Initial Results in the Use of Prony Methods to Determine the Damping and Modal Composition of Power System Dynamic Response Signals

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DOE/BP--1183

DE92 003493

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October 1988

U. S. Department of Energy
Bonneville Power Administration
Portland, Oregon

MASTER

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INITIAL RESULTS IN THE USE OF PRONY METHODS TO DETERMINE THE DAMPING
AND MODAL COMPOSITION OF POWER SYSTEM DYNAMIC RESPONSE SIGNALS

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10/05/88

I. INTRODUCTION

Prony analysis [1-11] is an emerging method that extends Fourier analysis by directly estimating the frequency, damping, strength, and relative phase of modal components present in a given signal. This is precisely the kind of information that power system engineers would like to extract from transient stability program (TSP) simulations and from large-scale system tests or disturbances.

A tool of this sort would be particularly valuable for TSP output analysis, where it promises to provide

- o parametric summaries for damping studies (data compression)
- o quantified information for adjusting remedial controls (sensitivity analysis and performance evaluation)
- o insight into modal interaction mechanisms (modal analysis)
- o reduced simulation times for damping evaluation (prediction)

These considerations lead BPA to contract with Dr. Louis Scharf (head of Parametrics, Inc. and a professor at The University of Colorado) for the writing of a FORTRAN program based upon his research into Prony methods. The effort was lead by Dr. Cedric DeMeure, who has just completed his doctoral research under the direction of Dr. Scharf. Dr. DeMeure produced the interactive FORTRAN programs TRANSCIENT and DTRANSCIENT. The major difference between them is that the latter uses double precision arithmetic throughout.

BPA has since made substantial changes to DTRANSCIENT. The objectives are to evaluate the method, to revise the code for utility applications, and to fortify both for use with larger models. Polynomial rooting, a critical and numerically demanding task, is now accomplished by a routine (QPOLY) that was extracted from the NASA program SAMSAN [12] and converted to quadruple precision. The revised DTRANSCIENT is now accessed as a subroutine, PRSPAK. For interactive use the driving program is PRONY. For batch use, however, PRSPAK has been absorbed into much more comprehensive driving logic which closely parallels that of the BPA Fourier analysis program SIGPAK [13] and its reduced derivative SIGPAKR [14]. The data structures and the protocols for use of this new program, SIGPAKZ, are very similar to those for the two Fourier analysis programs. All three readily accept signal data

from the BPA TSP, from BPA's Power System Disturbance Monitor (PSDM), and from a variety of special sources. The SIGPAKZ driver is generic enough that it can readily host other signal analysis algorithms which are more general than the prony method and its present extensions [15-17].

This report presents early results in the application of Prony analysis to power system problems. Key objectives are to

- o provide a brief mathematical description of Prony analysis.
- o report on progress in applying and evaluating SIGPAKZ.
- o outline the development status of the Prony code itself and needed enhancements to it.

Some of this material was presented orally to the WSCC 0.7 Hz Oscillation Ad Hoc Work Group on August 31 and on November 29, 1988.

II. A BRIEF DESCRIPTION OF PRONY'S METHOD

Like Fourier analysis, what might be called Prony analysis originated in an earlier century [1]. Its practical use has awaited the digital computer, and means for dealing with some inherently ill-conditioned mathematics.

Suppose that a linear, time-invariant dynamic system is brought to an "initial" state $x(t_0)=x_0$ at time t_0 , by means of some test input or disturbance. Then, if the input is removed and there are no subsequent inputs or disturbances to the system, it will "ring down" according to a differential equation of form

$$\dot{x} = A x \quad (1)$$

where x is the state of the system and n is the number of components in x (i.e., the order of the system). Let λ_i, p_i, q_i^T be respectively the eigenvalues, right eigenvectors, and left eigenvectors of $(n \times n)$ matrix A . (See Appendix A or [18] for details.) Then the solution to (1) can be expressed as

$$x(t) = \sum_{i=1}^n (q_i^T x_0) p_i \exp(\lambda_i t) \quad (2A)$$

$$= \sum_{i=1}^n R_i x_0 \exp(\lambda_i t) \quad (2B)$$

where $R_i = p_i q_i^T$ is an $(n \times n)$ residue matrix. Note that $q_i^T x_0$ in (2A) is scalar (that is, a simple constant). This implies that, though x_0 (with q_i^T) determines the stimulus to the mode associated with eigenvalue λ_i , the distribution of modal response among the components of x is entirely determined by the corresponding right eigenvector p_i . Consequently information about p_i can be extracted by an appropriate modal decomposition of $x(t)$.

For simplicity, suppose that there is just one output from the system and that it is of form

3

$$y(t) = C x(t). \quad (3)$$

Prony methods and their recent extensions are designed to directly estimate the parameters for the exponential terms in (2A) and/or (3), by fitting a function

$$\hat{y}(t) = \sum_{i=1}^Q A_i \exp(\sigma_i t) \cos(2\pi f_i t + \phi_i) \quad (4)$$

to an observed record for $y(t)$. In doing this it may also be necessary to model offsets, trends, noise, and other extraneous effects in the signal.

Let the record for $y(t)$ consist of N samples $y(t_k)=y(k)$, $k=0,1,\dots,N-1$, that are evenly spaced by an amount Δt . The strategy for obtaining a Prony solution (PRS) can be summarized as follows:

STEP 1: construct a discrete linear prediction model (LPM) that fits the record.

STEP 2: find the roots of the characteristic polynomial associated with the LPM of step 1.

STEP 3: using the roots of step 2 as the complex modal frequencies for the signal, determine the amplitude and initial phase for each mode.

These steps are performed in z -domain. For power system applications the eigenvalues would usually be translated to s -domain, consistent with equations (1)-(5).

Prony's main contribution is at step 1. Its development here parallels that of [2], pp. 378 and 379. For initial purposes, assume $N=2n$ and that the signal record is noise-free.

The notation is simplified if (4) is recast in the exponential form

$$\hat{y}(t) = \sum_{i=1}^n B_i \exp(\lambda_i t) \quad (5)$$

paralleling (2). At the sample times t_k this can be contracted to

$$\hat{y}(k) = \sum_{i=1}^P B_i z_i^k, \quad (6A)$$

$$z_i = \exp(\lambda_i \Delta t). \quad (6B)$$

The immediate objective is to find the B_i and z_i that produces $\hat{y}(k)=y(k)$ for all k . For insight as to how this can be done, apply (6A) at each t_k and form the following equation

$$\begin{bmatrix} B_1 z_1^0 & + & \dots & + B_n z_n^0 \\ B_1 z_1^1 & + & \dots & + B_n z_n^1 \\ & & \ddots & \\ & & & \ddots \\ B_1 z_1^{N-1} & + & \dots & + B_n z_n^{N-1} \end{bmatrix} = \begin{bmatrix} z_1^0 & z_2^0 & \dots & z_n^0 \\ z_1^1 & z_2^1 & \dots & z_n^1 \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ z_1^{N-1} & z_2^{N-1} & \dots & z_n^{N-1} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ \vdots \\ B_{N-1} \end{bmatrix} \quad (7A)$$

$$= \begin{bmatrix} y(0) \\ y(1) \\ \vdots \\ \vdots \\ y(N-1) \end{bmatrix} \cdot$$

This can be expressed more compactly as

$$ZB = Y. \quad (7B)$$

If the z_i are found then the eigenvalues λ_i can be calculated from them via (6B). The z_i are necessarily the roots of some n th-order polynomial with (unknown) coefficients a_i , and thus satisfy

$$z^n - (a_1 z^{n-1} + a_2 z^{n-2} + \dots + a_n z^0) = 0 \quad (8)$$

Next construct the $(1 \times N)$ matrix

$$A = [-a_n \ -a_{n-1} \ \dots \ -a_1 \ 1 \ 0 \ \dots \ 0] \triangleq [-a \ 1 \ 0] \quad (9)$$

and apply it to (7): after some minor re-ordering,

$$\begin{aligned} AY &= y(n) - [a_1 y(n-1) + \dots + a_n y(0)] \\ &= AZC \\ &= B_1 [z_n - (a_1 z + \dots + a_n z_1)] + \dots \\ &= 0 \end{aligned} \quad (10)$$

where the last step follows from the fact that each z_i satisfies (8). Since the initial time has been selected arbitrarily, (10) can be applied repeatedly to form

$$\begin{bmatrix} y(n-1) & y(n-2) & \dots & y(0) \\ y(n-0) & y(n-1) & \dots & y(1) \\ y(n+1) & y(n-0) & \dots & y(2) \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ y(N-2) & y(N-3) & \dots & y(N-n-1) \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} y(n+0) \\ y(n+1) \\ y(n+2) \\ \vdots \\ \vdots \\ y(N-1) \end{bmatrix} \cdot \quad (11)$$

Solution of this equation provides the z-domain polynomial in (8), which is then rooted for the z_i and, through (6B), the eigenvalues λ_i . This completes steps 1 and 2 of the basic Prony method. Step 3 is the solution of (7) for the complex amplitudes B_i .

Practical use of this approach requires some extensions and refinements. A major problem is that the true system dimension, n , may be unknown or may be so large that any fitted model must be a reduced-order approximation. Additional modes may be needed to fit signal offsets or noise. The array dimensions in (11) will usually differ from those shown, and tend to "overfit" the signal by using a generous number of samples and fitted modes. Singular-value analysis and other mechanisms are then used to adjust model features at each solution step. By design, the reconstructed signal $\hat{y}(t)$ will usually fit $y(t)$ inexactly. An appropriate measure for the quality of this fit, used here, is the "signal-to-noise" ratio

$$\text{SNR} = -20 \log \frac{\|\hat{y}(k) - y(k)\|}{\|y(k)\|} \quad (12)$$

where $\|\cdot\|$ denotes the usual root-mean-square norm and the SNR is in decibels (db).

III. SOME STRATEGIC ISSUES

Prony analysis has the potential of becoming a highly valuable tool for power system analysis, and for the design of remedial action schemes or stability controls. The present BPA effort is intended to assess its present capabilities, and to conduct or promote further development as needed.

There are many aspects to this. Those which are intrinsic to the method itself include

- o criteria for the model fit
- o software for achieving the model fit
- o software for rooting the predictor polynomial (8)

For a given record, there are questions as to

- o preprocessing, to mitigate the effects of noise or hidden inputs
- o how much of the record to use in the model fit
- o order of the fitted model
- o pruning and/or adjustment of the fitted model

The power system models ordinarily used in stability studies pose severe difficulties for Prony analysis (and for other methods that rely upon linearization). They are strongly nonlinear, and of dimensions that seem infinitely beyond those of models that any fitting procedure would

reliably construct. Linear characterizations can be developed for power system transient behavior but, if they are taken with respect to the actual operating point, they should be expected to vary with time. It appears that Prony analysis performs such a characterization implicitly.

The evaluation of Prony analysis in this context requires special attention to the factors below:

- o The Prony model will normally be of far lower order than the dynamic process underlying the signal record.
- o For large-signal cases, PRS results will change with the magnitude of the system disturbance or input.
- o For large-signal cases, PRS results will change with record length and position.
- o For large-signal cases, there is probably a maximum record length beyond which information is lost in the PRS.
- o For small-signal cases, substantial changes in record length should not produce material changes in PRS results.

These are being examined through a series of test cases, which range from very simple to rather difficult. Salient results are presented in the sections that follow. The map shown as Figure 0 indicates some of the place names associated with those cases taken from BPA system studies.

IV. PRS CHECK SERIES #0

This series of checks is based upon two elementary models. The first of these, shown in Figure 1, has two complex modes. Both have zero damping. Model #2 has the same structure and parameters, except that the 0.67 Hz mode has a damping of 0.02 and the 0.71 Hz mode has a damping of -0.005. The unit for damping here is inverse seconds, divided by 2π to be dimensionally consistent with frequency in Hz. (Later versions of SIGPAKZ may express damping as a percentage of the natural frequency $|f_i|$, to avoid possible ambiguities.)

Model #1 was introduced in [19], as a proposed benchmark for damping estimators. The modal frequencies are realistic for the western power system, and there is a risk that the modal damping may be so as well. Figure 1.0 illustrates that the direct examination of such damping can require very long simulations for correct results. A hoped-for benefit of Prony analysis is the minimization of simulation length.

Figures 1.1 through 1.4 show PRS results for successively longer values of the record length, TBAR. In all cases the sample spacing was $\Delta t = 0.10$ seconds. The solution logic, though permitted to develop a model of order 90, in each case recognized that just two significant (complex) modes were present and pruned the initial step 1 model to reflect this. Each figure actually shows two curves: the signal record, $y(t)$, and the response $\hat{y}(t)$ of the fitted Prony model (tagged by triangles). Excellent

results are obtained with a record just 2 seconds long, and they improve with record length. Figures 2.0 through 2.4 show like results for Model 2.

V. PRS CHECK SERIES #4

The basic model for PRS check series #4 has the frequency response shown in Figure 3. It represents a linear characterization of bus frequency response to small-signal control action during a major disturbance (see [20], Section V). It has 14 complex modes, and hence is of order 28. Some modes are closely spaced, as may be deduced from the beating effects in the impulse response of Figure 3.0.

Figures 3.1 through 3.3 show typical SIGPAKZ outputs. In the first of these, the plot header data indicates that the signal name is POUT 1/1, that the signal extends from 0.6 to 20.5 seconds, and that the SNR for the model fit is 120.87 db. This indicates an excellent fit, as may also be seen from the superposed curves. The "PRS table" shown in Figure 3.2 exactly reproduces the frequency and damping of the model poles. A corresponding "PRS locus" is shown in Figure 3.3. The header indicates that the locus represents a single solution, and that any mode with a relative amplitude of less than 0.01 has been trimmed from the locus.

It should be recognized that this is a fairly demanding model. Some of the modes are close together, and the model order (28) is high enough to present nontrivial dimension problems. This model, and variations of it, are of continuing value in the development of guidelines for the best use of SIGPAKZ.

VI. ANALYSIS OF KEMANO GENERATOR RESPONSE

The Kemano generator, in northwestern British Columbia, attaches to the main power system through a long radial connection (see Figure 0). Kemano has a frequency-domain "signature" that is conspicuous throughout the western power system.

Figure 4 shows the frequency response of Kemano generator power to the modulation of reactive load at the Malin 500 kv bus. This data was produced by Fourier analyzing the ringdown signal of Figure 4.0, and dividing the results by the Fourier transform of the applied pulse. The single dominant peak makes Kemano a good initial case for testing SIGPAKZ against transient stability output data.

Figure 4.1 shows the quality of the Prony fit for the first 15 seconds of Kemano ringdown. The full solution is indicated in Figure 4.2. All but one of the modes are complex, and a great many of them are very weak modes accessory to the fitting process. It is not unusual for signal offsets to produce modes near 0 Hz, or very near to the Nyquist frequency $1/(2\Delta t)$. Modes 1 and 56 appear to be of this type. For summary purposes it is usually more convenient to work with "trimmed" PRS tables, from which all modes that are very weak or that lie at uninteresting frequencies have been removed. Figure 4.3 shows a sequence of such tables, labeled as s-tables since they are expressed in s-domain rather than z-domain. Line 7 of the header indicates that all modes with a relative

weight below (TRIMTAB =) 0.20 have been trimmed from the display. (This normalization is performed with respect to the strongest mode within a designated frequency range FTRIML to FTRIMH.)

Linearized characteristics of stability output signals should be expected to vary with time (e.g., according to system stress). It is useful to examine such a signal by sliding a data window along it and processing the window contents (a sub-record) at preset positions. This provides an indication of dynamic variability, assists the identification of dominant modes, and checks the solution process for consistency. Figures 4.3 and 4.4 show results for a sliding-window analysis in which the window was advanced 10 samples (0.667 seconds) between successive solutions. The figures indicate that, consistent with the peak in Figure 4, Kemano is strongly involved in a mode that is essentially fixed near 0.628-0.629 Hz, with a damping near 0.0231-0.0215 (also scaled in "Hz"). Kemano is also involved in a strong mode near 0.77 Hz, which seems to be either more variable or less accurately estimated.

VII. MODE SHAPE VIA PRONY ANALYSIS

Figures 5 through 9.2 show other responses and PRS results corresponding to the Kemano ringdown discussed in the previous section. The 0.628 Hz "Kemano mode" is conspicuous throughout, in the PRS loci, and it is represented by sharp peaks in the frequency response at Grand Coulee, Shasta, and Palo Verde. The PRS tables show Grand Coulee and Shasta about 180 degrees behind Kemano for this mode, and Palo Verde about 370 degrees behind. Intermountain phasing is intermediate, at 250 degrees.

Except for Kemano, all signals show a significant mode near 0.76 Hz. The indicated damping for this mode is about 0.012-0.018 -- except at Grand Coulee, for which the damping is ten times higher. This result is persistent enough to raise the possibility of 2 modes at essentially the same natural frequency. The PRS tables indicate that Shasta is swinging against both Palo Verde, and that the phasing of Intermountain swings is once again intermediate.

Toward the end of the system ringdown, all signals other than Kemano show a mode near 0.868 Hz for which the damping is essentially zero. Phase data suggests that this may be Intermountain swinging against Palo Verde and Shasta, and those machines in turn swinging Coulee.

Continuation of this analysis would provide a progressively better view of the phase distribution for the eigenvectors associated with key modes (for which machine electrical power is implicitly being taken as a state variable). Insight into the interaction mechanisms for each mode can be considerably improved by examining the mode strengths at each machine, and by performing Prony analysis on major lines. In doing this, however, it is necessary to compensate for situations where the TSP output represents just one machine or circuit among several that are connected in parallel. Manual insertion of the necessary scale factors is laborious, and prone to error. The problem is a generic one in output analysis. Consideration ought be given to automatically inserting the needed scale factors in the TSP output itself.

VIII. EVALUATION OF REMEDIAL ACTION SCHEMES VIA PRONY ANALYSIS

This section treats two separate large-signal stability cases involving loss of the 3100 MW Celilo-Sylmar HVDC Intertie. In the reference case (93JTAS434) only standard remedial actions are taken, and growing oscillations are observed at the Malin 500 kv bus. These same actions are taken in the experimental case (93JTAS438). In addition, a 1000 MW discharge is taken from a (fictional) superconducting magnetic energy storage (SMES) unit at Sylmar. These cases are part of an initial determination of stability control benefits that a 20 MWH SMES unit might bring to the western system. In the present scenario such a device can serve as a spinning reserve equivalent for roughly two minutes.

Comparison of Figures 10 and 11 shows that the SMES power injection into the grid has reduced the level of the oscillations, and that it may have improved their damping. A rough indication of their modal content is provided by the autospectra of Figures 10.0 and 11.0. It is evident that the injection has also affected the natural frequency of the critical modes near 0.27 Hz and 0.70 Hz. The associated PRS tables and loci display these effects more clearly, in a quantitative format that is well suited to refinement of pulse level and timing.

IX. CONCLUSIONS

The BPA evaluation of Prony analysis has been very encouraging. It should be noted, though, that the work to this point has concentrated upon the effectiveness of the method rather than its efficiency. At present a large-scale case ($n=120$) may require up to 5 minutes on BPA's VAX 11/780. The bulk of this is probably due to the blanket use of quad precision in the polynomial rooter QPOLY. Future work will reduce this to the necessary minimum, and establish tighter bounds for the required model order.

Overall, though it is definitely slanted toward the expert user, SIGPAKZ is clearly ready to perform useful work. (Chuck Frank at EPRI aptly describes such programs as of "engineering grade".) Portability of the code developed under contract is limited somewhat by extensive use of features special to VAX computers, but these are gradually being removed.

Prony analysis promises to become a very useful tool for power system analysis. While it may well assume a place alongside eigenanalysis and Fourier analysis, it will not replace them. Each such tool has its own merits and applications. and provides a different view into power system (or model) behavior.

There are other emerging methods that may well improve upon Prony analysis, or be more generally applicable. Among these lattice filters [15-17] seem to be the most promising. BPA is presently reviewing this possibility with Dr. Scharf.

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APPENDIX A. EIGENVALUES AND RELATED TOPICSA1. THE EIGENVALUE PROBLEM

Given the system equation

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u, \quad (\text{A1})$$

find a transformation $\mathbf{x} = \mathbf{T}\mathbf{x}_m$ so that

$$\dot{\mathbf{x}}_m = \mathbf{\Lambda}\mathbf{x}_m + \mathbf{B}_m u, \quad (\text{A2A})$$

$$\mathbf{\Lambda} = \text{diag}(\lambda_1) = \begin{bmatrix} \lambda_1 & & 0 \\ & \lambda_2 & \\ & & \ddots \\ 0 & & & \lambda_n \end{bmatrix}. \quad (\text{A2B})$$

If this is successful, then the λ_i are the eigenvalues of $\mathbf{A}$ and they are all distinct (otherwise a Jordan form must be used). Note that

$$\dot{\mathbf{x}} = \mathbf{T}\dot{\mathbf{x}}_m = \mathbf{A}\mathbf{T}\mathbf{x}_m + \mathbf{B}u, \quad (\text{A3})$$

$$\dot{\mathbf{x}}_m = (\mathbf{T}^{-1}\mathbf{A}\mathbf{T})\mathbf{x}_m + (\mathbf{T}^{-1}\mathbf{B})u = \mathbf{\Lambda}\mathbf{x}_m + \mathbf{B}_m u. \quad (\text{A4})$$

Let $\mathbf{T}_j$ be column j of $\mathbf{T}$; then

$$\mathbf{A}\mathbf{T} = \mathbf{T}\mathbf{\Lambda} \rightarrow \mathbf{A}\mathbf{T}_j = \lambda_j \mathbf{T}_j \rightarrow (\mathbf{A} - \lambda_j \mathbf{I})\mathbf{T}_j = \mathbf{0}. \quad (\text{A5})$$

Since $\mathbf{T}_j$ is not the zero vector, this requires

$$\det(\mathbf{A} - \lambda_j \mathbf{I}) = |\mathbf{A} - \lambda_j \mathbf{I}| = a(\lambda_j) = 0. \quad (\text{A6})$$

$$\text{Let } \mathbf{T} = [\mathbf{p}_1 \ \dots \ \mathbf{p}_n] = \mathbf{P}, \quad \mathbf{T}^{-1} = \begin{bmatrix} \mathbf{q}_1^T \\ \vdots \\ \mathbf{q}_n^T \end{bmatrix} = \mathbf{Q}^T. \quad (\text{A7})$$

$$\text{Then } \mathbf{A}\mathbf{p}_i = \lambda_i \mathbf{p}_i, \quad \mathbf{q}_i^T \mathbf{A} = \lambda_i \mathbf{q}_i^T \quad (\text{A8})$$

where $\mathbf{p}_i$, $\mathbf{q}_i^T$ are respectively right and left eigenvectors of $\mathbf{A}$.

System "ringdown" from an initial state $x(t_0) = x_0$ can be found as follows:

$$\begin{aligned} x(s) &= [sI - A]^{-1} x_0 = PP^{-1}[sI - A]^{-1} PP^{-1} x_0 \\ &= P[sI - \Lambda]^{-1} P^{-1} x_0 \end{aligned} \quad (A9)$$

$$= \sum_{i=1}^n \frac{p_i(q_i^T x_0)}{s - \lambda_i} = \sum_{i=1}^n \frac{(q_i^T x_0) p_i}{s - \lambda_i},$$

$$x(t) = \sum_{i=1}^n |(q_i^T x_0) \exp(\lambda_i t)| p_i \quad (A10A)$$

$$= \sum_{i=1}^n R_i x_0 \exp(\lambda_i t) \quad (A10B)$$

(note that $q_i^T x_0$ is a scalar quantity. Kailath [17] terms $R_i = p_i q_i^T$ a residue matrix. One should note, however, that the "signal residues" for a particular x_0 are given by $R_i x_0$.)

Observations:

- a) Vector q_i^T determines the influence of x_0 upon mode i .
- b) Vector p_i determines the distribution of mode i among the components of $x(t)$.

A2. EIGENVECTORS AND PARTICIPATION FACTORS

Scaling uncertainties greatly reduce the direct usefulness of eigenvectors in determining system mode shape. The underlying transformation between x and x_m requires $Q^T = P^{-1}$, by which

$$\begin{aligned} q_j^T p_i &= 1 & \text{if } i = j, \\ &= 0 & \text{otherwise.} \end{aligned} \quad (A11)$$

This still leaves p_i indeterminate with regard to length and directional sense. Arbitrary scaling rules can resolve this, but leave a more important problem: effects due to relative scaling of the state variables themselves. An alternative is to inspect

$$p_{ki} = p_{ki} q_{ki} \quad (A12)$$

where p_{ki} and q_{ki} are the k th elements of p_i and q_i . These "participation factors" are dimensionless measures of state x_k in mode i . From (A10B), p_{ki} is also element kk of R_i , and thus represents the residue that is produced for mode i by a unit impulse in element i of x_0 .

A3. SINGULAR VALUES

Control theory, especially that for MIMO systems and robustness, makes heavy use of the singular-value decomposition

$$F = U\Sigma V. \quad (A13)$$

This decomposition includes the following features:

- a) Matrix F need not be square.
- b) Matrices U , V are orthogonal, and are constructed from the eigenvectors of AA^T , A^TA respectively.
- c) Σ is a diagonal matrix whose entries are the singular values σ_i of F , usually ordered by descending magnitude.

Singular value σ_i for a matrix F is the non-negative square root of the eigenvalue $\lambda_i[F^TF]$ for F^TF . For a square matrix A we have a special interest in the particular singular values

$$\bar{\sigma}[A] = \lambda_{\max}[A^TA] \quad (A14)$$

$$\underline{\sigma}[A] = \lambda_{\min}[A^TA]$$

Properties:

$$\underline{\sigma}[A] \leq |\lambda_i[A]| \leq \bar{\sigma}[A] \quad (A15A)$$

$$\max_{\|x\|=1} \|Ax\| = \bar{\sigma}[A] \quad (A15B)$$

$$\min_{\|x\|=1} \|Ax\| = \underline{\sigma}[A] \quad (A15C)$$

where $\|x\|$ is the Euclidian norm $(x_1^2 + \dots + x_n^2)^{1/2}$ of x .

APPENDIX B. KEY NAMES AND TERMINOLOGY

Discussion will be made easier by the introduction of some key terms associated with the Prony codes. To this end the more important program names and control parameters are introduced below.

DTRANSCIENT	The original Prony analysis program received from Drs. Louis Scharf and Cedric DeMeure, in the double-precision version.
PRONY	The direct BPA revision of DTRANSCIENT (for interactive use).
SIGPAKZ	The BPA extension of DTRANSCIENT, for batch use. Very similar to Fourier analysis program SIGPAKR.
PRSPAK	The primary subroutine for accessing the logic of DTRANSCIENT. Common to PRONY and SIGPAKZ.
PRS	Acronym for "Prony Solution". Analogous to use of "FFT" in the fast-Fourier transform logic of SIGPAK and SIGPAKR.
NN	Number of signal samples $y(k)$ provided to PRSPAK for fitting.
NNHAT	Number of signal samples $y(k)$ provided to PRSPAK for display of the constructed signal. Usually not less than NN.
T (or TSTEP)	Spacing of the samples $y(k)$, usually in seconds.
TSTART	Time of the first sample, $y(0)$.
TBAR	Nominal length of the record. Actually calculated as $NN \cdot TSTEP$, for consistency with FFT conventions.
LAPSTP	For "sliding-window" cases, this is the number of samples by which the window will be advanced for each record. The overlap for successive records is then $NN - LAPSTP$ points, or $(NN - LAPSTP)/NN$ percent.
LPOCON	Control for linear prediction order (in construction of the Prony model).
LPMCON	Control for linear prediction method.
FBCON	Control for direction of linear prediction (forward or backward).
PIRCON	Control on rank of the pseudo-inverse to the data matrix constructed from the signal record.

QCON	[to be amended, along with code in PRSPAK]
SNR	A measure of model fitting accuracy, expressed as a signal-to-noise ratio (in db). The calculation is $\text{SNR} = 20 \log \left \frac{\hat{y}(k) - y(k)}{y(k)} \right $ where $y(k)$ is Prony model response at time tk . SNR values of 20 db and 40 db would indicate accumulated fitting errors of 10% and 1%, respectively.
FTRIML, FTRIMH .	Modes at frequencies outside the range FTRIML to FTRIMH are regarded as potentially uninteresting. The relative weight of each mode is calculated with respect to the strongest mode within this range.
TRIMLPM	Any mode with a relative weight less than TRIMLPM will be deleted from the linear prediction model (within PRSPAK).
TRIMTAB	Any mode with a relative weight less than TRIMTAB will be deleted from the PRS table display.
TRIMLOC	Any mode with a relative weight less than TRIMLOC will be deleted from the PRS locus display.

FIGURE 0. GENERAL STRUCTURE OF THE WESTERN U.S. POWER SYSTEM

PRCKSO MODEL #1
 POLES: 0.0000 + J*0.66666667 HZ
 0.0000 + J*0.71428571 HZ

FIGURE 1. MODEL #1 FOR PRONY SOLUTION CHECK SERIES #0

FIGURE 1.0 RESPONSE OF PRCKSO MODEL #1 TO BRIEF PULSE INPUT

FIGURE 1.1. PRONY SOLUTION FOR PASCKSO MODEL #1
 TBAR = 2 SECONDS (20 SAMPLES)

FIGURE 1.2. PRONY SOLUTION FOR PASCKSO MODEL #1
 TBAR = 5 SECONDS (50 SAMPLES)

FIGURE 1.3. PRONY SOLUTION FOR PASCKSO MODEL #1
 TBAR = 10 SECONDS (100 SAMPLES)

FIGURE 1.4. PRONY SOLUTION FOR PASCKSO MODEL #1
 TBAR = 20 SECONDS (200 SAMPLES)

FIGURE 2.0 RESPONSE OF PRCKSO MODEL #2 TO BRIEF PULSE INPUT

FIGURE 2.1. PRONY SOLUTION FOR PRSCKSO MODEL #2
 TBAR = 2 SECONDS (20 SAMPLES)

FIGURE 2.2. PRONY SOLUTION FOR PRSCKSO MODEL #2
 TBAR = 5 SECONDS (10 SAMPLES)

FIGURE 2.3. PRONY SOLUTION FOR PASCKSO MODEL #3
TBAR = 10 SECONDS (100 SAMPLES)

FIGURE 2.4. PRONY SOLUTION FOR PASCKSO MODEL #2
TBAR = 20 SECONDS (200 SAMPLES)

FIGURE 3. FREQUENCY RESPONSE FOR PRCSK4 MODEL #1

FIGURE 3.0 IMPULSE RESPONSE OF PRCSK4 MODEL #1

SIGPAKZ ANALYSIS RESULTS:

PLOT # 1

27

C ** SIGPAKZ PLOTTING FOR PRS SIGNAL DATA (ON .F08 FILE)
 POUT 1/1 TSPAN=C0000.0,0019.93
 SNR = 120.87

FIGURE 3.1. PRONY FIT FOR PRSCKS4 MODEL #1
 TBAR = 20 SECONDS (200 SAMPLES)

*SIGNAL-TO-NOISE RATIO = 120.8700 FOR NMODES = 14

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.0239805	0.0367401	0.2690819	30.119507	0.0144529
2	0.0318409	0.0912621	0.1865634	116.554008	0.0100207
3	0.0596168	0.3045262	0.4499747	-4.998126	0.0241690
4	0.0508920	0.4608535	0.3286152	-119.239242	0.0176505
5	0.0438688	0.5357940	0.5348253	0.052731	0.0287265
6	0.0227360	0.5975186	0.5201265	76.963143	0.0279370
7	0.0857313	0.7275286	1.0000000	-53.600270	0.0537119
8	0.0257093	0.7426974	0.6577225	174.971951	0.0353275
9	0.0633062	1.0428168	0.1417231	-84.687450	0.0076122
10	0.0560974	1.1506412	0.1704997	-21.813123	0.0091579
11	0.0176936	1.2396401	0.0785724	-86.217684	0.0042203
12	0.0265640	1.2919787	0.0757616	-28.926462	0.0040693
13	0.0384194	1.5015666	0.1254782	167.056914	0.0067397
14	0.1446441	1.6059325	0.4546648	-61.027965	0.0244209

FIGURE 3.2. PRONY SOLUTION TABLE FOR PRACKS4 MODEL #1
TBRN = 20 SECONDS (200 SAMPLES)

SIGPAKZ ANALYSIS RESULTS:

PLOT # 1

C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)

NO. SOLUTIONS = 1

TRIMLOC = 0.10E-01

FIGURE 3.3. PRONY SOLUTION LOCUS FOR PRACKS4 MODEL #1
TBRN = 20 SECONDS (200 SAMPLES)

**SWX CASE 88J3NF08 :
 C ** SYSCHECK/SIGPAK VERSATEC PLOT
 G KEMANO 13.8 1 COULEE 2 13.8 1 4
 A22/A11 : INPUT =MAL MVR (WINDWD)

PLOT # 5
 ELECTRICAL POWER
 X 1.0000

29

FIGURE 4. FREQUENCY RESPONSE OF KEMANO ELECTRICAL POWER TO SHUNT REACTIVE CONTROL AT MALIN, CASE 88J3NF08

**SWX CASE 88J3NF08 :
 C ** SYSCHECK/SIGPAK PRINTER PLOT
 G KEMANO 13.8 1 COULEE 2 13.8 1 4
 SR 26 3: INPUT =MAL MVR

PLOT # 3
 ELECTRICAL POWER
 CX 1.000

FIGURE 4.0 KEMANO RINGDOWN FOR BRIEF MVAR LOAD PULSE AT MALIN

**SWX CASE 88J3NF08 : PLOT # 1
 C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)
 G KEMANO 13.8 1 COULEE 2 13.8 1 4 ELECTRICAL POWER
 SNR = 69.46

30

FIGURE 4.1. PRONY FIT TO KEMANO RINGDOWN SIGNAL (WINDOW #1)
 TBAR = 15 SECONDS (225 SAMPLES)

*SIGNAL-TO-NOISE RATIO = 69.4550 FOR NMODES = 56

31

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	-0.0000460	0.0000000	0.1523088	0.000000	3.5174259
2	0.0915927	0.2675953	0.0749189	-34.585042	1.7301808
3	0.0333544	0.2765569	0.0045555	26.705191	0.1052049
4	0.1505401	0.4082269	0.1406290	54.908092	3.2476931
5	0.0214040	0.6289195	1.0000000	-178.260646	23.0940471
6	0.1032774	0.6833275	0.2172331	-118.146087	5.0167906
7	0.0761593	0.7818811	0.8187142	7.611984	18.9074243
8	-0.0342414	0.8852576	0.0000984	117.391079	0.0022713
9	0.0531282	0.9918903	0.0059218	36.318231	0.1367582
10	0.0346007	1.0850276	0.0146690	160.064870	0.3387659
11	0.0493474	1.2629845	0.0122243	138.797424	0.2823090
12	0.0328537	1.4553512	0.0010945	-45.171140	0.0252755
13	-0.0000444	1.6369989	0.0000751	18.911008	0.0017340
14	0.0367627	1.7922192	0.0011554	-11.328628	0.0266833
15	0.0224287	1.9153405	0.0010680	8.779060	0.0246648
16	0.0091257	2.0201531	0.0006415	35.115921	0.0148146
17	0.0089710	2.1363135	0.0005466	20.470827	0.0126232
18	0.0107170	2.2881031	0.0003497	32.520493	0.0080766
19	-0.0068714	2.4511081	0.0001675	3.047096	0.0038681
20	0.0115853	2.5864875	0.0001996	24.368803	0.0046102
21	0.0049525	2.6979611	0.0002398	27.814094	0.0055382
22	0.0439122	2.8405924	0.0002739	41.669936	0.0063243
23	0.0275376	3.0113383	0.0001363	-33.819462	0.0031479
24	0.0630221	3.1999781	0.0010210	-81.371554	0.0235793
25	0.0205334	3.3300658	0.0005485	-68.497941	0.0126675
26	0.1319846	3.4501781	0.0028654	2.070048	0.0661729
27	-0.0025771	3.4833568	0.0001140	-178.794428	0.0026319
28	0.0028752	3.7066176	0.0001477	10.618966	0.0034109
29	0.0128177	3.8246755	0.0001688	26.992948	0.0038985
30	0.0109151	3.9756163	0.0001283	7.331337	0.0029619
31	0.5517183	4.1618478	0.0062445	61.626144	0.1442107
32	0.0216971	4.1691927	0.0000526	-67.170922	0.0012156
33	0.0098021	4.3142967	0.0000572	-92.366206	0.0013206
34	-0.0004969	4.4755527	0.0000534	63.598752	0.0012333
35	0.0312668	4.6226519	0.0001480	146.139239	0.0034169
36	0.0478082	4.7564981	0.0002534	174.006192	0.0058519
37	0.0311815	4.8826275	0.0000830	-101.038543	0.0019862
38	0.0018242	5.0131360	0.0000388	-54.327508	0.0008957
39	-0.0000629	5.1688172	0.0000593	116.174004	0.0013690
40	-0.0094376	5.2874752	0.0000363	131.216206	0.0008386
41	0.0074602	5.4286577	0.0000408	74.519539	0.0009419
42	-0.0176881	5.5949569	0.0000218	-101.694154	0.0005037
43	0.0100630	5.7445277	0.0000160	32.025836	0.0003689
44	-0.0028183	5.9290992	0.0000660	-119.989847	0.0015239
45	0.0166078	6.0784643	0.0001104	-63.357124	0.0025487
46	0.0257627	6.1997006	0.0000806	-49.818792	0.0018624
47	0.6857409	6.3231421	0.0049080	81.654835	0.1133464
48	-0.0040363	6.3798726	0.0000319	-33.627890	0.0007368
49	0.0148508	6.5186406	0.0001545	-159.873218	0.0035686
50	0.0157822	6.6492129	0.0001792	-154.327075	0.0041393
51	0.0075898	6.7918234	0.0001099	-177.170894	0.0025378
52	0.0327504	6.9368120	0.0002085	177.639661	0.0048142
53	0.0015317	7.1216662	0.0000713	70.649447	0.0016474
54	0.0161139	7.2265918	0.0001259	75.297842	0.0029075
55	0.0351333	7.4140312	0.0002848	4.085358	0.0065764
56	0.3885503	7.4999996	0.0020363	180.000000	0.0470258

FIGURE 4.2. PRONY SOLUTION TABLE FOR FIT TO KEMANO RINGDOWN (WINDOW #1)
TBAR = 15 SECONDS (225 SAMPLES)

** SIGPAKZ PROCESSING FOR 88J3NF08.SWX
 (INPUT SIGNAL = 400 MVAR PULSE AT MALIN)
 (CASE #20: KEMANO GENERATION) [SLIDING WINDOW, TBAR=15 SEC]

**PRONY S-TABLE FOR PRS NUMBER 1
 *SIGNAL-TO-NOISE RATIO = 69.4550 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
5	0.0214040	0.6289195	1.0000000	-178.260646	23.0940471
6	0.1032774	0.6833275	0.2172331	-118.146087	5.0167906
7	0.0761593	0.7818811	0.8187142	7.611984	18.9074243

**PRONY S-TABLE FOR PRS NUMBER 2
 *SIGNAL-TO-NOISE RATIO = 75.6260 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
6	0.0212416	0.6286833	1.0000000	-26.579108	20.8513308
7	0.0711585	0.7819447	0.5794028	-161.512752	12.0813190

**PRONY S-TABLE FOR PRS NUMBER 3
 *SIGNAL-TO-NOISE RATIO = 67.9670 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
6	0.0213526	0.6287557	1.0000000	124.125559	19.2038697
7	0.0724648	0.7764332	0.4830101	35.046527	9.2756624

**PRONY S-TABLE FOR PRS NUMBER 4
 *SIGNAL-TO-NOISE RATIO = 65.2870 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
5	0.0212042	0.6280298	1.0000000	-82.598303	17.3684915
7	0.0877736	0.7698994	0.5908038	-143.795953	10.2613704

**PRONY S-TABLE FOR PRS NUMBER 5
 *SIGNAL-TO-NOISE RATIO = 72.8740 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
6	0.0215034	0.6284879	1.0000000	66.594427	16.1728315
7	0.0644864	0.7700647	0.2488102	55.219579	4.0239653

FIGURE 4.3. PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO KEMANO RINGDOWN
 TBAR = 15 SECONDS (1225 SAMPLES)

**SWX CASE 88J3NF08 : PLOT # 1
 C ** SIGPAKZ PLOTTING FOR PRONT DATA (ON .F08 AND .F10 FILES)
 G KEMANO 13.8 1 COULEE 2 13.8 1 4 ELECTRICAL POWER
 NO. SOLUTIONS = 32 TRIMLOC = 0.20E+00

33

FIGURE 4.4. PRONT SOLUTION LOCUS FOR SLIDING-WINDOW FITS TO KEMANO RINGDOWN
 TBAR = 15 SECONDS (225 SAMPLES)

****SWX CASE 88J3NF08 :**
C ** SYSHECK/SIGPAK VERSATEC PLOT
G COULEE 2 13.8 1 COULEE 2 13.8 1 4
A22/R11 : INPUT =MAL MVR (WINDWD)

PLOT # 5

ELECTRICAL POWER
CX 1.00J

34

FIGURE 5. FREQUENCY RESPONSE OF GRAND COULEE ELECTRICAL POWER TO SHUNT
 REACTIVE CONTROL AT MALIN, CASE 88J3NF08

****SWX CASE 88J3NF08 :**
C ** SYSHECK/SIGPAK PRINTER PLOT
G COULEE 2 13.8 1 COULEE 2 13.8 1 4
R 20 3: INPUT =MAL MVR

PLOT # 5

ELECTRICAL POWER
CX 1.00J

FIGURE 5.0. GRAND COULEE RINGDOWN FOR BRIEF MVR LOAD PULSE AT MALIN

**PRONY S-TABLE FOR PRS NUMBER 1
 *SIGNAL-TO-NOISE RATIO = 76.9200 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.0000121	0.0000000	1.0000000	180.000000	12.7991281
5	0.1714490	0.5849845	0.6643203	-24.840629	8.5027202
6	0.0213050	0.6285543	0.2825898	2.211894	3.6169033
7	0.0935907	0.7885799	0.4576850	55.072924	5.8579688
9	0.1081152	1.0315457	0.3415994	-87.653386	4.3721745
10	0.0271046	1.1117995	0.3803402	-143.306714	4.8680235
12	0.0191384	1.4166899	0.2276238	-46.593526	2.9133867

**PRONY S-TABLE FOR PRS NUMBER 2
 *SIGNAL-TO-NOISE RATIO = 62.2740 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.2762722	0.0000000	0.2583904	180.000000	1.5116550
5	0.2252735	0.5064690	0.8847686	-169.312284	5.1761401
6	0.0208683	0.6284520	0.5496024	153.154691	3.2153256
7	0.1039441	0.7586371	0.8187653	-72.668157	4.7900024
10	0.0340882	1.1175964	1.0000000	106.202465	5.8502755
11	0.0570722	1.2150878	0.3604350	163.975121	2.1086440
12	0.0203240	1.4150188	0.4797156	-60.146025	2.8064682

**PRONY S-TABLE FOR PRS NUMBER 3
 *SIGNAL-TO-NOISE RATIO = 65.0990 FOR NMODES = 58
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
7	0.5653865	0.7645359	1.0000000	-95.086255	15.0051530
8	0.1225762	0.7654033	0.3308220	103.906899	4.9640347
10	0.0293104	1.0952112	0.2665533	109.931609	3.9996729
11	0.0609731	1.1020010	0.5932094	-7.572606	8.9011980

**PRONY S-TABLE FOR PRS NUMBER 4
 *SIGNAL-TO-NOISE RATIO = 65.9490 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.8260150	0.0000000	0.3252024	180.000000	1.4931377
6	0.0208481	0.6282780	0.5863109	95.389133	2.6919935
7	0.1263652	0.7557108	0.6649297	-61.299435	3.0529649
9	0.0641013	1.0629498	0.4536526	-112.340079	2.0829050
10	0.0319567	1.1047070	1.0000000	-40.197141	4.5914098
11	0.0507833	1.1960494	0.3625417	73.557191	1.6645777
12	0.0201382	1.4145743	0.5100473	-99.708609	2.3418363

**PRONY S-TABLE FOR PRS NUMBER 5
 *SIGNAL-TO-NOISE RATIO = 58.1000 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
5	0.0209409	0.6282848	0.7889842	-113.819176	2.4784325
6	0.1283117	0.7736774	0.6804827	104.520295	2.1375971
8	0.3238557	0.9472265	0.5225938	-94.268561	1.6416216
10	0.0288555	1.1158272	1.0000000	-164.928599	3.1412956
12	0.0199285	1.4144407	0.6781224	-119.891132	2.1301829
13	0.3696908	1.4763510	0.2945121	153.523109	0.9251494

FIGURE 5.1. PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO GRAND COULEE RINGDOWN
 TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 88J3NF08 :

PLOT # 1

C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)

G COULEE 2 13.8 1 COULEE 2 13.8 1 4 ELECTRICAL POWER

NO. SOLUTIONS = 32

TRIMLOC = 0.20E+00

36

FIGURE 5.2. PRONY SOLUTION LOCUS FOR SLIDING-WINDOW FITS TO GRAND COULEE RINGDOWN
TBAR = 15 SECONDS (225 SAMPLES)

##SWX CASE 88J3NF08 :

PLOT # 6

C ** SYSHECK/SIGPAK VERSATEC PLOT

G SHASTA 13.8 1 COULEE 2 13.8 1 4

ELECTRICAL POWER

A22/ALL : INPUT =MAL MVR (WINDOW)

EX 1.000

FIGURE 6. FREQUENCY RESPONSE OF SHASTA ELECTRICAL POWER TO SHUNT REACTIVE CONTROL AT MALIN, CASE 88J3NF08

##SWX CASE 88J3NF08 :

PLOT # 6

C ** SYSHECK/SIGPAK PRINTER PLOT

G SHASTA 13.8 1 COULEE 2 13.8 1 4

ELECTRICAL POWER

SR 32 3: INPUT =MAL MVR

EX 1.000

FIGURE 6.0. SHASTA RINGDOWN FOR BRIEF MVAR LOAD PULSE AT MALIN

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**PRONY S-TABLE FOR PRS NUMBER 1
*SIGNAL-TO-NOISE RATIO = 78.6570 FOR NMODES = 57
DISPLAY TRIM LEVEL= 0.20000E+00

MODE      DAMPING      FREQ (HZ)      REL WT      PHASE      AMPLITUDE
  2      0.0000147      0.0000000      0.6236347    180.000000    1.9351998
 11      0.0559060      1.1430360      1.0000000     57.416009    3.1030984

**PRONY S-TABLE FOR PRS NUMBER 2
*SIGNAL-TO-NOISE RATIO = 67.8140 FOR NMODES = 56
DISPLAY TRIM LEVEL= 0.20000E+00

MODE      DAMPING      FREQ (HZ)      REL WT      PHASE      AMPLITUDE
  8      0.0873423      0.9806037      0.3249831   -65.325787    0.8744046
  9      0.0604547      1.1160129      1.0000000    -3.692468    2.6906155

**PRONY S-TABLE FOR PRS NUMBER 3
*SIGNAL-TO-NOISE RATIO = 75.2930 FOR NMODES = 56
DISPLAY TRIM LEVEL= 0.20000E+00

MODE      DAMPING      FREQ (HZ)      REL WT      PHASE      AMPLITUDE
  8      0.1005724      0.9734286      0.3718138  -175.282491    0.7787704
  9      0.0618862      1.1112630      1.0000000   -88.646791    2.0945172

**PRONY S-TABLE FOR PRS NUMBER 4
*SIGNAL-TO-NOISE RATIO = 65.3750 FOR NMODES = 56
DISPLAY TRIM LEVEL= 0.20000E+00

MODE      DAMPING      FREQ (HZ)      REL WT      PHASE      AMPLITUDE
  2      0.2840114      0.1643471      0.3324675  -170.179473    0.3552443
  5      0.0206658      0.6281218      0.3275875    96.775829    0.3500300
  6      0.0175612      0.7547974      0.3268882   114.902072    0.3492823
  9      0.0513900      1.0959000      1.0000000  -162.723370    1.0685083
 14      0.1608307      1.7876513      0.2282731   -25.494541    0.2439117
 15      0.4064986      1.8421872      0.4125310   103.467051    0.4407928

**PRONY S-TABLE FOR PRS NUMBER 5
*SIGNAL-TO-NOISE RATIO = 66.1690 FOR NMODES = 56
DISPLAY TRIM LEVEL= 0.20000E+00

MODE      DAMPING      FREQ (HZ)      REL WT      PHASE      AMPLITUDE
  5      0.0205556      0.6281598      0.3596967  -112.657722    0.3192980
  6      0.0173369      0.7545595      0.3605438   -63.373701    0.3200499
  9      0.0526018      1.0955534      1.0000000   101.469387    0.8876867

```

FIGURE 6.1. PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO SHASTA
RINGDOWN
TBAR = 15 SECONDS (225 SAMPLES)

##SWX CASE 88J3NF08 : PLOT # 1
 C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)
 G SHASTA 13.8 1 COULEE 2 13.8 1 4 ELECTRICAL POWER
 NO. SOLUTIONS = 32 TRIMLOC = 0.20E+00

39

FIGURE 6.2. PRONY SOLUTION LOCUS FOR SLIDING-WINDOW FITS TO SHASTA RINGDOWN
 TBAR = 15 SECONDS (225 SAMPLES)

##SWX CASE 88J3NF08 :

PLOT # 4

C ** SISCHECK/SIGPAK VERSATEC PLOT

G PALOVRD1 24.0 1 COULEE 2 13.8 1 4

ELECTRICAL POWER

A22/A11 : INPUT =MAL MVR (WINDOW)

EX 1.000

40

FIGURE 7. FREQUENCY RESPONSE OF PALO VERDE ELECTRICAL POWER TO SHUNT REACTIVE CONTROL AT MALIN, CASE 88J3NF08

##SWX CASE 88J3NF08 :

PLOT # 4

C ** SISCHECK/SIGPAK PRINTER PLOT

G PALOVRD1 24.0 1 COULEE 2 13.8 1 4

ELECTRICAL POWER

SR 29 3: INPUT =MAL MVR

EX 1.000

FIGURE 7.0. PALO VERDE RINGDOWN FOR BRIEF MVAR LOAD PULSE AT MALIN

**PRONY S-TABLE FOR PRS NUMBER 1
 *SIGNAL-TO-NOISE RATIO = 71.0880 FOR NM0DES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

41

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.0784432	0.2537408	0.3884187	-125.115988	1.3452108
4	0.1099590	0.4582658	0.3954828	-127.855330	1.3696758
5	0.0215942	0.6294444	0.6143338	167.280802	2.1276230
6	0.0222847	0.7580719	0.5303981	108.103273	1.8369283
8	0.6530660	0.9475308	1.0000000	1.590849	3.4633010
9	0.0902369	0.9586493	0.7930519	-146.442701	2.7465775
10	0.0326451	1.0931824	0.3666928	16.532271	1.2699675
12	0.0974320	1.3501417	0.2851505	-44.868328	0.9875622

**PRONY S-TABLE FOR PRS NUMBER 2
 *SIGNAL-TO-NOISE RATIO = 62.4910 FOR NM0DES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
5	0.0187972	0.6302957	0.3667230	-46.289754	1.7011466
7	0.0540874	0.8138000	0.6002149	-110.655109	2.7842636
9	0.1960338	1.0045698	1.0000000	39.799072	4.6387779
10	0.0360547	1.0991668	0.2843185	-99.646175	1.3188904

**PRONY S-TABLE FOR PRS NUMBER 3
 *SIGNAL-TO-NOISE RATIO = 53.9140 FOR NM0DES = 55
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.0993002	0.2402758	0.4338793	45.386386	0.7174966
3	0.0608364	0.3106814	0.4470482	-112.273107	0.7392737
5	0.0203149	0.6286020	1.0000000	110.828939	1.6536778
6	0.0164000	0.7563073	0.6947976	113.628453	1.1489714
8	0.0696487	0.8997352	0.9493147	9.401998	1.5698606
9	0.0377948	1.0942890	0.7467464	178.167282	1.2348779
10	0.0560862	1.1991670	0.4006823	-142.071052	0.6625994
11	0.1062555	1.3394454	0.3559354	-106.002752	0.5886024

**PRONY S-TABLE FOR PRS NUMBER 4
 *SIGNAL-TO-NOISE RATIO = 51.1090 FOR NM0DES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	1.3117952	0.0000000	0.4612931	180.000000	0.7355995
4	0.0628569	0.2978800	0.4423503	-6.890386	0.7053924
6	0.0214090	0.6280366	1.0000000	-96.119448	1.5946467
7	0.0207875	0.7566131	0.8344029	-63.497948	1.3305778
10	0.0424768	1.0950723	0.8181547	78.654215	1.3046677
11	0.0623607	1.1970763	0.4492991	142.226322	0.7164733
12	0.1187711	1.3718049	0.3538183	172.008060	0.5642152

**PRONY S-TABLE FOR PRS NUMBER 5
 *SIGNAL-TO-NOISE RATIO = 60.2590 FOR NM0DES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
3	0.0685267	0.3029037	0.2629000	53.664514	0.6673165
5	0.0202937	0.6277372	0.5817735	54.819843	1.3723120
6	0.4352444	0.6863008	1.0000000	107.880798	2.3588422
7	0.0201897	0.7525882	0.4867526	126.663093	1.1481725
10	0.0399053	1.1064367	0.4156352	-45.820015	0.9804178
11	0.0755221	1.2236292	0.2523528	8.181061	0.5952605

FIGURE 7.1. PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO PALO VERDE
 RINGDOWN
 TBAR = 15 SECONDS (225 SAMPLES)

##SWX CASE 88J3NF08 :

PLOT # 1

C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)

G PALOVRD1 24.0 1 COULEE 2 13.8 1 4

ELECTRICAL POWER

NO. SOLUTIONS = 32

TRIMLOC = 0.20E+00

42

FIGURE 7.2. PRONY SOLUTION LOCI FOR SLIDING-WINDOW FITS TO PALO VERDE RINGDOWN
TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 88J3NF08 : PLOT # 7
 C ** SYSCHECK/SIGPAK VERSATEC PLOT
 G INTERMIG 26.0 1 COULEE 2 13.8 1 4 ELECTRICAL POWER
 A22/A11 : INPUT =MAL MVR (WINDWD) CX 1.00J

43

FIGURE 8. FREQUENCY RESPONSE OF INTERMOUNTAIN ELECTRICAL POWER TO SHUNT REACTIVE CONTROL AT MALIN, CASE 88J3NF08

**SWX CASE 88J3NF08 : PLOT # 7
 C ** SYSCHECK/SIGPAK PRINTER PLOT
 G INTERMIG 26.0 1 COULEE 2 13.8 1 4 ELECTRICAL POWER
 SR 24 3: INPUT =MAL MVR CX 1.00J

FIGURE 8.0. INTERMOUNTAIN RINGDOWN FOR BRIEF MVAR LOAD PULSE AT MALIN

**PRONY S-TABLE FOR PRS NUMBER 1
 *SIGNAL-TO-NOISE RATIO = 41.2730 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.0004547	0.0000000	0.2651484	0.0000000	0.4232691
3	0.3060890	0.0000000	1.0000000	180.000000	1.5963479
4	0.1541357	0.1894256	0.8136875	-45.107132	1.2989284
7	0.0228886	0.6259056	0.3307859	-72.335313	0.5280494
8	0.0242587	0.7686995	0.9225584	-11.878057	1.4727242
9	0.0135782	0.8698549	0.2368852	155.314818	0.3781512
10	0.0683574	1.0393390	0.8394789	-82.722458	1.3401004
11	0.0211222	1.1189360	0.3102971	148.161545	0.4953421
12	0.0951192	1.2562006	0.2615300	0.215356	0.4174929
13	0.1518059	1.3987931	0.7131960	168.337949	1.1385088

**PRONY S-TABLE FOR PRS NUMBER 2
 *SIGNAL-TO-NOISE RATIO = 39.7840 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
3	0.1616185	0.1724272	0.3679002	21.964036	0.4955053
6	0.0219559	0.6254471	0.3412128	78.938446	0.4595615
7	0.0246519	0.7681117	1.0000000	174.148297	1.3468473
8	0.0146653	0.8703887	0.2768451	1.872721	0.3728681
9	0.0648711	1.0389818	0.6930962	163.071025	0.9334948
10	0.0208640	1.1163789	0.3376111	64.640025	0.4547106
12	0.0871524	1.3473008	0.3423678	-150.844375	0.4611171
21	0.1137001	2.6514754	0.2245454	15.900442	0.3024284

**PRONY S-TABLE FOR PRS NUMBER 3
 *SIGNAL-TO-NOISE RATIO = 35.1830 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
36	4.5909934	4.6890331	1.0000000	-7.343048	18.4208121
57	7.5461307	7.4999996	0.9451398	180.000000	17.4102431

**PRONY S-TABLE FOR PRS NUMBER 4
 *SIGNAL-TO-NOISE RATIO = 33.9630 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.5674434	0.0000000	0.2202136	0.0000000	0.2287726
6	0.0228520	0.6261223	0.3853091	17.776547	0.4002848
7	0.0234593	0.7679752	1.0000000	-177.246773	1.0388667
8	0.0165688	0.8701703	0.3545205	59.168199	0.3682996
9	0.0643263	1.0206950	0.4411944	-30.447535	0.4583422
10	0.0230992	1.1177581	0.4093708	-126.184647	0.4252817
11	0.1414904	1.2984470	0.4347561	145.588309	0.4516536
28	0.6062894	3.5262053	0.2849384	-111.174224	0.2960130
52	0.4178921	6.9254830	0.2471036	-41.991753	0.2567077

**PRONY S-TABLE FOR PRS NUMBER 5
 *SIGNAL-TO-NOISE RATIO = 38.0900 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
6	0.0209670	0.6264725	0.3322948	166.792417	0.3360954
7	0.0251221	0.7679660	1.0000000	7.900476	1.0114372
8	0.0131034	0.8701600	0.2832670	-90.514821	0.2865068
9	0.0354755	1.0595370	0.3284814	102.020825	0.3322383

FIGURE 8.1. PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO INTERMOUNTAIN RINGDOWN
 TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 88J3NF08 : PLOT # 1
 C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)
 G INTERMIG 26.0 1 COULEE 2 13.8 1 4 ELECTRICAL POWER
 NO. SOLUTIONS = 32 TRIMLOC = 0.20E+00

45

FIGURE 8.2. PRONY SOLUTION LOCUS FOR SLIDING-WINDOW FITS TO INTERMOUNTAIN RINGDOWN
 TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 88J3NF08 :
 C ** SYSCHECK/SIGPAK VERSATEC PLOT
 L MALIN 500.0 ROUND MT500.0 1 6
 A22/A11 : INPUT =MAL MVR (WINDWD)

PLOT # 2

REAL POWER

[X 2.00]

46

FIGURE 9. FREQUENCY RESPONSE OF MALIN-RND MTN LINE POWER TO SHUNT
 REACTIVE CONTROL AT MALIN, CASE 88J3NF08

**SWX CASE 88J3NF08 :
 C ** SYSCHECK/SIGPAK PRINTER PLOT
 L MALIN 500.0 ROUND MT500.0 1 6
 SR 1 1: INPUT =MAL MVR

PLOT # 2

REAL POWER

[X 2.00]

FIGURE 9.0. MALIN-RND MTN RINGDOWN FOR BRIEF MVAR LOAD PULSE AT MALIN

**PRONY S-TABLE FOR PRS NUMBER 1
 *SIGNAL-TO-NOISE RATIO = 80.8200 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.0000225	0.0000000	0.8824101	180.000000	29.0897142
4	0.0728815	0.2888887	0.6251564	-72.417115	20.6090340
5	0.2008923	0.3621256	1.0000000	30.566841	32.9662054
8	0.0237263	0.7633214	0.2453349	66.868575	8.0877593

**PRONY S-TABLE FOR PRS NUMBER 2
 *SIGNAL-TO-NOISE RATIO = 64.0440 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.2998617	0.0000000	0.6942648	180.000000	5.9093813
4	0.0644633	0.2994547	1.0000000	-18.044282	8.5117115
5	0.0891269	0.5165796	0.2294768	23.290965	1.9532404
7	0.0225862	0.7609123	0.8109101	-104.318721	6.9022330
9	0.0686053	1.0022057	0.4426215	46.090300	3.7674665

**PRONY S-TABLE FOR PRS NUMBER 3
 *SIGNAL-TO-NOISE RATIO = 57.8350 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
3	0.0859255	0.2168223	0.3341491	100.954514	2.0757543
4	0.0631280	0.2988781	0.9852736	56.788432	6.1205793
5	0.1071129	0.5340866	0.3984711	133.979158	2.4753265
7	0.0226366	0.7587513	1.0000000	83.799456	6.2120607
9	0.0797884	1.0271776	0.7429854	-105.909806	4.6154701
11	0.0846850	1.1659624	0.4154877	15.745507	2.5810348
13	0.1081001	1.3835734	0.2330754	57.844196	1.4478785

**PRONY S-TABLE FOR PRS NUMBER 4
 *SIGNAL-TO-NOISE RATIO = 56.9560 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
4	0.0643141	0.3016693	0.7054667	120.320395	4.8699238
7	0.0207480	0.7584268	0.7472865	-93.591542	5.1586112
9	0.0659586	1.0548875	0.4538175	79.251891	3.1327586
10	0.0278928	1.1240294	0.2096558	98.218372	1.4472798
11	0.3744082	1.1551334	1.0000000	-123.749944	6.9031235
12	0.1174704	1.2907154	0.3282809	92.248690	2.2661635

**PRONY S-TABLE FOR PRS NUMBER 5
 *SIGNAL-TO-NOISE RATIO = 58.0320 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
3	0.0651264	0.3017567	0.8171294	-168.153081	3.8035728
5	0.1234960	0.4639326	0.2082107	112.733075	0.9691789
6	0.0210196	0.6337859	0.2538329	-142.524135	1.1815407
7	0.0204478	0.7576536	1.0000000	90.343356	4.6547984
9	0.0596480	1.0530185	0.4109279	-29.701167	1.9127867
10	0.0262728	1.1252890	0.2915823	2.172341	1.3572566
11	0.1171720	1.2802904	0.2628437	56.469880	1.2234845

FIGURE 9.1. PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO MALIN-RND MTN
 RINGDOWN
 TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 88J3NF08 : PLOT # 1
 C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)
 L MALIN 500.0 ROUND MT500.0 1 6 REAL POWER
 NO. SOLUTIONS = 32 TRIMLOC = 0.20E+00

48

FIGURE 9.2. PRONY SOLUTION LOCUS FOR SLIDING-WINDOW FITS TO MALIN-AND MTN RINGDOWN
 TBAA = 15 SECONDS (225 SAMPLES)

**SWX CASE 93JTAS434 :
 C ** SYSHECK/SIGPAK PRINTER PLOT
 B MALIN 500.0 2
 SR 48 2: INPUT =MALIN V

PLOT # 1

VOLTAGE

[X 1.00]

FIGURE 10. MALIN 500 KV VOLTAGE SWINGS FOLLOWING 3100 MW HVDC BIPOLE LOSS,
 CASE 93JTAS434

**SWX CASE 93JTAS434 :
 C ** SYSHECK/SIGPAK VERSATEC PLOT
 B MALIN 500.0 2
 ALL FFT : INPUT =MALIN V (WINDOW)

PLOT # 2

VOLTAGE

[X 1.00]

FIGURE 10.0. AUTOSPECTRUM OF MALIN VOLTAGE SWINGS, CASE 93JTAS434
 (SIGNAL HANNED TWICE)

**PRONY S-TABLE FOR PRS NUMBER 1
 *SIGNAL-TO-NOISE RATIO = 71.0370 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.2507711	0.0000000	0.2245312	180.000000	0.0253453
2	-0.0033904	0.0000000	0.7853385	180.000000	0.0886496
4	0.0533181	0.2524768	1.0000000	-52.518535	0.1128808
5	0.0517744	0.2947856	0.4310798	75.799699	0.0486606
8	-0.0028251	0.7069375	0.5746017	30.730795	0.0648615
9	0.0818172	0.7679518	0.2086905	-159.276406	0.0235571

**PRONY S-TABLE FOR PRS NUMBER 2
 *SIGNAL-TO-NOISE RATIO = 63.8420 FOR NMODES = 55
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.2333248	0.0000000	0.2428668	180.000000	0.0151514
2	-0.0112851	0.0178693	0.2387316	145.318381	0.0148934
3	0.0438085	0.2545110	0.9964704	-15.964311	0.0621653
4	0.0779187	0.3018175	0.8023276	84.725816	0.0500536
7	-0.0037762	0.7075482	1.0000000	-160.685480	0.0623854

**PRONY S-TABLE FOR PRS NUMBER 3
 *SIGNAL-TO-NOISE RATIO = 71.8300 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.0116725	0.0000000	0.5404121	0.000000	0.0322512
3	0.0382744	0.2608543	0.6669554	17.768453	0.0398031
4	0.0979031	0.2727004	0.9993710	134.237450	0.0596413
7	-0.0050119	0.7090000	1.0000000	6.047108	0.0596788

**PRONY S-TABLE FOR PRS NUMBER 4
 *SIGNAL-TO-NOISE RATIO = 65.8330 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	-0.0091296	0.0156373	0.3346139	159.521664	0.0240047
3	0.0408693	0.2481736	0.4526176	119.002078	0.0324701
7	-0.0002819	0.7089000	1.0000000	173.306371	0.0717385

**PRONY S-TABLE FOR PRS NUMBER 5
 *SIGNAL-TO-NOISE RATIO = 62.1770 FOR NMODES = 57
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.0212016	0.0000000	0.4792317	0.000000	0.0308228
3	0.0306766	0.2459238	0.3086705	176.621719	0.0198528
7	-0.0036296	0.7100582	1.0000000	-14.916527	0.0643171

FIGURE 10.1. PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO MALIN VOLTAGE
 SWINGS, CASE 930TAS434
 TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 93JTAS434 : PLOT # 1
 C ** SIGPAKZ PLOTTING FOR PRONY DATA (ON .F08 AND .F10 FILES)
 B MALIN 500.0 2 VOLTAGE
 NO. SOLUTIONS = 22 TRIMLOC = 0.20E+00

51

FIGURE 10.2. PRONY SOLUTION LOCUS FOR SLIDING-WINDOW FITS TO MALIN VOLTAGE
 SWINGS, CASE 93JTAS434
 TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 93JTAS438 :
 C ** SISCHECK/SIGPAK PRINTER PLOT
 B MALIN 500.0 2
 SR 48 2: INPUT =MALIN V

PLOT # 1

VOLTAGE

EX 1.000

52

FIGURE 11. MALIN 500 KV VOLTAGE SWINGS FOLLOWING 3100 MW HVDC BIPOLE LOSS
 AND 1000 MW SHES PULSE, CASE 93JTAS438

**SWX CASE 93JTAS438 :
 C ** SISCHECK/SIGPAK VERSATEC PLOT
 B MALIN 500.0 2
 ALL FFT : INPUT =MALIN V (WINDOW)

PLOT # 2

VOLTAGE

EX 1.000

FIGURE 11.9 AUTOSPECTRUM OF MALIN VOLTAGE SWINGS, CASE 93JTAS438
 (SIGNAL BANNED TAILED)

**PRONY S-TABLE FOR PRS NUMBER 1
 *SIGNAL-TO-NOISE RATIO = 63.6400 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	-0.0007505	0.0000000	0.6998179	180.000000	0.0323224
3	0.0486296	0.2742443	0.7132557	-14.813149	0.0329431
5	0.1165835	0.4729539	0.3774820	-169.544116	0.0174347
6	0.0072559	0.7391544	0.9067387	92.743713	0.0418794
7	0.0215525	0.7871297	0.3196454	-111.680377	0.0147634
10	0.1416762	1.1002561	1.0000000	-111.256658	0.0461869
11	0.2027071	1.1946111	0.9995692	28.978326	0.0461670

**PRONY S-TABLE FOR PRS NUMBER 2
 *SIGNAL-TO-NOISE RATIO = 40.4560 FOR NMODES = 55
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
2	0.0010892	0.0000000	0.4330416	0.000000	0.0174303
3	0.0503860	0.2724491	0.7105371	55.444561	0.0285998
5	0.3267843	0.4976419	0.9852078	-97.503347	0.0396555
6	0.0060984	0.7406040	1.0000000	-97.372869	0.0402509
7	0.0430224	0.7991343	0.4355697	39.490016	0.0175321
10	0.1043088	1.1630711	0.2039446	86.648172	0.0082090
15	0.3878178	1.9598462	0.2225328	130.219279	0.0089571

**PRONY S-TABLE FOR PRS NUMBER 3
 *SIGNAL-TO-NOISE RATIO = 34.8860 FOR NMODES = 55
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
4	0.0514083	0.2737419	0.5540265	118.951168	0.0240772
7	0.0070342	0.7418911	1.0000000	77.429644	0.0434585
8	0.0471773	0.7740529	0.4772593	-119.475627	0.0207410

**PRONY S-TABLE FOR PRS NUMBER 4
 *SIGNAL-TO-NOISE RATIO = 72.6300 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
1	0.0116693	0.0000000	0.5204470	180.000000	0.0173990
2	0.0069002	0.0000000	0.8536619	0.000000	0.0285387
3	0.0520962	0.2750464	0.6002498	-176.898812	0.0200669
7	0.0033004	0.7397810	1.0000000	-102.013156	0.0334309

**PRONY S-TABLE FOR PRS NUMBER 5
 *SIGNAL-TO-NOISE RATIO = 68.7030 FOR NMODES = 56
 DISPLAY TRIM LEVEL= 0.20000E+00

MODE	DAMPING	FREQ (HZ)	REL WT	PHASE	AMPLITUDE
3	0.0524898	0.2752722	0.4870417	-110.935757	0.0163811
7	0.0037329	0.7411541	1.0000000	72.205805	0.0336339

FIGURE 11.1 PRONY SOLUTION TABLE FOR SLIDING-WINDOW FITS TO MALIN VOLTAGE SWINGS, CASE 93JTAS438
 TBAR = 15 SECONDS (225 SAMPLES)

**SWX CASE 93JTAS438 : PLOT # 1
 C ** SIGPAKZ PLOTTING FOR PRONT DATA (ON .F08 AND .F10 FILES)
 B MALIN 500.0 2 VOLTAGE
 NO. SOLUTIONS = 28 TRIMLOC = 0.20E+00

54

FIGURE 11.2. PRONT SOLUTION LOCUS FOR SLIDING-WINDOW FITS TO MALIN VOLTAGE
 SWINGS, CASE 93JTAS438
 TBAR = 15 SECONDS (225 SAMPLES)

END

**DATE
FILMED**

01/09/91