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Synchronized Phasor Measurements Applications User Guide

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Consortium for Electricity Reliability Technology Solutions

CAISO-CERTS

Synchronized Phasor Measurements Applications User Guide

Prepared by
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1.0 Overview

1.1 Introduction

This user guide is intended for the operations engineering staff that will be utilizing synchronized phasor measurement (SPM) base applications to measure and analyze post disturbance analysis. This will be done via an integration of three separate tools. They are as follows:

- PSMTools - Pacific Northwest National lab
- Synchronized Phasor Management Outlook tool - Southern California Edison
- Streamreader and PhasorFile tools – Bonneville Power Administration

Information for hands-on use of these tools is presented in the *Tools* section of this User's Guide. Theoretical background information, such as systems architecture, engineering value information, and fundamentals that are not directly applicable to the hands-on use of the tools, is available in the Appendix.

For the purposes of this Users Guide, these three tools will collectively be referred to as Synchronized Phasor Measurement Tools (SPM).

PSMTools R 12 – The system developed at Pacific Northwest National Lab (PNNL), was developed for analysis only, and was not designed for monitoring.

Phasor Management Outlook Tool R 0.9 – The system developed at Southern California Edison was intended for both monitoring and analyzing the data.

StreamReader and PhasorFile Tools R 1.0 – The system developed at Bonneville was intended for monitoring the data only. There is no function for analysis

The four major processes for the utilization of synchronized phase measurements are:

- Data Acquisition
- Post Disturbance Analysis
- Result analysis, Model Validation, and Remediation Planning
- RAS Threshold Validation

Further details for each of these high level processes can be found in the Appendix.

This guide is intended for *post disturbance* analysis and model validation only. Once the data has been gathered, the raw data can be cleaned and filtered and the post disturbance analysis can begin. Phase-2 of the CERTS project will produce a complement user guide for dispatchers.

1.2 How to Access SPM Tools

The Post Disturbance Analysis Tools are available on the Windows desktop for users who have had them installed. There is a folder on the desktop called *Post Disturbance Analysis Tools* with four different icons in it. They are:

PSMTools R 12

Phasor Management Outlook Tool R 0.9

Streamreader and PhasorFile Tools R 1.0

Each tool represents fundamentally similar functionality which all utilize the same data as input. The difference is that each of the tools was tailored for slightly different purposes, one for monitoring, one for assessment, and one for both.

2.0 Tools

2.1 PSMTools R12

The first tool is PSMTools, developed by Pacific Northwest National Lab.

2.1.1 Introduction

This section is a basic guide to operation of **PSMTools**. Depending upon context, ***PSM*** may denote either power system monitor or power system measurements. In the latter sense it is taken to include synthetic measurements produced through computer simulations.

As seen in figure 2.1-1, in order for PSMTools to execute properly, it requires different inputs, such as case control templates, custom menus, Metlab generic tools sets, add-on toolsets, as well as response data in PSMTools standard format. The output can be either hardcopy, automatic documentation, or results files among others.

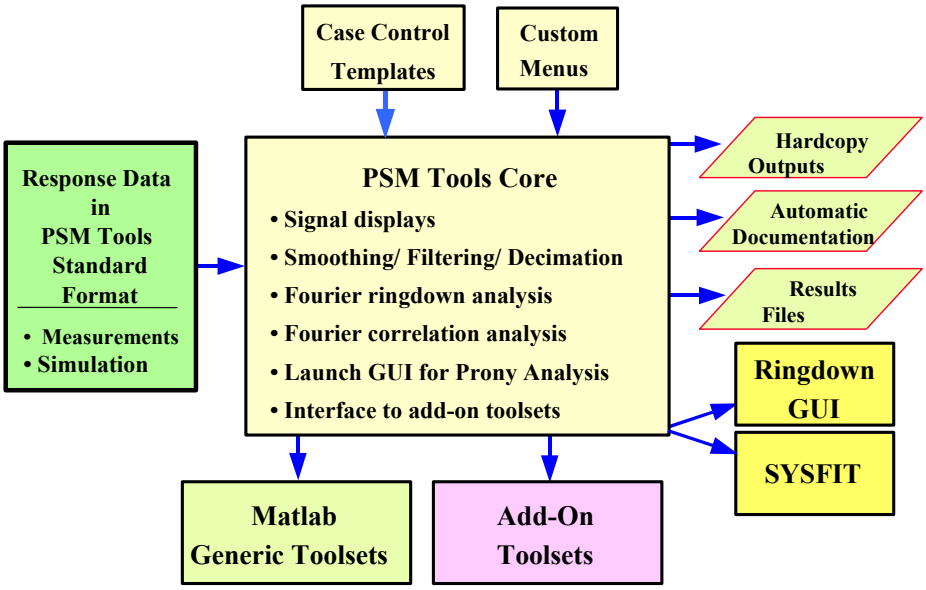


Figure 2.1-1

PSMTools is the most general of the analysis toolsets contained among the WAMS technologies. Broadly described, the defining functionalities for PSMTools are to import PSM data into a standardized processing environment, and to provide a flexible structure there for signal analysis and disturbance assessment. PSMTools can accept and integrate data from all major phasor monitor types now operating within the western power system, and from the more important transient stability programs. New features, such as translators for additional data sources, are readily added by knowledgeable users or by key developers at the Pacific Northwest National Laboratory (**PNNL**).

The key functionalities of PSMTools include the following:

- **Import** of measured or simulated PSM data into the Matlab environment. This includes extraction of designated signals from multiple PSM records and linking them together. The data sources accommodated include BPA's Phasor Data Concentrator (**PDC**), the BPA PPSM and PSAM, the Macrodyne PMU, and leading computer programs for simulation of power system dynamics.
- **Export** of extracted signals and analysis results from the Matlab environment into other environments.
- **Alignment and Merging** of signals extracted from multiple data sources, which need not be of the same type. E.g., signals collected on one or more PDC units can be merged with signals collected on PPSM units.
- **Interactive batch processing** of the following kinds:
  - repair of record defects such as lost PMU messages
  - calculation of derived signals, such as rms signals based upon phasor data
  - graphical displays for signals and computational results
  - filtering, smoothing, and decimation of extracted signals
  - spectral analysis via Fourier periodograms [i,ii]
  - Fourier ringdown analysis of transient waveforms
  - launching of the Ringdown GUI for Prony analysis of transient waveforms or correlation functions
  - launching of the SYSFIT program for frequency domain fitting of structured models to transfer function data*
  - launching of Matlab add-on toolsets (e.g., wavelet analysis and controller design)
- **automatic documentation** of processing cases.
- **automatic reruns** of interactive processing cases*
- **automatic scanning** of PSM archives to detect and summarize dynamic events*

Asterisks here indicate features that are custom, experimental, or in some other respect not available for general distribution.

2.1.2 Getting Started with PSMTools – Examining the Installation for Future Upgrades

This is a tutorial Section intended for new users of PSMTools, and for users who may not be experienced with Matlab. Experienced users may prefer to review it quickly and then proceed to later Sections.

Software for the Dynamic System Identification (**DSI**) Toolbox is distributed in two primary folders, one for the Ringdown GUI and one for PSMTools. The primary PSM Tools folder usually has a name like **Source** and a directory structure as indicated in

Figure 2.1-1. In this particular case the folder has been named **Source_010301**, where the appended digit string indicates the distribution date. Usual practice is to make a working copy of the primary folder, with the distribution date omitted from the folder name.

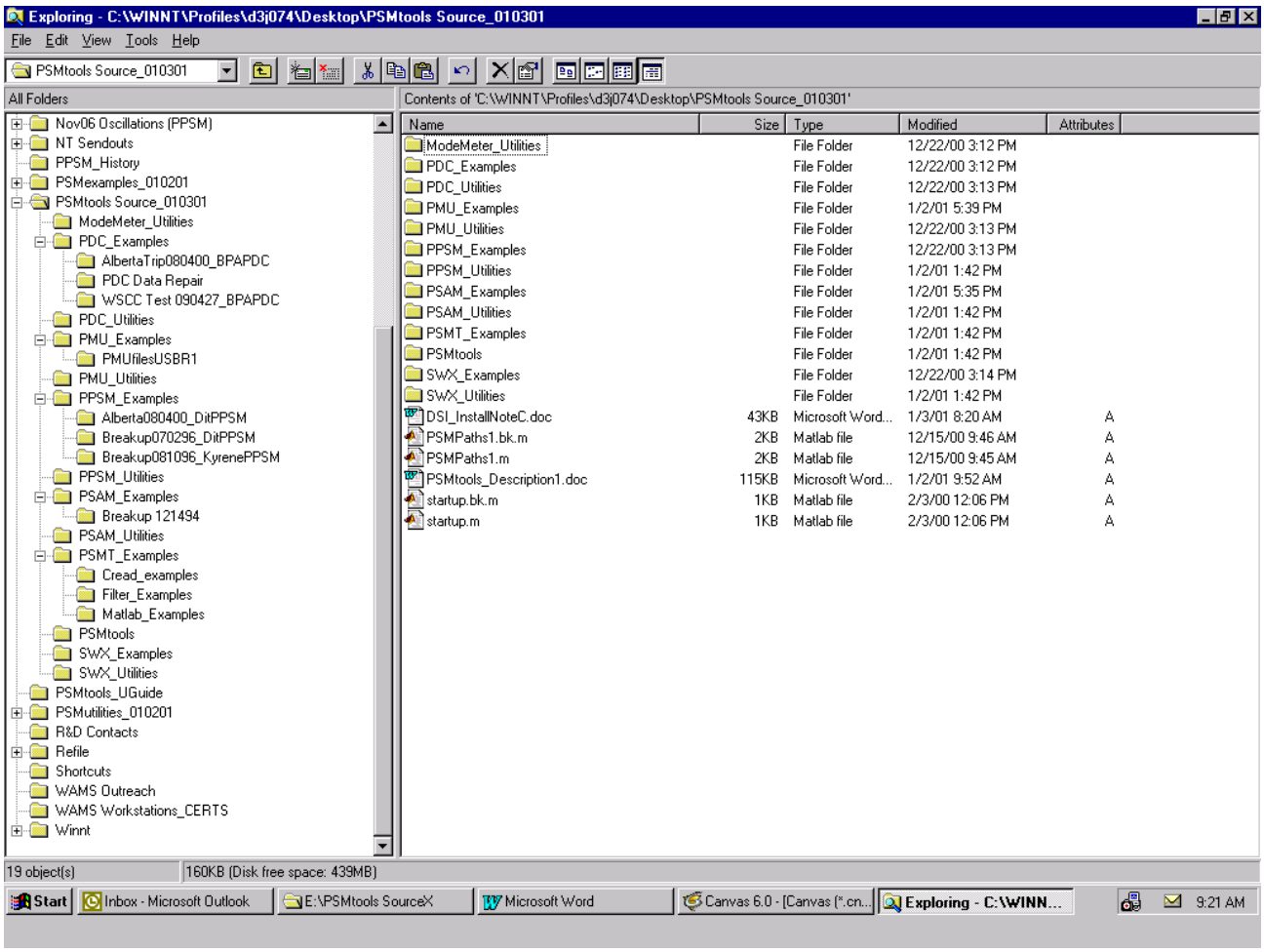


Figure 2.1-2

The upper-level subfolders within Source are of two kinds:

- **Software folders**:
  –
  – folders with names like **PDC_Utilities**
- **Example folders**:
  – **PSMT_Examples**
  – folders with names like **PDC_Examples**

Installation is done in two steps:]

a) ***"Drag and drop"*** each of the two primary folders, from the medium where it was received, to an appropriate location on the user's PC.

b) ***Set Matlab paths*** to the contents of each primary folder, so that Matlab can find the contents while processing. The Set Path command in Matlab 6.0 does this in one step, but users of Matlab 5.3 should launch a utility with a name like **PSMpaths1**.

Partial updates to the DSI Toolbox usually involve just the first step. This requires that the new primary folder have the same name and internal directory structure as the one to be updated. Then "dropping" the new version of the primary folder onto the older one will cause new file versions to replace earlier ones, and the original paths remain correct.

2.1.3 Naming Things in Matlab

Matlab treats **variable names** as **case sensitive** – **caseID** and **caseid** would denote two different variables. Matlab does not treat **file names** as case sensitive, however. Since Matlab functions are stored as files and referenced by the names of the containing files, a function name like **PSMsave** can also be written as **psmsave**.

Various names in Matlab are reserved for built-in functions. Those most commonly encountered include **if, else, for, while, try, break, continue, end**. Depending upon context, Matlab will sometimes allow the user to employ reserved names that are more specialized. It is best to avoid this where possible, however.

2.1.4 Basic Types of Matlab files

Source contains three basic types of Matlab file. The types are indicated in the file names, which end with character strings ***.m, .p***, or ***.mat***. A representative example of each file type is discussed below.

MatlabEx1.m

An **m-file** can be either a **function**, or a **script**. A function is declared to be such in the first command, which will then define input and output variables. A script will simply process whatever variables happen to be present in the Matlab workspace.

The contents of an m-file can be viewed or modified with the Matlab editor. One can do this by double-clicking on the m-file icon, or by entering the command ***edit MatlabEx1*** into the Matlab Command Window (**MCW**). Entering the command ***MatlabEx1*** will launch the m-file (i.e., cause it to execute).

PSMsave.p

A **p-file** is a "parsed" version of a corresponding m-file. A p-file corresponds to the compiled code modules of some other computer languages, and cannot be examined with the editor.

NOTE: p-files take precedence on the Matlab path, so Matlab would use an old p-file in preference to a newly edited m-file that has the same name. Mysteries of this sort can often be resolved through commands like ***which PSMsave*** (to find out which version is in use on the path). To learn more about the ***which*** function and other functions related to it, use the command ***help which***.

WSCC_Breakup_081096Ex1.mat

A **mat-file** is a Matlab binary file for data storage. The contents are variables exported from the Matlab workspace. The mat-file stores not just the value of each

variable, but also its name and all attributes. Loading such variables back into the Matlab workspace restores them in full. This also overstores any previous variables that have the same names as those returning from the mat-file.

A mat-file cannot be edited, but its contents can be determined in summary form through a command like ***whos -file WSCC_Breakup_081096Ex1.mat.*** To learn more about the ***whos*** function and other functions related to it, use the command ***help whos***.

The variables contained in this file are standard for PSM data that has been translated into PSMTools (**PSMT**) format, and the file itself is called a **PSMT data file**. The rather long name assigned to this file reflects typical practice in working with PSM data. Placing key information within file names is a useful aid in navigating among the many thousands of files that such work commonly involves.

Using the whos command to check contents of a mat-file in PSMT format

```
>> whos -file WSCC_Breakup_081096Ex1.mat
  Name          Size        Bytes  Class

  CFname        1x18           36  char array (global)
  CaseComR      31x77        4774  char array
  PSMfiles      2x29          116  char array (global)
  PSMreftimes   1x2            16  double array (global)
  PSMsigsX      14000x8      896000  double array
  PSMtype       1x4            8  char array (global)
  chankeyX      8x41         656  char array
  namesX        8x34         544  char array
  tstep         1x1            8  double array

  Grand total is 115070 elements using 902158 bytes
```

The previously extracted signals are stored as columns of array **PSMsigsX**, of which the first column is time. Character array **namesX** contains the signal names, and **chankeyX** provides a numeric "key" to the channels.

2.1.5 Examining the Internal Documentation for a PSMT Data File

Every PSMT file contains a text array with the name **CaseComR** (or sometimes just **CaseCom**). This is a **case processing log** that indicates the source of the PSM data, what has been done to the data, and where to find processing results that are stored externally to the PSMT data file.

The nature of a particular PSMT data file can be determined by loading CaseComR into the Matlab workspace and displaying it. This can be done for **WSCC_Breakup_081096Ex1.mat** by the following two commands:

>> load WSCC_Breakup_081096Ex1.mat CaseComR
>> CaseComR

CaseComR is sometimes too large for convenient display. In such case a command like the one below can be used to display selected lines:

>> CaseComR(1:20,:)

In this particular command the entry ***1:20*** indicates lines 1 through 20, and the colon ***:*** is a "wild card" symbol indicating that the full line length should be used.

Some of the more important information shown in CaseComR is also stored as separate variables, both for user convenience and for use in continued processing. Variables CFname and PSMtype indicate the data source, and variables PSMfiles and PSMreftimes indicate the names and reference times for the data files from which signals in PSMsigsX were extracted.

When variables are reloaded from a .mat file they will overstore any previous variables of the same names. For this reason the internal documentation for an active case is developed as **CaseCom** but stored and retrieved as **CaseComR**.

Examining CaseComR

```
>> load WSCC_Breakup_081096Ex1.mat CaseComR
>> CaseComR
CaseComR =

Case ID   = WSCC Breakup_081096 Example1
Case Time = 01/08/01_11:22:38
Example data for use of PSMTools -- Event is WSCC breakup of August 10, 1996
In PSM Utility PSMbrowser: General Browsing

Starting menu = Interactive selection of channels(modified)
ChansX=
[9  33  34  37   6   5  11]
PPSM File Extracted = Files@DITT 08_10_96 15H41m20s
Time Step =    0.05000    Max Time =  349.950
PPSM Reference Time = 3048705680.00000 Seconds
PPSM Reference Time = 10-Aug-1996 22:41:20.000 GMT Standard
PPSM File Extracted = Files@DITT 08_10_96 15H47m10s
Time Step =    0.05000    Max Time =  349.950
PPSM Reference Time = 3048706030.00000 Seconds
PPSM Reference Time = 10-Aug-1996 22:47:10.000 GMT Standard

In PPSMload:    2 Files Extracted:
Time axis has been inserted at column 1 of signal array
No decimation during signal extraction
Time Step =    0.05000    Max Time =  699.950
Configuration file = Dittmer #9 Listing

%   1  Time (sec)
%   2  Malin-Round Mountain #1 MW (MW)
%   3  BCH Custer MW (MW)
%   4  BCH Boundary MW (MW)
%   5  LADWP Celilo 230 kV MW (MW)
%   6  Tacoma 230 kV - Bus Frequency (Hz)
%   7  Tacoma 230 kV Bus Voltage (kV)
%   8  Malin-Round Mountain #1 kV (kV)
```

Examining chankeyX

```
» load WSCC_Breakup_081096Ex1.mat chankeyX
» chankeyX
chankeyX =
%  1  Time (sec)
%  2  Malin-Round Mountain #1 MW (MW)
%  3  BCH Custer MW (MW)
%  4  BCH Boundary MW (MW)
%  5  LADWP Celilo 230 kV MW (MW)
%  6  Tacoma 230 kV - Bus Frequency (Hz)
%  7  Tacoma 230 kV Bus Voltage (kV)
%  8  Malin-Round Mountain #1 kV (kV)
```

2.1.6 Navigating to .mat Files

The name of a file like **WSCC_Breakup_081096Ex1.mat** may not be known exactly, and the file might not be located on the Matlab path. A user can "browse" for the file of interest with some general tool such as **Widows Explorer** or **Find File**. This may require sorting through numerous files that are of the wrong type, however.

Within Matlab, the command ***uiload*** will launch a dialog box that seeks mat-files only. Another option is to set the Matlab working directory (e.g., with the ***cd*** command) and then use the ***dir*** command to generate a corresponding directory. Such functionalities are built into PSMTools. If the installation was done correctly, tools for navigating to the files of interest will be presented automatically.

Many folder names in PSMTools and in the user's PSM data archives are likely to contain blanks. The ***cd*** command, and some others, will refuse to process such names unless the name is included within single quotes.

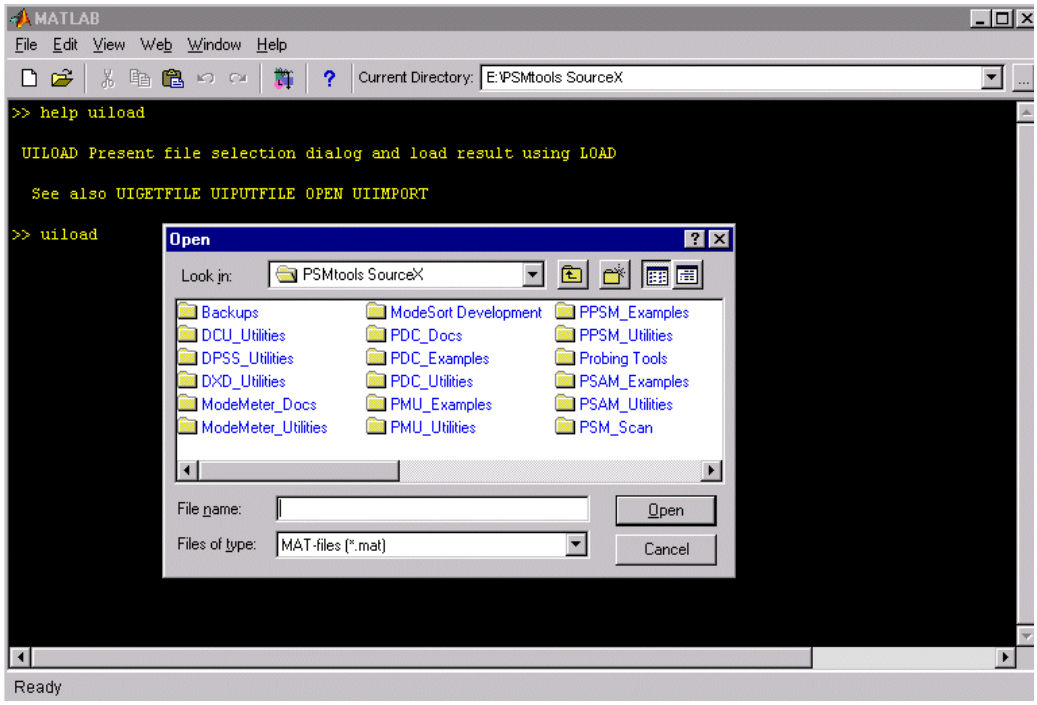


Figure 2.1-3

Accommodating blanks in the *cd* command

>> which BPA2_0006072029.dst
E:\ SourceX\PDC_Examples\WSCC Test 060700_BPAPDC\BPA2_0006072029.dst
>> cd E:\ SourceX\PDC_Examples\WSCC Test 060700_BPAPDC
??? Error using ==> cd
Too many input arguments.

>> cd 'E:\ SourceX\PDC_Examples\WSCC Test 060700_BPAPDC\'
>> dir

.	BPA2_0006072014.dst	PDCbrowse_Ex1.bk.m
..	BPA2_0006072029.dst	PDCbrowse_Ex1.m
BPA1X_122099.ini	PDCbrowseEx1.m	WSCCtests_060700Ex1.mat

2.1.7 Other File Types Associated With PSMTools

The primary folder for PSMTools contains a variety of document files of types **.doc**, **.xcl**, and **.txt**. In most cases these files were generated with Microsoft Word, Microsoft Excel, or the Windows Notepad. Presence of **.bk** in a file name like **DSI_InstallNoteC.bk.doc** indicates a backup version to some important file that has the same name except for the **.bk**.

PSM data are contained in **raw data files**, which are usually accompanied by a **configuration file** unique to the data source. Some examples are shown below.

Typical names for PSM raw data files

Phasor Data Concentrator (PDC) Units

Data files	Configuration files
BPA1_9904272040_B7.dst	BPA1X_122099.ini
BPA2_0006072029.dst	
BPA2_0006072014.dst	
BPAS_0006072015.dst	
wapa_0006072012.dst	WAPAX_110398.ini
wapa_0006072017.dst	
SCES_0006072012.dst	sce1X_122999.ini
SCES_0006072015.dst	

Portable Power System Monitor (PPSM) Units

Data files	Configuration files
Files@DIT2 06-07-00 13H07m05s	Dittmer #18 Listing.txt
Files@DIT2 06-07-00 13H13m05s	
Files@GC22 06_07_00 13h13m40s	COULEE G22 LISTING.txt
Files@GC22 06_07_00 13h14m30s	
Files@GC22 06_07_00 13h15m20s	
Files@MPSN 06-07-00 A14H10m00s	Midpoint #1 Listing
Files@MPSN 06-07-00 A14H20m00s	

Transient Stability Programs

Data files	Configuration files
HS030BrakeA_Genpower.swx.txt	(none as yet)
HS030BrakeA_Lines.swx.txt	

2.1.8 Using data from a file of supported format

- Start the Ringdown Analysis Tool by typing ringdown at the MATLAB command prompt. The window shown in Figure 4-1 appears.
- Click the **File** button. The window switches to that shown below.
- Click the button for the appropriate file type.

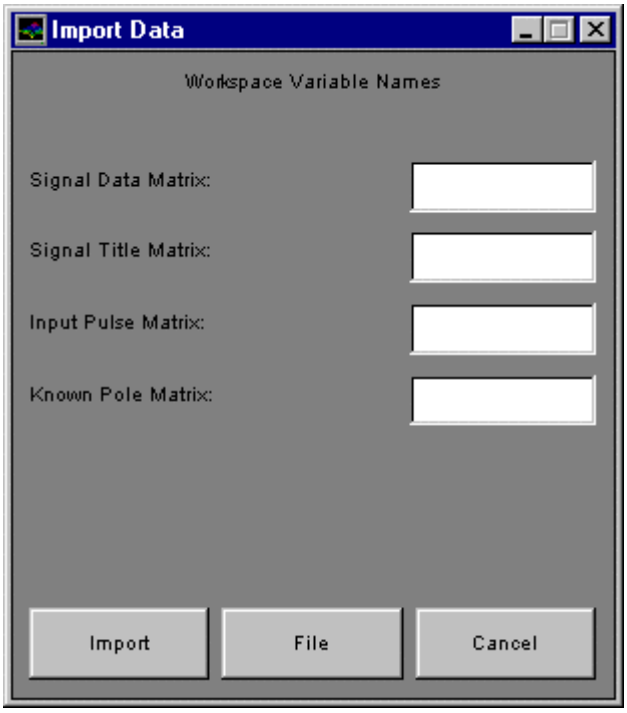


Figure 2.1-4

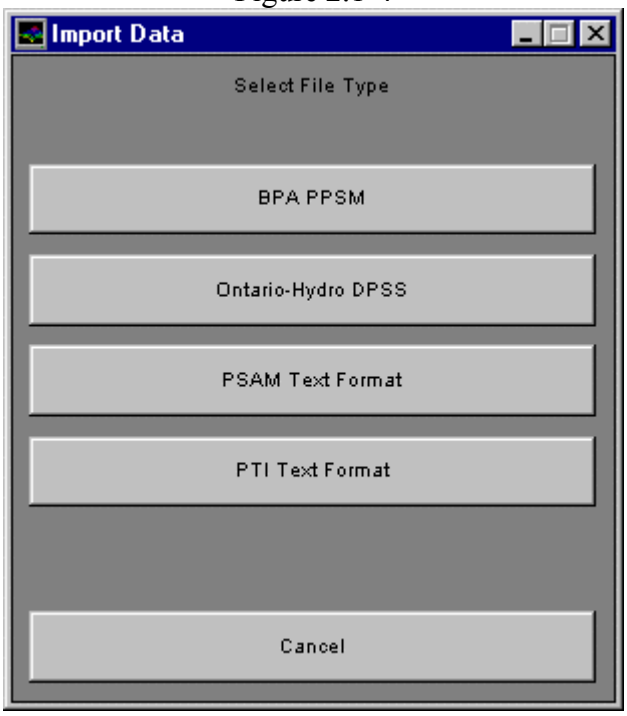


Figure 2.1-5

2.1.8.1 BPA PPSM Files

Data files from the PPSM consist of one or more files containing raw binary data from multiple acquisition channels and a Data Acquisition System (DAS) listing file

containing channel names, units, and scaling information. Later versions of the PPSM may embed the DAS listing in each of the binary files eliminating the need for a separate DAS file. Options in the PPSM file reader allow the user to override using the embedded DAS listing (if present), read and link one or more signals from multiple files, and decimate the data (without pre-filtering) while loading. Steps for reading PPSM files are outlined below:

- Click the button labeled **BPA PPSM** in the window shown in Figure 4-2.
- In the dialog box that appears, click **Yes** to use embedded DAS listings (if present) or **No** to select a DAS listing file. A file selection dialog box will appear.
- Select the first PPSM binary file to read and press **OK**. The file selection dialog box will appear again.
- Select the next file to read and press **OK**. Repeat this and the previous step until all of the binary files from which data is to be linked are selected. Press **Cancel** after the last file has been selected.
- If prompted to select a DAS listing, navigate to and select the DAS listing file requested by the dialog box. Press **OK**. Provided there are no file read errors, the window in Figure 4-2 changes to that shown in Figure 4-3. Note: Actual numbers and channel names may differ from that shown.

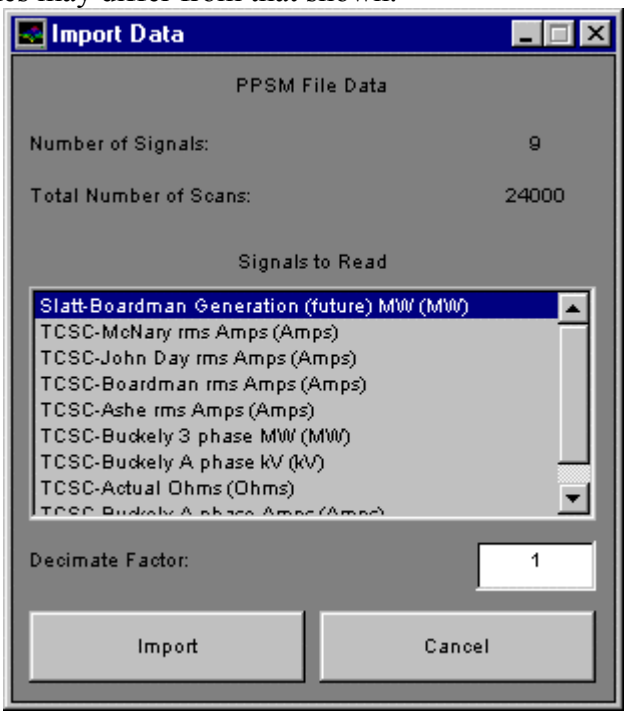


Figure 2.1-6

- Select one or more signals to read by using the SHIFT and/or CTRL keys and clicking on the signal names.
- Enter a factor by which to decimate the signal data while reading. Enter 1 for no decimation.
- Press **Import**. If there are no read errors, after several seconds the Ringdown Analysis Tool should open.

2.1.8.2 Ontario – Hydro DPSS files

- Click the button labeled **Ontario – Hydro DPSS** in the window shown in Figure 4-2. A file selection dialog box will appear.
- Select the file containing the data to read. If there are no read errors, after several seconds the Ringdown Analysis Tool should open.

2.1.8.3 BPA PSAM text format files

- Click the button labeled **PSAM Text Format** in the window shown in Figure 4-2. A file selection dialog box will appear.
- Select the file containing the data to read. If there are no read errors, after several seconds the Ringdown Analysis Tool should open.

2.1.8.4 PTI text format files

- Click the button labeled **PTI Text Format** in the window shown in Figure 4-2. A file selection dialog box will appear.
- Select the file containing the data to read. If there are no read errors, after several seconds the Ringdown Analysis Tool should open.

2.1.9 Using data from the MATLAB workspace

If the data to be analyzed is not in a file of supported format, it must first be loaded into MATLAB and converted to workspace variables of proper format. This is described below. Consult the MATLAB documentation for MATLAB file reading commands or functions for generating simulated data.

The Ringdown Analysis Tool requires one input and will allow up to four. The required input is a matrix containing the signal data to analyze. The optional inputs allow for signal titles, known input pulses, and known system pole locations. In the sections that follow, the generic names *outdat, titles, inpulses,* and *poles* will be used to refer to the signal data, titles, input pulses, and known pole locations matrices, respectively.

2.1.9.1 Signal or System Response Data Matrix

The signal data is entered in a matrix of the form

$$outdat = \begin{bmatrix} 0 & y_{10} & \cdots & y_{m0} & \cdots & y_{(M+1)0} \\ T & y_{11} & \cdots & y_{m1} & \cdots & y_{(M+1)1} \\ 2T & y_{12} & \cdots & y_{m2} & \cdots & y_{(M+1)2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & y_{1(N_1-1)} & \vdots & \vdots & \vdots & y_{(M+1)(N_M-1)} \\ \vdots & 0 & \vdots & \vdots & \vdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ (N-1)T & 0 & \cdots & y_{m(N-1)} & \cdots & 0 \end{bmatrix}$$

Figure 2.1-7

where T is the sample period used to acquire the data, M is the number of signals to analyze, $N_1, \ldots, N_M$ are the number of samples from signals 1 through M respectively, and $N = \max(N_1, \ldots, N_M)$. Samples from each signal must correspond to the times in column 1.

2.1.9.2 Title Matrix

If signal titles are known and it is desired to have these appear in plots and results files, they can be input to the tool using a MATLAB string matrix with each row containing a title for the corresponding signal in *outdat*. Consult the MATLAB documentation or online help for instructions on creating string matrices. One useful function is str2mat. Type

help str2mat

at the MATLAB command prompt usage instructions. If there are no titles, the title input should be entered as an empty string matrix (‘’).

2.1.9.3 Input Pulse Matrix

The Ringdown Analysis Tool allows transfer function parameter identification assuming the signal data is from a system driven by a finite-length rectangular input pulse-train as shown in Figure 2 – 2. Referring to Figure 2 – 2, the pulses are entered in an L by 2 matrix

$$inpulses = \begin{bmatrix} D_1 & c_0 \\ D_2 & c_1 \\ \vdots & \vdots \\ D_{L+1} & c_L \end{bmatrix}$$

Figure 2.1-8

where L is the number of pulses and the first pulse is assumed to switch in to effect at time zero ($D_0 = 0$). If there are no input pulses, the input pulse input should be entered as an empty matrix ([]).

2.1.9.4 Known Pole Matrix

If it is desired to incorporate known or assumed system pole locations into a Prony analysis, they can be entered as a single column vector where complex poles are listed in conjucate pairs and occupy two rows and purely real poles occupy one. The user can choose to perform a full calculation where a model containing the known plus additional poles is identified or can choose to just calculate residues for the poles entered. Assuming n damping coefficients and frequencies are known, the known pole matrix takes the form

$$poles = \begin{bmatrix} \sigma_1 + j\omega_1 \\ \sigma_1 - j\omega_1 \\ \sigma_2 + j\omega_2 \\ \sigma_2 - j\omega_2 \\ \vdots \\ \sigma_i \\ \vdots \\ \sigma_n + j\omega_n \\ \sigma_n - j\omega_n \end{bmatrix}$$

Figure 2.1-9

where σ_1 , …, σ_n are the damping coefficients and ω_1 , …, ω_n are the frequencies. If no poles are to be entered, the *poles* input should be an empty matrix ([]).

2.1.9.5 Starting the tool using the Data Import GUI

- At the MATLAB command prompt, type ringdown and press Enter. The window shown in Figure 4-1 appears.
- Type the workspace variable names in the appropriate fields.
- Click the **Import** button. If the workspace variables exist and are of the proper format, the tool should open.

2.1.9.6 Starting the tool directly from the command prompt

- At the MATLAB command prompt, type ringdown(*outdat, titles, inpulses, poles*) substituting the actual workspace variable names for the inputs. Press Enter. If the workspace variables exist and are of the proper format, the tool should open.

2.1.10 Ringdown Analysis Tool Setup Screen

The main Ringdown Analysis Tool GUI consists of two screens, a Setup screen for performing Fourier analysis and pre-conditioning data for a Prony analysis, and a Results screen for viewing the results from a Prony analysis. This section will discuss the Setup screen controls and the options available for pre-conditioning data prior to performing a Prony or Fourier analysis. The Results screen will be discussed later.
Once the tool has successfully launched, a title screen is displayed briefly and the Setup screen appears. Figure 4-4 shows a typical Setup screen.

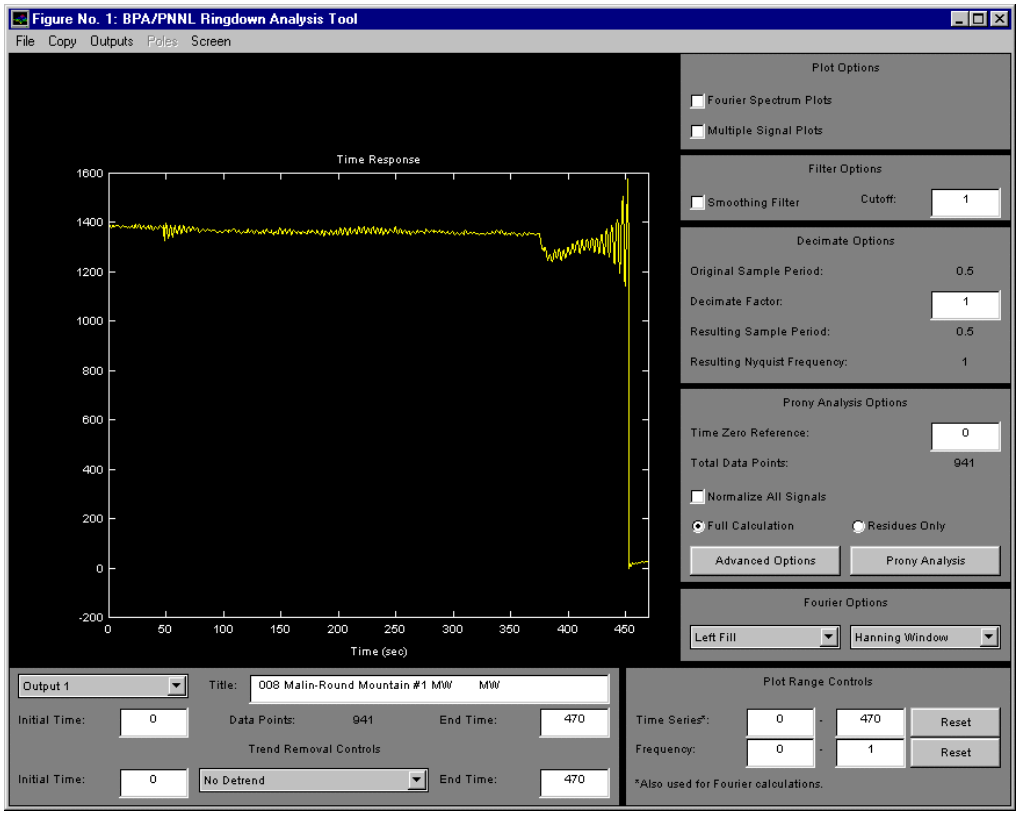


Figure 2.1-10

The Setup screen controls fall into the following categories

- Menus, at the top of the window
- Plot select controls
- Filter controls
- Decimate controls
- Prony Analysis controls that apply to all signals
- Fourier Analysis controls
- Plot Range controls
- Prony Analysis controls that apply to signals individually

The menus appear at the top of both the Setup and Results screens. Certain menu options are disabled depending on which plots are visible.

2.1.10.1 File Menu

The File menu contains the following options:

- **Import Data:** Opens the Import Data window shown in Figure 4-1 and allows the user to import new data into the tool. The user is prompted as to whether to overwrite current data and results before loading new data.
- **Export Results:** Opens the Export Results GUI. This option is disabled until a Prony analysis has been performed and will be discussed later in this manual.

- **Preferences:** Opens the Preferences GUI. This option will be discussed later.
- **Exit Ringdown Tool:** Closes the Ringdown Analysis Tool and all supporting GUI's.

2.1.10.2 Copy Menu

The Copy menu contains the following options for generating graphics that can be copied to other tools:

- **Time Response Plot:** Copies the visible time response plot to a separate MATLAB figure. This will have options for copying to the clipboard for use in other applications.
- **Frequency Plots:** Copies the visible frequency domain plots to a separate figure. The magnitude, phase, or both can be copied. This option is enabled only when frequency domain plots are visible.
- **Pole-Zero Plot:** Copies the visible pole-zero plot to a separate figure. This option is enabled only when the Results screen and pole-zero plot are visible.
- **Active Mode Parameters:** Copies the parameters selected in the Results screen mode table to a separate figure. This option is enabled only when the Results screen is visible.

2.1.10.4 Outputs Menu

This menu selects which signals will be displayed in the multi-signal time and frequency domain plots on the Setup screen. These signals will also be used for calculating a multi-output Prony analysis model if that option is used. Up to six signals can be selected at one time.

2.1.10.5 Poles Menu

This menu selects known pole locations to include in a Prony analysis model. It is enabled if known poles are entered on startup and after a Prony analysis has been performed.

2.1.10.6 Screen Menu

- **Setup Screen:** Makes the Setup screen visible.
- **Results Screen:** Makes the Results screen visible. This option is disabled until a Prony analysis is performed.
- **About:** Displays the Ringdown Analysis Tool title screen.

2.1.11 Plot Select Controls

These controls appear under the header **Plot Options.**

- **Fourier Spectrum Plots:** Selects if Fourier Spectrum plots are visible. These show the frequency spectrum estimated using a Discrete Fourier Transform (DFT) operation for each time response plot signal.
- **Multiple Signal Plots:** Selects if the time and frequency spectrum plots show a single signal or all signals to include in a Prony analysis.

2.1.12 Filter Options

These controls allow a smoothing filter to be applied to the data in the time response plot. The filter used is described in [????] and is applied before data is decimated (see Decimate Options below). It can thus serve to reduce aliasing effects.

- **Smoothing Filter:** Selects if the filter is applied. The time and frequency spectrum plots change to reflect the filtering. The filter is applied to all signals simultaneously.
- **Cutoff:** Sets the filter cutoff frequency.

2.1.13 Decimate Options

- **Original Sample Period:** Displays the sample period for the signal data input to the tool.
- **Decimate Factor:** Sets the factor by which data to be used in Prony or Fourier analyses is decimated. Set this to 1 for no decimation. All signals to be analyzed are decimated by this factor.
- **Resulting Sample Period:** Displays the sample period for the data after decimation.
- **Resulting Nyquist Frequency:** Displays the Nyquist frequency for the data calculated using the resulting sample period. This can provide guidance for setting the **Cutoff** control value if the smoothing filter is used to reduce aliasing.

2.1.14 Prony Analysis Options

These controls select options that apply to all signals simultaneously.

- **Time Zero Reference:** Sets the time the Prony analysis model will reference as time zero. This is adjusted to correspond to a time in the signal data matrix. If input pulses are used, this is the time where the first pulse switches into effect. Time response plot axes tick labels change to become relative to the time zero reference.
- **Total Data Points:** Displays the total number of data points to be used in the Prony analysis. This is the sum of the numbers of data points from all signals.
- **Normalize All Signals:** Selects if all Prony analysis signals will be normalized so the maximum absolute amplitude of each signal is 1. This can sometimes reduce numerical problems when a multi-output model is identified.
- **Full Calculation:** Selects if a full Prony analysis is to be performed. This involves estimating a set of poles and the corresponding residues. One or more poles can be selected from the **Poles** menu to also be included in the model.
- **Residues Only:** Allows a residues-only calculation to be performed where residues are calculated for a pre-selected set of poles. This control is disabled until one or more poles are selected in the **Poles** menu.
- **Advanced Options:** Shows the Prony analysis Advanced Options screen. This will be discussed later in this manual.
- **Display Plots:** Closes the Advanced Options screen and makes the Setup screen plots visible. This control is visible only if the Advanced Options screen is active.
- **Prony Analysis:** Performs a Prony analysis on the selected signal data. If the analysis is successful, the Results screen becomes visible.

Note: The **Prony Analysis** button is disabled if the total number of data points Is greater than 1024. This number can be changed by adjusting the time-zero reference or decimate values and also the initial and end times for each signal.

2.1.15 Fourier Options

- **Fill Control:** Selects options for zero padding of data prior to performing the DFT operation. Currently available options are Left Fill and No Fill. If Left Fill is selected, all signals to be analyzed are doubled in length by zero padding to the left before calculating the DFT.
- **Window Control:** Selects if a window is applied to all signals before calculating the DFT. Currently available options are Hanning Window and No Window. If zero filling is used, the window is applied after zero filling.

2.1.16 Prony Analysis Controls for each signal

These controls are located on the Setup screen beneath the time and frequency spectrum plots.

- **Output Number:** Selects the signal displayed when the **Multiple Signal Plots** control is deselected. In the control descriptions that follow, the signal selected by this control will be referred to as the currently selected signal.
- **Title:** Title for the currently selected signal. If signal titles are entered when the tool is first started, this control displays the title entered for this signal. This control is editable, allowing the user to modify the title.
- **Initial Time:** Selects the time of the initial point from the currently selected signal to use in the Prony analysis. This is relative to the time zero reference and is not allowed to be less than zero.
- **End Time:** Selects the time of the last point from the currently selected signal to use in the Prony analysis. This is also relative to the time zero reference and is not allowed to be greater than the last sample time in the signal data matrix minus the time zero reference.
- **Data Points:** Displays the number of points from the currently selected signal that will be used in the Prony analysis.
- **Detrend Control:** Selects a method for calculating a linear trend to remove from the currently selected signal. Available methods are remove initial value, remove mean value, remove final value, and remove ramp. This control can also reset the initial and final point times used for the trend calculation so they are equal to those used for the Prony analysis. The time and frequency spectrum plots update to reflect the detrended signal.
- **Detrend Initial Time:** Selects the time of the initial point used for the trend calculation. This is relative to the time zero reference.
- **Detrend End Time:** Selects the time of the final point used for the trend calculation. This is relative to the time zero reference.

Note: Although the trend is subtracted from the entire signal, only the data between the initial and end points is used to calculate the trend.
Additional guidance for setting these controls can be found in Volume 4, the *DSI Toolbox Application Guide*.

2.1.17 Plot Range Controls

- **Time Series:** Sets the horizontal axis limits for the time series plot. These are also the initial and end times used to select data for Fourier calculations. Numbers in these controls are relative to the **Time Zero Reference** control value.
- **Time Series Reset:** Resets the time series display limits to the initial and end times for the currently selected signal.
- **Frequency:** Sets the horizontal axis limits for the frequency spectrum plots.
- **Frequency Reset:** Resets the frequency plot axis limits to zero and the Nyquist frequency.

2.1.18 Advanced Options Screen Controls

When the **Advanced Options** button is selected, the setup screen changes appearance.

.

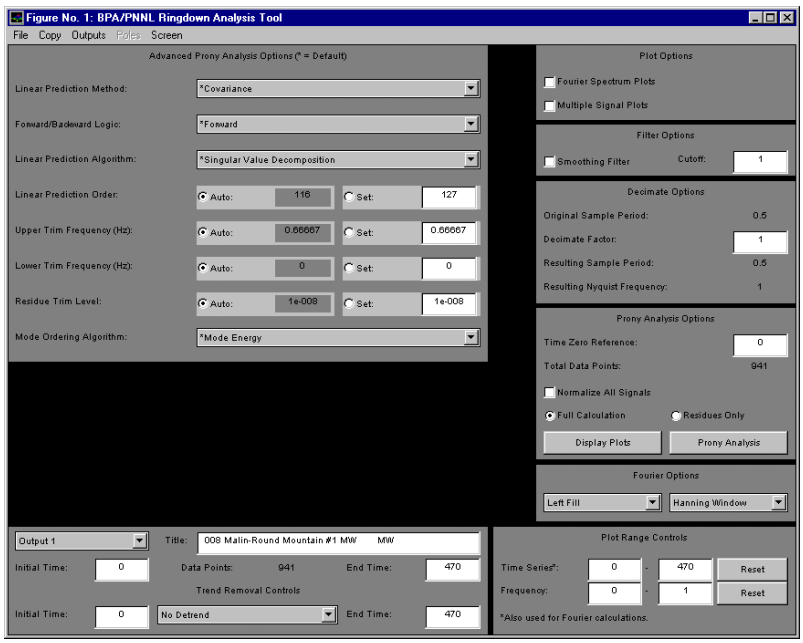


Figure 2.1-11

This screen has the following controls:

- **Linear Prediction Method:** Used in creating the linear prediction matrix for estimation of pole locations. Options are Correlation, Pre-windowed, Covariance, and Post-windowed.
- **Forward/Backward Logic:** Also used in creating the linear prediction matrix. Options are Forward, Forward-Backward, Backward.
- **Linear Prediction Algorithm:** Selects the algorithm used to solve the linear prediction equations. Options are Singular-Value Decomposition, QR Factorization, and Total Least Squares.
- **Linear Prediction Order:**
- **Upper Trim Frequency:**
- **Lower Trim Frequency:**
- **Residue Trim Level:**

- **Mode Ordering Algorithm:** Selects the method used to rank the modes identified by the Prony analysis. Options are Akaike Final Prediction Error and Mode Energy.

Note: Default options for the above controls are denoted by an asterisk for menu controls, and appear by the Auto label on numerical controls. It is recommended that these be selected for most cases.

2.1.19 Ringdown Analysis Tool Results Screen

When a Prony analysis has been successfully performed, the Ringdown Analysis Tool Results screen appears, as shown below.

.

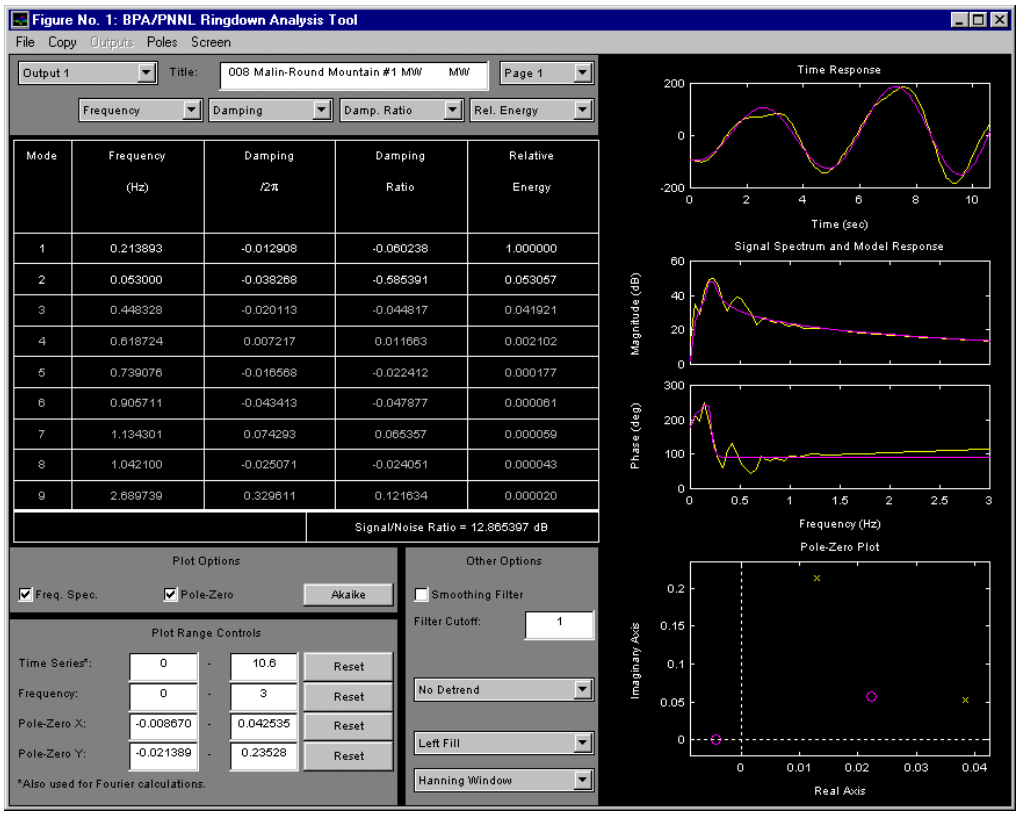


Figure 2.1-12

The Results screen provides options for viewing individual or combinations of mode responses from the model identified by the Prony analysis. Options are also available plotting frequency domain data or poles and zeros. The Results screen controls fall into the following categories

- Menus, at the top of the window
- Mode Table parameter select controls
- Mode Table parameters
- Plot select controls
- Plot Range controls
- Filter and Fourier analysis options

The Results screen menus function similarly to those on the Setup screen and are discussed above.

2.1.20 Mode Table Parameter Select Controls

The Mode Table displays the model parameters identified by the Prony analysis. This group of controls is above the Mode Table.

- **Output Number:** Selects the model output for which to display parameters. In the control descriptions that follow, the output selected by this control will be referred to as the currently selected output.
- **Title:** Displays the title for the signal the currently selected output models. This control is editable, allowing the user to modify the title.
- **Page Control:** Selects which modes from the currently selected output are displayed when there are more modes than mode table rows.
- **Mode Table Column Controls:** Select which parameters are displayed in the corresponding mode table column.

2.1.21 Mode Table Parameters

The mode table parameters serve as controls to select which mode responses are included in the time and frequency domain plots. If input pulses are used, a feed-forward term is identified and can also be selected for inclusion. To select or deselect a parameter

- Move the mouse pointer over any text in the row for the desired mode. Click over this text. The mode parameter should change color and the plots should be redrawn.
- Click the text object again to deselect the mode.
- To quickly select/deselect multiple modes, hold down the SHIFT key and click on mode text objects. Click the Select or Deselect buttons above the Mode Table to select or deselect the modes.

2.1.22 Plot Select Controls

These controls appear under the header **Plot Options**.

- **Frequency Spectrum:** Selects if plots displaying the frequency spectrum for the signal and model response data are displayed.

Note: The frequency spectrum of the signal is calculated using a DFT operation and that of the model is calculated by evaluating the model at each frequency for which there is a DFT spectrum point. This can lead to significant differences in the displayed spectrums when input pulses are present.

- **Pole-Zero Plot:** Selects if a plot displaying the poles and zeros of the model comprised of the selected mode table parameters is displayed. This is updated as parameters are selected or deselected.
- **Akaike:** Launches a separate figure with a plot of the Akaike Final Prediction Error for the currently selected output model.

2.1.23 Plot Range Controls

- **Time Series:** Sets the horizontal axis limits for the time series plot. These are also the initial and end times used to select data for Fourier calculations.

- **Time Series Reset:** Resets the time series display limits to the initial and end times used in the Prony analysis.
- **Frequency:** Sets the horizontal axis limits for the frequency spectrum plots.
- **Frequency Reset:** Resets the frequency plot axis limits to zero and the Nyquist frequency.
- **Pole-Zero X**: Sets the horizontal axis limits for the pole-zero plot.
- **Pole-Zero X Reset**: Resets the pole-zero plot horizontal limits so all poles and zeros are visible.
- **Pole-Zero Y**: Sets the vertical axis limits for the pole-zero plot.
- **Pole-Zero Y Reset**: Resets the pole-zero plot vertical limits so all poles and zeros are visible.

2.1.24 Filter and Fourier Analysis Options

- **Smoothing Filter:** Selects if the filter is applied to the signal data before plotting and calculating the Fourier spectrum.
- **Cutoff:** Sets the filter cutoff frequency.
- **Detrend Control:** Selects a method for calculating a linear trend to remove from the signal and model response before displaying and estimating the Fourier spectrum. Available methods are remove initial value, remove mean value, remove final value, and remove ramp.
- **Fill Control:** See the Setup screen fill control description above.
- **Window Control:** See the Setup screen window control description above.

2.1.25 Export Results GUI

When the **Export Results** option in the **File** menu is selected, the following window appears.

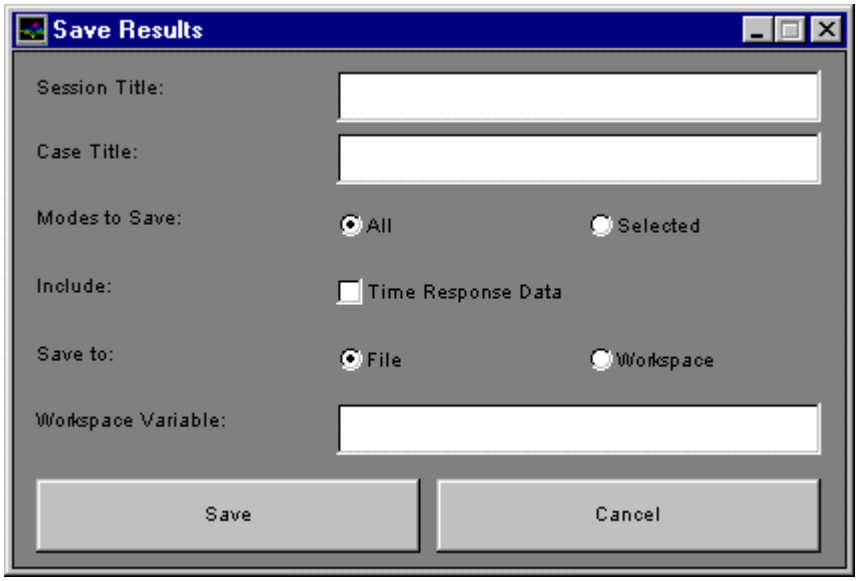


Figure 2.1-13

These controls allow the user to save Prony analysis results to a text file or export the model to the MATLAB workspace for further analysis. If the file option is selected, results are saved in a tab-delimited ASCII text file. If the workspace option is selected, a structure (described below) containing the results is saved in the MATLAB workspace.

- **Session Title:** Displays the title to appear at the top of a new results file.
- **Case Title:** Displays the title to appear with the results for the current case.
- **Modes to Save:** Selects if all modes or just those selected in the Mode Table are saved to the results file or exported to the workspace.
- **Include Time Response Data:** If this option is selected, the signal data and corresponding model response samples will be saved to the results file or exported to the workspace.
- **Save to:** Selects if results will be saved to a file or exported to the workspace.
- **Workspace variable:** Displays the variable name for the data structure exported to the MATLAB workspace containing the results. A name must be entered here before selecting Save to Workspace.
- **Save:** Saves the results to a file or the MATLAB workspace. If the file option is used, the user is prompted to select a file to create or to which to append the results.
- **Cancel:** Closes the Save Results window.

2.1.26 Prony Analysis Results Data Structure

When the Prony analysis results are exported to the MATLAB workspace, they are saved in a structure with the following fields. Refer to the MATLAB documentation for referencing fields in MATLAB structures.

- **Titles:** String matrix containing signal titles.
- **Pol:** Complex matrix containing identified poles for each signal.
- **Bres:** Complex matrix containing signal residues for identified poles.
- **Res:** Complex matrix containing transfer function residues for identified poles.
- **Thru:** Matrix containing feed-forward terms for each output model.
- **Releng:** Matrix containing the relative energy in each mode's response. There is a column for each signal and energies are expressed relative to the highest energy mode in the corresponding output model.
- **Afpe:** Matrix containing Akaike Final Prediction Error quantities for each mode in each output model.
- **Sigmoddat:** Matrix containing signal and model response data for selected modes in each output. The first column is time, the second is data from the first signal response, and the third is data from the first model response. Data for other outputs is listed similarly but without a time column.

2.1.27 Preferences GUI

When the **Preferences** option is selected from the **File** menu, the following window appears.

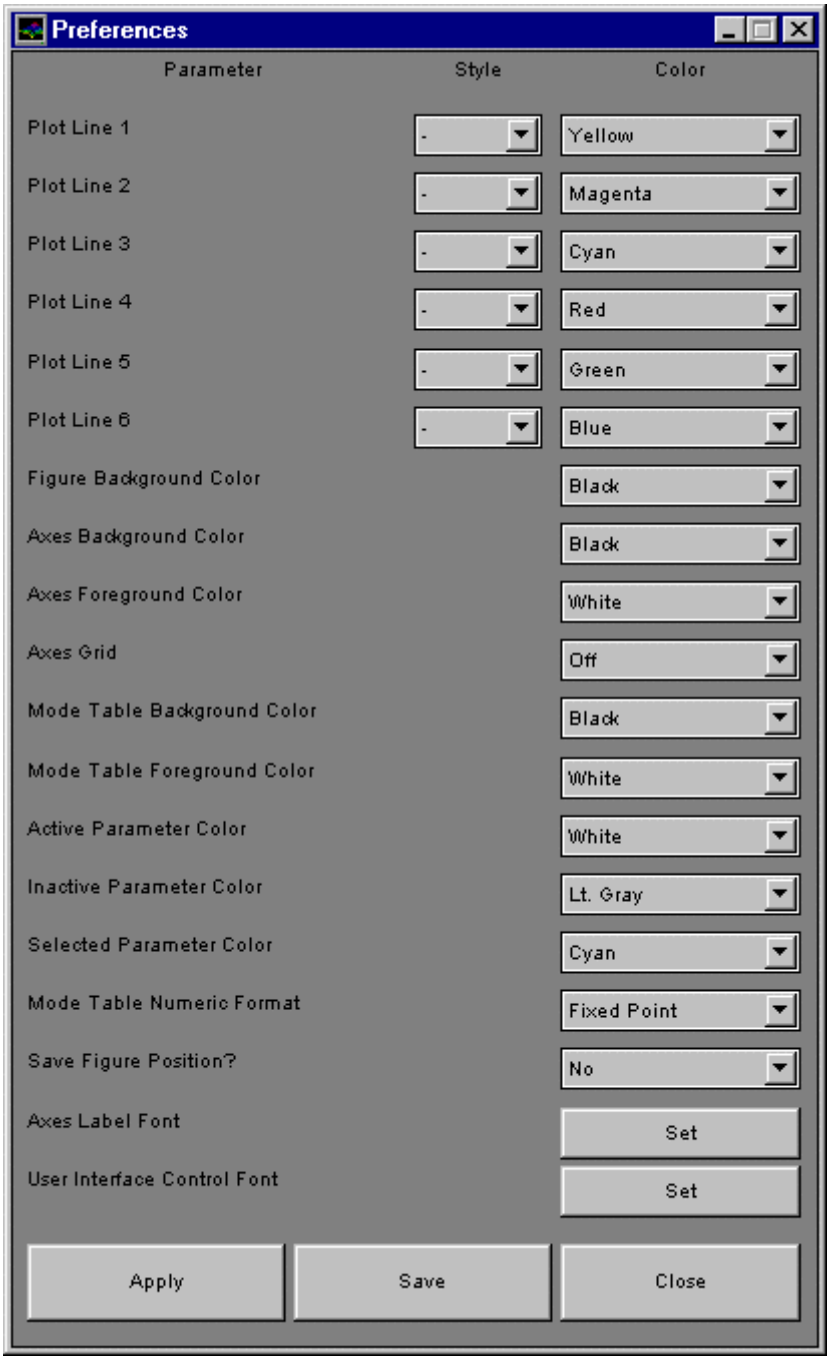


Figure 2.1-14

This window allows the user to customize several Ringdown Analysis Tool attributes and optionally save these to a file that is read when the tool is started in the future. Documentation for this window is not yet available.

2.2 Phasor Management Outlook System

The second tool is the Phasor Management Outlook System , developed by Southern California Edison.

2.2.1 Introduction

The Southern California Edison Synchronous Phasor Management Outlook system is intended for both monitoring and analysis. The SPM Power System Outlook menu bar works just like other Windows programs. The options from the top menu bar are:

- File
- View
- Replay
- Plot
- PMU View
- PMU Analysis

The user can click a menu bar option's hotkey (for example, Alt F displays the File menu) to see a pull-down list of menu options that provides either commands, another level of menus or dialog boxes.

2.2.2 File

Clicking the **File** menu opens options. This option enables the user to load a disturbance or stream file into the tool. Starting the SPM Power System Outlook the user enables the File option. The other menu bar options are disabled because disturbance file or stream file must be selected first.

The File menu option allows the user to chose one of the following four options:

- Open Disturbance File
- Open Stream File
- Automatic Screening and Exit.

Normally the user goes directly to **Open Disturbance File** or **Open Stream File.** The disturbance and stream files are numbered:

Company Name/Identifier	SCE
PDC Number	1
Year	01
Month	02
Day	13
Hour	10
Minute	31
Type of File	.dist

Figure 2.2-1

An "S" in the PDC number indicates that the file is a stream file.

The **Open PDC Disturbance File** dialog box allows the user to select the disturbance or stream file from the respective directory. All the files that appear in the dialog box are disturbance files because the directory selected was the list of disturbance or stream files.

2.2.2.1 Open Disturbance File or Open Stream File

As soon as a disturbance file is selected the tool converts the PDC binary file and shows the user a progress bar indicating the status of that conversion. The data in the disturbance and stream files is recorded as binary data, which is converted to real physical data using a system INI file. The conversion will not be completed if the disturbance file is not consistent with the INI file.

2.2.2.2 Automatic Screening

The Automatic Screening option enables a user to select the files from the disturbance files that exceed user-defined specified limits. These limits include voltage deviation, frequency deviation or df/dt (frequency variation with respect to time). The files can be sorted for a specified period between *Beginning Date* and *Ending Date*. The form *Automatic Screening of PMU Disturbance Files* provides the date parameters for data selection.

2.2.3 View

Options to view are as follows:

- PDC Header
- PDC Raw File
- PDC Event
- Replay

2.2.3.1 PDC Header

Power System Outlook contains a form that allows the user to view the *Event Header File* In addition to displaying all header data to the user, this form allows user functionality to embed a disturbance description of up to 75 characters into the disturbance file for future reference. This function provides an easy method for identifying disturbance files from a set of actual disturbances. The three buttons on the left side, for each one of the levels of voltage, allows the user to obtain the plots for voltage, currents and to execute a replay of the respective voltage phasors. Following is an example for this screen:

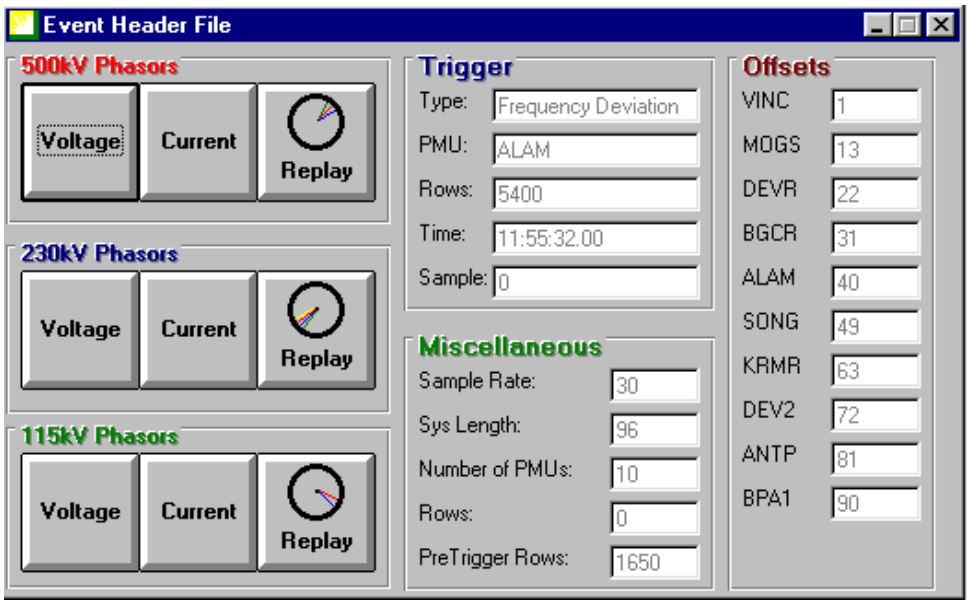


Figure 2.2-2

2.2.3.2 PDC Raw File

This file presents a matrix with the data for just 1% of the file. The purpose of this file is to allow the user to review the raw data to verify the proper saving of the disturbance data for all the PMUs and respective channels. The data is displayed in matrix format, and can be exported via a button at the bottom of the screen.

2.2.3.3 PDC Event

This command executes the elaboration of the raw file matrix that contains the data in the disturbance file. Tabs separate the different levels of voltage.

2.2.4 Replay

This option allows the user to execute the replay of the voltage phasor for each level of voltage separately or for all the voltage levels. The options are:

- Angle, Magnitude, and Time
- Voltage Vs. Time

Functionality to replay voltage phasors is included to provide the user a tracking tool to better look at overall system behavior. The corresponding 500-kV / 230-kV / 115 kV voltage phasors of the "captured" disturbance event are replayed as a polar plot. The plot is created selecting the desired phasors to replay from the Replay file menu. The replay functionality can also be enabled from the voltage plots selecting the toolbar button with the "clock" icon. Following is an example of this screen:

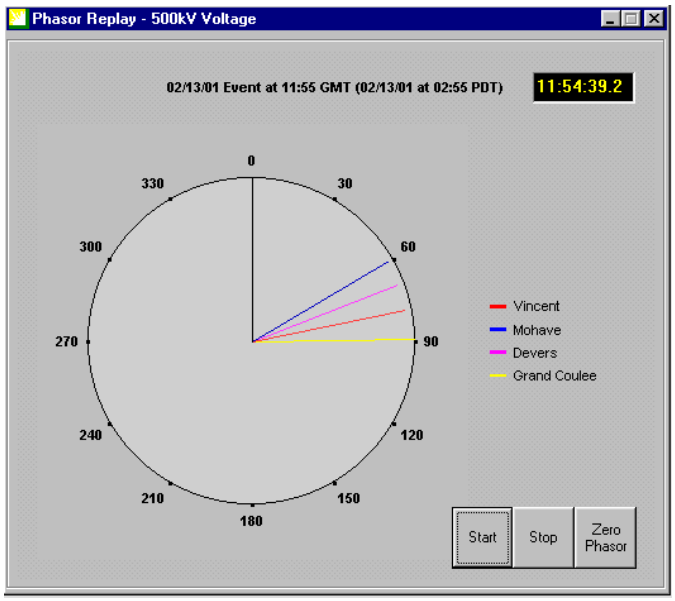


Figure 2.2-3

This option also includes tool tips. These tool tips are available on all buttons in order to assist the user in identifying the button's purpose. In most cases, the button's purpose is quite obvious from simply reading the button's label but may not be so obvious for toolbar buttons that contain no labels.

A digital clock is included which displays pre-trigger time in yellow font. At the time of trigger, the font of the digital clock changes color from yellow to red to indicate start of the disturbance event.

The three buttons on the bottom right side allows the user to start or to stop the replay or even to change the reference. Pressing the start button begins the replay functionality. Pressing the stop button stops the replay functionality.

The default reference value for all voltage phasors is the nominal 60-Hz. The reference value can be changed to be one of the recorded phasors. To change the reference value

simply select the button labeled Zero Phasor. This button can be selected prior to starting the replay of the event or during the replay.

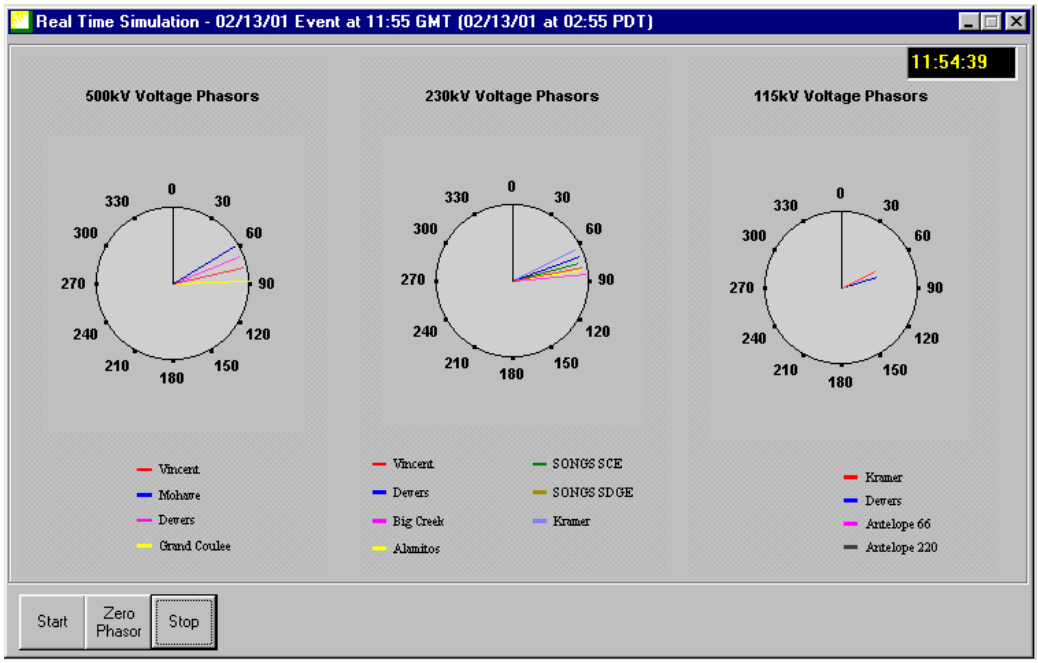


Figure 2.2-4

2.2.5 Plot

The Plot option offers the creation of plots for voltage, currents, megawatts, megavars and angles for level of voltage, and also the plots for frequency and the rate of variation of frequency (df/dt). The options are

- Voltage
- Currents
- Megawatts
- MegaVARS
- Angles
- Frequency
- df/dt.

2.2.5.1 Voltage

Bus voltage phasors are scaled and plotted on a line graph as a function of time. Three different plots are used to display the bus voltage phasors. One plot is used to display all 500-kV voltage phasors; the second one is used to display all 230-kV voltage phasors and

the third one to display all 115-kV and below voltage phasors. The reason for grouping and displaying voltage phasors according to the voltage level is to allow visual display of small fluctuations that would otherwise be masked due to the large y-axis scale required if 500-kV, 230-kV and 115-kV were plotted together.

The 500-kV voltage plot is created by selecting the Plot | Voltage | 500kV option from the Main form. Selecting the Plot | Voltage | 230 kV option creates the 230-kV voltage plot and so on. Following is an example of the output:

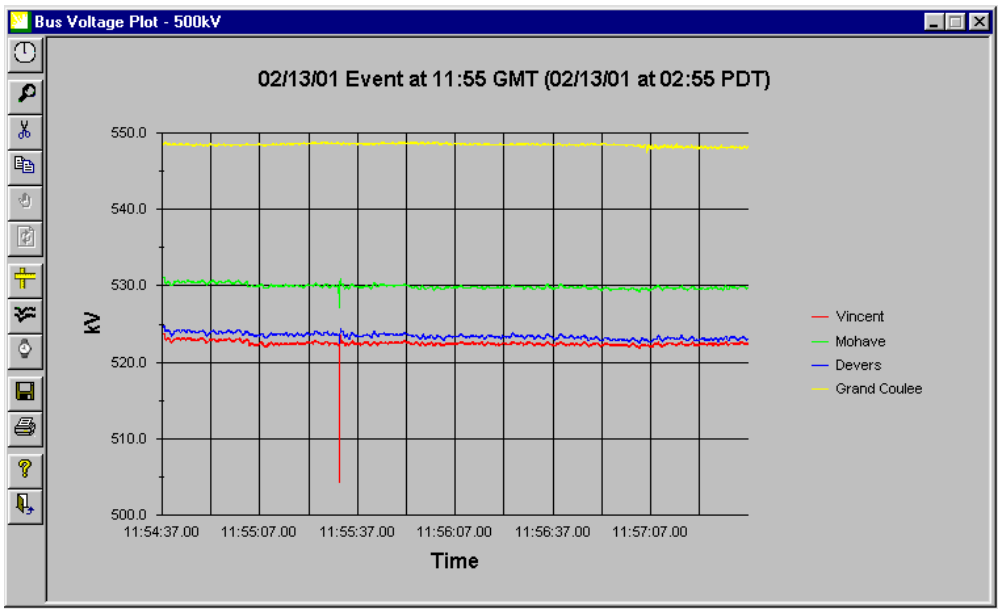


Figure 2.2-5

Moving the mouse over the toolbar the user can obtain additional information (the toolbar contains "hot spots" allowing the user to click on them for more information)

2.2.5.2 Current Phasors

Line current phasors are scaled and plotted on a line graph as a function of time. Three different plots are used to display the line current phasors. One plot is used to display all 500-kV line current phasors; a second is used to display all 230-kV line current phasors and a third to display all 115-kV line current phasors. The reason for grouping and displaying current phasors according to the voltage level is to allow visual display of small fluctuations that would otherwise be masked due to the large y-axis scale required if 500-kV and 230-kV were plotted together.

The 500-kV current plot is created by selecting the *Plot | Current | 500kV* option from the main menu located across the top of the main form. Selecting the *Plot | Current | 230 kV* option creates the 230-kV current plot.

Figure 32, below, is a sample 500-kV line current plot. The toolbar has the same buttons already explained in the previous section. Move the mouse over the toolbar to obtain additional information (the toolbar contains "hot spots" allowing you to click on them for more information).

2.2.5.3 Megawatt and Megavars Plots

Although the Synchronized Phasor Measurement Units do not measure power, it is possible to build those functions knowing voltages, currents and angles. The Power System Outlook Tool does the proper calculations and offers that possibility to the users.

2.2.6 Toolbar Options

The toolbar options are listed below. They are defined in greater detail in the sections that follow:

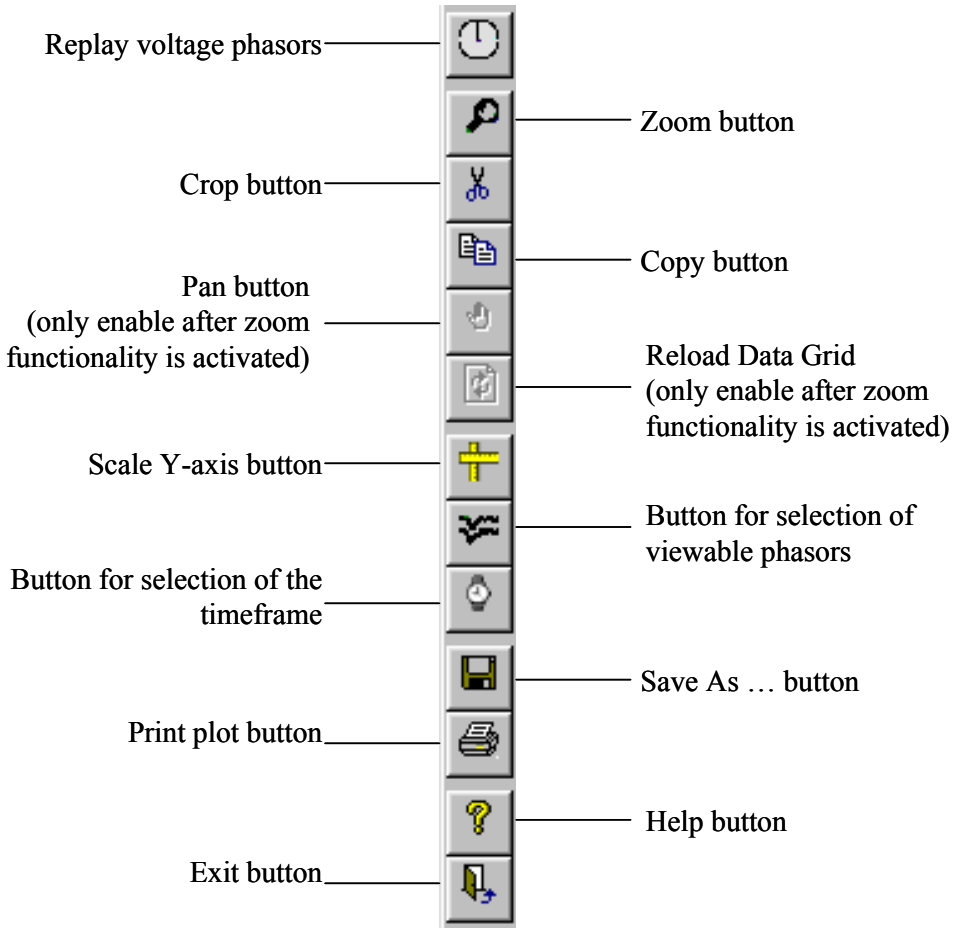


Figure 2.2-6

2.2.6.1 Replay Voltage Phasors

Pressing this button allows the user to replay the voltage phasors that are in the plot.

2.2.6.2 Zoom Button

Zoom functionality is included to provide the user a better look at small fluctuations. In order to zoom, the zoom function must first be enabled by pressing the button with the magnifying lens icon located in the toolbar. Once the user has enabled the zoom, double click the left mouse button to make the plot "bigger." The plot is enlarged one zoom level every time the left mouse button is double clicked.

Unzoom is accomplished in the same manner except that the shift key is required to be pressed while double-clicking the left mouse button. This process reduces the plot by one zoom level every time the left mouse button is double-click with the shift key held down.

2.2.6.3 Crop Functionality

There may be times when the user may need to only concentrate on a portion of the disturbance event. The crop functionality is included to provide the user a method to eliminate the display of data not relevant to his needs. In order to crop, the crop function must first be enabled by pressing the button with the scissors' icon located in the toolbar. Once the user has enabled the crop, click and hold the left mouse button and drag a desired distance, which covers the area of interest, and release the mouse button. The data creating the plot is stripped to only the data points between the start point (point where mouse button was clicked and held) and end point (point where mouse button was released).

2.2.6.4 Copy Button

Pressing this button allows the user to copy the plot.

2.2.6.5 Pan Functionality

Use the pan functionality to move the plot within the displayable area so the desired plot area can be viewed. In order to pan, the pan function must first be enabled by pressing the button with the hand icon located in the toolbar.

Once the user has enabled the pan, they must do the following:

- Click and hold the left mouse button on the plot to select the plot.
- Drag the mouse with the left button held down to pan the plot the desired direction.
- The previously displayed plot moves with the movement of the mouse.
- The plot area not previously displayed does not show until the left mouse button is released.
- Repeat this process until the desired area is reached.

Move the mouse over the toolbar to obtain additional information (the toolbar contains "hot spots" with more information)

2.2.6.6 Reset Button

The reset button on the toolbar (icon with the sheet and two arrows) re-populates the data grid with all original data points and resets the plot to the default settings. This button reloads the data grid if it was cropped and resets the plot to default size and location

2.2.6.7 Select Viewable Phasors

The select viewable phasors button on the toolbar (icon with the plot of two parallel waves) allows the user to chose desired phasors to view. Pressing the button will open the window with the list of phasors that are plotted. Only the phasors with the check mark on the box at the left side of the phasor name will be part of the plot. By default all the phasors are selected.

After the selection the new graph only will show the plot of the phasor previously selected. This option can be executed several times to see the behavior of independent phasors.

2.2.6.8 ScaleY-axis Functionality

The y-axis scale, by default, encompasses all data being displayed. There may be times when the y-axis scale needs to be changed in order to increase or decrease the y-axis bandwidth. This change can be done in two different ways. The first is the use of the scale y-axis function, which is performed by pressing the button on the toolbar with rulers as its icon. This function loads a window with the existing maximum and minimum y-axis values. The maximum and minimum values can be changed in this window to the desired new maximum and minimum value.

Clicking the OK button scales the y-axis to reflect the new maximum and minimum values. Clicking the Cancel button disregards any changes made and retains the existing maximum and minimum y-axis values. Changes to these values are reflected on the plot when the OK button is pressed.

The second method to change the y-axis scale is to use the right mouse button to directly access First Impression's methods and properties. Clicking on the right mouse button opens a floating window, which allows access to the plot data, plot properties and plot methods. The properties include those associated with the plot, series, axis, legend, title and footnote. The methods include copy, paste, print, load and save as functions.

Some windows are only displayed by right click of the mouse. To scale the Y-Axis, the user must select the Axis option. This will extend a new layer on the window that contains Axis... Labels... and Title... options

Note: This function is only available if the zoom and crop functions have not been performed.

2.2.6.9 Select Time Frame

There may be times when the x-axis scale needs to be changed in order to focus the attention on a specific period of time. This change can be done in two different ways. The first is the use of the selection time frame function, which is performed by pressing the button on the toolbar with the watch as its icon. This function loads a window with predefined points to start and to end the time.

Clicking the *Set Options* button scales the plot to reflect the new time period values. Clicking the *Cancel* button (X) disregards any changes made and retains the existing time period values.

The predefined points are separated in two groups, one to start time and the other to end time. Option buttons in each group act in a mutually exclusive fashion. Only one option button can be selected at any one time. Changes to these values are reflected on the plot when the *Set Options* button is pressed.

2.2.6.10Save As

This button saves data utilized to create plot in .csv format.

2.2.6.11Print Plot

This button prints the plot to the local or network printer.

2.2.7 PMU View

This option allows the user to view the data of one specific PMU. The user can choose among the list of PMU installed. Southern California Edison (SCE), currently, has 10 stations with PMUs installed. They are as follows:

VINC	Vincent
MOGS	Mohave
DEVR	Devers 500 K-v
BGCR	Big Creek
ALAM	Alamitos
SONG	San Onofre
KRMR	Kramer
DEV2	Devers 230 k-V
ANTP	Antelope
BPA1	Connection with BPA

Figure 2.2-7

Within PMU View the user has several options to see the functions for voltage, currents, megawatts, megavars, frequency and deviations from nominal values (voltage, frequency) or deviations from average values before the trigger (currents, megawatts and megavars). Also functions of dp/df and dp/d(angle) are available.

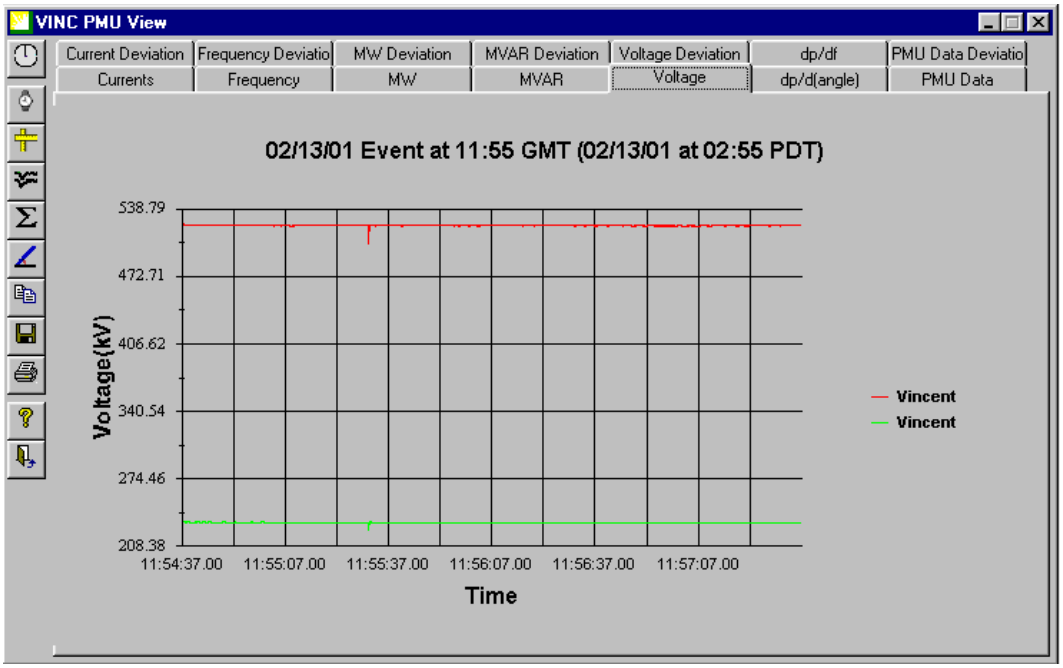


Figure 2.2-8

Options available from this screen are:

- Current Deviation
- Frequency Deviation
- MW Deviation
- MVAR Deviation
- Voltage Deviation
- Dp/df
- PMU Data Deviation
- Currents
- Frequency
- MW
- MVAR
- Voltage
- Dp/df (angle)
- PMU Data

Tabs for Currents, Frequency and Megavars offer equivalent plots to the user. However, within the toolbar buttons, there is one for addition of plots. The additional button is available just for currents, megawatts and megavars. The button with the angle icon allows the user to change the reference for the dp/d(angle) plot.

The last two tabs, PMU Data and PMU Data Deviation, allows the user to see all the data, i.e., the three minutes data with 30 samples per second. The user can save the data in a .csv data file just pressing the icon with the diskette in the icon. Figure 46 shows the PMU Data for Vincent.

The PMU Data Deviation tab shows an equivalent table to the one in Figure 46, but with the deviations from nominal values (voltage and frequency) or from averages before trigger (currents, megawatts and megavars). All values in this matrix are expressed in percentages.

2.2.8 PMU Analysis

The PMU Analysis option allows the user to do some analyses using the disturbance or stream file data at PMU level as shown in the selection offered. The options are **VINC, MOGS, DEVR, BGCR, ALAM, SONG, KRMR, DEV2, ANTP, and BPA1**

This analysis is just available at PMU level. Once the user choose the PMU, the tool presents a dashboard with some option tabs. They are:

- PMU Analysis
- Low Pass Filter
- Mode Analysis Frequency
- Mode Analysis MW
- Vector Power Replay

Following is a sample of the screen:

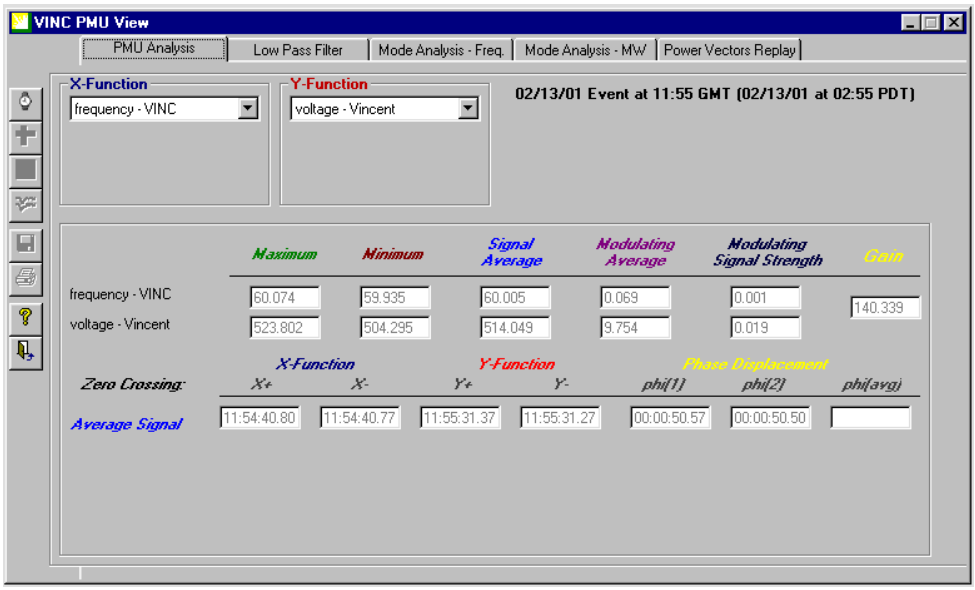


Figure 2.2-9

2.2.8.1 <u>PMU Analysis</u>

Using the down arrows in X-Function and Y-Function the user can select and combine any function from that PMU. Functions include Frequency, voltages, currents, megawatts and megavars. The selection of any couple of functions modifies the values shown below that refer specifically to the relationship between those two functions. The Gain value, for the case in Figure 57, is the voltage variation per one hertz variation in frequency. The other windows show, for each function, the maximum and minimum values, the average value, the modulating average and the modulating signal strength.

$$\text{Signal Avg} = \frac{\text{Max} + \text{Min}}{2} \qquad \text{Modulating. Avg} = \frac{\text{Max} - \text{Min}}{2}$$

$$\text{Mod Sign Strg} = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}} \qquad \text{Gain} = \frac{\text{Delta Y}}{\text{Delta X}} = \frac{(\text{Mod. Avg})y}{(\text{Mod Avg})x}$$

X+ = Function cross average from negative to positive
X- = Function cross average from positive to negative
T = Time
Phi(1) = (TY+) – (TX-) Phi(2) = (TY-) – (TX-)

2.2.8.2 <u>Mode Analysis Frequency</u>

The Mode Analysis consists in the tool of a filter to the Frequency function.

Typically, the user will be able to see the frequencies between 0.1 to 1.1 Hz, filtered out from the frequency or the power output files.

In the toolbar, the button with the icon 'normal distribution function between two parallel lines', allows the user to select a specific bandwidth, among nine previously selected or even to select his/her own bandwidth. Figure 49 shows the bandwidths options offered to the user

2.2.8.3 Mode Analysis MW

This tab offers to the user the same previous explained capability applied to power data. Figure 52 shows the plot after the selection of a bandwidth of 0.5 to 0.65 Hz.

2.2.8.4 Vector Power Replay

Functionality to replay power vectors is included to provide the user a tracking tool to better look at overall system behavior

2.3 Streamreader and Phasor FileTools

The third tool consists of Streamreader and Phasor Filef tools, developed by Bonneville.

2.3.1 Introduction

Bonneville Power Administration (BPA) has developed tools called Streamreader and PhasorFile. They each have their own icon on the Windows Desktop, and they are both geared entirely for analysis, and no monitoring. Streamreader is primarily for monitoring, phasor file is for analysis.

PhasorFile is a tool specifically written to access, display, and convert phasor measurement data recorded in the Phasor data File format developed by BPA in conjunction with other WSCC utilities. The tool allows viewing files either on a host PC file system (including networked files) or on a remote FTP server. It will download the file then either display the raw data or display the data scaled to engineering units using a special scaling file. The scaled data display presents 4 simultaneous plots with numerous plotting, sizing, and comparison functions. It has a special print function as well. The tool will convert the file into an ASCII or Matlab file for examination with other tools. It requires a monitor with at least 600 X 800 resolution using any of the Windows operating systems.

Steamreader is a tool specifically written to read the real time Phasor Data Concentrator (PDC) output and display it on the screen or archive it on disc, or both. It requires the following:

- A monitor with at least 1024 X 768 resolution using any of the Windows operating systems.
- 266 MHz or greater
- 32 MB of memory
- When the file storing option is used, data is stored continuously on disc in files with the file length and number of hours of storage specified by the user. The user can also specify the traces to be displayed on the screen.

2.3.2 Using PhasorFile

The main window that displays when the Phasor File tool is executed has thee main sections:

- Selecting Files to View
- Retrieving Files to View
- Viewing Data
- Data Table Display

The main window is displayed below:

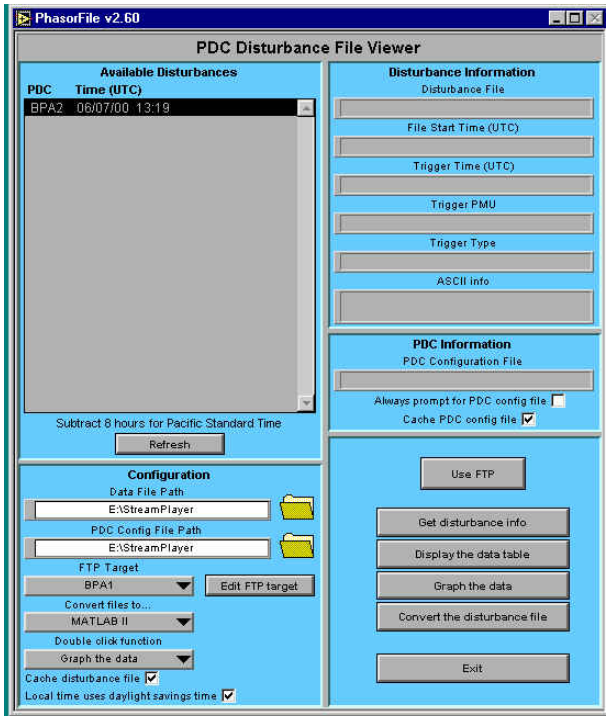


Figure 2.3-1

Process:
View files from directory selected under 'Data File Path' or by FTP using FTP target
With FTP, transfer file over (lower right window)
With local directory, select file
Use 'Get Disturbance info' button to load selected file
Select Available Disturbance File (upper left window)
Refresh file to select after FTP
View configuration information after FTP (display only)
View disturbance file information (right left window – display only)
View or graph data (right bottom window)

2.3.2.1 Selecting Files to View

If the top button in the lower right block says *USE FTP*, the files displayed in the *Available Disturbances* window are from the Data File Path in the window just below it.

If the button says *Use Local Disk* then the files displayed are from a remote FTP server. The server is selected by the *FTP Target Button* in the middle lower left hand block.

- Select the target server by pressing the arrow on the window.
- Set up FTP targets with the *Edit FTP Target* button. Just fill in the blanks and save the settings.

- If there is no server or data available, an error message will be displayed and the window will be blank.
- If *Use FTP* is displayed, the files shown are in the *Data File Path* window.
- To change this file, click on the folder symbol to the right of the window and select the desired directory.
- To go up in the directory tree, double click on the double dot symbol (..).To go down the directory tree, double click on the directory listing.
- Highlight the directory in which you wish to view data files and press OK.
- The *Available Disturbances* window should show the disturbances files in that directory. Note that it will only display files with prescribed file name and an extension of .dst.
- The *PDC Config File Path* window displays the path for the configuration files that will be used to convert the data to engineering units. It is the same as the path above.

2.3.2.2 Retrieving Files to View

- Once the user locates a desired file in the selection screen, highlight the file and click on the Get Disturbance button.
- In the case of FTP, the file will first be downloaded to the Data File Path directory and then loaded not memory.
- A window will pop up asking the user to select a config file.
- A prompt will appear with the disturbance file prefix, but will take any file selected.
- If the file does not match the data, the system will issue a warning but will continue, probably scaling the data incorrectly.
- The upper right hand box will display information about the file as read from the header. The various check boxes are conveniences based on multiple uses.
- Always Prompt…allows the user viewing files from different sources and PDC configurations to always be sure to get the correct configuration. Normally this should be left unchecked
- Cache PDC Config saves the configuration when another file of the same configuration is to be viewed. It is normally checked.
- Cache disturbance file saves files in memory when the user is going back and forth among files. This saves loading time. This should be left unchecked since it requires substantial memory.
- Local time uses…accounts for daylight savings when the local time option is used in the data viewer.

2.3.2.3 Viewing Data

Display the data table shows the raw data in a table format as it is described in the format description. It also displays the header information in parsed format. The config file is not used here, even though there is a prompt for it.

Graph the data shows the data in graphical format converted to engineering units using the config file information. It also performs conversions for secondary units such as Watts, Vars and Phase differences. Some status information is also viewable such as sync and data valid.

2.3.2.4 Data Table Display

- The data table is a large array where each row is a sample corresponding to an instant of time ,and each column is a data item. Each column is a 4 byte (32 bit) block of data represented by 8 hexadecimal characters. Use the upper sector to move the rows displayed up and down, and the lower one left to right. The numbers give the array position of the upper left-hand element of the display.
- Use the pop down arrows to move the table view one digit at a time. Position the cursor, left click and drag to highlight several digits in the selector box, and then type in new numbers to move a larger distance in the table.
- The PMU offset from the header shows the start column for the block of data for each PMU. The first row corresponds to the File Start Time, and each row increments from that point on according to the sample rate
- Use the scroll down arrows to move through the ID and offset sections. The Stream Data window shows if the data was recorded on a PDC or a Stream Reader.
- The PMU Config is normally taken from the first sample, but in the case of one that happens to be invalid, it will search through the data table to find a valid one and display the information..

Following is the screen that displays when Display the Data Table is selected:

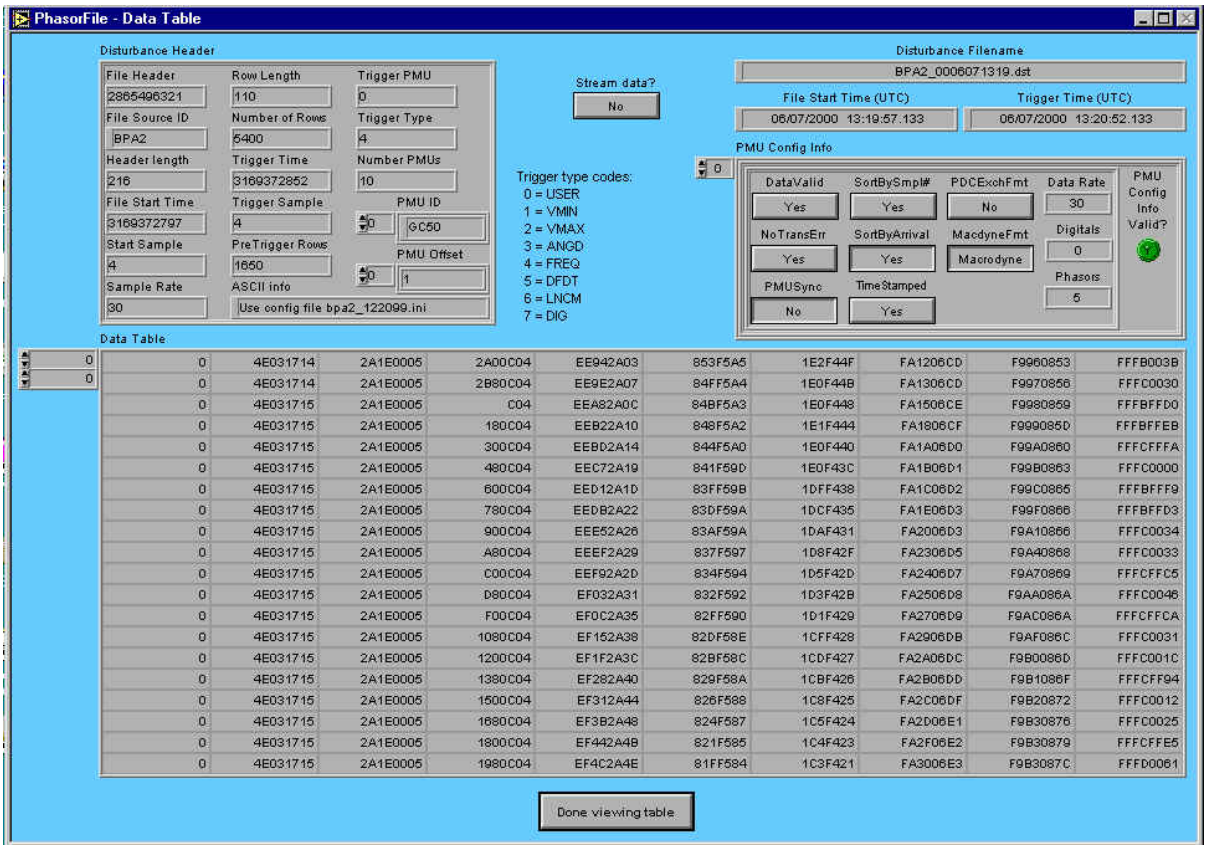

PhasorFile - Data Table
Disturbance Header
File Header
2865496321
Row Length
110
Trigger PMU
0
File Source ID
BPA2
Number of Rows
5400
Trigger Type
4
Header length
216
Trigger Time
3169372852
Number PMUs
10
File Start Time
3169372797
Trigger Sample
4
PMU ID
0
GC50
Start Sample
4
PreTrigger Rows
1650
PMU Offset
0
1
Sample Rate
30
ASCII info
Use config file bpa2_122099.ini
Stream data?
No
Trigger type codes:
0 = USER
1 = VMIN
2 = VMAX
3 = ANGD
4 = FREQ
5 = DFDT
6 = LNCM
7 = DIG
Disturbance Filename
BPA2_0006071319.dst
File Start Time (UTC)
06/07/2000 13:19:57.133
Trigger Time (UTC)
06/07/2000 13:20:52.133
PMU Config Info
0
DataValid
Yes
SortBySmpl#
Yes
PDCExchFmt
No
Data Rate
30
NoTransErr
Yes
SortByArrival
Yes
MacdyneFmt
Macrodyne
Digitals
0
PMUSync
No
TimeStamped
Yes
Phasors
5
PMU Config Info Valid?
Data Table
0
0
0 4E031714 2A1E0005 2A00C04 EE942A03 853F5A5 1E2F44F FA1206CD F9960853 FFFB003B
0 4E031714 2A1E0005 2B80C04 EE9E2A07 84FF5A4 1E0F44B FA1306CD F9970856 FFFC0030
0 4E031715 2A1E0005 C04 EEA82A0C 84BF5A3 1E0F448 FA1506CE F9980859 FFFBFFD0
0 4E031715 2A1E0005 180C04 EEB22A10 848F5A2 1E1F444 FA1806CF F999085D FFFBFFEB
0 4E031715 2A1E0005 300C04 EEBD2A14 844F5A0 1E0F440 FA1A06D0 F99A0860 FFFCFFFA
0 4E031715 2A1E0005 480C04 EEC72A19 841F59D 1E0F43C FA1B06D1 F99B0863 FFFC0000
0 4E031715 2A1E0005 600C04 EED12A1D 83FF59B 1DFF438 FA1C06D2 F99C0865 FFFBFFF9
0 4E031715 2A1E0005 780C04 EEDB2A22 83DF59A 1DCF435 FA1E06D3 F99F0866 FFFBFFD3
0 4E031715 2A1E0005 900C04 EEE52A26 83AF59A 1DAF431 FA2006D3 F9A10866 FFFC0034
0 4E031715 2A1E0005 A80C04 EEEF2A29 837F597 1D8F42F FA2306D5 F9A40868 FFFC0033
0 4E031715 2A1E0005 C00C04 EEF92A2D 834F594 1D5F42D FA2406D7 F9A70869 FFFCFFC5
0 4E031715 2A1E0005 D80C04 EF032A31 832F592 1D3F42B FA2506D8 F9AA086A FFFC0046
0 4E031715 2A1E0005 F00C04 EF0C2A35 82FF590 1D1F429 FA2706D9 F9AC086A FFFCFFCA
0 4E031715 2A1E0005 1080C04 EF152A38 82DF58E 1CFF428 FA2906DB F9AF086C FFFC0031
0 4E031715 2A1E0005 1200C04 EF1F2A3C 82BF58C 1CDF427 FA2A06DC F9B0086D FFFC001C
0 4E031715 2A1E0005 1380C04 EF282A40 829F58A 1CBF426 FA2B06DD F9B1086F FFFCFF94
0 4E031715 2A1E0005 1500C04 EF312A44 826F588 1C8F425 FA2C06DF F9B20872 FFFC0012
0 4E031715 2A1E0005 1680C04 EF3B2A48 824F587 1C5F424 FA2D06E1 F9B30876 FFFC0025
0 4E031715 2A1E0005 1800C04 EF442A4B 821F585 1C4F423 FA2F06E2 F9B30879 FFFCFFE5
0 4E031715 2A1E0005 1980C04 EF4C2A4E 81FF584 1C3F421 FA3006E3 F9B3087C FFFD0061
Done viewing table

Figure 2.3-2

Following is the window that displays when *Graph the Data* is selected:

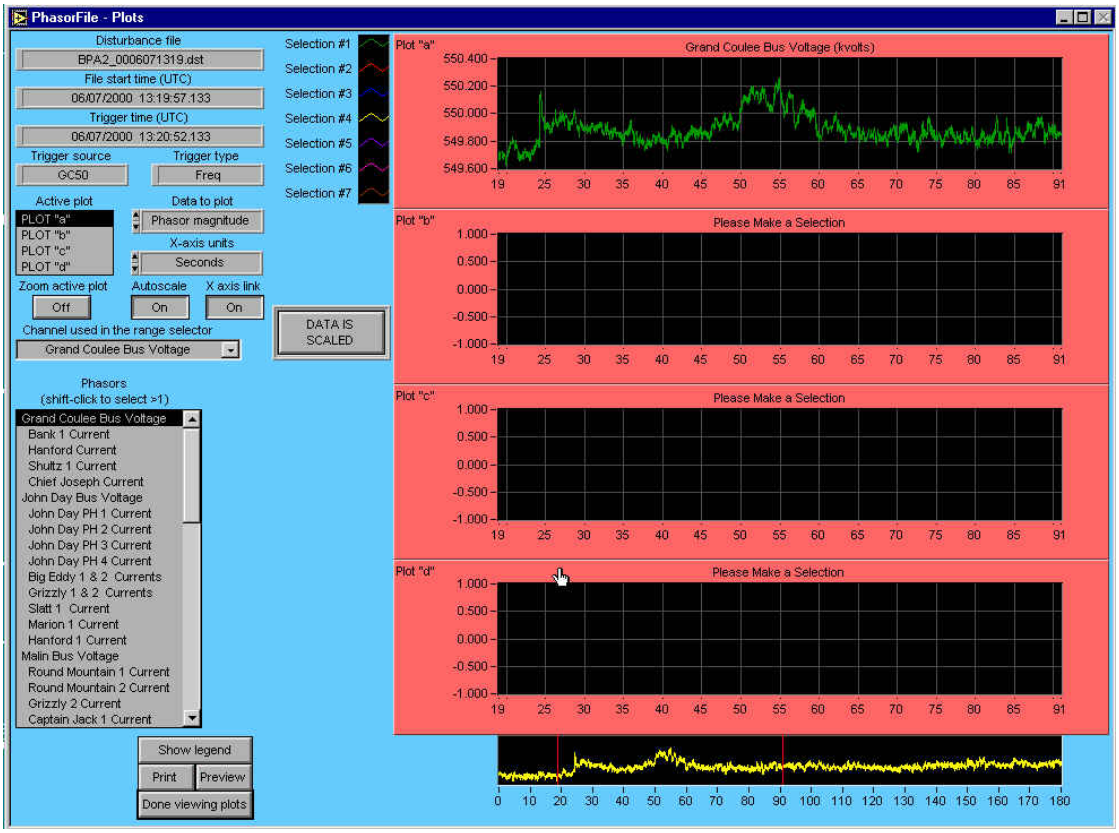


Figure 2.3-3

Following is the window that displays when *Convert the Disturbance File* is selected:
NO—this is the stream reader!! There is no display window for convert, only a progress bar.

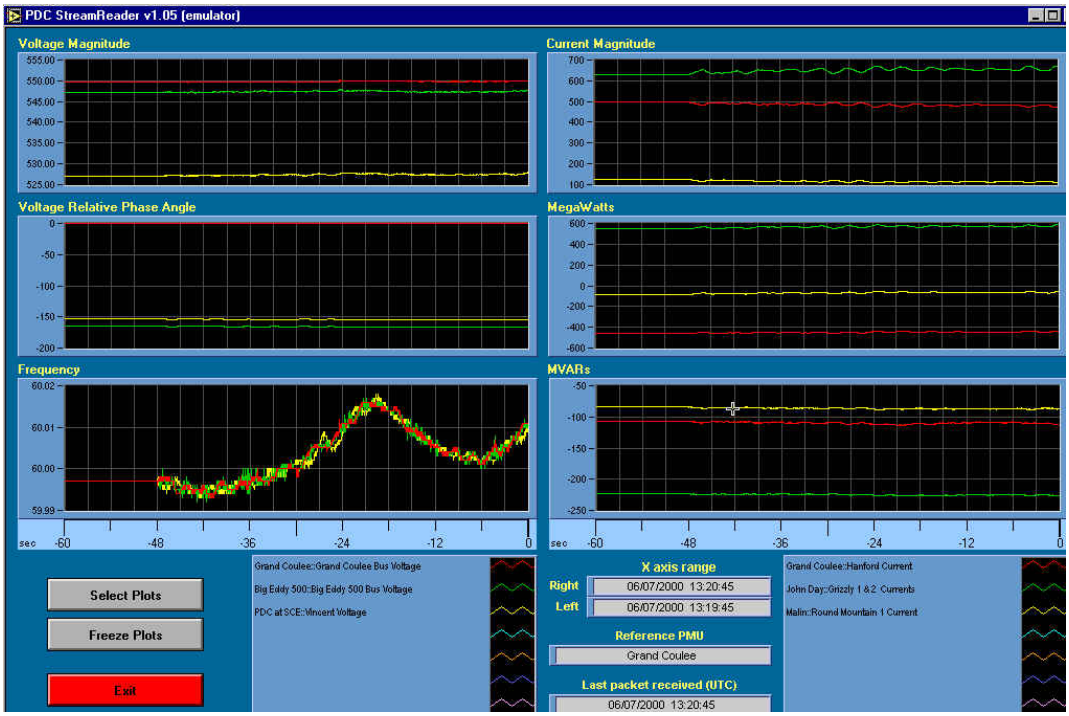


Figure 2.3-4

2.3.3 Configuring SteamReader

StreamReader inputs data from the PDC with Ethernet using UDP/IP. The user will have to ensure the proper Ethernet connection has been made, and Windows has the TCP.IP (which includes UDP) drivers installed for the interface. The tool will automatically connect to this interface.

SteamReader requires its own configuration file (PDCSteamReader.ini) located in the same directory as the tool, and a configuration file for the graphical display (BPA1.ini). The tool automatically updates changes to its own configuration file. It will run without the data display configuration file, but data will not be scaled. This configuration file is the same as the one used to scale data from the stored phasor files.

2.3.4 Selecting Operating Parameters

An auto-start dialog box will start if auto-start is enabled. This is the default. If it has been previously configured and is satisfactory, allow the application to start and run. Otherwise, click on OK to go into configuration.

Clicking on the display and typing in values or in some cases using browsing or selector arrows, changes the configuration panel values. Once you are finished setting up the configuration, click ok *Done* or press the return key. The function will start.

Once started, you can only reconfigure by stopping the program and restarting.

Following are the operating parameters:

StreamReader ID	When the StreamReader records files continuously on disc, it will use the format XXXX_010203160423, where XXXX = the StreamReader ID. The rest is the start time of the file in YYMMDDHHMMSS format. In this example, the file started at February 3, 2001 at 16:04:23.
ASCII Information	This is up to 80 characters that will be recorded in the info block of the data file. The user may enter anything. Typically it references the proper configuration file.
PDC Config File	This is the config file used to scale the data displays. If data is not being displayed, this is not needed. Select the file to be used.
Data Display	Selects whether the real time data display will be active. If no one is using the display, disabling the function diminishes the possibility of losing data being archived.
Data Archive	Selects whether the continuous archive function will be enabled.
Display Update Time	Selects how often the display will be updated. More often, it tasks more processor time and diminishes the PC ability to perform other simultaneous tasks, as well as increases

	the possibility of losing incoming data. Less often produces a jerkier display, with corresponding delays in seeing the latest information.
Archive Path	This is the directory in which the archived data files will be stored. All files will be stored in the same directory.
Archive Length	The Archiver will store data continuously for the specified number of hours, then erase the oldest file and replace it with a new one. This way it always maintains a continuous record for the given number of hours in the past from the present time. Specify any number of hours desired. The disc space indicator will show how much space will be required (and consequently if the disc is too small for the setting).
File Length	Specified the length of time each file will capture data. Files will start on even minute, even hour rollover. The tradeoff is small files (1-2 min). But the are numerous and harder to manage, even though they are easier to store and send. Larger files (5+ min) are much easier to manage but harder to transport. 3-5 min files have been found to be the most successful.
Sample Rate	Must be set to correspond with the PDC. As of 01/01/01 this is always 30.
Disc Viewer	Shows disc size and availability parameters. Once values are entered into the Archive Path and Archive Length, this will be updated.
Auto Start	This will allow the tool to start without intervention using existing parameters. Without it, this config panel will always be called at startup.
UDP Data Port	The PDC sends data to a specific port, and this must look at the same port. As of 01/01/01, this is always 3050.

Note: Disc usage and file size depend on the number of PMUs sending data and how much data each sends. The indicator estimates this from the config file and should be close.

An average data rate is about 90 KB/min/PMU. If the user has 8 PMUs feeding the PDC, the PDC will be outputting about 720 KB/min for data storage. At this rate, a 3 min file will be 2.16 MB and a 5 min file will be 3.6 MB. The overall data storage requirement is 43 MB/hr or 1 GB/day. Real requirements can vary from this estimate by 25% depending on the system configuration.

2.3.5 Graphical display

The display shows system voltage parameters on the left and current derived parameters on the right. The config file tells the tool which are currents and which are voltages. This display cannot be changed. Multiple quantities can be displayed and those displayed are

shown at the bottom. All plots are auto-scaled, so as values change they can be observed changing on the plot scale.

- *Last Packet Received* gives the time of the latest message so the user can verify the time.
- The reference Phasor is used for displaying the voltage phase angles. These are all relative phase angles, and require a reference source.
- *X-axis* is the horizontal or time axis; range is how long a time span is displayed. Left is the time at the left end of the display. Right is the time at the right end of the display.
- *Select Plots* brings up a screen where the quantities being observed can be selected as well as the X-axis range and reference PMU. When this is selected, the current display will continue but may drop some data during the transition. On return, if any selections are changed all current display data will be discarded and the display started over. If nothing is changed, the display will continue as before.
- *Freeze Plots* holds the current. When de-selected, the display updates to current data immediately. Frozen displays cannot be re-scaled.

2.3.6 Selecting Quantities to View

- Click on *Select Plots* to bring up a selection screen. The display is from the currently selected config (*.ini) file. If none is selected it will be left blank.
- Select values using the mouse and scroll bars. For more than one selection, hold down the shift key.
- Use the mouse to select *Reference Phasor* and *Chart Time*. The reference phasor is used for the phase angle display. The reference phasor phase angle is subtracted from the phase angle of each displayed phasor to display the difference (modulo 180 degrees). Phasors whose angle leads the reference will be positive, and those that lag the reference will be negative.
- Voltage magnitude can be in kV or PU (per unit), which is helpful for displaying different bus voltages at the same time. The nominal PU value is taken from the config file.
- Click on OK to accept changes, Cancel to keep old ones. Value is automatically saved in the configuration file.

Appendix

A.1 Fundamentals

A phasor is the vector representation of an AC waveform, where:

$V = A \sin(2 \pi 60 t + f) = A e^{j f}$

Note--We usually use f for frequency and the Greek phi or theta for angle, but of course this works. The figure lost the angle phi, and they are not f as is shown in the formula.

See below for more detail on the relationship between wave and phasor forms (j and f).

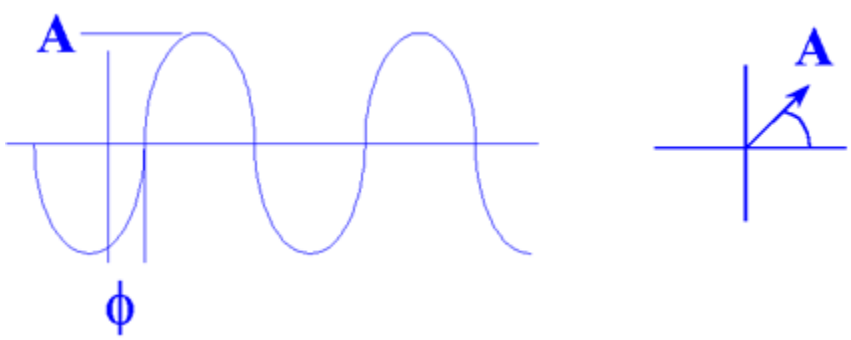


Figure A-1

Why Phasors?

Phasors are system-wide measurements that measure key power system parameters. They are highly accurate, have high bandwidth, and very low noise. This provides a .05% phasor with 0.1-degree phase resolution, a frequency measurement of 0.0001 HZ, and one cycle measurement time.
The phasors are transmitted as shown above, and MW and MVAR are computed below.

MW and MVAR are readily computed. Phasors are transmitted in rectangular coordinates as shown below, where:

Power $P = V I \cos(q - f) = VI = Vx\ Ix + Vy\ Iy$

And

Reactive Power $Q = V I \sin(q - f) = V (jI) = Vy\ Ix - V\ x\ Iy$

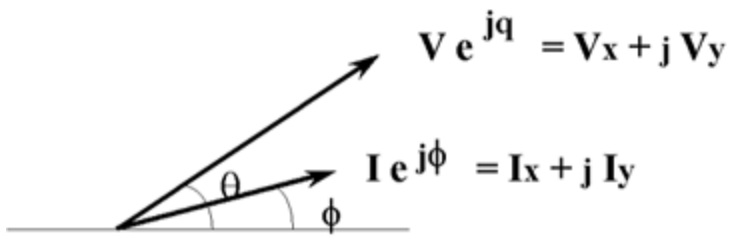


Figure A-2

Frequency is the rate of phase change, where:

F = △ ((q – f) / (t_2 – t_1)

This formula is not right.
The above algorithm uses estimation over several samples to minimize noise and round off errors.

A compact measurement set contains the following:

- A substation with three line currents, and one bus of voltage
- An analogue measurement of 10 numbers – 3W, 3 VAR, 3 I, IV, and three additional measurements or an added line
- A phasor measurement with 8 numbers – 3 I, I V (X2), and one additional measurement or two added lines.

Phasor Measurement

Phasors are measured in PMU's or *Phasor Measurement Units.* Samples of this are AC waveforms with an n A/D converter.

Phasor measurements mathematically derive complex phasors from waveform samples. They use a precise time reference to apply a time tag to a complex phasor.

The figure below captures the phasor measurement process as implemented in a typical PMU:

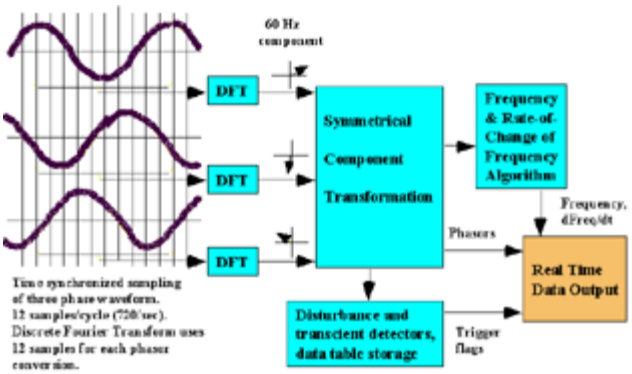


Figure A-3

Below is a functional diagram of the phasor measurement system:

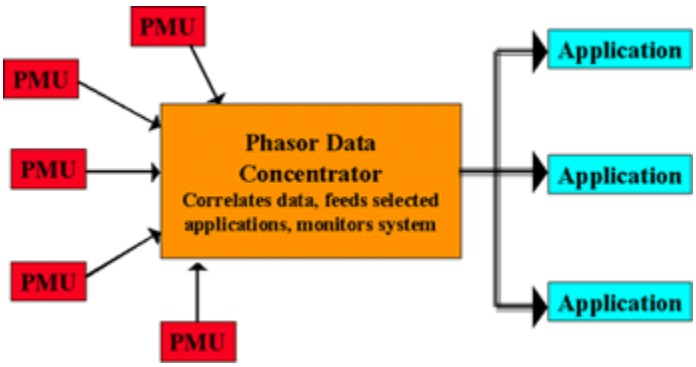


Figure A-4

Prony Analysis

The primary analysis technique used in the Ringdown Analysis Tool is Prony analysis. Coupled with standard Fourier analysis and filtering algorithms, Prony analysis provides considerable information from a system's ringdown. In this chapter, we provide an overview of Prony's method. For those interested, more information can be obtained by reviewing the literature..

Prony's method, first published in 1795 is a mathematical strategy for fitting a linear combination of exponential terms to signals sampled equally in time. Numerical advantages of Prony analysis make it well suited for approximating high-order signals with an optimum low-order model. In a sense, it is an extension of Fourier analysis in that not only are amplitude, frequency, and phase information identified, modal damping estimates are also obtained.

Consider a set of M signals $y_m(t)$, $m = 1, ..., M$, that share a common set of poles. An example would be the step response of a linear system measured at multiple outputs. The mth output is modeled as

$$\hat{y}_m(t) = \sum_{i=1}^{n} A_{m,i} e^{\sigma_i t} \cos(\omega_i t + \phi_{m,i})$$

where $A_{m,i}$ and $\square_{m,i,}$ are the amplitude and phase at frequency $\square_i$ with damping $\square_i$. Using Euler's relation, (2.1) can also be written as

$$\hat{y}_m(t) = \sum_{i=1}^{n} \left(B_{m,i} e^{\lambda_i t} + B^*{}_{m,i} e^{\lambda^*{}_i t} \right)$$

where $B_{m,i}$ and $\square_i$ are complex ($B_{m,i}{}^*$ is the complex conjugate of $B_{m,i}$), and

$$B_{m,i} = \frac{A_{m,i}}{2} e^{j\phi_{m,i}} = \frac{A_{m,i}}{2} \angle \phi_{m,i}$$

$$\lambda_i = \sigma_i + j\omega_i$$

The B_{mi}'s are termed the **output residues** and the $\square_i$'s are the poles (also called modes or eigenvalues).

Assume that y_m is sampled at a period of T for a total of N_m samples ($y_m(kT)$, $k = 1, 2, ..., N_m$-1). Prony analysis determines the amplitude, phase, frequency, and damping terms that minimize the least squares difference between y_m (kT) and (2.2) with $t = kT$ for $k = 1, 2, ..., N_m$- 1. The frequency terms ($\square_i$'s) are allowed to be zero, which results in a pure exponential decay term.

Three numerically intensive problems must be solved in Prony analysis. The first is the solution of an over-determined set of linear equations, and the second is the rooting of a high-order polynomial. These are required for calculating the $\square_i$'s. The third problem involves the calculation of the $B_{m,i}$'s, which also requires the solution of an over-determined set of equations. Both sets of over-determined equations are of unique form, which allows them to be solved using special techniques. **It is recommended that the default solution options be employed as experience has proven these to work well.**

In general, there are four formulations for solving the problem, which relate to assumptions placed upon the initial and post conditions of the data. The initial conditions of the data relate to $y_m(kT)$ for $k < 0$, and the post conditions relate to $y_m(kT)$ for $k > N_m - 1$. If no assumptions are made concerning the initial and post conditions, then the problem is termed the covariance problem. **The covariance problem is applicable to analyzing dynamic system responses to a disturbance or probing inputs**. If initial conditions are forced to be zero (i.e., $y_m(kT) = 0$ for $k < 0$), then the formulation is termed the prewindow problem. Similarly, if post conditions are forced to be zero (i.e., $y_m(kT) = 0$ for $k > N_m - 1$), then it is termed the post-window problem. Forcing both initial and post conditions to be zero is the correlation problem. Most system ringdowns do not fall under the pre-, post-window, or correlation assumptions.

Model Order

In real-life applications, the order of the system (i.e., the number of terms in the model) is rarely known. For many systems, a ringdown can consist of hundreds of modes plus noise, but it is usually dominated by a few modes. For such a situation, it is unrealistic to expect Prony analysis to accurately identify all terms except the more dominant ones. To obtain accurate identification of the dominant modes, the model order is assumed to be the maximum allowed by the data (approximately one-half the number of data points). Effectively, this allows the Prony analysis extra degrees of freedom to fit a model to both the dominant modes and the noise and lightly excited modes. Then the modes are ordered using an error criterion known as the Akaike information criterion (AIC) [5] or they are ordered according to the energy contained in the mode response. The energy and AIC options are selected by the user.

Essentially, the AIC is a function that decreases as the model's response becomes closer to the actual data, and increases as more parameters are used for the model (i.e., as the order of the model increases). The minimum of this function represents an optimal trade-off between model order and the accuracy of the fit. Although the theoretical minimum occurs at the optimal order, in practice it usually occurs at a model-order greater than the actual. The best method for determining the model order is to simply plot the models response against the data and to incrementally add modes until the model's response accurately represents the data. Modes are added according to the ordering from the AIC.

If the energy option is used, the modes are ordered according to the energy they contain over the fitting window. After they are ordered, the AIC is calculated for each order and the model order is estimated as above. Theoretically, the AIC is a more acceptable method of re-ordering, but in practice, errors can occur for very closely spaced modes. For most cases, the

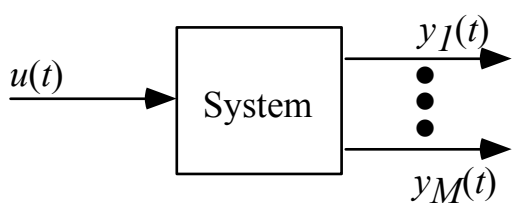
energy method provides similar results as the AIC approach, but does not have problems with very closely spaced modes. Because of this, **it is recommended that the energy method be used**.

Using Prony Analysis For System Identification

Consider the system where $u(t)$ is the input to the system at time t, and $y_1(t)$, $y_2(t)$, ..., $y_M(t)$ are the outputs at t. Let $G_m(s)$ be a Laplace-domain linear estimate of the system transfer function from u to y_m. From linear system theory, $G_m(s)$ can be represented in three different forms: ratio of zeros over poles; ratio of polynomials; and summation of residue terms (called the parallel form). The parallel form has certain numerical advantages in representing high-order systems; therefore, let us write $G_m(s)$ as

$$G_m(s) = K_m + \sum_{i=1}^{n} \left(\frac{R_{m,i}}{s - \lambda_i} + \frac{R_{m,i}^*}{s - \lambda_i^*} \right)$$

where the $R_{m,i}$'s and λ_i's are allowed to be real or complex. Complex λ_i's represent oscillatory modes and the real λ_i's correspond to critically damped modes. For convenience, we will call (2.5) an n-mode transfer function. K_m is termed the feed-forward constant as it directly multiplies the input signal. The λ_i's are the system poles or eigenvalues, and $R_{m,i}$ is **transfer function** residue for λ_i. In order to represent a system as (2.5), we must assume that the poles are distinct, that is, λ_i is not equal to λ_p for i not equal to p. Formulations incorporating repeated poles are contained in [10], but, in the current version of this software, repeated roots are not supported.



Lets assume that the input to the system is a finite-length square-wave pulse-train. In this case, $u(t)$ can be represented in the Laplace domain as

$$U(s) = \sum_{i=0}^{L} c_i \frac{e^{-sD_i} - e^{-sD_{i+1}}}{s}$$

Figure 4 shows a plot of the input for $L = 2$. The D_j's are the switch times, and the c_j's are the pulse amplitudes.

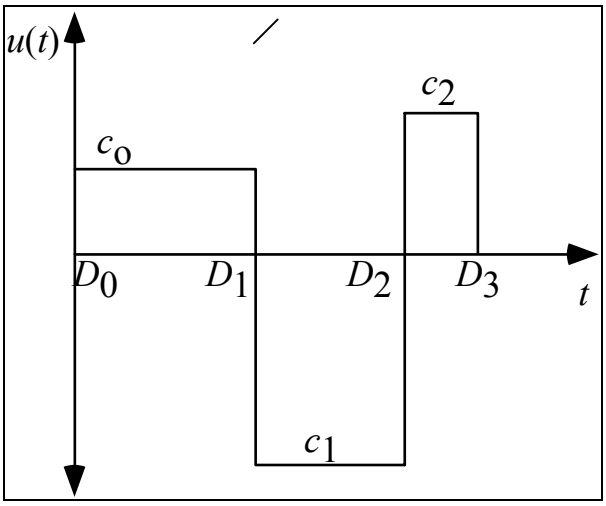


Figure A-5

A.2 Engineering Value

The purpose of monitoring facilities is to ***avoid system disturbances***, not just to record them. Measured information is a major input to the many decision processes that planning and operation involve. The following are the key components and considerations relative to system monitoring.

- *Value* The information has the same value as the decisions based upon it.
- *Level of investment* Measured information is considered insurance against operational uncertainty. How much insurance is enough? How much information is too much?
- *Monitoring tools* In addition to event recording, monitor facilities should support both direct tests and analysis of the power system as well as real time system operations (operator alerts, cross triggers, etc.)
- *Monitor recording options* All monitoring should evaluate data in real time, using event detection logic (EDL) to trigger "snapshot" recordings of special activity or conditions. It should also record all data continuously, then apply EDL to archived records.
- Following are the EDL considerations:
  - *EDL tune-up is ongoing:* automatic detection of significant abnormal system behavior requires comprehensive examination and knowledge of normal behavior.
  - *Real time EDL rarely detects the onset of distant events.* Snapshot monitors often miss the conditions contributing to major disturbances (e.g., cascading outages).
  - *EDL for scanning continuously recorded archives can be simplified* and/or desensitized for use in real time, as a refinement to the "triggers" now in use, as well as for scanning and characterization of snapshot archives.
- Value engineering:
  - *Functionality* is the key issue: Who needs to see what, where, when, in what form? Why – what decisions hinge upon the information?
  - *Staff costs* (engineering, operations, maintenance) are dominant in power system monitoring. Compared to these, hardware is free – configure the hardware to minimize staff costs.
  - *Continuous recording, in combination with a competent archive scanner,* provides the best value engineering for wide area measurements of power system dynamics.
  - *The archive scanner* required for continuous recording can and should be designed for the overall monitor facility. Better integration and more timely access increases information value while lowering staff costs.
  - *Ease of use hastens workflow* and reduces direct staff costs, but generally requires that data be translated into multiple work environments.

- *User participation is essential* to development and operation of high performance monitor facilities. It is highly desirable that custom data interfaces and EDL be directly accessible for modification by the user, and that this require a minimum of special skills.
- *Refinement of measurement tools* is an essential part of the system engineering process.

A.3 System Architecture

Following is a schematic of the system architecture:

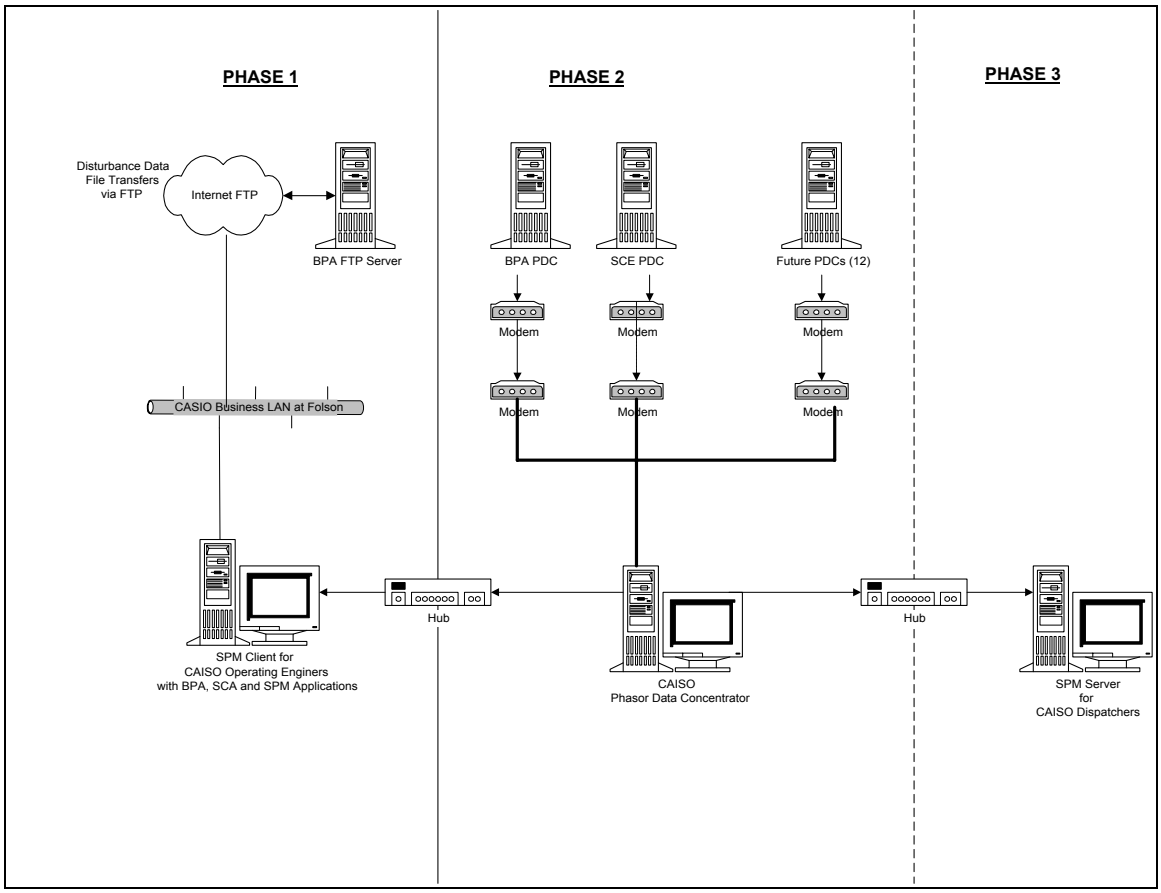


Figure A-6

A.3 Processes

Following is a hierarchical view of SPM based on areas of functionality, irrespective of organizational unit. A hierarchical overview of functions provides business owners with an understanding of the structure and composition of a functional area.

Figure A-7 illustrates a functional decomposition. It provides a sample of the internal hierarchy of the work processes in relation to the SPM functions.

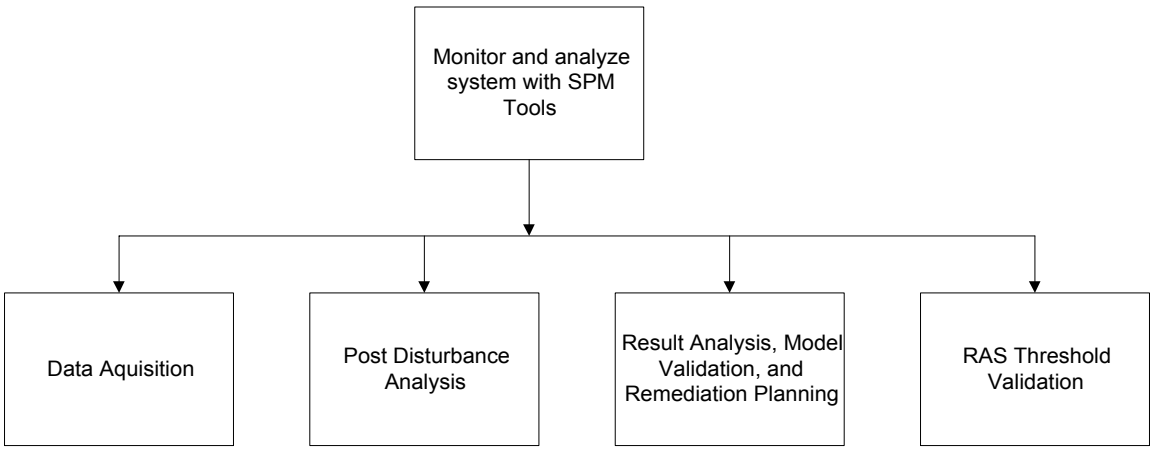


Figure A-7

Decomposition is also done for each function to determine the processes performed within a function. Processes consist of an organized group of activities that together create an output of value to a customer. Activities consolidate a group of related tasks that occur over time to produce results.

Figure A-8 demonstrates the relationship between functions, processes, activities, and tasks for data acquisition. In the example, data acquisition is the function; phasor measurement unit data acquisition is the process; and acquire data for CAISO is the activity. Activities are fundamental building blocks for the process model.

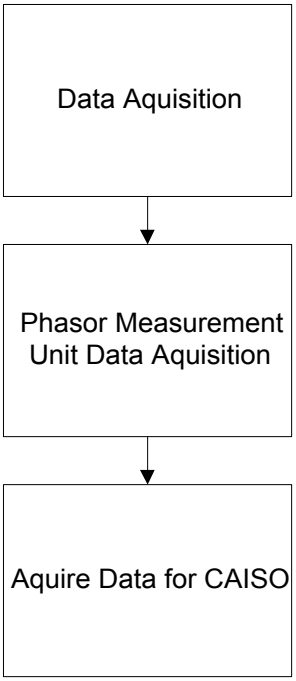


Figure A-8

Figure A-9 is an example of the as-is processes for the Data Acquisition activity. As detailed below, the purpose of this activity is to collect data from the Phasor Measurement Units (PMU) on the Phasor Data Concentrators (PDC), and download the data to the CAISO server.

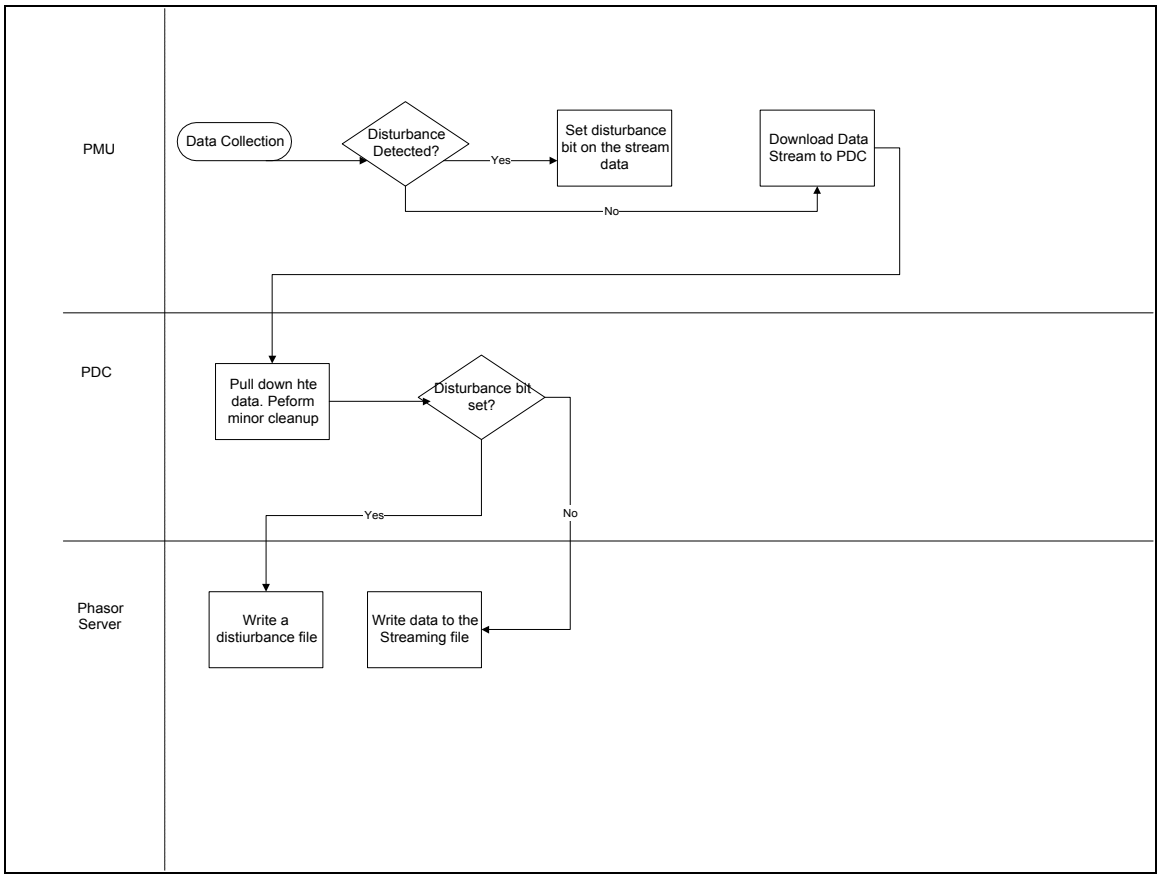


Figure A-8

For further reference information, see *DSITools Power System Model Analysis Application Guide*, Volume 4, 1995-1998 Battelle Memorial Institute, by Daniel Trudnowski, John Hauer and Graham Rogers.