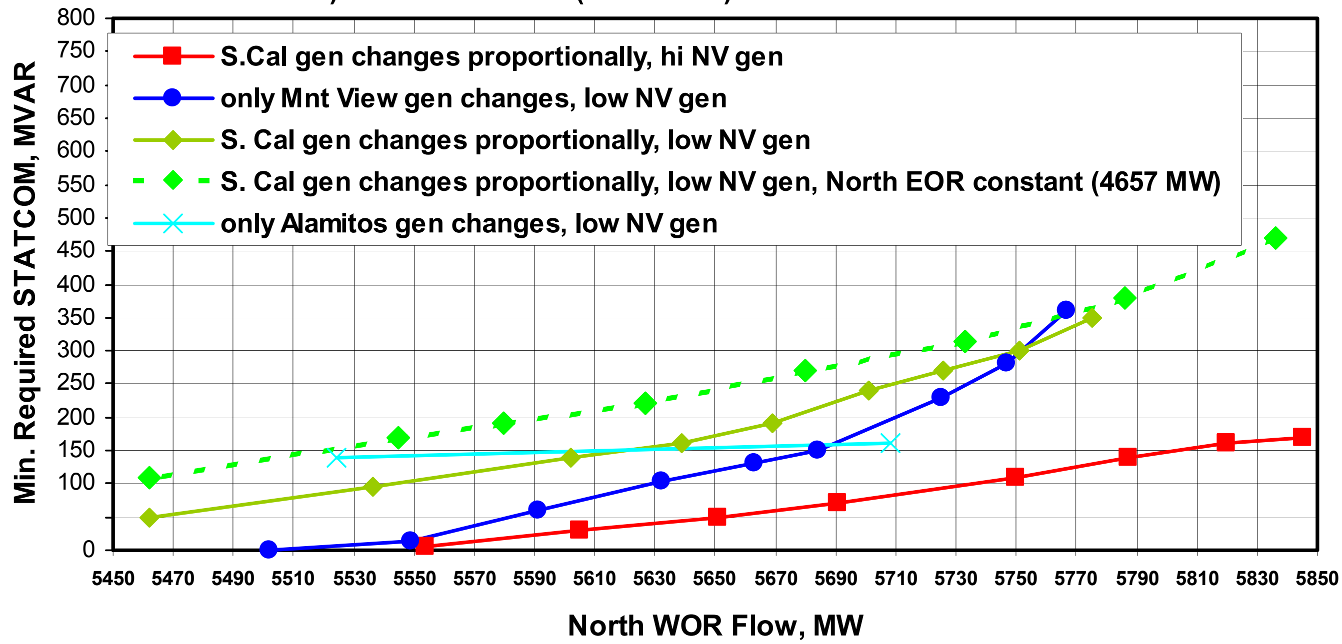


Fig.6.5. REQUIRED REACTIVE SUPPORT VS. NORTH WOR FLOW HASSAYAMPA INERTIA (26437 MWsec), PV WEST (3420 MW), SCE LOAD (13650 MW), NORTH EOR (4657 MW) HELD CONSTANT

As can be seen from the plots, the required reactive support is different with different modeling of the Southern California, Nevada and Arizona generation. The studies identified different amount of required reactive support even with the same North WOR, Palo Verde West and Northern EOR flows, depending on the generation dispatch.

The next figure (Fig 6.6) shows the dependency of the required reactive support on the North WOR flow when the Palo Verde West and Palo Verde East flows are held constant, and the North EOR flow varies. Flows on the North WOR were varied by changing generation in Southern California and adjusting generation at Hassayampa and North Arizona so that the flows on Palo Verde West and Palo Verde East would be constant. For comparison, this figure also includes a curve when the North EOR flow is held constant and the Palo Verde East flow varies.

Fig.6.6. REQUIRED REACTIVE SUPPORT VS. NORTH WOR FLOW HASSAYAMPA INERTIA (26437 MWsec), PV WEST (3420 MW), PV EAST (3947 MW) AND SCE LOAD (13650 MW) HELD CONSTANT



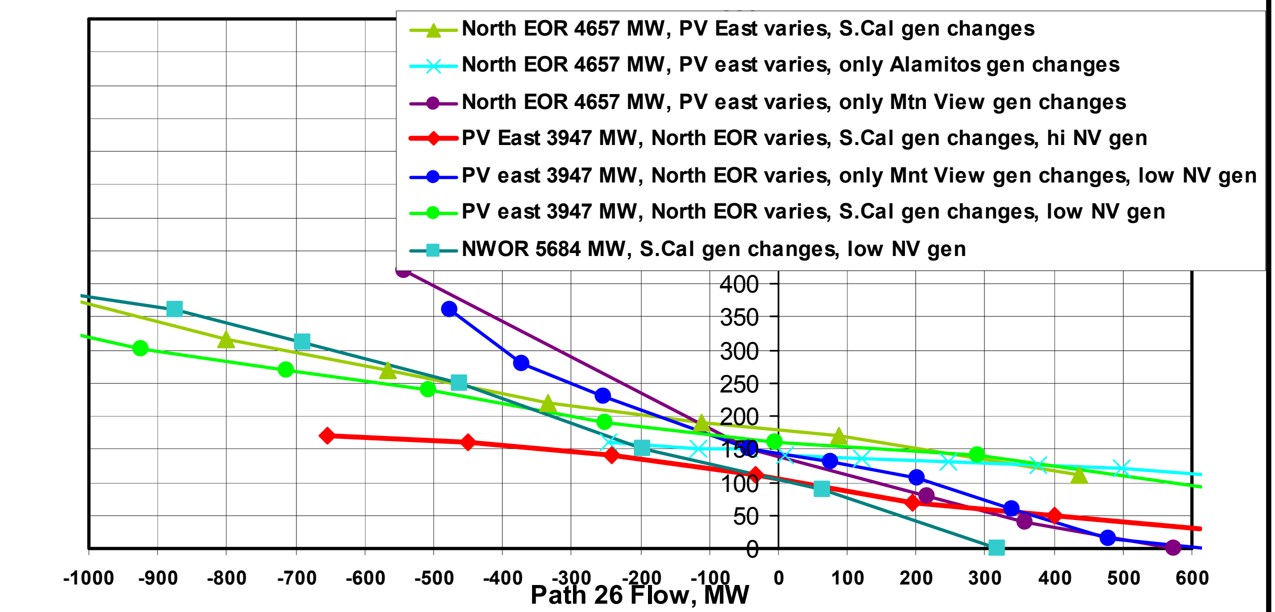
As in the previous simulations, the plot also shows that the required reactive support depends substantially on the generation dispatch and on the flows that are held constant. Dynamic simulations with only Alamitos generation varying and Arizona generation adjusted to hold the Palo Verde West and Palo Verde East flows constant showed that the required reactive support is not very dependent on this generation. The required reactive support was 140 MVAR with the minimum Alamitos generation and North WOR flow of 5524 MW and 160 MVAR with maximum Alamitos generation and North WOR flow of 5708 MW. These results are consistent with the results when North EOR was held constant and Palo Verde East flow was varied (Fig.6.5.)

6.3. Northern California to Southern California transfers (Path 26)

As in the previous study, the impact of Path 26 (Midway-Vincent) flow was studied by varying generation in Southern California, Nevada and Arizona. Flow on the Palo Verde West lines was held constant. The inertia of the Hassayampa generation was also held constant, since the same units were modeled in all the cases. To eliminate the impact of reactive support and inertia, no generation units were added or removed in this study, only their output was changed. To eliminate the impact of load, no loads were changed.

The study showed that the required reactive support was substantially impacted by the generation dispatch. The required reactive support depended more on which generation was varied than on which flows (Palo Verde East or North EOR) were held constant. The results of this study are shown in Fig. 6.7. Path 26 flow has positive sign in the North-to-South direction. As can be seen from the plots, the higher the flow in the south-to-north direction, or the longer the distance that the power from the Arizona plants is transferred, the higher the required reactive support.

Fig.6.7. REQUIRED REACTIVE SUPPORT VS. PATH 26 FLOW HASSAYAMPA INERTIA (26437 MWsec), PV WEST (3420 MW), SCE LOAD HELD CONSTANT



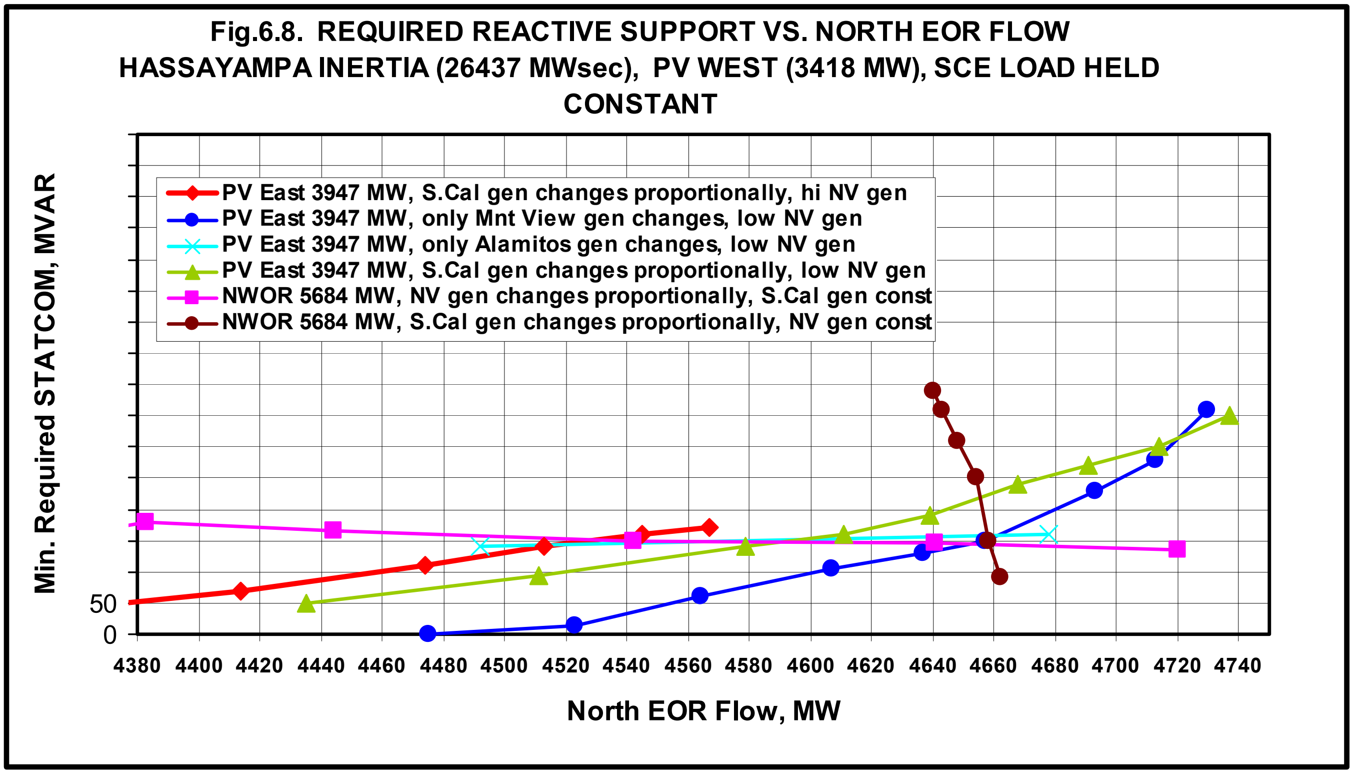
6.4. Pacific DC Intertie to Southern California transfers (Path 65)

The impact of the Pacific DC Intertie on the required reactive support was studied by changing scheduled power on the DC Intertie. However, if nothing else except for DC schedules changed, this caused only redistribution of flow between the Pacific DC Intertie, Path 26 and COI. No impact on the required reactive support was identified. Therefore, if flow from Northern to Southern California is included in a new nomogram, flow on the Pacific DC Intertie should be added to the Path 26 flow.

6.5. Arizona to Nevada transfers (Northern EOR)

The northern EOR lines include the Navajo-Crystal, Eldorado-Moenkopi, Perkins-Mead and Liberty-Peacock lines.

To exclude the impact of load and inertia, the load and the amount of generation units on-line were held constant in all the simulations. The flow on the Palo Verde West lines was also held constant to exclude the impact of this factor. Dynamic stability simulations of the Hassayampa-North Gila outage were run with the Palo Verde East flow held constant, as well as with the North WOR flow held constant. The results are shown in Fig. 6.8.



As can be seen from the plot, the required reactive support depends more on the generation dispatch than on the North EOR flow. With the same northern EOR flow the required reactive support may be substantially different, depending on the generation levels at Hassayampa, in Southern California, and in Nevada.

Conclusion

The Palo Verde West flow has the highest impact on the required reactive support. The Palo Verde East flow has some impact, but it is lower than impact of the Palo Verde West flow and depends on which other flows are held constant. Impacts of the North WOR, North EOR and Path 26 flows substantially depend on the modeling assumptions and most likely would not be reliable factors in developing the new nomogram of the transfer limits from Arizona to Southern California if they were considered alone. Possible factors for the new Arizona-Southern California transfer nomogram for the dynamic stability may be the flow on the Palo Verde West lines, combined flow to the Southern California from the North (North SCIT) and the Palo Verde East flow.

7. Sensitivity to System Modeling

As the studies showed, the required reactive support can be different depending on the load and the generation dispatch, even if the flows on the major paths are the same. The following figures further illustrate this point. In these studies, the generating units on-line in California and Arizona were modeled the same in all the cases. Thus, inertia was held constant. The flows on the northern and southern (Palo Verde West) EOR lines were also held constant. The flows on the other paths varied by changing either the generation dispatch or Southern California load.

In the studies illustrated in Fig. 7.1, the flow on the Palo Verde East lines was varied by changing either the generation in different areas or the load in Southern California. The northern EOR flow was held constant. Duke's power plant at Harry Allen in Nevada was added to the base case in order to allow more variance in the flows.

The plot shows that under the conditions modeled, the required dynamic reactive support does not depend on the Palo Verde East flow if only the generation dispatch in Nevada and Arizona changes and the load and generation in California is held constant. However, the reactive support depends on the Southern California load and generation dispatch. Even with the same flows on the major transmission lines (Palo Verde West, Palo Verde East, EOR), the required reactive support is different depending on the generation level in north Arizona (Glen Canyon and Navajo power plants) and on the Southern California load and generation. As can be seen from the plots, this difference can be as large as 300 MVAR.

Fig.7.1. REQUIRED REACTIVE SUPPORT VS. PALO VERDE EAST FLOW HASSAYAMPA INERTIA (26437 MWsec), NORTH EOR (4452 MW)AND PV WEST FLOW (3420 MW) HELD CONSTANT. Duke power plant at Harry Allen modeled

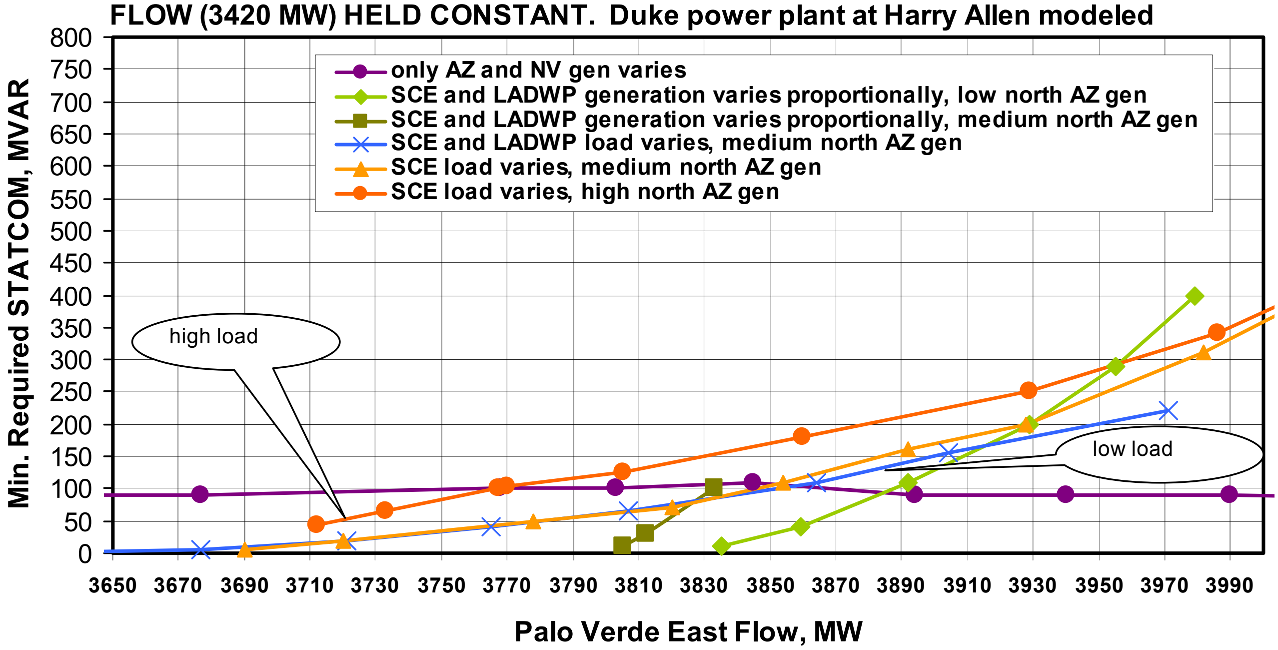


Fig. 7.2 illustrates the required reactive support versus North WOR flow under the same conditions: constant inertia, North EOR and Palo Verde West flows. As can be seen from the plots, the required reactive support depends substantially on the modeling assumptions and may be different even if the major flows are the same.

Fig.7.2. REQUIRED REACTIVE SUPPORT VS. North WOR FLOW HASSAYAMPA INERTIA (26437 MWsec), NORTH EOR (4452 MW)AND PV WEST FLOW (3420 MW) HELD CONSTANT. Duke power plant at Harry Allen modeled

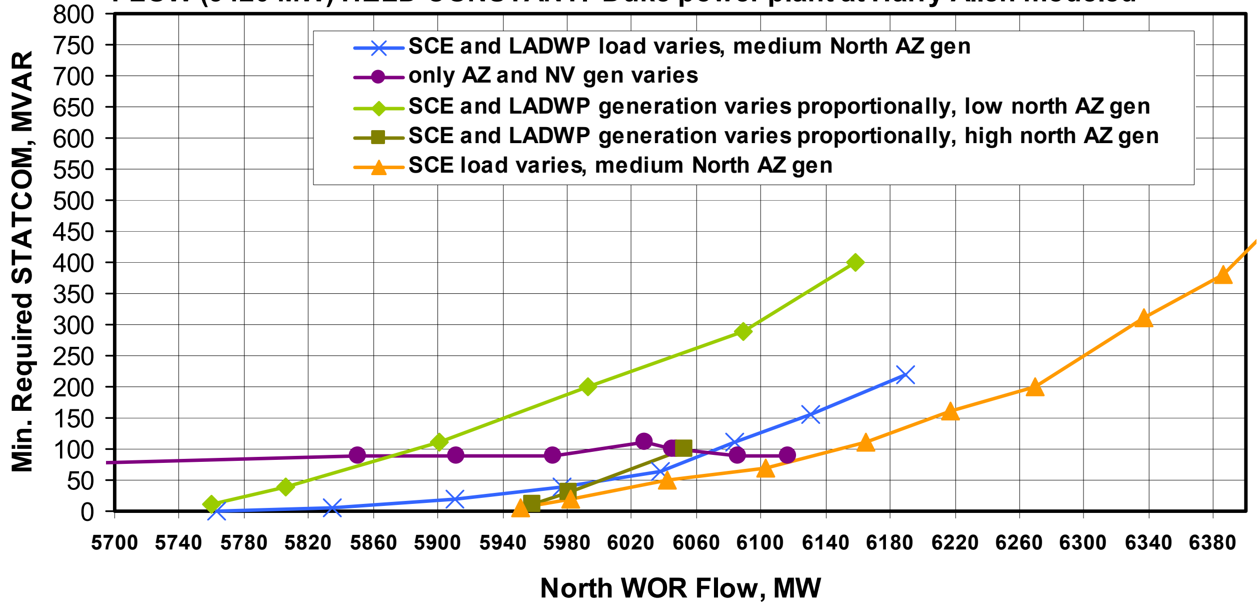
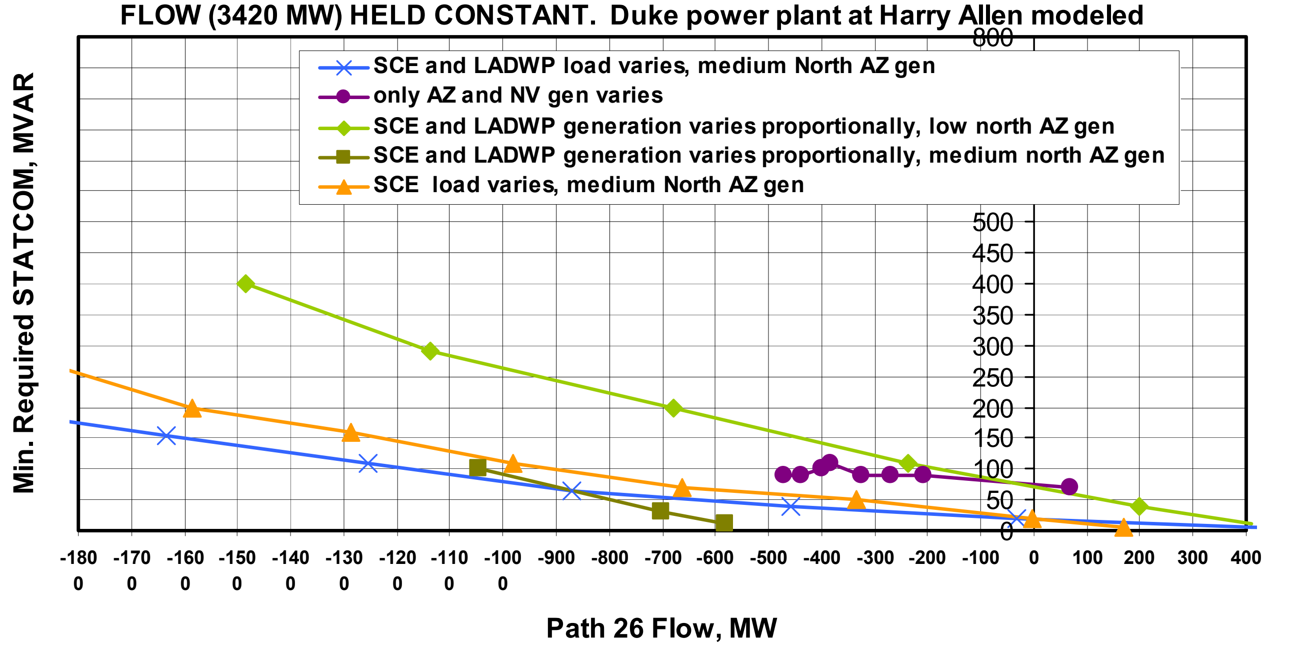


Fig. 7.3 illustrates the same concept with regard to Path 26 flow.

Fig.7.3. REQUIRED REACTIVE SUPPORT VS. PATH 26 FLOW HASSAYAMPA INERTIA (26437 MWsec), NORTH EOR (4452 MW)AND PV WEST FLOW (3420 MW) HELD CONSTANT. Duke power plant at Harry Allen modeled



Conclusion

Required dynamic reactive support is impacted by variety of factors and substantially depends on the system modeling (load and generation dispatch). There are other factors impacting the system dynamic stability performance in addition to the Palo Verde West, Palo Verde East, Path 26, West and East-of-River flows and the machine inertia.

8. Conceptual Nomogram of the Arizona-Southern California Transfers

Based on the results of the dynamic stability studies, the main principals for the nomogram for the transfers from Arizona to Southern California were developed. It should be noted that this nomogram will only be valid for dynamic stability, there may be more limitations based on thermal overloads or post-transient violations.

As the studies described in this report showed, the main factors that impact the need for dynamic reactive support are:

1) Power transfer from Palo Verde and Hassyampa (Palo Verde West flow),
2) Machine inertia of the Palo Verde/Hassayampa/Gila River generators plus one-half of the inertia in the rest of Arizona.
3) Flow to Southern California from the north (to identify how far the power from Arizona is transferred).
4) Palo Verde East flow (to identify the stress on the sending end of the system).

Although other factors have some impact, such as reactive support from the on-line units in Southern California, the studies indicate that this impact is less significant. Dynamic stability simulations of the Hassayampa-North Gila outage were performed with the assumption of a 600 MVAR SVC at the Devers 500 kV bus and a variety of other assumptions regarding California, Arizona and Nevada load and generation. A 600 MVAR SVC was chosen as the California ISO recommendation based on the results of these studies.

The studies showed that the most reasonable values to be chosen as the independent variables, and thus axis values for the nomogram, would be: Palo Verde West flow, machine inertia at Hassayampa plus one-half of the machine inertia in the rest of Arizona, North SCIT flow (which includes all the SCIT flows minus the flows from Palo Verde and Imperial Valley) and Palo Verde East flow. Other values studied and rejected as the basis for the nomogram were: south of Lugo flow, flow on the Northern West-of-River lines, Path 26 together with the Pacific DC Intertie flow, flow on the eastern SCIT lines, and North East-of-River flow. The reasons for not including these values were that they either did not significantly impact the voltage dip at Devers (for example, North EOR flow) or because these flows alone were not sufficient to develop the full nomogram (for example, including only Path 26 and PDCI flows were not sufficient without including flow on the transmission lines from Las Vegas to Los Angeles).

During the simulations, changes in the flows were modeled by varying Southern California, Arizona and Nevada load and generation. The study results are summarized in Fig. 8.1.

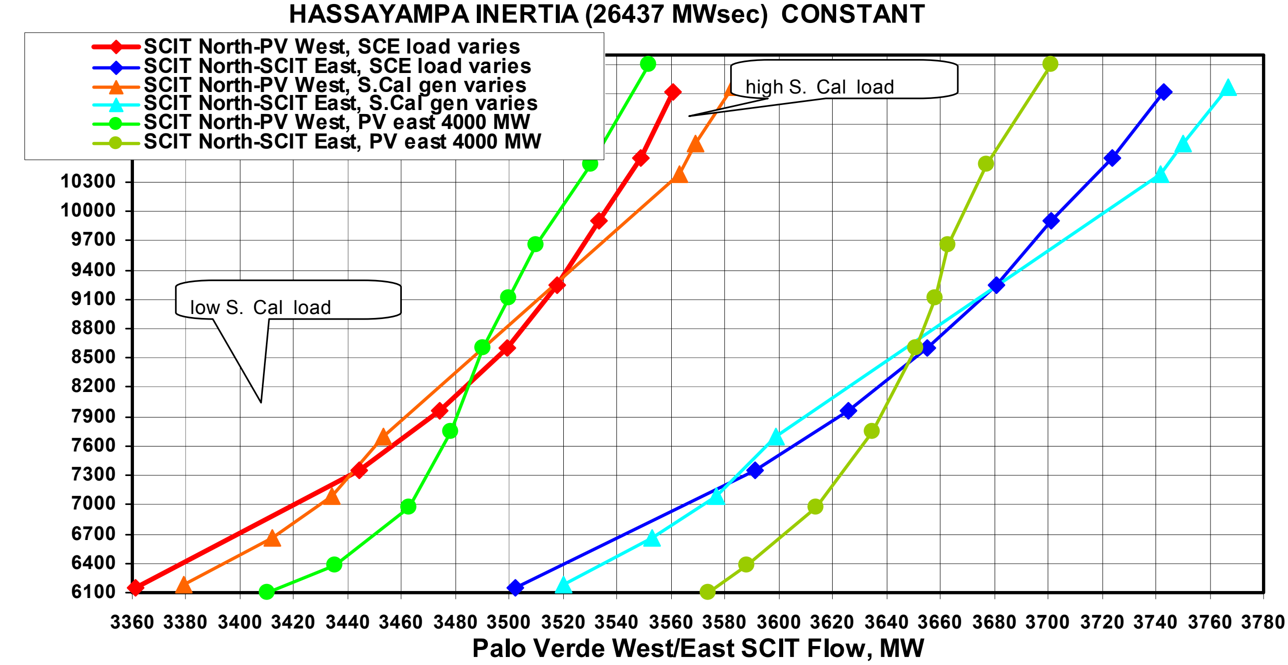


Fig.8.1 NOMOGRAM PALO VERDE WEST/ NORTH SCIT HASSAYAMPA INERTIA (26437 MWsec) CONSTANT

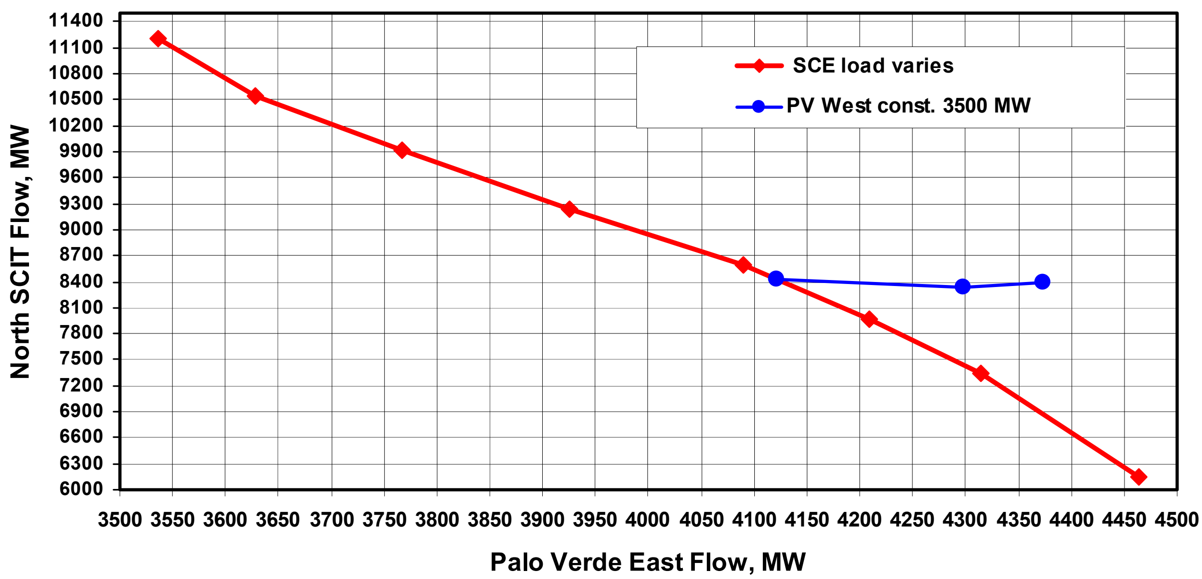
Plots in Fig. 8.1 shows a slight difference in the nomogram boundary depending on whether load or generation is varied. The same figure also shows that one of the nomogram axis could be either Palo Verde West flow or the combined flow on the eastern SCIT lines (Palo Verde – Devers, North Gila-Imperial Valley 500 kV lines, Julian Hinds-Mirage, El Centro-Imperial Valley, Ramon-Mirage and Coachella-Valley 230 kV lines). To simplify the nomogram, it is recommended to select only Palo Verde West (Palo Verde – Devers and Hassayampa-North Gila 500 kV) line flow as the nomogram axis.

The dynamic stability simulations were performed with the Palo Verde East flow varying (generation in northern Arizona and Nevada were held constant), as well as with the Palo Verde East flow held constant by adjusting Nevada and northern Arizona generation. As can be seen from Fig. 8.1, the dependency between the Palo Verde West and North SCIT flows would be different with the different Palo Verde East flows. Therefore, the Palo Verde East flow should be also considered in developing the nomogram even if its impact is smaller than the impact of the Palo Verde West flow.

It should be noted that in Fig. 8.1, the operational area (where would be no criteria violations) is above the curves (i.e., the area where the Palo Verde West flow would be lower and North SCIT flow would be higher). The existing SCIT/EOR nomogram has an operational area below the nomogram boundaries, which means that if the existing SCIT/EOR nomogram were used, both EOR and SCIT flows should be lower than the nomogram boundaries.

The next figure shows dependency between the Palo Verde East and North SCIT flows. As can be seen from the plots, with the Palo Verde West flow constant, there is no correlation between the North SCIT and the Palo Verde East flows.

Fig.8.2 NOMOGRAM PALO VERDE EAST/ NORTH SCIT HASSAYAMPA INERTIA (26437 MWsec) CONSTANT



The curve showing dependency between the North SCIT and Palo Verde East flows is really a result of Palo Verde West flow varying as a result of changes in Southern California load.

Figure 8.3 shows dependency between the Palo Verde West and Palo Verde East flows. As can be seen from the plots, and as mentioned earlier, there is only a slight difference in the nomogram depending on Southern California load or generation dispatch.

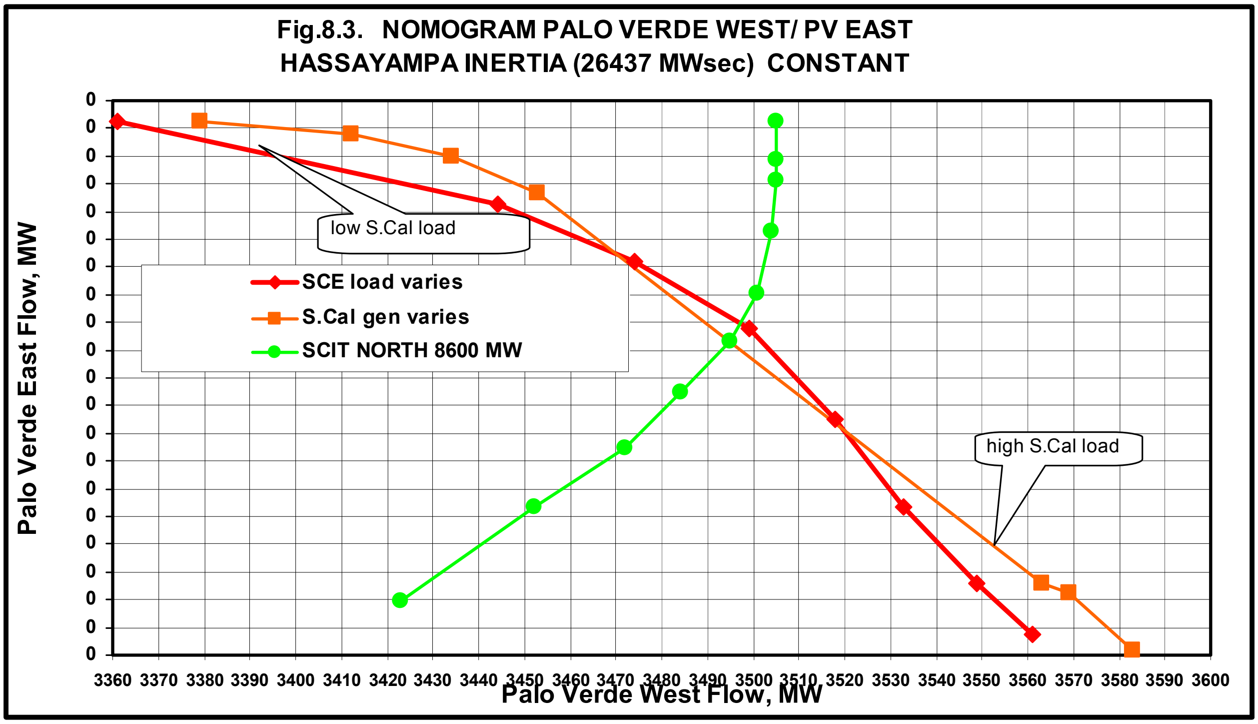


Fig.8.3. NOMOGRAM PALO VERDE WEST/ PV EAST HASSAYAMPA INERTIA (26437 MWsec) CONSTANT

The dependency is significantly different if the North SCIT flow is held constant. If only Southern California load or generation varies, and the load and generation in Nevada and northern Arizona is constant, with an increase in load, both Palo Verde West and North SCIT flows increase. In this case, the higher the Southern California load, the higher the Palo Verde West flow and the lower the Palo Verde East flow since generation and load east of Palo Verde is held constant. However, if the North SCIT flow is held constant, an increase in the Southern California load will require an even higher Palo Verde West flow, therefore higher generation at Hassayampa, part of which will go east increasing the Palo Verde East flow. With the North SCIT flow constant, the operational area (where would be no criteria violations) is above the green curve, and with the North SCIT flow varied, it is below the red curve.

It should be also noted that there is a dependency between the flows and thus the nomogram is non-linear. This point is illustrated in the following figure.

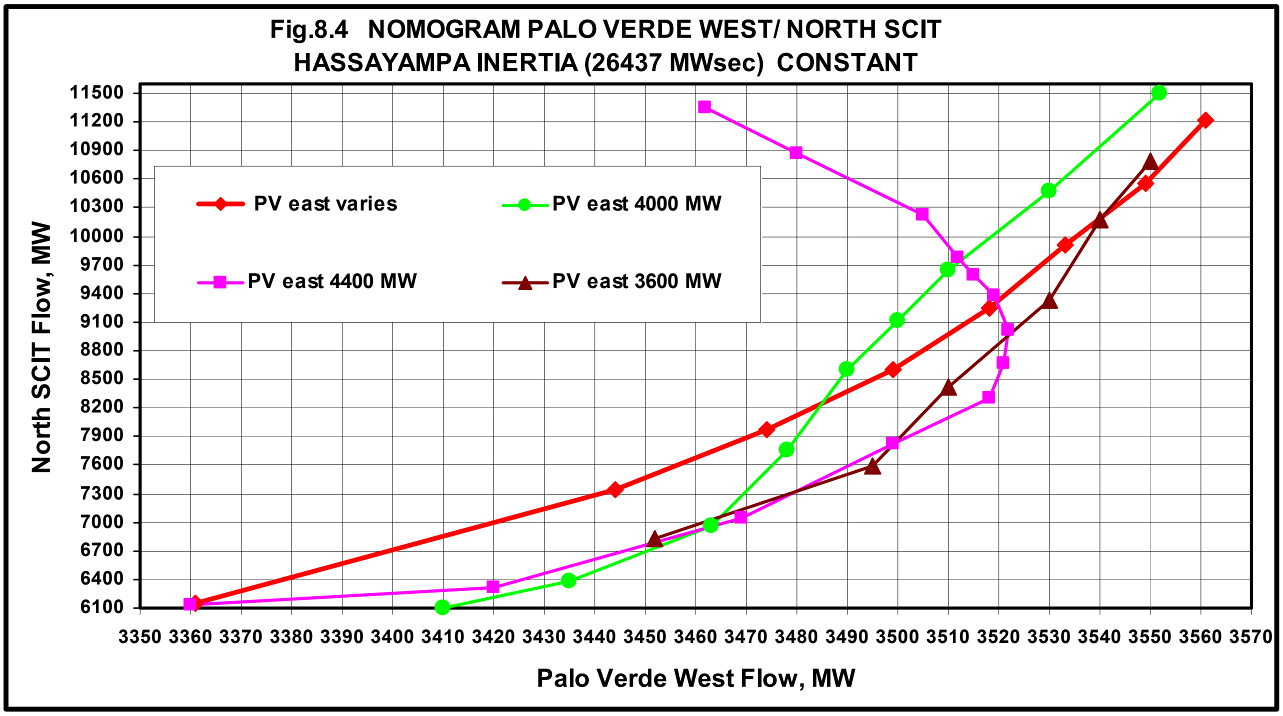


Figure 8.4 shows dependency between the Palo Verde West and North SCIT flows with different Palo Verde East flows. To hold the Palo Verde East flow constant, generation and load in Nevada and northern Arizona were adjusted. Changes in the North SCIT flow were modeled by changing Southern California load. As can be seen from the plots, with low Palo Verde West flow, the dependency is close to linear. With an increase in Southern California load and with high Palo Verde East flow (high northern Arizona and Nevada load or low generation), at some point the Palo Verde West flow needs to be decreased to avoid the dynamic stability criteria violations because the system is so stressed that the power from Palo Verde and Hassayampa cannot be delivered in both west and east directions. High Southern California load should be compensated more from the north than from the east in this case (see the curve with 4400 MW Palo Verde East flow). With low Palo Verde East flow (low Nevada and Arizona load or high Nevada and Northern Arizona generation), an increase in the Southern California load is covered both from the east and from the north without the need to limit the Palo Verde West flow due to the criteria violations.

To summarize the studies, it can be concluded that the Arizona-Southern California transfer nomogram is very complicated due to the many factors involved and due to the non-linearity of these factors. The nomogram can be developed using the four factors mentioned above (Palo Verde West, North SCIT and Palo Verde East flows and Arizona machine inertia). For a certain level of inertia, a three dimensional nomogram of the Palo Verde West, north SCIT and Palo Verde East flows can be developed. However, due to the non-linearity it will have a very complicated form. The nomogram also can be developed as two-dimensional series of curves, for example dependency between Palo Verde West and north SCIT flow with different levels of the Palo Verde East flow and Arizona machine inertia. To simplify the nomogram, the Palo Verde West and Palo Verde East flows can be combined in one value. However, with the North SCIT flow held constant, the impact of the Palo Verde West flow is approximately from three to 12 times higher than the impact of the Palo Verde East flow. Therefore, the nomogram value axis can be represented approximately as Palo Verde West flow plus 20% of the Palo Verde East flow. Such a representation would be very approximate, since impact of the Palo Verde West and Palo Verde East flows is significantly non-linear.

It should be noted that impact of the Palo Verde East flow was substantially smaller in the case when the North EOR flow was held constant (see section 6.1, Fig. 6.2) than when the North SCIT flow was held constant. It can be explained by the fact that the Palo Verde West, Palo Verde East, North EOR and North SCIT flows are interdependent. With increase in the Hassayampa generation, and thus increase in the Palo Verde West flow, also Palo Verde East and North EOR flows increase and North SCIT flow decreases. To hold the North EOR flow constant in the studies, Nevada generation was increased. It caused decrease in the Palo Verde East and North SCIT flow and increase in the Palo Verde West flow. If not North EOR, but North SCIT flow is held constant, to bring the North SCIT flow back to the value before the increase in the Hassayampa generation, Southern California generation need to be decreased. This causes increase in the North EOR flow and Palo Verde West flow and decrease in the Palo Verde East flow. This is why the impact of the Palo Verde East flow is much higher in the case when the North SCIT is held constant than when the North EOR held constant.

This way, the nomogram will represent a series of curves with different levels of machine inertia. It should be noted that machine inertia in this case would be machine inertia at Palo Verde and Hassayampa plus 50% of inertia in the rest of Arizona.