APPLICATION OF EIGENANALYSIS TO THE WESTERN NORTH AMERICAN POWER SYSTEM

Yakout Mansour, Senior Member
Powertech Labs Inc. (A B.C. Hydro Subsidiary Company)
Surrey, B.C., CANADA

ABSTRACT

This paper describes the application of new developments in the area of eigen analysis to identify the nature and sources of interarea oscillations observed recently in some parts of the Western System Coordinating Council network. The procedure is described and the results of the eigen analysis are confirmed by time simulation.

KEYWORDS

Eigen Analysis, Eigen Values, Linear Analysis, Frequency Domain Analysis, Dynamic Stability, Small Signal Analysis, Interarea Oscillations, Low Frequency Oscillations.

INTRODUCTION

Interarea oscillations drew the attention of the utility industry in the late 1960's and early 1970's with the extended implementation of the long distance EHV transmission, heavy power transfer, and modern static exciters. The latter contributed to the deterioration of the system damping. As a result, damping devices such as power system stabilizers and, more recently, static VAr compensators were widely applied.

The operating characteristics of many power networks around the world, in general, and most of the North American networks, in particular, have been changing considerably over the last two decades [1]:

1- Economic constraints associated with the price of energy production and capital investment made it attractive to transfer massive amounts of energy across utility borders. Now, more than 40% of the power generated by major utilities is sold to other utilities. Moreover, power transfer among utilities have more than doubled since 1971.
2- Investments in transmission seems to be the hardest to justify. Between 1975 and 1987 load growth of the NERC utilities was more than 50%, new generation was 48%, and transmission grew only 13%. In some regions, the transmission is now fully loaded 95% of the time.
3- The figures are not expected to be any better in the near future. Load growth is outpacing expansion: many systems reported 5 to 10% load increase last year and 19 utilities reported more than 10%. Meanwhile, system expansion plans are not calling for any thing close to these figures.

The stressed nature of nowadays power system networks, described above, reflected clear finger prints on the operating characteristics in the form of transient stability, dynamic stability, and voltage stability limitations to mention a few. The WSCC interconnected network is no exception and was, in fact, one of the earliest networks alerted by low frequency interarea oscillations over its major tielines. Over time, with the continuing stressing of the tielines, the natural expansions, and the implementation of new controllers, the dominant frequencies of oscillation have been drifting in magnitude and damping showing problem modes from time to time. Recently, modes around 0.7 Hz have been showing strongly in planning studies on major tielines especially in the southern networks in California and Arizona. These oscillations have been representing significant limitations on power transfer among those utilities. A work group has been formed to study the nature and the sources of these oscillations and recommend solutions.

The work reported in this paper shows the progress of part of the investigations using an eigen analysis approach. It should be strongly emphasized here that none of the published results indicate any deficiency in any utility's procedure to damp interarea oscillations. Rather, it is the result of a constructive collective effort by member utilities to identify and resolve a problem.

The WSCC STUDY

The WSCC study reported here is based on the 1988 heavy winter base case. The system model includes over 2300 buses, 4300 branches, 291 fully represented generators (including all main and supplementary controllers), 84 classical generator models, and 3 D.C. lines. The number of state variables in this case is close to 4000. The scope of the study is summarized below:

1- Identify the modes of oscillation corresponding to frequencies around 0.7 Hz.
2- For every mode of interest, examine the damping, the mode shape, and the relative participation of the various machines.
3- Identify the factors contributing negatively to system damping at the modes of interest.
4- Recommend remedial measures to improve system damping.

The study is scheduled to conclude in March, 1990. Therefore, the results reported here should be interpreted as progress rather than final.

The computational tools used in this study are:

1- B.C. Hydro's modified version of EPRI's Dynamic Equivalencing Program "DYNEQU3". This package is capable of providing reduced order dynamic equivalents for large system models of up to 12000 buses including full representation of generators, main and supplementary control devices.
2- EPRI's Multiple Area Small Signal Analysis Program "MASS" [2]. This program is capable of calculating all the eigen values, eigen vectors and participation vectors for systems of up to 500 state variables.
3- EPRI's Program for Eigen Analysis of Large Systems "PEALS". This program calculates one eigen value at a time for systems of up to 22000 state variables. The program uses an initial condition for the mode

of oscillation to iteratively converge to the correct mode by minimizing the torque equation of a perturbed generator which is highly participating in this mode. Both the initial value and the perturbed generator are defined by the user as will be explained later.

4- Ontario Hydro's Partial Eigen analysis of Large Power Systems "PELPS". This program is capable of calculating a set of eigen values around a certain mode, defined by the user, using the Anoldi's Method.

5- Power Technologies Inc. (PTI) PSS/E power system simulation package.

RESULTS

The Reduced Order System Model

In order to accurately identify all the modes in the neighbourhood of 0.7 Hz using PEALS or PELPS, it is important to determine reasonable initial guess' for the eigen values associated with the modes of interest and the machines (or groups of machines) highly participating in these modes. The dominant inertial eigen values of the system were scanned using the MASS program. DYNEQU3 was used to reduce the order of the study system to within the MASS capability (500 states). Since the modes of interest are primarily inertial, only machine dynamics were included, i.e. all controls were excluded. Moreover, system loads were represented by constant impedance for both active and reactive components. The desired reduction was achieved by limiting the angle tolerance on the coherent grouping of the dynamic aggregation to 3 degrees. The coherency of the groups of machines was based on a simulated fault at Table Mountain bus which is known to excite oscillation frequencies around the modes of interest. Table 1 shows all the eigen values corresponding to frequencies of oscillation of less than 1 Hz. in the reduced order model. If one wishes to limit the detailed investigation to the frequencies reasonably close to 0.7 Hz, then modes #5-8 would be a good start (0.59, 0.67, 0.7, and 0.76 Hz respectively). The close proximity of the four modes identified alerts the analyst to the challenge expected in tracking the drift in each mode as the system conditions change and also suggests excluding the Fourier Transform based techniques in analyzing simulation results unless the simulation time is exceptionally long.

The Full System Model

The information obtained from the analysis of the reduced order model were used to zoom on the corresponding modes in the full system model using PEALS and/or PELPS. In order to be able to correlate the changes in system damping to specific factors, variations in the modelling details and system conditions were studied one at a time. Table 2 summarizes the results of four cases with variety of modelling details but with normal system conditions. Only those modes between 0.6 and 0.8 Hz are shown. Case #1 included the machine dynamics excluding the dynamics associated with main controls, supplementary controls and D.C. lines. System loads were represented as constant current for the real part and constant impedance for the imaginary part. The D.C. lines were replaced by positive and negative injections at the rectifier and the inverter ends respectively. When excitation dynamics were included, damping was severely reduced but then was considerably improved when the supplementary stabilizing controllers (PSS's) were included. Governor dynamics did not have any noticeable effects on damping. Case #2 shows the effect of exciters, PSS's and governors on system damping at the modes of concern. Comparing the results of case #2 to those of case #1, it is clear that even though PSS's were tuned to provide maximum damping at a much lower frequency (0.3 Hz), the effect at the frequencies around 0.7 Hz is still considerably positive. This conclusion eliminates some suspicions among member utilities that PSS settings may not be covering reasonably wide range of frequencies.

The quantitative effect of load modelling was investigated by changing the representation of the real part in case #2 from constant current to constant impedance. The results are shown under case #3: The 0.6 Hz mode damping increased by about 25%, the 0.76 Hz mode shifted to 0.78 Hz and damping increased by about 25%, the 0.765 Hz mode shifted to 0.78 Hz and damping increased by about 20% while the 0.78 Hz mode shifted to 0.75 Hz with virtually no change in damping.

Case #4, compared to case #2, shows the effect of D.C. line control: The results show negative effect on system damping at some of the modes, more noticeably at 0.756 Hz. The D.C. line control in the system model in case #4 represents constant power control while the static representation in case #2 represents an ideal constant current control. Thus, the D.C. line control as it exists in the system model has a negative effect on system damping around the mode of concern.

Two different contingencies have been reported to be causing poorly damped or undamped oscillations in planning studies: 1) A fault at Palo Verde 500 kV bus (Arizona) followed by tripping the 500 kV line between Palo Verde and Devers, or 2) Loss of the Pacific D.C. Intertie. It wasn't clear, however, whether the oscillations are caused by nonlinearities due to combination of system stress and the severity of the disturbance or is it the lack of damping in the post contingency system.

Table 3 shows the eigen values of the system under abnormal conditions:

Case #5 shows the eigen values of the system with Palo Verde - Devers line out of service. Compared to case #4, the 0.756 Hz mode shifted down to 0.72 Hz with more than 60% reduction in damping. The other three modes have virtually not been affected. The contribution of the D.C. control to the poor damping in this case was examined by replacing the D.C. line flow by ideal constant current injections and the results are shown under case #6 in Table 3. Comparing the results of case #6 to those of Cases #2 and #4, it is concluded that the D.C. control contribution to the poor damping of case #5 is more than that due to the additional stress of the system caused by the loss of the transmission line.

The eigen values of the system with the Pacific D.C. Intertie out of service is listed under case #7 in Table 3. Again, compared to case #4, the same mode identified in case #5 is associated with poor damping. A further stressed case was created by applying the two contingencies at the same time: tripping the Palo Verde - Devers line and blocking the Pacific D.C. Intertie. The results are shown as case #8 in Table 3. Now, the problem mode shifted down to 0.68 Hz and became negatively damped. Again, the other modes were virtually unaffected.

Tables 4, 5 and 6 shows the dominant machines in the eigen and participation vectors associated with the poorly damped mode in cases #5, 7, and 8 respectively. The mode, in all three cases, is dominated by the PG&E area against some machines in Utah, New Mexico, Southern California, and Arizona. It is also interesting to note that out of all the North Western System, only one plant in British Columbia is strongly participating in this mode. It should also be noted here that this phenomenon is well recognized in the day to day system experience. Figures 1, 2, and 3 show the shapes of the modes associated with cases #4, 5, and 7. The mode shapes associated with case #8 is very similar to those of case #7 and, therefore, were not listed. The "+" and "-" signs indicate antiphase swing, "0" indicate no participation, and "+ -" indicate antiphase oscillation within the same area. Because of the distinct characteristics of the mode shape of the Kemano machines w.r.t. the B.C. Hydro system, British Columbia is represented as two parts in these figures. Also, because of the physical distance and the load concentration in the north and south parts of California, the Californian network is represented as two parts: PG&E in the north and Los Angeles Department of Water and Power (LADWP), Southern California Edison, and San Diego Power & Light in the south.

Time Simulation Results

The contingencies described earlier were simulated using a time simulation package (PSS/E). Figure 4 shows the response of machines in British Columbia, Utah, PG&E, and Arizona to a 4 cycle fault at Palo Verde 500 kV bus without line tripping. Figure 5 shows the response to the same fault followed by tripping the Palo Verde - Devers line. Figure 6 shows the response to blocking the D.C. Intertie while the Palo Verde - Devers line is out of service. Visual examination of the damping in Figures 4, 5, and 6 shows close relative correlation to the eigen analysis of cases #4, 5, and 8 in Table 3 in spite of the presence of the nonlinearities associated with the initiation of the disturbance. Furthermore, a 1400 MW-1 second pulse at Chief Joe 500 kV bus (BPA) was simulated to test the response of the normal system and the post contingency system configuration corresponding to cases #5 and #8. The results are shown in Figures 7-9. Again, the results visually correlate very well to those obtained by the eigen analysis. Also, note that the Helms machine (PG&E) oscillates in antiphase with the other machines as indicated by the mode shapes in Tables 4-6. Thus, based on the foregoing analysis, it is clear that the lack of damping is associated with the post contingency system and is well explained by linear analysis.

These results were further confirmed by an independent study conducted at the Salt River Project to investigate corrective actions to improve the system damping at modes around 0.7 Hz. The study showed that an SVC located between the two groups of machines identified as the two ends of the eigen vectors of Tables 4-6 and tuned to damp 0.7 Hz oscillations would have a superior effect compared to other locations out of the boundaries of the identified areas. The details of this study are out of the scope of this publication and will be the subject of a separate one.

CONCLUSION

Eigen analysis proved to be invaluable in identifying the frequencies, the damping, the shape and the participation of the individual machines in the 0.7 Hz modes which have been representing major limitations on the WSCC system operation. The close proximity of the modes identified in the neighbourhood of the frequency of concern leaves little doubt that other frequency response based techniques could reliably and efficiently analyze the problem.

The Small Signal Analysis Software Package developed recently under an EPRI project proved to be an invaluable tool in analyzing the problem.

REFERENCES

[1] John E. Koeler, "Keynote", Proceedings: Bulk Power System Voltage Phenomena - Voltage Stability & Security, September,1988.

[2] Small Disturbance Stability Analysis Program Package Development, EPRI RP2447-1, Final Report, November,1987.

BIOGRAPHY

Yakout Mansour was born in Alexandria, Egypt in 1947. He obtained his B.Sc. in electrical engineering from the University of Alexandria, Egypt in 1971 and the M.Sc. in electrical engineering from the University of Calgary, Alberta, Canada, in 1977. His engineering practice included 4 years of utility experience in Egypt, 2 years of consulting experience with the Montreal Engineering Co., Calgary, Alberta, Canada, 10 years of system planning experience with B.C. Hydro before moving to Powertech Labs Inc. (A B.C. Hydro subsidiary company) in his present capacity as manager of System Analysis and Control.

Mr. Mansour is a senior member of IEEE, member of the Power Engineering Committee, member of the System Dynamic Performance Subcommittee, chairman of the Working Group on Voltage Instability, and member of the Task Force on Dynamic Load Modeling, all of the IEEE. He also serves as a member of several working groups and project advisor for the Canadian Electrical Association, the Electric Power Research Institute, and the Western System Coordinating Council.

Mr. Mansour is a registered professional engineer in the Provinces of British Columbia, and Alberta, CANADA.

Table 1
LOW FREQUENCY MODES
REDUCED ORDER SYSTEM MODEL

EIGEN VALUE	FREQUENCY (Hz)
− 0.094 + J 1.73	0.275
− 0.131 + J 2.77	0.44
− 0.124 + J 2.89	0.46
− 0.84 + J 3.54	0.564
− 0.102 + J 3.7	0.588
− 0.089 + J 4.18	0.665
− 0.095 + J 4.42	0.704
− 0.134 + J 4.78	0.76
− 0.123 + J 5.17	0.823
− 0.177 + J 5.31	0.845
− 0.227 + J 5.62	0.895
− 0.163 + J 5.7	0.907
− 0.147 + J 5.94	0.946
− 0.092 + J 6.00	0.955
− 0.173 + J 6.27	0.998

Table 2
1988 HEAVY WINTER CASE
NORMAL SYSTEM
EIGEN VALUES

CASE #1	CASE #2
-0.0934 + J 3.78 : 0.6 Hz	-0.19 + J 3.83 : 0.61 Hz
-0.1098 + J 4.58 : 0.729 Hz	-0.2075 + J 4.785 : 0.762 Hz
-0.1168 + J 4.66 : 0.741 Hz	-0.704 + J 4.8 : 0.765 Hz
-0.1278 + J 4.90 : 0.781 Hz	-0.356 + J 4.89 : 0.779 Hz
CASE #3	**CASE #4**
-0.26 + J 3.7 : 0.59 Hz	-0.197 + J 3.796 : 0.604 Hz
-0.361 + J 4.71 : 0.75 Hz	-0.1467 + J 4.747 : 0.756 Hz
-0.252 + J 4.91 : 0.78 Hz	-0.39 + J 4.787 : 0.762 Hz
-0.835 + J 4.92 : 0.784 Hz	-0.536 + J 5.038 : 0.802 Hz

CASE #1 : GENERATORS ONLY, NO CONTROL.
CONSTANT I MW AND CONSTANT Z MVAR LOAD.

CASE #2 : GENERATORS, EXCITERS, PSS's, AND GOV.
CONSTANT I MW AND CONSTANT Z MVAR LOAD.

CASE #3 : GENERATORS, EXCITERS, PSS's, AND GOV.
CONSTANT Z MW AND CONSTANT Z MVAR LOAD.

CASE #4 : SAME AS CASE #2 PLUS D.C. LINKS MODEL.

Table 3
1988 HEAVY WINTER CASE
ABNORMAL SYSTEM
EIGEN VALUES

CASE #5	CASE #6
-0.2100 + J 3.78 : 0.6 Hz	-0.20 + J 3.81 : 0.61 Hz
-0.0565 + J 4.43 : 0.721 Hz	-0.1470 + J 4.620 : 0.735 Hz
-0.3840 + J 4.77 : 0.760 Hz	-0.400 + J 4.88 : 0.777 Hz
-0.5395 + J 5.07 : 0.807 Hz	-0.680 + J 4.84 : 0.770 Hz
CASE #7	**CASE #8**
-0.20 + J 3.74 : 0.60 Hz	-0.233 + J 3.74 : 0.6 Hz
-0.075 + J 4.62 : 0.73 Hz	+0.030 + J 4.30 : 0.68 Hz
-0.391 + J 4.76 : 0.76 Hz	-0.361 + J 4.74 : 0.755 Hz
-0.492 + J 4.97 : 0.791 Hz	-0.51 + J 5.06 : 0.8 Hz

CASE #4*
-0.197 + J 3.796 : 0.604 Hz
-0.1467 + J 4.747 : 0.756 Hz
-0.39 + J 4.787 : 0.762 Hz
-0.536 + J 5.038 : 0.802 Hz

CASE #5 : PALO VERDE - DEVERS 500 kV LINE OUT OF SERVICE.
MACHINES, EXCITERS, PSS's, GOV, AND D.C.
CONSTANT I MW AND CONSTANT Z MVAR LOAD.

CASE #6 : SAME AS CASE #5 BUT WITHOUT D.C. MODEL.

CASE #7 : BLOCK BIPOLE D.C., REST OF THE SYSTEM NORMAL.
CONSTANT I MW AND CONSTANT Z MVAR LOAD.

CASE #8 : BLOCK BIPOLE D.C., PALO VERDE - DEVERS O.O.S.
CONSTANT I MW AND CONSTANT Z MVAR LOAD.

* REPEATED HERE FOR COMPARISON.

Table 4
1988 HEAVY WINTER CASE
PALO VERDE - DEVERS LINE OUT OF SERVICE
0.72 Hz MODE (-0.057 + J 4.43)

EIGEN VECTOR				PARTICIPATION VECTOR		
GEN	AREA	MAG	PH	GEN	AREA	MAG
GEYSER34	PG&E	1.0	-176	HELMS G	PG&E	1.0
HELMS G	PG&E	0.9	169	BIGCREEK	S.CAL	0.6
GEYSER78	PG&E	0.9	-176	KEMANO	B.C.	0.5
BIGCREEK	S.CAL	0.8	-165	GEYSER D	PG&E	0.4
MELONES	PG&E	0.7	-156	FCNGN4CC	ARIZ	0.3
GEYSER B	PG&E	0.7	-175	RNCHSECO	PG&E	0.3
GEYSER D	PG&E	0.7	-175	GEYSER C	PG&E	0.3
GEYSER A	PG&E	0.6	-175	MOSS 7	PG&E	0.3
GEYSER C	PG&E	0.6	-175	GEYSER B	PG&E	0.2
FOLSOM1	PG&E	0.6	-178	MELONES	PG&E	0.2
FOLSOM23	PG&E	0.6	-178	GEYSER34	PG&E	0.2
KERCKHOF	PG&E	0.6	-179	DIABLO1	PG&E	0.2
	..			GEYSER78	PG&E	0.2
	..			DIABLO2	PG&E	0.2
--------				PTS7SWNG	PG&E	0.2
				COMANCHE	COLRD	0.2
INTERM2G	UTAH	0.3	19.5			
EHUNTR 1	UTAH	0.2	5.0			
INTERM1G	UTAH	0.3	19.5			
EHUNTR 2	UTAH	0.2	4.8			
NEWMANG6	N.MEX	0.3	-25.4			
MOHAV2CC	S.CAL	0.3	-22.3			
MOHAV1CC	S.CAL	0.3	-22.3			
APACHCT3	ARIZ	0.3	-21.5			
FCNGN4CC	ARIZ	0.3	-26.8			
HOVRA3A4	WAPA	0.4	-17.4			
NEWMAN45	N.MEX	0.5	-32.3			
BLNDL G1	UTAH	0.5	4.5			

Table 5
1988 HEAVY WINTER CASE
BLOCK BIPOLE D.C. LINK
0.73 Hz MODE (-0.075 + J 4.62)

EIGEN VECTOR				PARTICIPATION VECTOR		
GEN	AREA	MAG	PH	GEN	AREA	MAG
GEYSER34	PG&E	1.0	6.8	HELMS G	PG&E	1.0
GEYSER78	PG&E	0.9	6.9	GEYSER D	PG&E	0.6
HELMS G	PG&E	0.8	-9.2	GEYSER C	PG&E	0.5
GEYSER B	PG&E	0.6	7.3	RNCHSECO	PG&E	0.4
GEYSER D	PG&E	0.6	7.6	FCNGN4CC	ARIZ	0.3
GEYSER A	PG&E	0.6	6.8	GEYSER34	PG&E	0.3
GEYSER C	PG&E	0.6	7.5	MOSS 7	PG&E	0.3
MELONES	PG&E	0.6	-22	GEYSER B	PG&E	0.3
FOLSOM1	PG&E	0.6	5.3	KEMANO	B.C.	0.2
FOLSOM23	PG&E	0.6	5.0	GEYSER78	PG&E	0.2
POTRERO3	PG&E	0.5	5.1	MELONES	PG&E	0.2
ROCKCREQ	PG&E	0.5	5.9	NEWMAN45	N.MEX	0.2
	..			PTS7SWNG	PG&E	0.2
--------	..			HYATTGEN	PG&E	0.2
				SHASTA	PG&E	0.2
PEGS1	N.MEX	0.3	162.4			
APACHST3	ARIZ	0.3	167.9			
HOVRA5-7	WAPA	0.3	179.4			
MOHAV2CC	S.CAL	0.3	156.3			
MOHAV1CC	S.CAL	0.3	156.3			
FCNGN4CC	ARIZ	0.3	153.6			
ELBUTTEG	N.MEX	0.3	166.5			
HOVRA3A4	WAPA	0.3	176.5			
NEWMANG3	N.MEX	0.3	163.8			
FCNGN4CC	ARIZ	0.5	131.6			
NEWMANG2	N.MEX	0.3	162.4			
NEWMANG6	N.MEX	0.4	163.5			
APACHCT3	ARIZ	0.4	169.8			
BLNDL G1	UTAH	0.4	158.3			
NEWMAN45	N.MEX	0.6	156.5			

Table 6
1988 HEAVY WINTER CASE
BLOCK BIPOLE D.C. LINK
PALO VERDE - DEVERS O.O.S.
0.68 Hz MODE (+0.030 + J 4.30)

EIGEN VECTOR				PARTICIPATION VECTOR		
GEN	AREA	MAG	PH	GEN	AREA	MAG
GEYSER34	PG&E	1.0	0.8	HELMS G	PG&E	1.0
GEYSER78	PG&E	0.9	1.2	GEYSER D	PG&E	0.5
HELMS G	PG&E	0.9	-11.	BIGCREEK	S.CAL	0.5
BIGCREEK	S.CA	0.8	9.9	KEMANO	B.C.	0.4
MELONES	PG&E	0.8	-22.	RNCHSECO	PG&E	0.4
GEYSER B	PG&E	0.7	3.1	GEYSER C	PG&E	0.4
GEYSER D	PG&E	0.7	3.3	MOSS 7	PG&E	0.4
GEYSER A	PG&E	0.7	2.8	FCNGN4CC	ARIZ	0.3
GEYSER C	PG&E	0.7	3.3	GEYSER B	PG&E	0.3
FOLSOM1	PG&E	0.6	1.0	MELONES	PG&E	0.2
FOLSOM23	PG&E	0.6	0.4	GEYSER34	PG&E	0.2
POTRERO3	PG&E	0.6	1.6	PTS7SWNG	PG&E	0.2
HNTRS2-4	PG&E	0.6	1.0	DIABLO1	PG&E	0.2
PTSB 6	PG&E	0.6	-0.4	GEYSER78	PG&E	0.2
	..			DIABLO2	PG&E	0.2
	..					

RDGR2GEN	NEVAD	0.2	168.1			
NEWMANG6	N.MEX	0.2	146.8			
APACHCT3	ARIZ	0.3	149.2			
HOOVERNS	WAPA	0.3	148.7			
MOHAV2CC	S.CAL	0.3	153.2			
MOHAV1CC	S.CAL	0.3	153.2			
FCNGN4CC	ARIZ	0.3	154.2			
HOVEN5-7	WAPA	0.3	159.8			
FCNGN4CC	ARIZ	0.4	135.1			
MOHAV2CC	S.CAL	0.3	144.7			
MOHAV1CC	S.CAL	0.3	144.7			
HOVRA5-7	WAPA	0.3	161.7			
NEWMAN45	N.MEX	0.4	139.8			
BLNDL G1	UTAH	0.4	-170.			
HOVRA3A4	WAPA	0.5	157.7			

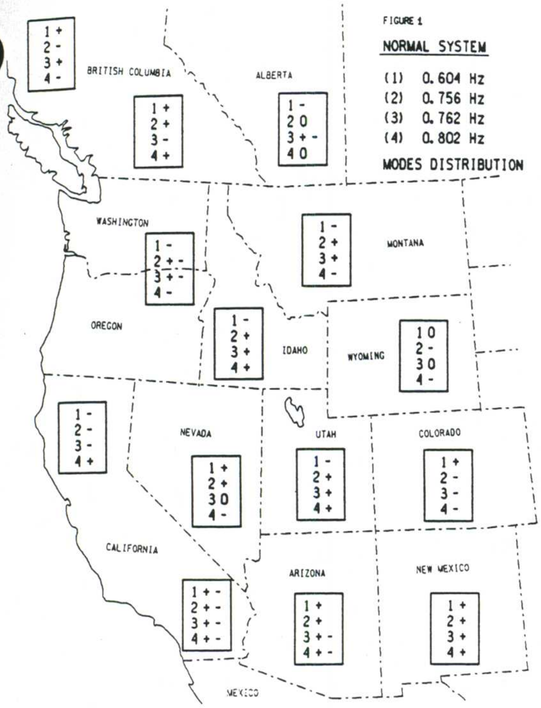


FIGURE 1

NORMAL SYSTEM

(1) 0.604 Hz
(2) 0.756 Hz
(3) 0.762 Hz
(4) 0.802 Hz

MODES DISTRIBUTION

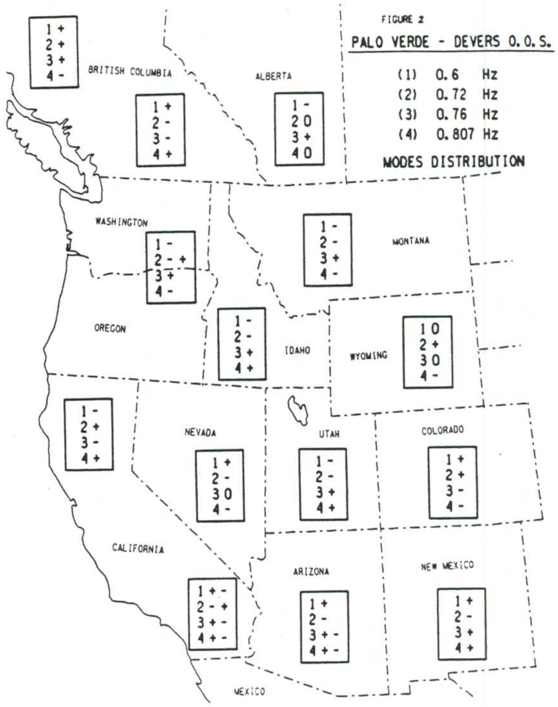


FIGURE 2

PALO VERDE - DEVERS O.O.S.

(1) 0.6 Hz
(2) 0.72 Hz
(3) 0.76 Hz
(4) 0.807 Hz

MODES DISTRIBUTION

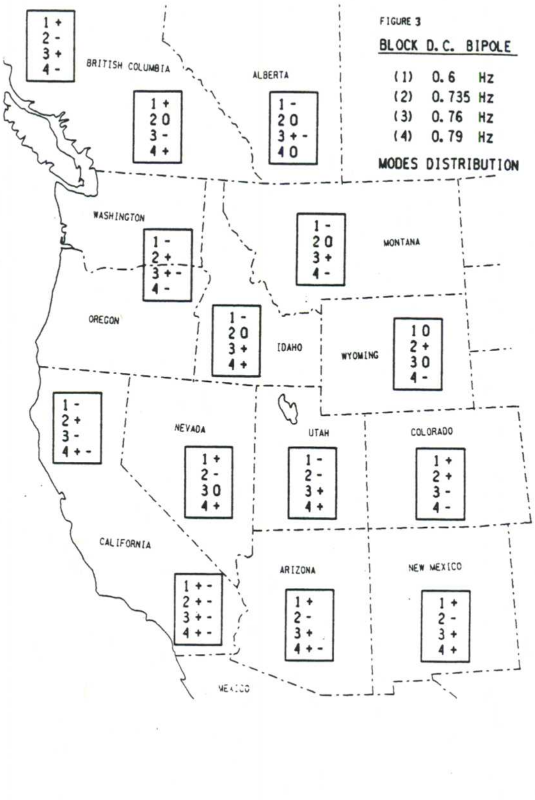


FIGURE 3

BLOCK D.C. BIPOLE

(1) 0.6 Hz
(2) 0.735 Hz
(3) 0.76 Hz
(4) 0.79 Hz

MODES DISTRIBUTION

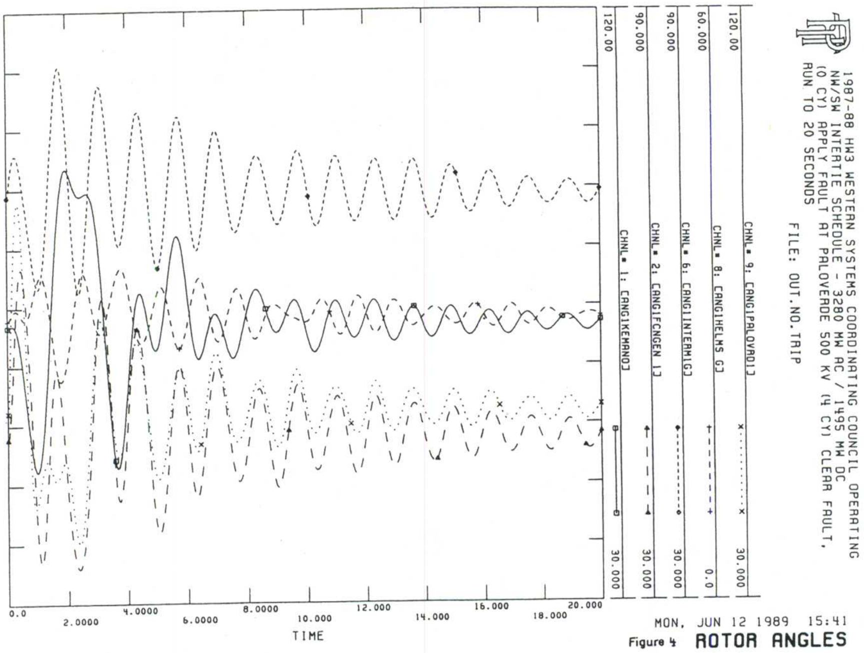


Figure 4 **ROTOR ANGLES**

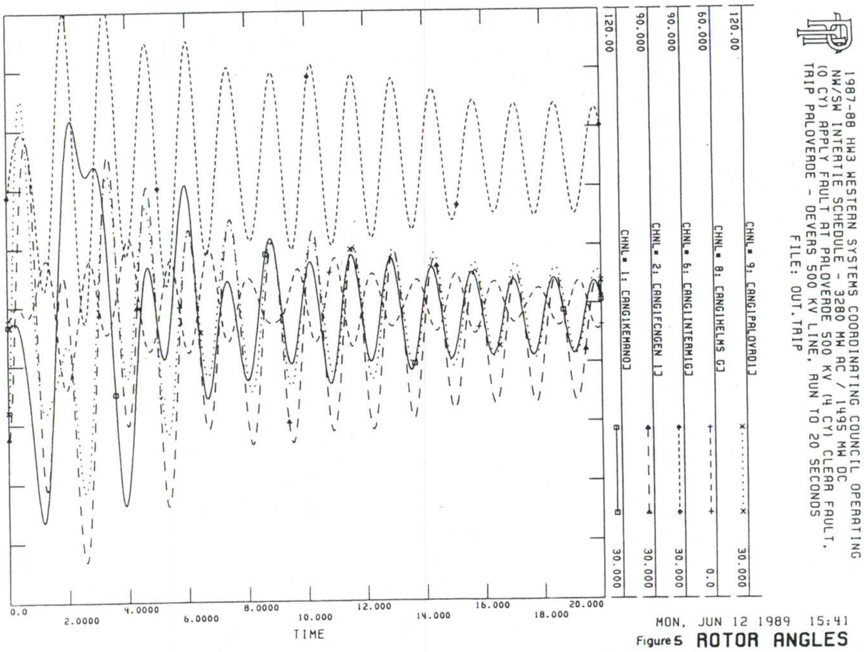
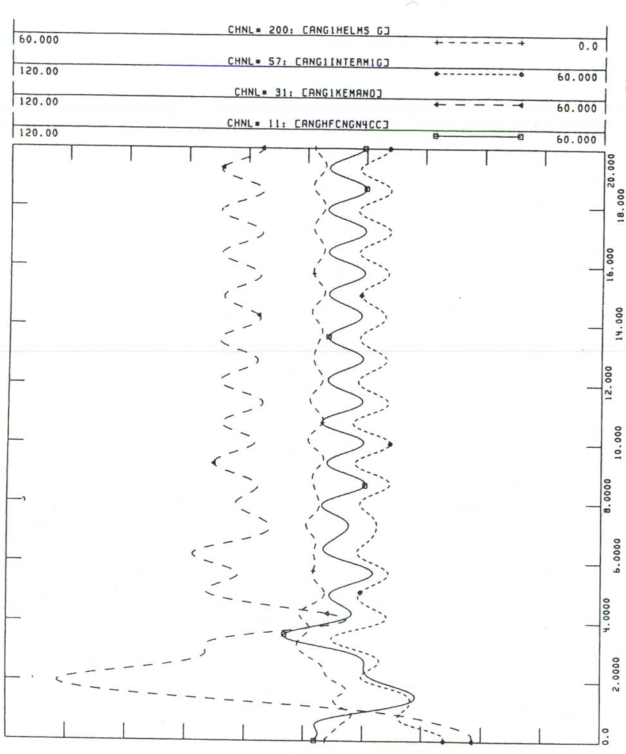


Figure 5 **ROTOR ANGLES**

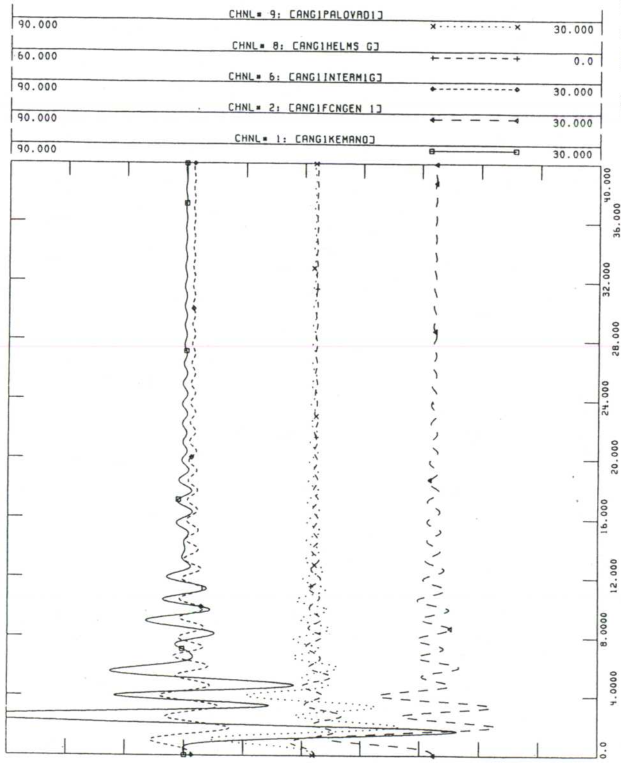
1987-88 HW3 WESTERN SYSTEMS COORDINATING COUNCIL OPERATING
NW/SW INTERTIE SCHEDULE - 3280 MW AC / 1495 MW DC
PREFAULT CONDITIONS: PALOVERDE - DEVERS 500 KV OOS
(0) BLOCK DC LINES 1 & 2, RUN TO 20 SECONDS
FILE: OUT.PALDEVOS.BLOCKDC



WED, JUN 28 1989 09:22

Figure 6 **ROTOR ANGLES**

1987-88 HW3 WESTERN SYSTEMS COORDINATING COUNCIL OPERATING
NW/SW INTERTIE SCHEDULE - 3280 MW AC / 1495 MW DC
(0 S) APPLY CHIEF JOSEPH 230KV 1400MW BRAKE FOR 1.0 SECOND
(1 S) REMOVE BRAKE, RUN TO 40 SECONDS; PALOVERDE-DEVERS I/S
FILE: OUT.CHIEFJOBRAKE.PAS.DEV.IS



WED, JUN 14 1989 09:06

Figure 7 **ROTOR ANGLES**

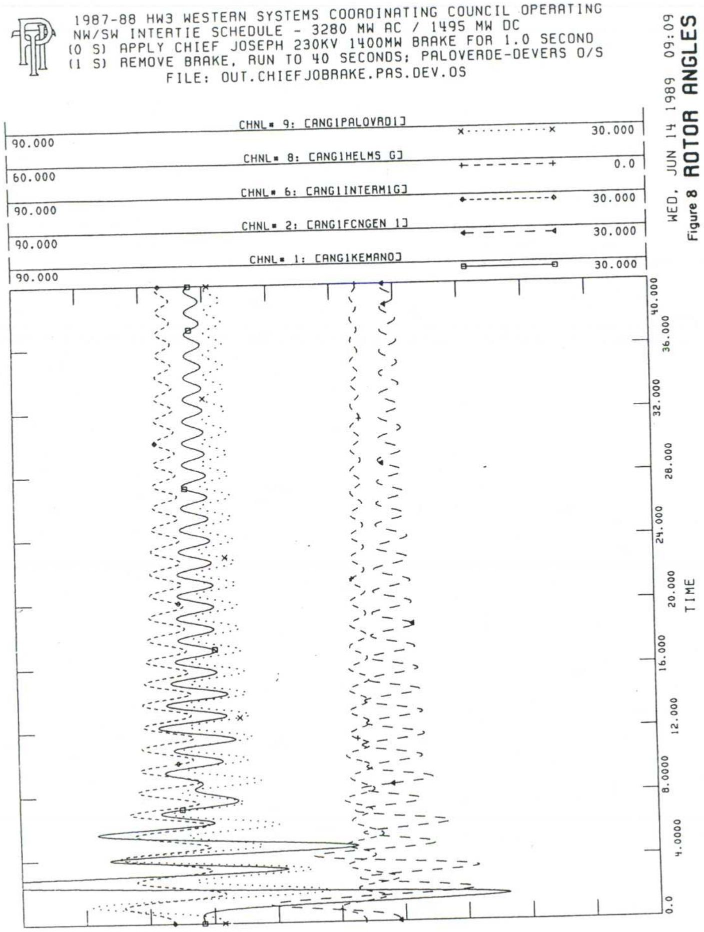


Figure 8 **ROTOR ANGLES**

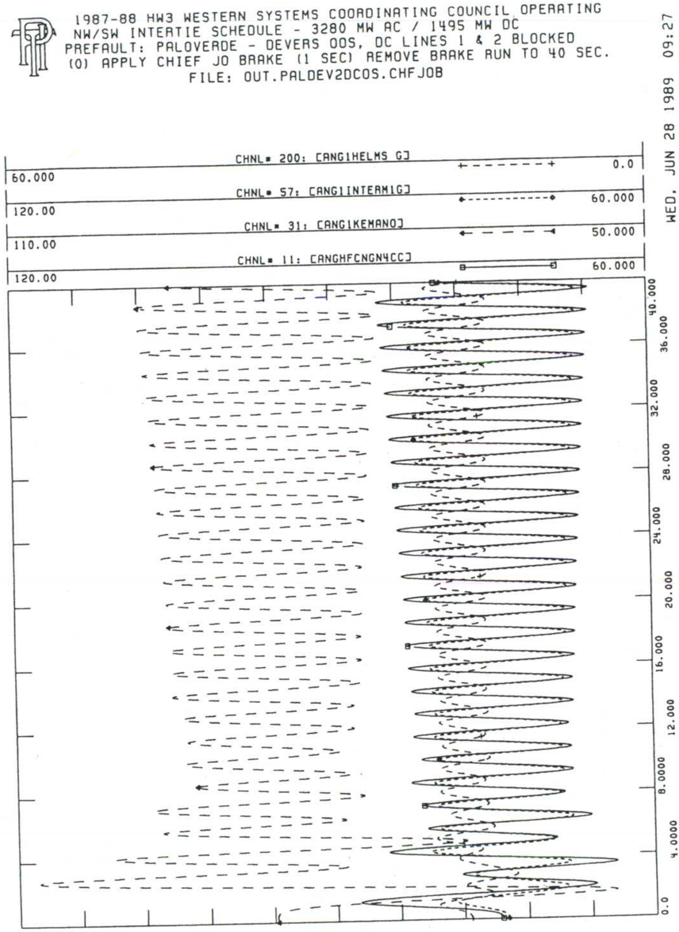


Figure 9 **ROTOR ANGLES**