PNNL-28016

Archive Walker Software

Setting Up and Reviewing Analyses with the Archive Walker GUI

September 2018

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Contents

1.0 Introduction

Archive Walker (AW) is a tool designed to ingest, analyze, and visualize PMU data and the power system events that can be found within it. It is open source, with development funded by Bonneville Power Administration (BPA) and the US Department of Energy (DOE). The goal of AW is to bring value to archives of PMU data by enabling analysis with a set of built in event detectors and reducing the overhead required to prototype and deploy new analysis methods.

2.0 Installing and Launching Archive Walker

The AW tool is compatible with the Windows operating system. It is composed of two components: an underlying MATLAB engine and a user interface written in the .NET framework. These components rely on the MATLAB runtime and the .NET framework, both of which can be downloaded for free. First, download .NET framework 4.6.1 at https://www.microsoft.com/en-US/download/details.aspx?id=49982. Next, download the R2017a (9.2) MATLAB runtime at https://www.mathworks.com/products/compiler/matlab-runtime.html. Finally, transfer the executables downloaded from these links to the computer that will host AW and run them to install the .NET framework and MATLAB runtime.

Next, AW can be downloaded as a zip file at https://github.com/pnnl/archive_walker/releases. Once downloaded, unzip the file by right clicking on it. The resulting folder contains the following:

- dlls (folder)
- ExampleData (folder)
- Projects (folder)
- BAWGUI.exe
- BAWGUI.exe.config

There is no installation necessary. Simply double click the BAWGUI.exe file to launch AW. There will be a brief delay the first time the tool is launched.

Examples of the GUI's layout are presented in Figure 1 and Figure 2. The *Project* panel on the left side of the screens will be discussed in Section 3. The *Signal Selection* panel visible on the right side of the screen when the *Settings* page is selected will be described in Section 4. Sections 5-9 discuss the *Settings* tabs used to configure AW, and Section 10 covers how to review results under the *Results* page.

The discussion in Section 10 utilizes the preloaded example data and results included in the download of AW. These examples cover each of the detectors. The data is stored in the *ExampleData* folder and the results are stored in the *Projects* folder. To access these examples, ensure that the specified results storage location is the *Projects* folder (see Section 3 for instructions). When the GUI is opened for the first time, the results path defaults to this folder.

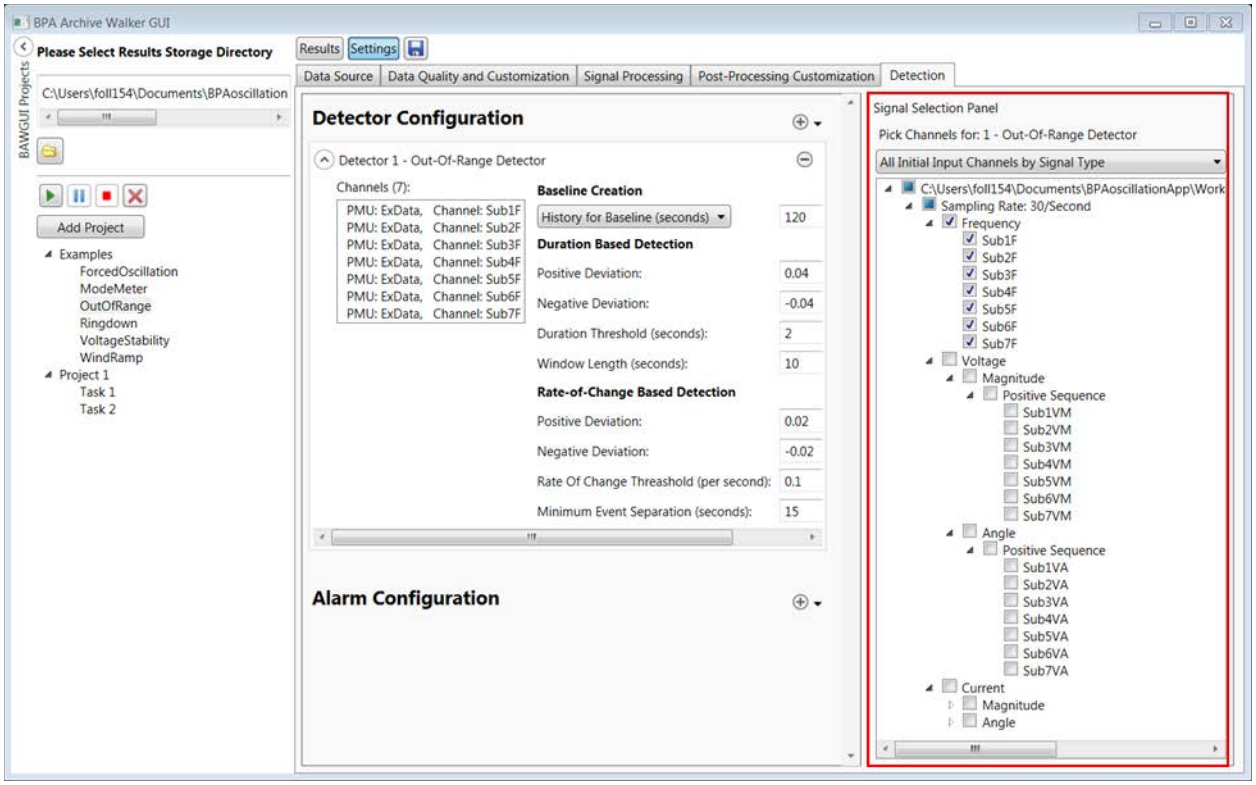

Figure 1: Example GUI layout with Settings page selected.

Figure 2: Example GUI layout with Results page selected.

The final step in preparing to use AW is choosing where results should be stored. AW was designed to allow detailed review of detection results while minimizing required disk space. Still, analyses of large archives may require significant storage. The amount of storage required is dependent on factors such as the number of PMUs in the dataset, the sampling rate, and the number of preprocessing steps, but it is on the order of one GB for each day of data. The *Projects* folder mentioned earlier in this section serves as the storage location for results the first time AW is opened. If this is undesirable, create a new folder where you would like results to be stored. The path to this folder will be entered in the GUI before beginning analysis.

3.0 Project Panel

The panel along the left side of the GUI (see the red box in Figure 3) allows the user to set up projects and specify where results should be stored. The path at the top of the panel specifies where results will be stored. Clicking the folder button below the path allows the user to select a different path for results. The first time AW is opened, the *Projects* folder included in the zip file is selected as the results storage location. This folder contains examples that are described in Section 10.4.

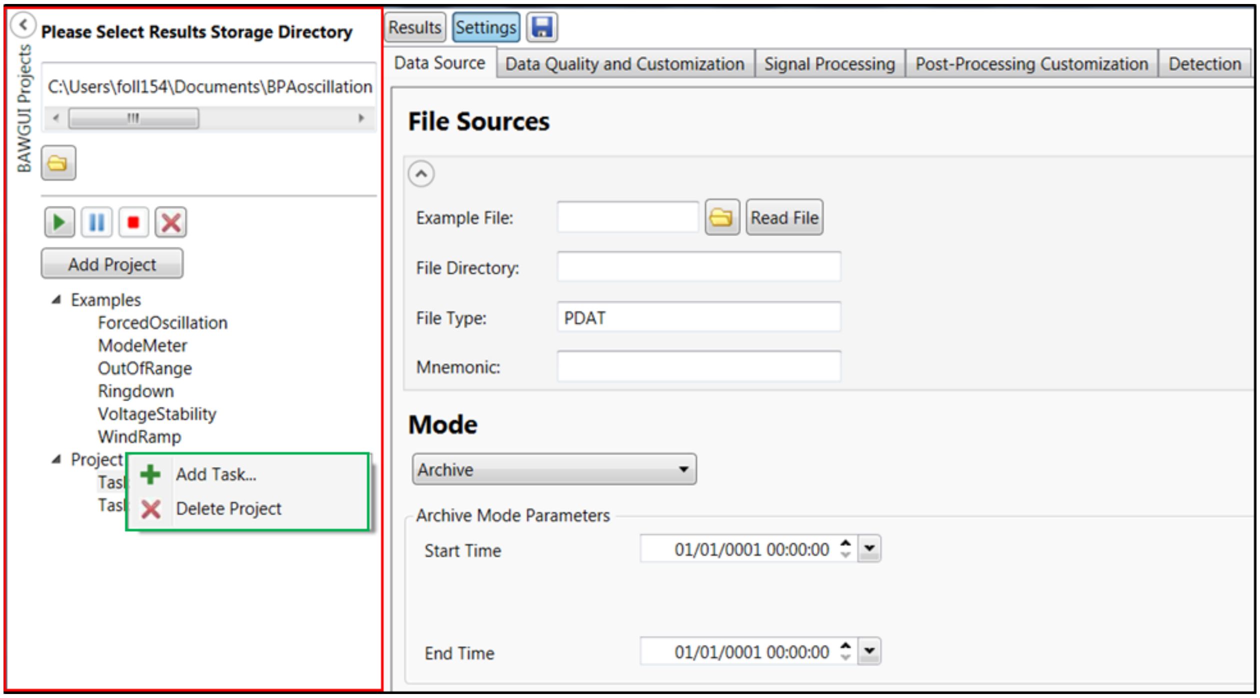

Figure 3: Project panel (left) and Settings page (right).

Results are organized into *projects* and *tasks*. A task is comprised of a set of results associated with a specific analysis setup. Tasks are stored within projects for organizational clarity. After a project is added by clicking the “Add Project” button, tasks can be created by right clicking on the project name (see the green box in Figure 3). Right clicking also allows the entire project to be deleted. New tasks are also created when the save button is clicked after the setup of an existing task is altered.

Once the setup for a task is complete, it can be applied to data by clicking the play button (green arrow). While a task is running, a green arrow appears next to the task name. The remaining buttons allow a task to be paused/resumed, stopped, or deleted.

4.0 Signal Selection Panel

The panel on the right side of the GUI, indicated by the red box in Figure 1, is used to select signals when setting up analyses. The dropdown at the top of the panel provides options for how to select signals. The options fall in three categories: 1) Initial set of signals contained in the data, 2) output signals from previous tabs, and 3) inputs and outputs from steps on the current tab. For the first two categories, the signals can be organized by PMU or by signal type. Signals are also organized by their sampling rate because all signals at the input to any step in AW must have the same sampling rate. In the following, the ringdown detector example, which is discussed in more detail in Section 10.4.3, will be used to illustrate the functionality of the *Signal Selection* panel.

Examples of the three categories of signal selection are illustrated in Figures 4, 5, and 6. In Figure 4, the first step of the analysis setup is to unwrap voltage angles included in the input data. The data is being organized by signal type, rather than PMU, because only voltage angles are of interest. After unwrapping, a filter is applied to the signals before passing them into a multirate step. When the same set of signals is desired for multiple steps, it is convenient to use the *Output Channels by Step* option in the dropdown, as in Figure 5. In the figure, the inputs to multirate processing can be selected easily by clicking either the *Step 1* or *Step 2* checkboxes (note that the signals are identical). After signal processing, the signals are ready to be passed to the ringdown detector. In Figure 6, these signals are selected by displaying outputs from the *Signal Processing Tab*. At each step, the functionality of the *Signal Selection Tab* makes it easier to locate the signals of interest, making it significantly easier to configure AW. Details on the setup process are provided in the following sections.

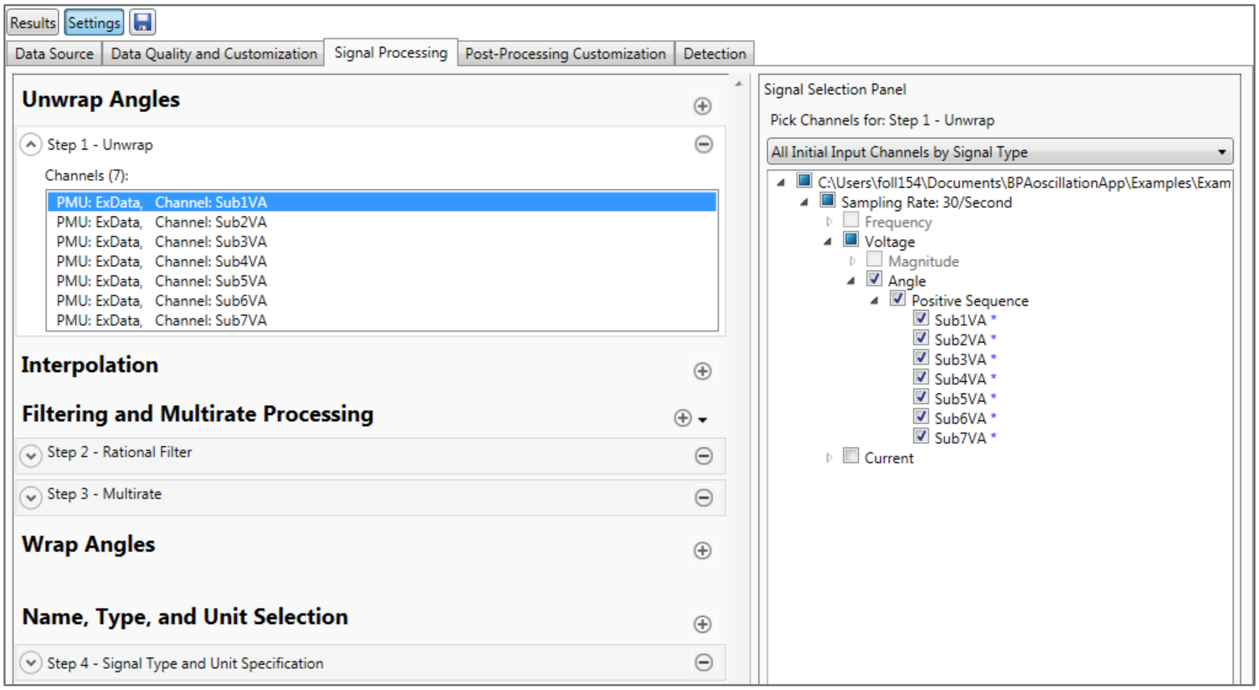

Figure 4: Selecting voltage angle signals to be unwrapped from the input data using the Signal Selection panel.

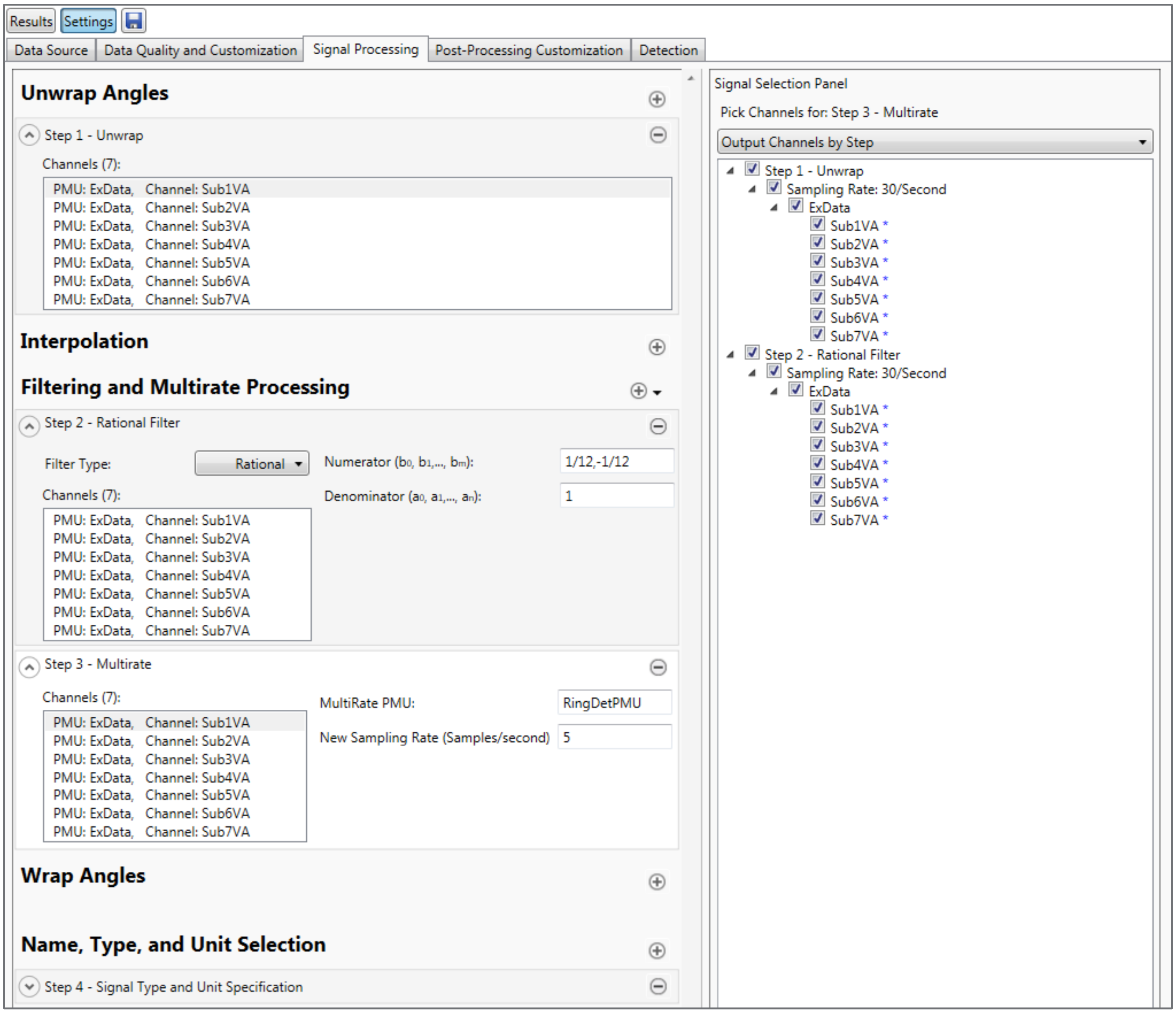

Figure 5: Selecting signals from previous steps for input to the multirate processor using the Signal Selection panel.

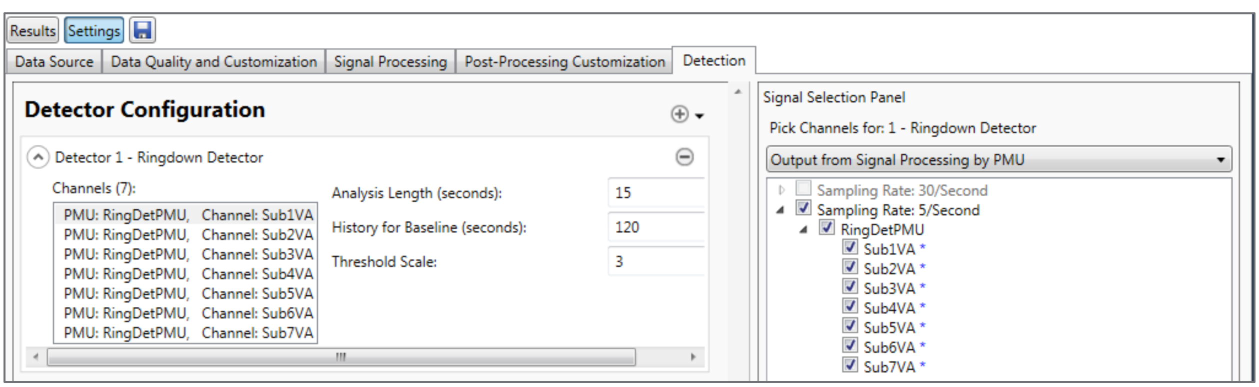

Figure 6: Selecting signals from the Signal Processing Tab for analysis with the ringdown detector using the Signal Selection panel.

5.0 Data Sources Tab

This tab allows the user to specify which files of PMU data should be examined.

5.1 File Sources Panel

The user specifies example files, from which the GUI automatically determines the locations, formatting, and naming conventions of the data. Multiple file sources can be specified, allowing the user to, for example, analyze their own data and data from partner utilities at the same time. All files from different sources must be of the same type and have corresponding timestamps. However, different sources can have different sampling rates.

5.1.1 Example File Field

AW must know which signals will be available for analysis, so an example file is required. The path to the example file can be entered into the field manually, or the user can navigate to it using the folder button next to the field (see Figure 3). Once the field is filled, clicking the *Read File* button will load the PMU and signal names into the GUI for display while setting up analyses. It also automatically fills the *File Directory*, *File Type*, and *Mnemonic* fields for the user's review. These fields cannot be edited directly, but their entries are described in Sections 5.1.2, 5.1.3, and 5.1.4 to provide additional information about how data should be stored.

After a task is executed, it cannot be modified without saving it as a new task to prevent results from being destroyed inadvertently. The exception is the example file. As detailed in Section 11, the example file can be updated so that data and results can be shared by different users.

5.1.2 File Directory Field

Specifies the main folder containing a source of data files. It can have any name, but subfolders must adhere to the following convention. Inside the main folder, PMU data is sorted by timestamp into folders with names corresponding to the four-digit year of the timestamp. Within each year folder, PMU data is sorted by timestamp into folders with names corresponding to the convention *YYMMDD*, where *YY* corresponds to the two-digit year, *MM* corresponds to the two-digit month, and *DD* corresponds to the two-digit day of the month. Individual data files are stored within the folders specifying the date. For example, with a main folder path of C:\PMUdata, the path to the folder containing data files timestamped at any time on November 2, 2014 would be

C:\PMUdata\2014\141102.

5.1.3 File Type Field

Specifies the format of the data. All file sources must use the same file type.

5.1.3.1 PDAT

A custom file type used by the Bonneville Power Administration (BPA).

5.1.3.2 JSIS CSV

A generic format for CSV files developed by the Western Electricity Coordinating Council (WECC) Joint Synchronized Information Subcommittee (JSIS). Figure 7 contains the relevant section from the JSIS document "WECC Guideline for Data Format Used in Engineering Analysis Applications of Disturbance and Simulated Data." The full list of signal types and units compatible with Archive Walker are listed in Table 1.

The simplistic CSV format can be:

Line 1 – signal names

Line 2 – signal type

Line 3 – units

Line 4 – description

The number of columns in "header" rows is the same as the number of columns in "data."

The data is coma separated values.

Example of CSV file opened in Excel:

Time	P001_BC_ALB	P003_BC_NW	P_Malin_RoundMt_1_500	P_Malin_RoundMt_2_500	INGLEDOW_500_VMAG	INGLEDOW_500_VANG
Type	P	P	P	P	VPM	VPA
second	MW	MW	MW	MW	KV	DEG
Time	pif_1_0_1_1	pif_3_0_1_1	pbr_40687_30005_1_1	pbr_40687_30005_2_2	vbus_50194_0_1_1	abus_50194_0_1_1
-0.0083332	-526.588501	-2057.893555	1485.296875	1532.442749	528.065002	84.742546
-0.0041666	-526.591309	-2057.893066	1485.040039	1532.174927	528.065735	84.742561
0.0583324	-526.681396	-2057.911865	1484.336304	1531.438843	528.083374	84.744308
0.1208314	-526.755737	-2057.812744	1484.045532	1531.134277	528.093872	84.745201
0.1833305	-526.848083	-2057.582764	1483.639038	1530.709106	528.097961	84.746063
0.2458295	-526.955383	-2057.321289	1483.314453	1530.370972	528.103638	84.747025
0.3083286	-527.078369	-2057.011719	1482.944824	1529.986816	528.110107	84.748573
0.3708276	-527.212341	-2056.639404	1482.63855	1529.669067	528.118774	84.750961
0.4333267	-527.352661	-2056.23584	1482.444702	1529.468872	528.130737	84.754433

Figure 7: Information on the JSIS-CSV format from the JSIS document "WECC Guideline for Data Format Used in Engineering Analysis Applications of Disturbance and Simulated Data."

Table 1. List of Signal Types and Units Compatible with Archive Walker.

Type	Description	Units
F	Bus frequency	Hz
VPM	Positive Sequence RMS voltage magnitude	kV
VPA	Positive Sequence voltage angle	DEG
IPM	Positive Sequence RMS current magnitude	Amps or kAmps
IPA	Positive Sequence current angle	DEG
P	Active power	MW
Q	Reactive power	MVAR

5.1.4 Mnemonic Field

Files are expected to adhere to the following convention:

MNEMONIC_YYYYMMDD_HHMMSS.csv(pdat)

where *MNEMONIC* is a set of characters excluding underscore, *YYYYMMDD* specifies the file's start date, and *HHMMSS* specifies the file's start time. The *MNEMONIC* portion of the name should appear in the Mnemonic field.

5.2 Mode Panel

The user specifies which data should be analyzed and how the tool should move through the files.

5.2.1 Mode Selection Dropdown

The user specifies the mode that the tool should operate in.

5.2.1.1 Archive

Runs from a user-specified range of times, immediately skipping over any missed files.

5.2.1.2 Real Time

Begins processing from the most recently available file (selected based on computer's system clock in UTC) and continues to process files as they become available. If a file is missing, the tool will wait a user-specified amount of time for it to be written.

5.2.1.3 Hybrid

The tool begins in Archive mode before transitioning to Real Time mode.

5.2.2 Start Time Field

In Archive and Hybrid modes, specifies the timestamp of the first file to be processed.

5.2.3 End Time Field

In Archive mode, specifies the timestamp of the last file to be processed.

5.2.4 Waiting Fields

When Real Time or Hybrid mode is selected, a set of fields will appear allowing the user to specify how the tool should handle data no longer being available (first sentence) and gaps in the data (second sentence).

5.2.5 Hybrid Transition Field

When Hybrid mode is selected, a field will appear as part of a sentence to allow the user to specify when the tool should transition from Archive mode to Real Time mode.

6.0 Data Quality and Customization Tab

The user specifies which data quality filters should be implemented and how custom signals should be created from the base signals in the data files. Filters and customizations are added by clicking the ⊕ dropdown in the upper right corner of the panel.

6.1 Data Quality Filters

These filters allow the user to examine signals for data that is missing, corrupt, or otherwise compromised. Later, in the Data Processing Tab, the user can specify how to interpolate through periods of bad/missing data.

6.1.1 Status Flags

Filters the data based on status flags stored alongside the data in the processed files. Note that this is the only data quality filter that operates on all signals from a particular PMU, rather than on specific signals. Also note that JSIS-CSV files do not contain status flags.

6.1.2 Zeros

This filter flags missing data where zero was used as a placeholder.

6.1.3 Missing

This filter flags missing data that was not replaced by a placeholder.

6.1.4 Nominal Voltage

This filter flags voltage phasors based on the nominal value of the voltage magnitude. The user specifies the nominal voltage along with upper and lower thresholds as multipliers. For example, if the nominal voltage is set at 100 kV, the lower threshold is 0.7, and the upper threshold is 1.2, any voltage magnitude measurements outside the range [70 kV, 120 kV] will be flagged. Things to note:

- The filter accepts signals that are either voltage phasors (complex representation combining magnitude and angle) or voltage magnitudes.
- If a voltage magnitude is selected, the tool will attempt to flag the corresponding voltage angle as well. This functionality depends on the naming convention used in PDAT files. Thus, if JSIS-CSV files are being used, voltage magnitudes and angles should be combined into phasors using customizations before applying this filter.
- The nominal voltage should always be specified in kV. The tool automatically accounts for signals with units of volts.
- The tool does not account for line-neutral versus line-line orientations. Thus, the nominal voltage must be specified to match the way measurements are reported.

6.1.5 Nominal Frequency

This filter flags frequency data based on the nominal system frequency. To allow short excursions that are unrealistic for long time ranges, the filter employs two stages.

In the first stage, the entire file is considered. If frequency measurements fall outside the upper and lower thresholds for more than the portion of the file specified by the *Portion of File* field, all frequency measurements from the file are discarded.

In the second stage, individual samples that fall outside the specified upper and lower threshold are discarded.

6.1.6 Outlier

This filter is intended to flag measurements that fall unrealistically far from surrounding measurements. The standard deviation of the signal is calculated, and then measurements falling more than the standard deviation times the multiplier specified in the *Number of Standard Deviations* field away from the signal's median are flagged. Things to note:

- It is not appropriate for angle signals.
- If a voltage or current magnitude is selected, the tool will attempt to flag the corresponding angle as well. This functionality depends on the naming convention used in PDAT files. Thus, if JSIS-CSV files are being used, the corresponding angle signals may not be flagged.

6.1.7 Stale Data

This filter flags measurements that take on the same value for multiple samples, i.e., are stale. If measurements remain unchanged for the number of samples specified by the *Threshold* field, they are flagged.

Because stale frequency measurements often indicate that all measurements from the PMU are unreliable, the user also has the option to flag all measurements from the PMU if the considered signal is a frequency signal. This option should generally not be used with JSIS-CSV files containing measurements from multiple PMUs.

6.1.8 Data Frame

If several signals from a PMU are found to be unreliable for a set of timestamps, all signals from the PMU may be unreliable for those timestamps. This filter will flag all signals from the PMU at timestamps where the percentage of signals in the PMU with flagged data exceeds the user-specified limit. This filter should generally not be used with JSIS-CSV files containing measurements from multiple PMUs.

6.1.9 Channel

If many of a signal's measurements are found to be unreliable, all of the signal's measurements in the file may be unreliable. This filter will flag all measurements in signals where the percentage of flagged measurements in the signal exceeds the user-specified limit.

6.1.10 Entire PMU
If many of a PMU’s measurements are found to be unreliable, all of the PMU’s measurements in the file may be unreliable. This filter will flag all measurements in PMUs where the percentage of flagged measurements in the PMU exceeds the user-specified limit. This filter should generally not be used with JSIS-CSV files containing measurements from multiple PMUs.

6.1.11 Angle Wrapping
Angle measurements from PMUs are typically wrapped to $[-\pi, \pi]$ or [-180º, 180º]. In some JSIS-CSV files, the wrapping may be performed improperly, leaving a value near zero in the middle of the wrap. This filter identifies such occurrences by flagging successive angle jumps larger than the user-specified threshold. Typically, 90º ($\pi/2$ radians) is a good choice for the threshold.

6.2 Signal Customizations
Signal customizations allow the user to manipulate the signals stored in the data files to create new signals for analysis. These new signals are stored in “custom PMUs” which are structured just as the original PMUs are. When parameterizing each of the customizations, the user is required to specify the name of the custom PMU and signal. Custom signals of identical length created in separate steps can be stored in the same custom PMU.

When multiple signals are involved in a customization, they must have the same sampling rate. Customizations can again be performed after multirate processing (implemented on the Signal Processing tab) is used to align sampling rates. This second round of customizations is implemented on the Post-Processing Customization tab.

6.2.1 Scalar Repetition
This customization allows creating a signal composed of a constant value. Such signals can be useful within other customizations. The signal type and units should be chosen carefully to ensure compatibility in later customization steps. For example, signals must have identical types and units to be added together. The *PMU for Time Source* field specifies which PMU’s timestamps should be used for the creation of the new signal.

6.2.2 Addition
This customization allows any number of signals with identical signal types and units to be added together.

6.2.3 Subtraction
This customization allows one signal to be subtracted from another with identical signal type and unit.

6.2.4 Multiplication
This customization allows any number of signals to be multiplied together. If more than one non-scalar signal is included, the custom signal type and unit are set to *Other*. Otherwise, the non-scalar signal's type and unit are retained.

6.2.5 Division
This customization allows one signal to be divided by another. If signal units agree, the result is a scalar. If divisor is a scalar, the custom signal retains the type and unit of the dividend. Otherwise, the custom signal's type and unit are set to *Other*.

6.2.6 Exponential
This customization allows each measurement in a signal to be raised to an exponent.

6.2.7 Sign Reversal
This customization changes the sign of each measurement, e.g., positive to negative and negative to positive.

6.2.8 Absolute Value
This customization takes the absolute value of each input signal and returns corresponding custom signals.

6.2.9 Real Component
This customization takes the real component of each input signal and returns corresponding custom signals.

6.2.10 Imaginary Component
This customization takes the imaginary component of each input signal and returns corresponding custom signals.

6.2.11 Angle Calculation
This customization takes the angle of each input signal (assumed to be complex) and returns corresponding custom signals with units of radians. Input signals with a phasor signal type produce custom signals with corresponding angles, e.g., inputting a phase B voltage phasor results in a phase B voltage angle type for the custom signal.

6.2.12 Complex Conjugate
This customization takes the complex conjugate of each input signal and returns corresponding custom signals.

6.2.13 Phasor Creation

This customization combines input magnitude and angle signals and produces custom signals in phasor representation. Signal types for magnitudes and angles must be compatible, i.e., current magnitudes with current angles and voltage magnitudes with voltage angles. The resulting custom signals are assigned types and units based on the inputs.

6.2.14 Power Calculation

This customization allows active, reactive, complex, and apparent power to be calculated from input voltages and currents. The inputs can be specified as either phasors or magnitude/angle pairs. The custom signal type and unit are assigned based on the units of the inputs.

6.2.15 Signal Type/Unit

This customization allows the type and unit of a signal to be specified. It makes no change to the input signal’s measurements. This customization is useful for ensuring a signal’s compatibility with other signals in customizations or for certain detectors.

6.2.16 Metric Prefix Customization

This customization changes the metric prefix for signals and adjusts the signal’s scaling appropriately.

6.2.17 Angle Conversion

This customization changes the units of angle signals either from radians to degrees or from degrees to radians, depending on the input signal. The units of the custom signals are selected appropriately.

7.0 Signal Processing Tab

On this tab, the user can implement a variety of signal processing functions to prepare the data for analysis by detectors.

7.1 Unwrap Angles

Angle measurements from PMUs are typically wrapped to [-π, π] or [-180º, 180º]. The jumps introduced by wrapping prevent proper application of filters and bad/missing data interpolation. Angle signals listed in this section are unwrapped to allow filters and interpolation to be performed.

7.2 Interpolation

To replace measurements that are flagged as bad/missing, interpolation can be applied to each signal. If *Constant* is selected in the *Type* field, corrupt measurements are replaced by the last good value. If *Linear* is selected, corrupt measurements are replaced by selecting values along the line connecting the good value preceding the corrupt measurements to the good value following the corrupt measurements. The *Limit* field specifies the maximum number of samples that can be interpolated. Sections of flagged data longer than this limit are not replaced and are excluded from further analysis.

7.3 Filtering and Multirate Processing

In this section, filters are applied to signals to remove unwanted frequency content and multirate processing is applied to change the sampling rates of signals.

7.3.1 Filters

Filters can be specified based on their coefficients, or the user can specify parameters and the tool will automatically design the filter. The *Filter Type* dropdown offers the following options.

7.3.1.1 Rational

The user specifies the numerator and denominator coefficients of an IIR filter (FIR if the denominator coefficient is one). Each coefficient should be separated by a comma. Note that *Rational* refers to how the filter is specified; the high-pass and low-pass filters described in the following sections are also rational filters.

7.3.1.2 High-Pass

The user specifies the order and cutoff frequency for a high-pass Butterworth filter designed by the tool.

7.3.1.3 Low-Pass

The user specifies the passband ripple as a positive dB value, stopband ripple as a positive dB value, passband cutoff frequency in Hz, and stopband cutoff frequency in Hz of a low-pass Parks-McClellan equiripple FIR filter designed by the tool.

7.3.2 Multirate Processing

Multirate processing is used to adjust the sampling rate of signals to improve or speed up analysis and to make signals at different sampling rates compatible.

Similar to the custom PMUs created during customization steps, multirate PMUs are created to store the outputs of multirate processing steps. A unique name must be specified for each different multirate processing step.

The user can choose to specify the new sampling rate in the following ways.

7.3.2.1 Specify New Sampling Rate

The desired sampling rate, which must be an integer multiple or factor of the current sampling rate, is specified in units of samples per second. An appropriate low-pass filter is applied as part of the processing.

7.3.2.2 Specify Upsampling/Downsampling Factors

If only the upsampling factor is specified, then the signal is expanded (zeros placed between each sample). If only the downsampling factor is specified, then samples are removed. In these cases, no filtering is applied. If both upsampling and downsampling factors are specified, then the signal is expanded, appropriately low-pass filtered, and then downsampled.

7.4 Wrap Angles

If desired, angle measurements unwrapped in the *Unwrap Angles* section can be wrapped again in this section.

7.5 Name, Type, and Unit Selection

Processing may effectively change the type and units of a signal, e.g., high-pass filtered voltage angle signals are closely related to frequency. Further, some of the tool’s detectors allow only specific signal types to be analyzed. Thus, this section allows the user to easily change the type and unit of several signals, rather than one at a time.

Alternatively, the name of a single signal can be changed. This can improve clarity. For example, suppose a voltage angle signal named *Bus1.ANG* is high-pass filtered and becomes closely related to frequency. It may improve clarity for the user if the signal is renamed *Bus1.DerivedFrequency*. When a single signal is considered, the type and units can also be changed.

8.0 Post-Processing Customization Tab

After signal processing has been completed, further signal customizations can be completed. This is particularly useful for combining signals that were initially at different sampling rates. All of the customizations are implemented as described in the *Data Quality and Customization Tab* section. Note that only customizations are available; all data quality checks are completed before the signal processing steps.

9.0 Detection Tab

On this tab, detectors are configured to examine data for events. For some detectors, alarms to highlight the most important events are also parameterized.

9.1 Detector Configuration

In this section, individual detectors are configured. Fields that can be left empty have an initial value of *Optional*. If these fields are not populated, default values will be selected. The following sections describe each of the detectors and their parameters. Along with the detectors included in the open-source release of AW, a modified version of the tool also includes the voltage stability detector and mode meter described in Sections 9.1.6 and 9.1.7.

9.1.1 Periodogram Based Forced Oscillation Detector

The periodogram based forced oscillation detector operates on relatively long record lengths (greater than 10 minutes), is very sensitive, and produces highly accurate estimates of forced oscillation frequencies. For details see:

> J. Follum, F. Tuffner and U. Agrawal, "Applications of a new nonparametric estimator of ambient power system spectra for measurements containing forced oscillations," 2017 IEEE Power & Energy Society General Meeting, Chicago, IL, 2017, pp. 1-5.

This detector can only be applied to signals of the following types: real power, reactive power, apparent power, frequency, and OTHER.

Parameters are as follows.

9.1.1.1 Mode
Signals listed for the detector can be processed individually or simultaneously. When operated in multichannel mode, the detector is more sensitive to system-wide events and less sensitive to local events.

9.1.1.2 Analysis Length
The total amount of data that is to be examined. Typical values range between 600 and 1800 seconds. This is the parameter K in the supplied reference.

9.1.1.3 Window Type
Different windows applied to the data will provide slightly different detection performance.

9.1.1.4 Frequency Interval
Specifies the distance between evaluated frequencies. This interval should be no larger than the inverse of the analysis length.

9.1.1.5 Window Length
The amount of data in overlapping windows used to estimate the ambient spectrum. This is the parameter M in the supplied reference.

9.1.1.6 Window Overlap
The amount of overlap between windows when the ambient spectrum is estimated. A typical selection is one half the window length.

9.1.1.7 Median Filter Width
The frequency range corresponding to the order of the frequency-domain median filter used while estimating the ambient spectrum. Using the median filter order N_m from the supplied reference, this is N_m-1 multiplied by the frequency interval.

9.1.1.8 Probability of False Detection
The probability that a detection will occur even though a forced oscillation is not present. The probability can only be reduced at cost to the related probability that an oscillation will be detected when it is present. This probability is expected as a value between zero and one, with typical values close to zero.

9.1.1.9 Minimum Frequency
The lower end of the frequency range to be examined for forced oscillations.

9.1.1.10 Maximum Frequency
The upper end of the frequency range to be examined for forced oscillations. The selected value cannot exceed one-half of the sampling rate.

9.1.1.11 Frequency Tolerance

Forced oscillations must be separated in frequency by at least this amount to be considered separate events.

9.1.2 Spectral Coherence Based Forced Oscillation Detector

The spectral coherence based forced oscillation detector operates on relatively short record lengths (approximately one to two minutes), allowing it to detect large oscillations quickly. For details see:

> J. Follum, "Detection of Forced Oscillations in Power Systems with Multichannel Methods," PNNL-24681, Pacific Northwest National Laboratory, Richland, WA, 2015,

which can be found using the search tool at https://www.pnnl.gov/publications/. This detector can only be applied to signals of the following types: real power, reactive power, apparent power, frequency, and OTHER.

Parameters are as follows.

9.1.2.1 Mode

Signals listed for the detector can be processed individually or simultaneously. When operated in multichannel mode, the detector is more sensitive to system-wide events and less sensitive to local events.

9.1.2.2 Analysis Length

The length of overlapping segments used in the spectral coherence calculation. Typical values are in the neighborhood of 60 seconds.

9.1.2.3 Delay

The amount of delay between the overlapping segments used in the spectral coherence calculation. Typical values are in the neighborhood of 10 seconds. This is the parameter Δn in the supplied reference.

9.1.2.4 Number of Delays

The number of overlapping segments included in the spectral coherence calculation. The minimum value is two. This is parameter $D+1$ in the supplied reference.

9.1.2.5 Threshold Scale

This parameter controls detection performance. Lower values will increase sensitivity but will increase false detections. Larger values require stronger evidence to trigger a detection but will decrease false detections. The lowest acceptable value is one, but many false detections will occur for this setting. A typical selection is three. This is parameter c in the supplied reference.

9.1.2.6 Window Type

Different windows applied to the data will provide slightly different detection performance.

9.1.2.7 Frequency Interval

Specifies the distance between evaluated frequencies. This interval should be no larger than the inverse of the window length.

9.1.2.8 Window Length
The amount of data in overlapping windows used to calculate the spectral coherence. Typically, a value several times smaller than the analysis length should be selected.

9.1.2.9 Window Overlap
The amount of overlap between windows when the spectral coherence is estimated. A typical selection is one half the window length.

9.1.2.10 Minimum Frequency
The lower end of the frequency range to be examined for forced oscillations.

9.1.2.11 Maximum Frequency
The upper end of the frequency range to be examined for forced oscillations. The selected value cannot exceed one-half of the sampling rate.

9.1.2.12 Frequency Tolerance
Forced oscillations must be separated in frequency by at least this amount to be considered separate events.

9.1.3 Out-of-Range Detector
This detector operates by comparing incoming data to a set of thresholds. The thresholds are referenced from a baseline specified as a nominal value by the user or by averaging over a window. The detector has two stages. In the first stage, detection occurs if the signal remains outside of the thresholds for a certain duration. In the second stage, detection occurs if the signal exceeds its thresholds while simultaneously exceeding a rate-of-change threshold.

Parameters are as follows.

9.1.3.1 Nominal Value
The nominal value of all included signals. Serves as the reference for detection thresholds.

9.1.3.2 History for Baseline
The amount of data used to establish a baseline. The resulting average serves as the reference for detection thresholds.

9.1.3.3 Window Length
The amount of data considered in the duration based detector.

9.1.3.4 Duration Threshold
The amount of data that must exceed thresholds to trigger the duration based detector.

9.1.3.5 Rate of Change Threshold
The amount of change per second that must be achieved for detection to occur with the rate-of-change based detector.

9.1.3.6 Positive Deviation
How far above the baseline value the upper threshold resides. Specified separately for each stage of the detector as a positive value.

9.1.3.7 Negative Deviation
How far below the baseline value the lower threshold resides. Specified separately for each stage of the detector as a negative value.

9.1.4 Ringdown Detector
This detector is based on the root mean square (RMS) energy in a signal. It operates by comparing the RMS energy over recent data to a baseline established from a longer history of data. This detector can only be applied to signals of the following types: real power, frequency, and OTHER.

Parameters are as follows.

9.1.4.1 Analysis Length
The amount of data to use in the calculation of the RMS energy. This value should approximate the length of ringdowns.

9.1.4.2 History for Baseline
The amount of data used to establish a baseline. Typical values are in the neighborhood of 120 seconds.

9.1.4.3 Threshold Scale
This parameter controls detection performance. Lower values will increase sensitivity but will increase false detections. Larger values require stronger evidence to trigger a detection but will decrease false detections. The lowest acceptable value is one, but many false detections will occur for this setting. A typical selection is three.

9.1.5 Wind Ramp Detector
This detector examines data (typically conceived as measurements of power production from wind farms) for evidence of ramping. To do this, the tool applies low pass filters to the measurements to capture trends. The user can select from two filters included with the tool, one for short trends on the order of minutes and one for long trends on the order of hours. This detector can only be applied to signals of the following types: real power, reactive power, and OTHER. The default values for the wind ramp detector parameters are guidelines for application to real power measurements.

Parameters are as follows.

9.1.5.1 Minimum Ramp Size
The smallest an upward or downward trend in the signal may be in order to trigger a detection.

9.1.5.2 Maximum Ramp Size
The largest an upward or downward trend in the signal may be in order to trigger a detection.

9.1.5.3 Minimum Ramp Duration
The shortest a trend in the signal may be in order to trigger a detection.

9.1.5.4 Maximum Ramp Duration
The longest a trend in the signal may be in order to trigger a detection.

9.1.6 Voltage Stability Detector
This detector seeks to identify oncoming local voltage instability using approaches based on representing the surrounding power system with a Thevenin equivalent. Five algorithms are available for calculating the Thevenin equivalent. Based on the resulting Thevenin impedance and the bus's load impedance a stability metric is calculated. The AW tool detects when the metric, which typically varies between 0 and 1, falls below a user-defined threshold.

When setting up a voltage stability detector, checkboxes are used to indicate which of the Thevenin estimation algorithms are to be implemented. Some of the algorithms operate on a window of data. The length of these windows are specified in the *Analysis Length* fields. After methods are selected, sites can be configured. A site typically corresponds to a single substation. However, if multiple substations are closely linked, they can be considered together as a single site. In the parameter names that follow, *branch* refers to a line sourcing or sinking power for the site, while *shunt* refers to a line acting exclusively as a sink, such as a reactor bank. The full list of parameters is as follows.

9.1.6.1 Name
A name used to identify the site when results are displayed.

9.1.6.2 Stability Threshold
A threshold for the stability metric between zero and one. If the metric falls below this value, an event will be triggered.

9.1.6.3 Voltage Bus Magnitude
The signal supplying measurements of the site's bus voltage magnitude. Measurements must be for the positive sequence component with units of Volts measured line-neutral. If multiple entries are specified, the voltage bus will be represented as their average.

9.1.6.4 Voltage Bus Angle
The signal supplying measurements of the site's bus voltage angle. Measurements must be for the positive sequence component with units of degrees measured line-neutral. If multiple entries are specified, the voltage bus will be represented as their average.

9.1.6.5 Branch (Shunt) Active Power
The signal supplying measurements of active power flowing on a branch (shunt) connected to the site. Units must be three-phase MW. If omitted, the active power is calculated based on the supplied voltage bus and branch (shunt) current measurements.

9.1.6.6 Branch (Shunt) Reactive Power

The signal supplying measurements of reactive power flowing on a branch (shunt) connected to the site. Units must be three-phase MVAR. If omitted, the reactive power is calculated based on the supplied voltage bus and branch (shunt) current measurements.

9.1.6.7 Branch (Shunt) Current Magnitude

The signal supplying measurements of the magnitude of current flowing on a branch (shunt) connected to the site. Measurements must be for the positive sequence component with units of Amps.

9.1.6.8 Branch (Shunt) Current Angle

The signal supplying measurements of the angle of current flowing on a branch (shunt) connected to the site. Measurements must be for the positive sequence component with units of degrees.

9.1.7 Mode Meter

The mode meter tool in AW is intended to be used as a data generator for baselining studies, rather than as an actual detector. Along with estimates of electromechanical modes, it captures system conditions as a set of measurements. Together, this data can be used to better understand how system conditions impact the modes. A mode meter can associate estimates of several different modes with a set of system condition signals. A separate mode meter implementation is needed for each set of system condition signals to be tracked. Descriptions of the parameters for the mode meter tool follow.

9.1.7.1 Mode Meter Name

The name of the mode meter to be configured. This entry is used to distinguish the mode meter in the results.

9.1.7.2 Oscillation Baselining Signals

The list of measurements that comprise the system conditions. The value of these measurements are captured each time the modes are estimated so that a baseline can be established.

9.1.7.3 Mode of Interest

Name of the mode that is being estimated. This entry is used to distinguish the mode in the results.

9.1.7.4 Minimum Frequency

The lowest acceptable frequency estimate for the mode of interest.

9.1.7.5 Nominal Frequency

An estimate of the mode’s frequency used in selecting a mode estimate from the set of pole estimates produced by the mode meter algorithms.

9.1.7.6 Maximum Frequency

The maximum acceptable frequency estimate for the mode of interest.

9.1.7.7 Maximum Damping Ratio

The maximum acceptable damping ratio estimate for the mode of interest.

9.1.7.8 Signal Selection
The signals that are selected specific to each mode are the signals used to estimate the mode.

9.1.7.9 Analysis Length
The amount of data used to generate mode estimates.

9.1.7.10 Retroactive Continuity Status
To obtain a mode estimate, it must be selected from a set of pole estimates produced by the algorithms. When retroactive continuity is on, AW will return to time periods where more than one pole estimate fell in the specified frequency range. It then makes adjustments where it appears that the wrong pole estimate was selected.

9.1.7.11 Retroactive Continuity Maximum Length
To ensure that the retroactive continuity functionality does not alter estimates from long periods where mode estimates remained stable, a maximum length for the time periods that qualify to be adjusted is specified.

9.1.7.12 Method
This dropdown allows the user to select a mode meter algorithm. Here *YW* stands for *Yule Walker*, *LS* stands for *Least Squares*, *ARMA* stands for the *AutoRegressive Moving Average* model, and *+S* indicates that detected forced oscillations are incorporated into the model as sinusoids.

9.1.7.13 AR Model Order
Model order for the autoregressive (AR) portion of the ARMA model used to estimate the modes.

9.1.7.14 MA Model Order
Model order for the moving average (MA) portion of the ARMA model used to estimate the modes.

9.1.7.15 Exaggerated AR Model Order
The model order of the high-order autoregressive (AR) model used in the first stage of least squares algorithms.

9.1.7.16 Number of Equations
The number of equations to use in the Yule-Walker algorithms.

9.1.7.17 Number of Equations with FO Present
The number of equations to use in the YW-ARMA+S algorithm when a forced oscillation (FO) is detected.

9.1.7.18 Forced Oscillation Detection Parameters
For the LS-ARMA+S and YW-ARMA+S algorithms, the periodogram-based forced oscillation detector is implemented. See Section 9.1.1 for descriptions of the parameters.

9.2 Alarm Configuration

To help ensure that the most significant forced oscillation results are displayed prominently, parameters can be selected to set alarm flags associated with each detected event. The ringdown detector also has one parameter intended to limit displayed results to true ringdowns.

9.2.1 Periodogram Based Forced Oscillation Alarming

Alarms for forced oscillations detected with the periodogram algorithm are based on the duration and signal-to-noise ratio (SNR) of the oscillation, as depicted in Figure 8. Alarm flags are set for forced oscillations with SNR/duration pairs exceeding the threshold in red. The user selects the five parameters in the figure.

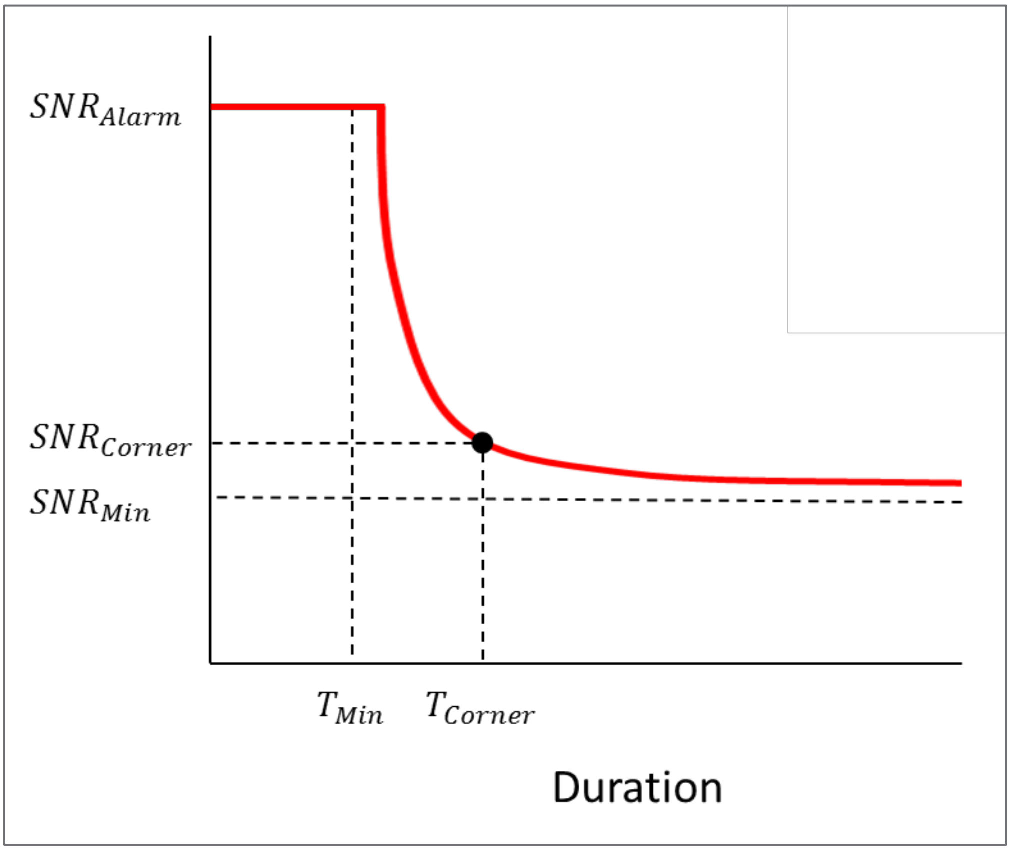

Figure 8: Alarm configuration diagram for periodogram based forced oscillation detection.

9.2.2 Spectral Coherence Based Forced Oscillation Alarming

Alarms for forced oscillations detected with the spectral coherence algorithm are based on the duration and coherence of the oscillation, as depicted in the figure below. Alarm flags are set for forced oscillations with coherence/duration pairs exceeding the threshold in red. The user selects the five parameters in the figure. All Coherence values should range from zero to one.

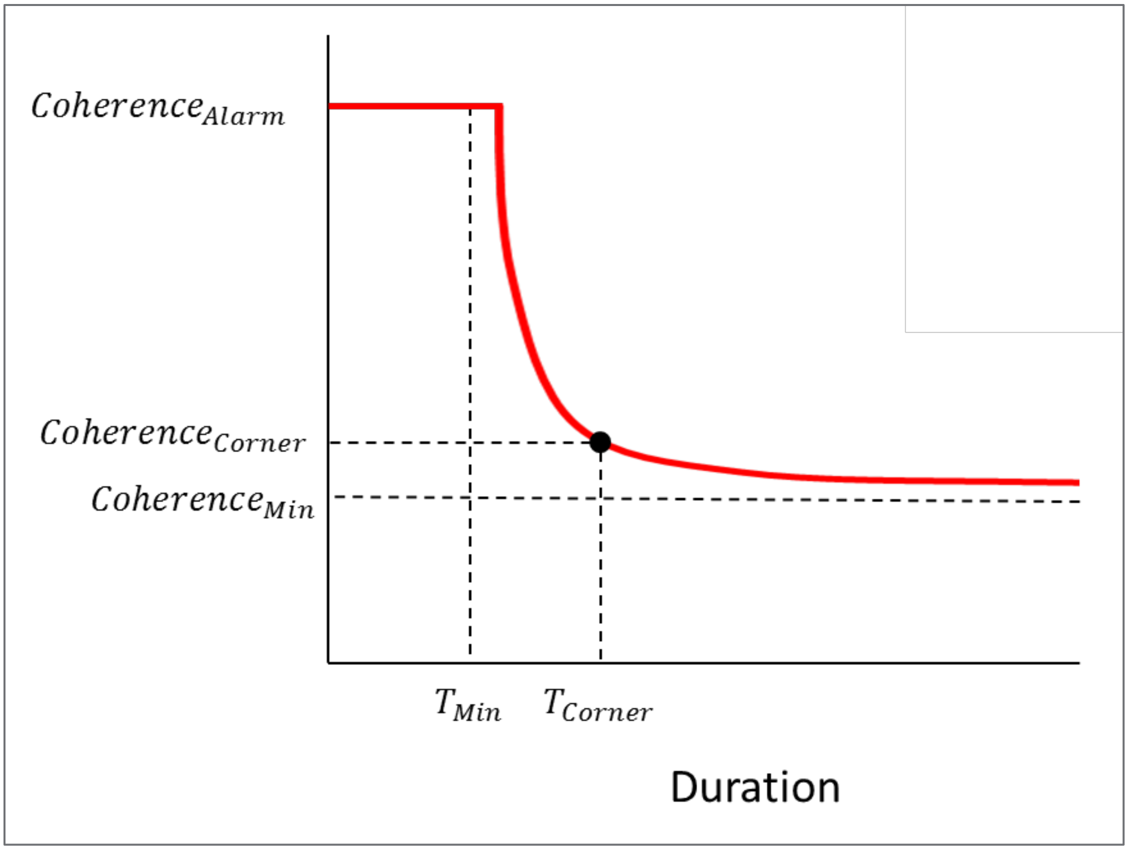

Figure 9: Alarm configuration diagram for spectral coherence based forced oscillation detection.

9.2.3 Ringdown Alarming

The ringdown detector is based on signal energy and will detect any event of sufficient energy, even if it is too long to realistically be a ringdown. Thus, the user may set a maximum duration for detected ringdowns. High-energy events of longer duration will be discarded.

10.0 Reviewing Results

This section covers all of the tabs under the *Results* page. Before the appearance of results in the GUI is described, it will be useful to provide background on how results are stored in Section 10.1 and a general approach to reviewing results that follows naturally in Section 10.2. An overview of methods for interacting with the GUI is provided in Section 10.3. With this foundation, specific examples are provided in Section 10.4 for each detector using the examples included with the download of AW. Note that the mode meter is designed as a data generator, rather than an actual detector, so it is an exception to much of what follows. Details are provided in Section 10.4.6).

10.1 Results Hierarchy

The goal of the storage approach implemented within AW is to allow detailed review of a detector's behavior while minimizing the amount of storage required. To accomplish objective, results are stored in a hierarchy, which is represented in Figure 10. At the top level, a set of XML files store high-level information about individual events, such as start time, extreme value, and number of channels that the event was detected in. These results require very little disk space, but they contain a very limited amount of information. At the next level of the hierarchy, extrema (maximum and minimum values) of analyzed signals are stored at regular intervals. These intervals are much longer than PMU reporting rates to keep required disk space to a minimum and to allow fast loading into the GUI. Sudden deviations and long trends in signals can be identified and compared with the high-level event information stored in XMLs. At the final level of the hierarchy, information needed to perfectly recreate an analysis is stored at regular intervals. Using this information, detector performance and analyzed signals can be reviewed for specific intervals of time. This hierarchy lends itself to the general approach to reviewing results that was implemented across all detectors. It is described in the following section.

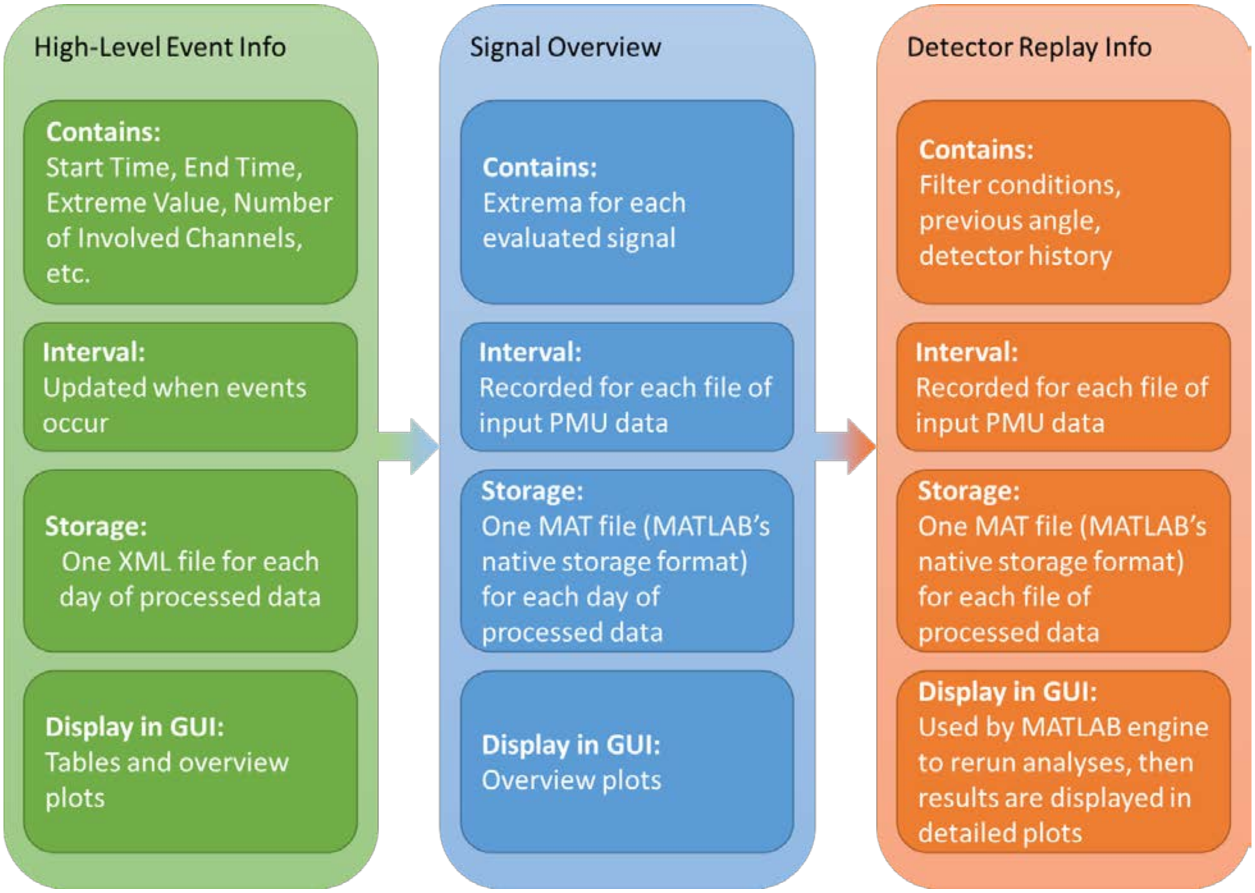

Figure 10: Diagram of the results storage hierarchy.

10.2 General Approach

Though the results tabs for each detector are unique, they utilize aspects of the results hierarchy in similar ways. For the time period of interest, high-level event information is presented in tables. These tables are automatically updated based on the start- and end-time fields at the top of the tabs. They list when the event occurred, which signals it was detected in, and provide an indication of severity specific to each detector. These tables can be used to identify which events are of highest interest.

Once the tables have been used to identify a general time period of interest, the *Overview* button can be used to retrieve signal extrema. The resulting plots also indicate where events were detected, providing the user with an overview of what transpired. From these overview plots, specific time periods for more detailed analysis can be selected.

After zooming in on the overview plots, clicking the *Retrieve Detail* button will rerun the detectors. While the analysis is rerunning, a green arrow will appear next to the task name. The time required to rerun is approximately the same as the time the analysis took when it was initially conducted, so it is important to choose periods for detailed analysis wisely. In many cases, a meaningful rerun can be conducted in several seconds. If the rerun requires too much time, clicking the *Cancel* button will end the rerun and display the detailed results that were retrieved. Once it completes, plots are generated to display the analyzed signals and details about each detector's operation. These can be used to gain insight into the event and check detector settings.

The general approach holds for each of the detectors, though not all of them use each level of the results hierarchy. Details are provided in the following section.

10.3 Interacting with the GUI

The tables and plots used in the AW GUI are interactive and can be manipulated in several ways. The best way to learn these capabilities is through experience with the tool, but a list of common features and helpful hints is provided here to help the user get started.

- Plots can be zoomed by scrolling the mouse wheel while hovering over the plot or its vertical or horizontal axes
- Holding the left mouse button while dragging the cursor will zoom to the highlighted region of a plot
- To pan within a plot, hold down the right mouse button while moving the cursor
- To reset the range of a plot, press *a* on the keyboard
- After clicking on a plot, it can be copied to the clipboard by pressing *Ctrl+c* on the keyboard
- Additional information about a trace in a plot can be obtained by hovering over the trace or holding down the left mouse button while pointing at it
- Entries in tables can be selected to display additional information in associated plots or tables
- Sections in the GUI can be collapsed by clicking the  symbols

10.4 Examples

This section discusses navigation of results for each detector using the preloaded example data and results included in the AW download (see Section 2). The data is stored in the *ExampleData* folder and the results are stored in the *Projects* folder. To access these examples, ensure that the specified results storage location is the *Projects* folder (see Section 3 for instructions). When the GUI is opened for the first time, the results path defaults to this folder. The following subsections assume that this step has already been completed.

Because AW reruns analyses to provide detailed results, the user must input the path to the proper example file for each task. Instructions will be provided in each of the following subsections to navigate this procedure. Section 11 provides further explanation.

10.4.1 Forced Oscillation Detectors

In the *Project* panel, select the *ForcedOscillation* task. If this step has not been completed previously, the GUI will produce a dialogue box indicating that the example file cannot be found. Navigate to the *Data Source* tab on the *Settings* page. In the *Example File* field, enter the full path to

\ExampleData\ForcedOscillation\2017\170203\ ExData_20170203_000000.csv

The *ExampleData* folder was included in the download of AW (see Section 2). Note that if you navigate to the example file using the GUI, you will need to select *JSIS_CSV files* in the lower right hand corner of the File Explorer window to see the files. Next, click the *Read File* button to load the settings and results. Finally, navigate to the *Forced Oscillations* tab on the *Results* page.

The GUI automatically selects the starting time range as the most recent day with an event, in this case February 3, 2017, and will appear as in Figure 11. The plot in the upper left displays the frequencies (y-axis) and time ranges (x-axis) of detected oscillations. The start- and end-points of oscillations that triggered an alarm are highlighted with red dots. Results are also presented in tables. The table below the plot lists oscillations by frequency. Clicking on an entry in the table updates the table in the upper right, which displays individual occurrences. Clicking on an occurrence entry highlights the occurrence in the plot (note the thicker blue line in the plot) and lists the signals that were involved in the occurrence in the table in the lower right of the screen.

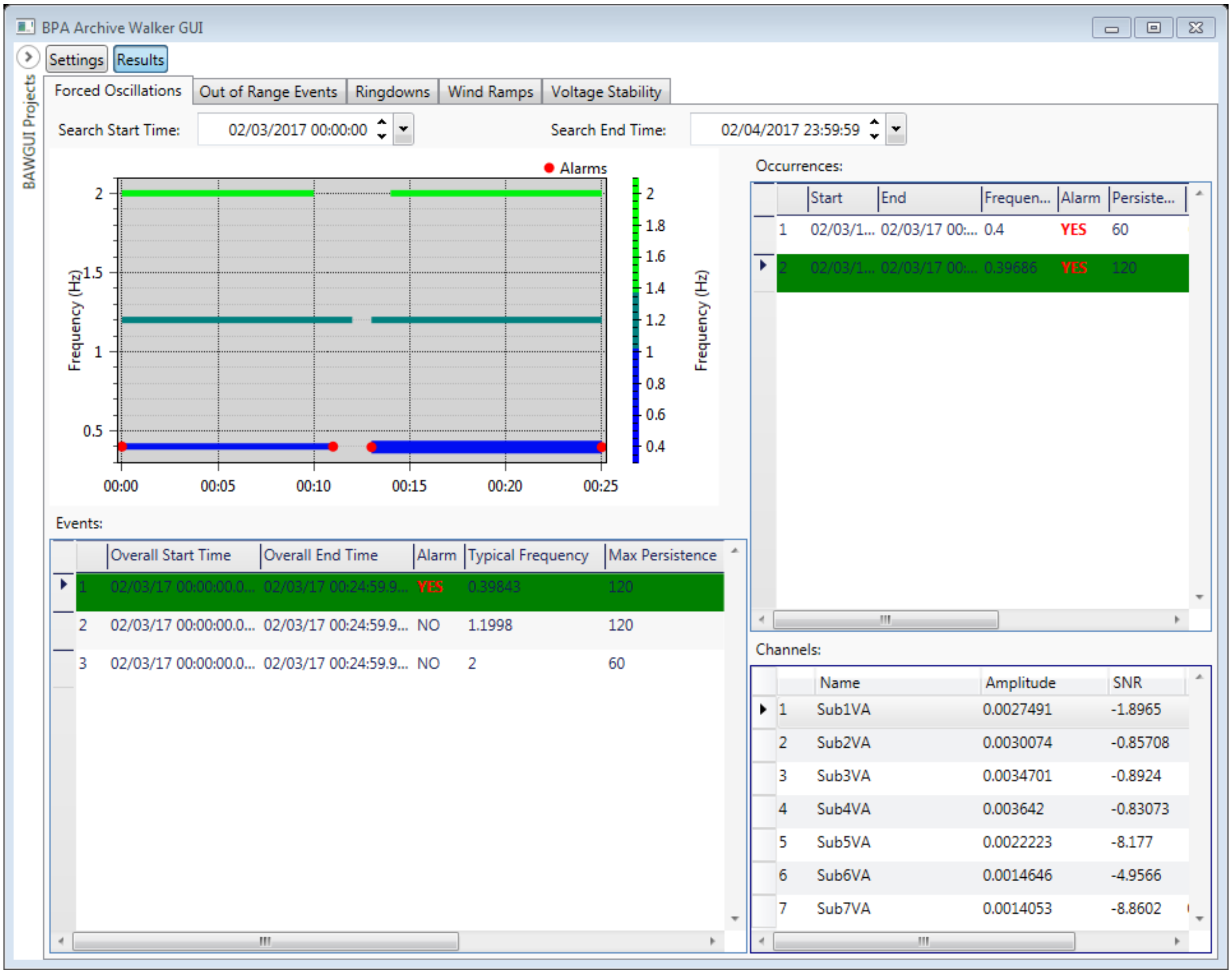

Figure 11: GUI display after loading results for the forced oscillation detector.

10.4.2 Out-of-Range Detector

In the *Project* panel, select the *OutOfRange* task. If this step has not been completed previously, the GUI will produce a dialogue box indicating that the example file cannot be found. Navigate to the *Data Source* tab on the *Settings* page. In the *Example File* field, enter the full path to

\ExampleData\OutOfRange\2017\170425\ ExData_20170425_000000.csv

The *ExampleData* folder was included in the download of AW (see Section 2). Note that if you navigate to the example file using the GUI, you will need to select *JSIS_CSV files* in the lower right hand corner of the File Explorer window to see the files. Next, click the *Read File* button to load the settings and results. Finally, navigate to the *Out of Range Events* tab on the *Results* page.

The GUI automatically selects the starting time range as the most recent day with an event, in this case April 25, 2017. The upper table lists events, while the lower table lists each of the signals that the event was detected in. In this case, two events were detected. Click the *Overview* button to load the extrema for the analyzed signals. Once done, the GUI will appear as in Figure 12, with the overview plot to the left. Note that even with this course data, distinguishing characteristics of the events can be observed. The first event involves a sudden decrease in frequency, while the second was captured because of a sudden increase. In the overview plot, the event selected in the upper table is highlighted. To select a different event, simply click it in the table.

To obtain detailed information about the second event, begin by zooming in on it, as in Figure 13. Note that the table of events automatically updates to contain only events within the selected time period. Clicking the *Retrieve Detail* button reruns the analysis and creates additional plots, as displayed in Figure 13. The top plot in the *Detection Details* section displays all of the analyzed signals. Below it, thumbnails are provided for each of these signals. Clicking on the thumbnail will display three plots: the signal with detection limits, performance of the "duration" stage of the detector, and performance of the "out-of-range" stage of the detector (see Section 9.1.3).

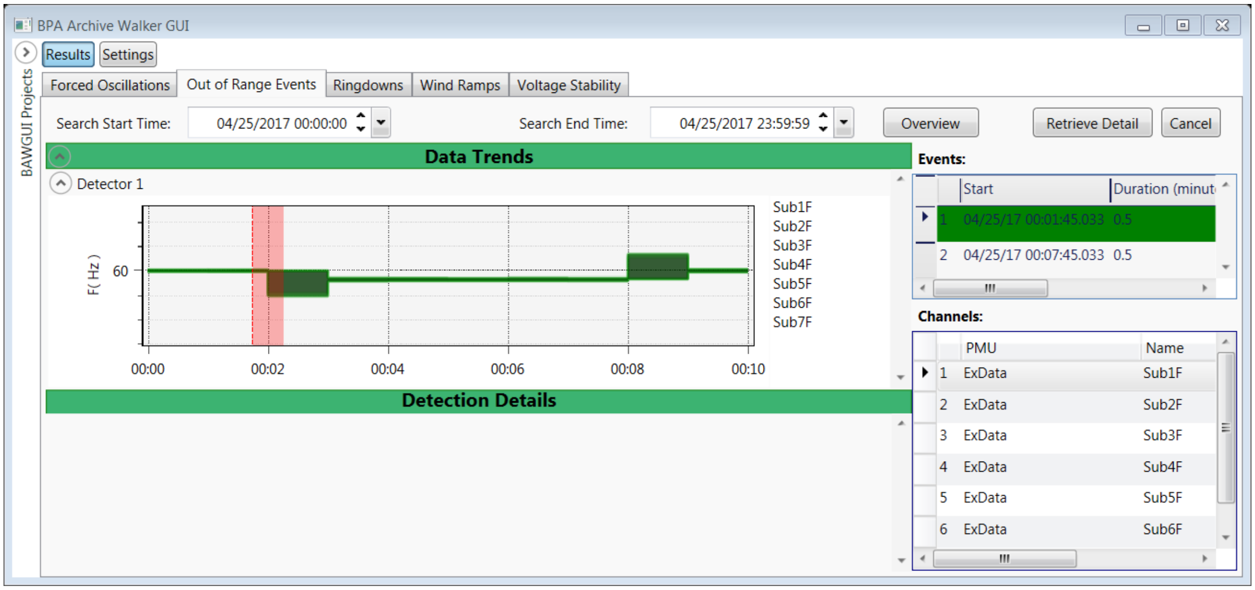

Figure 12: GUI display after loading overview results for the out-of-range detector.

Figure 13: GUI display after retrieving detailed information about an out-of-range event.

10.4.3 Ringdown Detector

In the *Project* panel, select the *Ringdown* task. If this step has not been completed previously, the GUI will produce a dialogue box indicating that the example file cannot be found. Navigate to the *Data Source* tab on the *Settings* page. In the *Example File* field, enter the full path to

\ExampleData\Ringdown\2017\170523\ExData_20170523_000000.csv

The *ExampleData* folder was included in the download of AW (see Section 2). Note that if you navigate to the example file using the GUI, you will need to select *JSIS_CSV files* in the lower right hand corner of the File Explorer window to see the files. Next, click the *Read File* button to load the settings and results. Finally, navigate to the *Ringdowns* tab on the *Results* page.

The GUI automatically selects the starting time range as the most recent day with an event, in this case May 23, 2017. The upper table lists events, while the lower table lists each of the signals that the event was detected in. In this case, two events were detected. Click the *Overview* button to load the extrema for the analyzed signals. Once done, the GUI will appear as in Figure 14, with the overview plot to the left. Note that even with this course data, it is clear that the first event is less severe than the second. In the overview plot, the event selected in the upper table is highlighted. To select a different event, simply click it in the table.

To obtain detailed information about the second event, begin by zooming in on it, as in Figure 15. Note that the table of events automatically updates to contain only events within the selected time period. Clicking the *Retrieve Detail* button reruns the analysis and creates additional plots, as displayed in Figure 15. The top plot in the *Detection Details* section displays all of the analyzed signals. Below it, thumbnails are provided for each of these signals. Clicking on the thumbnail will display a plot of the signal and a plot of the detector's operation (see Section 9.1.4).

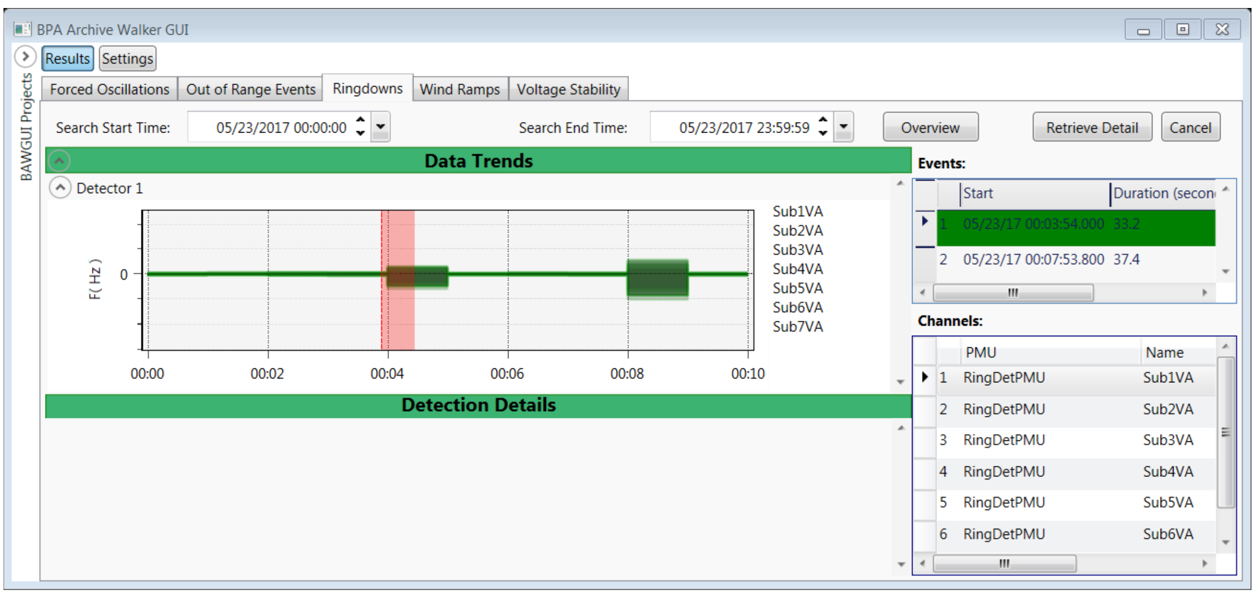

Figure 14: GUI display after loading overview results for the ringdown detector.

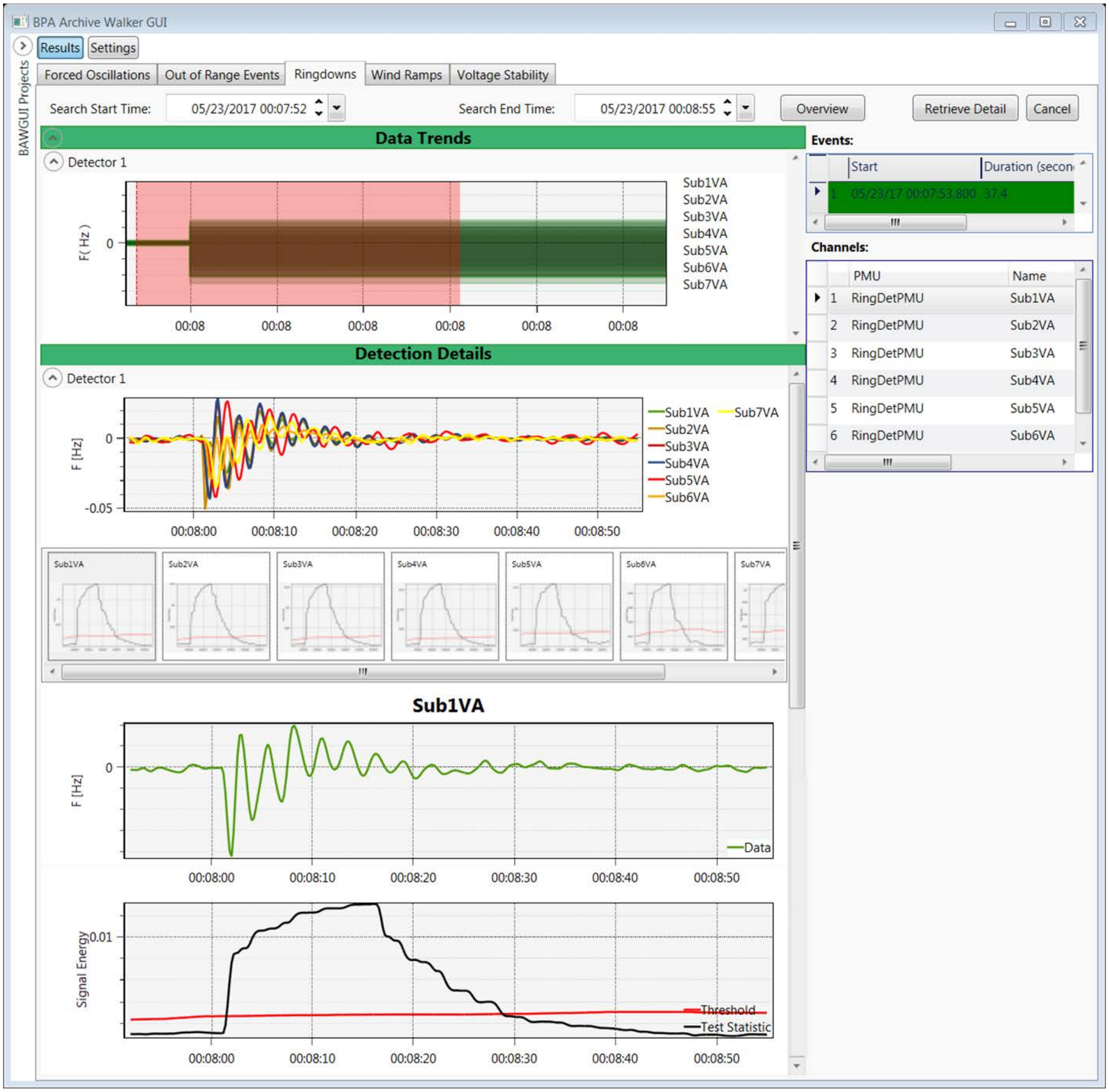

Figure 15: GUI display after retrieving detailed information about a ringdown.

10.4.4 Wind Ramp Detector

In the *Project* panel, select the *WindRamp* task. If this step has not been completed previously, the GUI will produce a dialogue box indicating that the example file cannot be found. Navigate to the *Data Source* tab on the *Settings* page. In the *Example File* field, enter the full path to

\ExampleData\WindRamp\2017\170203\ExData_20170203_000000.csv

The *ExampleData* folder was included in the download of AW (see Section 2). Note that if you navigate to the example file using the GUI, you will need to select *JSIS_CSV files* in the lower right hand corner of the File Explorer window to see the files. Next, click the *Read File* button to load the settings and results. Finally, navigate to the *Wind Ramps* tab on the *Results* page.

The GUI automatically selects the starting time range as the most recent day with an event, in this case February 3, 2017. The table lists events active during the selected time range. In this case, two events were detected. Click the *Overview* button to load the extrema for the analyzed signals. Once done, the GUI will appear as in Figure 16, with the overview plot below the table. In the overview plot, the event selected in the table is highlighted. To select a different event, simply click it in the table.

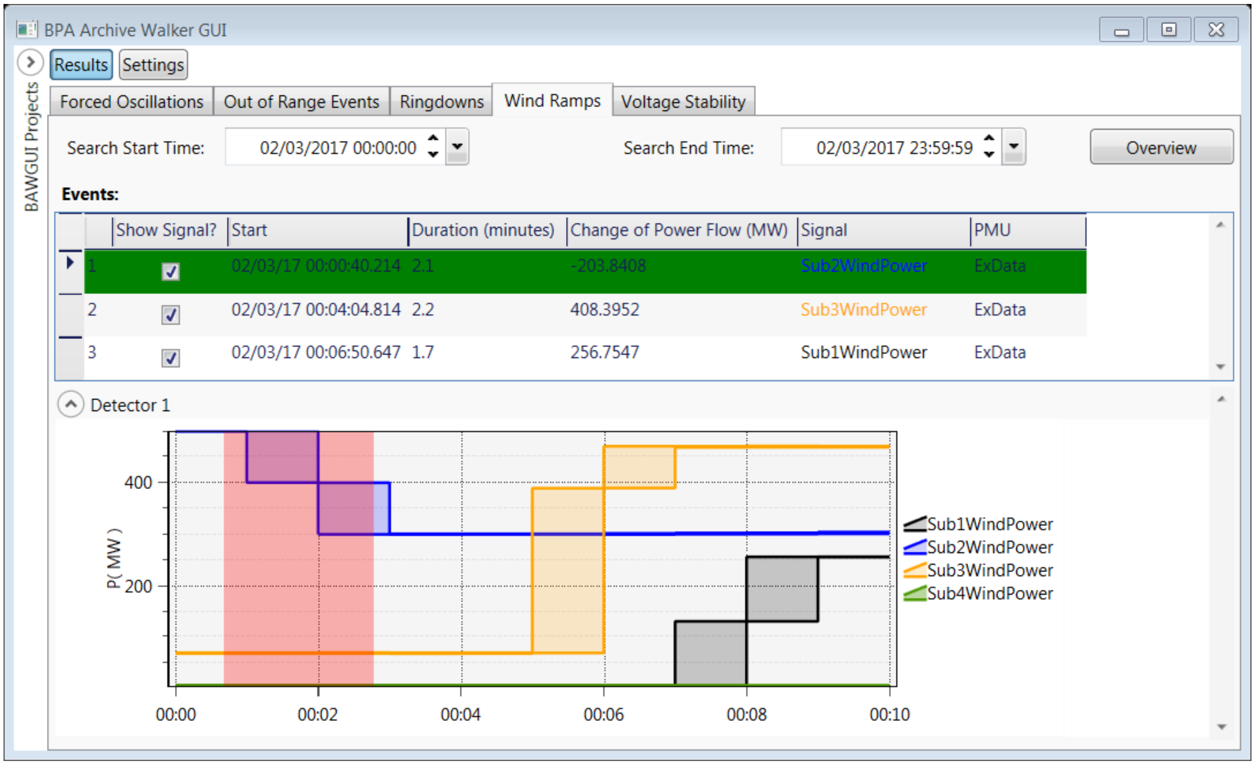

Figure 16: GUI display after loading overview results for the wind ramp detector

10.4.5 Voltage Stability Detector

In the *Project* panel, select the *VoltageStability* task. If this step has not been completed previously, the GUI will produce a dialogue box indicating that the example file cannot be found. Navigate to the *Data Source* tab on the *Settings* page. In the *Example File* field, enter the full path to

**\ExampleData\VoltageStability\2017\170425\ExData_20170425_000000.csv*

The *ExampleData* folder was included in the download of AW (see Section 2). Note that if you navigate to the example file using the GUI, you will need to select *JSIS_CSV files* in the lower right hand corner of the File Explorer window to see the files. Next, click the *Read File* button to load the settings and results. Finally, navigate to the *Voltage Stability* tab on the *Results* page.

The GUI automatically selects the starting time range as the most recent day with an event, in this case April 25, 2017. The upper table lists events, while the lower table lists each of the sites that the event was detected in. In this case, nine events were detected. Click the *Overview* button to load the extrema for the analyzed signals. Once done, the GUI will appear as in Figure 17. Under the *Stability Indices* banner, the extrema of the stability metrics derived for each of the included Thevenin estimation algorithms are plotted. In the example all five methods are implemented, but in the figure the results from three of them have been collapsed. Under the *Out-of-Range Data Trends* banner, overview plots from all out-of-range detectors are plotted. The red rectangles that are overlaid indicate detected events. These plots are provided because out-of-range voltage events are useful when considering voltage stability.

To obtain detailed information about the decaying stability, zoom from approximately 00:04:00 to 00:15:59 and set the *Preiction Delay* field to 30 seconds. Next, click the *Retrieve Detail* button to rerun the analysis and generate additional plots, as displayed in Figure 18. The plots under the *Validation* banner include the measured bus voltage and an estimate of the voltage based on the Thevenin equivalent. Good agreement between these values is one indicator that the Thevenin equivalent is a good approximation. Clicking on the thumbnails allows the results from different Thevenin equivalent estimation methods to be reviewed.

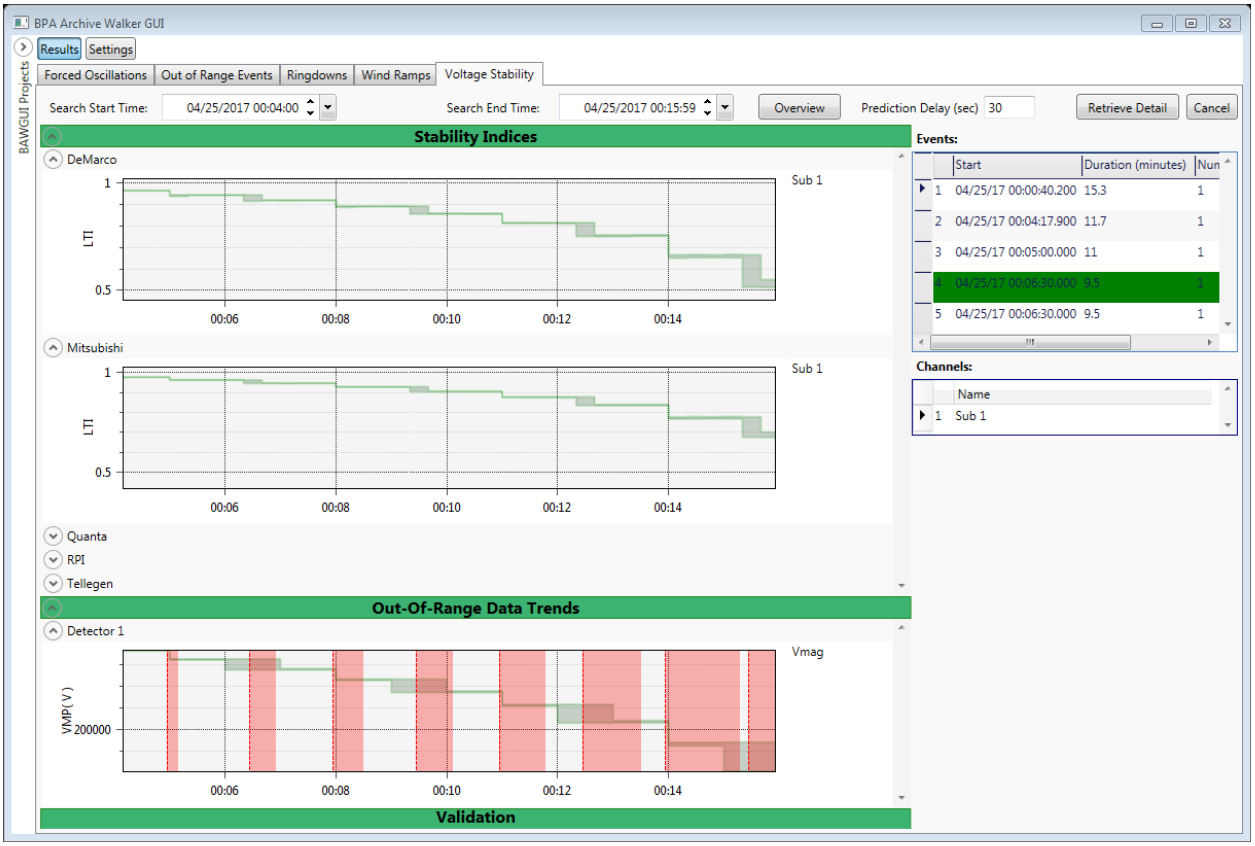

Figure 17: GUI display after loading overview results for the voltage stability detector.

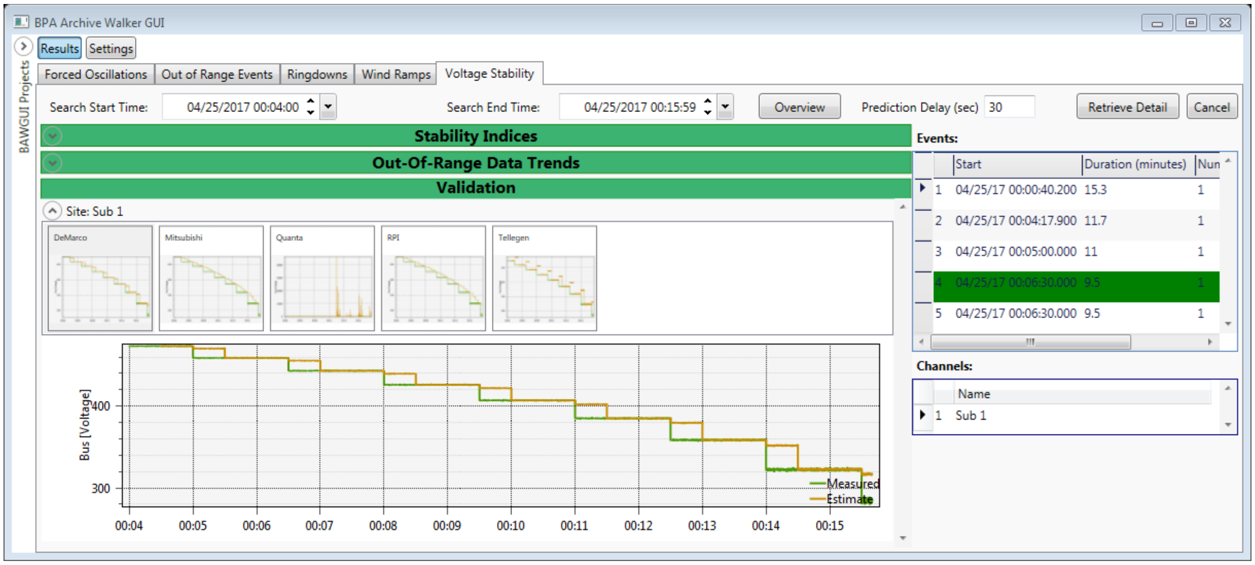

Figure 18: GUI display after retrieving detailed information about the decaying voltage stability.

10.4.6 Mode Meter

In the *Project* panel, select the *ModeMeter* task. If this step has not been completed previously, the GUI will produce a dialogue box indicating that the example file cannot be found. Navigate to the *Data Source* tab on the *Settings* page. In the *Example File* field, enter the full path to

\ExampleData\ModeMeter\2017\170523\ExData_20170523_000000.csv

The *ExampleData* folder was included in the download of AW (see Section 2). Note that if you navigate to the example file using the GUI, you will need to select *JSIS_CSV files* in the lower right hand corner of the File Explorer window to see the files. Next, click the *Read File* button to load the settings.

As discussed in Section 9.1.7, the mode meter tool is used to generate data, rather than to detect events. Thus, the output of the mode meter tool is not displayed on the *Results* page. To see the output of the mode meter example, navigate to the folder

\Projects\Project_Examples\Task_ModeMeter\Event\MM\Meter1

The *Projects* folder was included in the download of AW (See Section 2). The folder name *Meter1* corresponds to the *Mode Meter Name* parameter in the setup of the tool. The file *170523.csv* contains the results for May 23, 2017. These results are displayed in Figure 19. Column A contains timestamps, columns B through H contain measurements to capture system conditions, and columns I and J contain damping ratio and frequency estimates, respectively. The timestamps specify the time that the mode estimates were generated and the system conditions were collected. For the system condition measurements, row 2 lists the signal names, row 3 contains the signal type, and row 4 specifies the units. For the mode estimates, row 2 contains the name of the mode specified in the *Mode of Interest* field in the tool's setup, row 3 specifies the signal used to generate the estimate, and row 4 lists the mode meter algorithm. In this example, system frequency measurements are collected alongside estimates of a system mode near 0.22 Hz.

	A	B	C	D	E	F	G	H	I	J
1	Time	OperatingValue	OperatingValue_1	OperatingValue_2	OperatingValue_3	OperatingValue_4	OperatingValue_5	OperatingValue_6	DampingRatio	Frequency
2		Sub1F	Sub2F	Sub3F	Sub4F	Sub5F	Sub6F	Sub7F	Mode1	Mode1
3		F	F	F	F	F	F	F	Sub5VA	Sub5VA
4	Hrs	Hz	Hz	Hz	Hz	Hz	Hz	Hz	YW_ARMA	YW_ARMA
5	0.167	60	59.999	60	60	59.999	60	60	0.085755	0.21593
6	0.183	60.001	60.001	60.001	60.001	60.003	60	59.999	0.091761	0.21781
7	0.2	59.999	60	59.999	59.999	60	60	60.001	0.089061	0.21751
8	0.217	59.999	59.999	60	60	59.997	59.999	59.999	0.091159	0.21831
9	0.233	60	60	60	60	59.999	60.001	60.001	0.086616	0.21644
10	0.25	59.999	59.999	59.999	59.999	60	60	59.999	0.084936	0.21777
11	0.267	60	60	60	60	59.999	59.999	59.999	0.07757	0.22044
12	0.283	60	60	60	60	59.998	60.001	60	0.080608	0.21672
13	0.3	59.999	59.999	59.998	59.998	60	59.999	59.999	0.061797	0.2173
14	0.317	60	60.001	60.001	60.001	59.999	59.998	59.998	0.061118	0.21745
15	0.333	59.999	60	59.999	59.999	59.999	60	59.998	0.054714	0.21904

Figure 19: Example output of the mode meter tool contained in 170523.csv.

11.0 Transferring the Location of Results and Data

Results and data can be moved for convenience or collaboration between AW users. The processes for handling changes to the location of results and data are distinct and will be described separately.

Moving results is straightforward, but requires a high-level understanding of AW's storage structure. For the results storage path, projects, and tasks in the example *Project* panel of Figure 20, AW automatically generates the subfolders in Figure 21. The results of each task are stored in a folder together. These task folders are stored in the folder for their associated project. To transfer results, simply move the folders at any level in Figure 21. Note that if individual tasks are moved, they must be placed under new folders that match the naming convention *Project_ProjectName*, where *ProjectName* can be selected by the user. When moving whole project folders, it is best practice to place them in a location occupied only by other AW project folders. After relocating the results, simply select the new results storage location in the GUI's *Project* panel (see Section 3). The results can then be viewed from their new location.

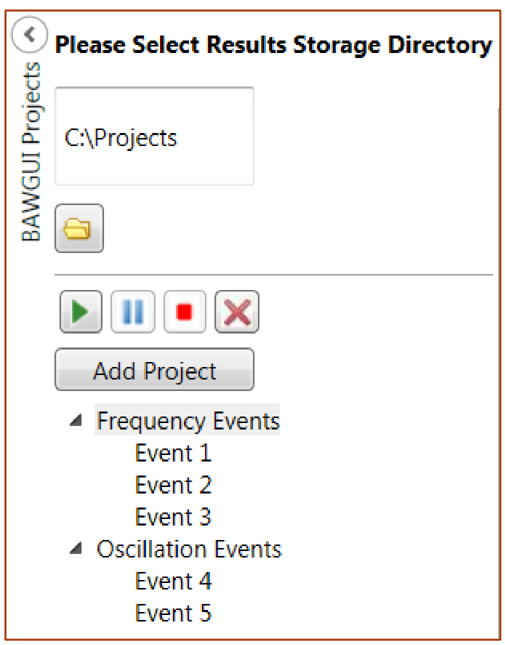

Figure 20: Example Project panel.

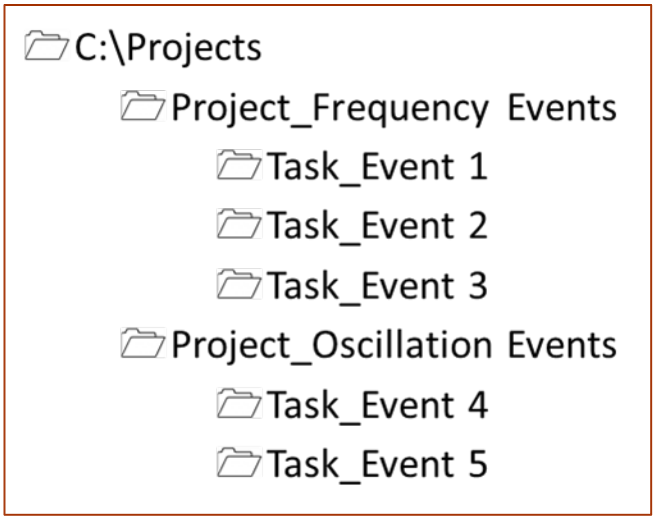

Figure 21: Structure of results storage corresponding to the projects and tasks in Figure 20.

After AW analyzes a set of data, it still relies on the data to produce a detailed review of results (see Section 10.1). If the data is moved after a task is saved, the user must specify the new location in the GUI. Each time a task is selected, the GUI determines whether the example file entered on the *Data Source* tab is available. If it is, it reads the file and populates the *Settings* page and the *Signal Selection* panel. If it is not, the GUI requests that the user enter a new example file. When selecting a task after moving the analyzed data, the GUI will make this request. In response, navigate to the *Data Source* tab under the *Settings* page. Enter the new path to the example file and click the *Read File* button. The GUI will update the configuration file for the task and then populate the *Settings* page and the *Signal Selection* panel. Once this is done, results can be reviewed as usual.

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