Phasor Grid Dynamics Analyzer™

A stand-alone application for offline forensics, enabling power system planners and engineers to perform quick turnaround analysis as well as detailed analysis of system dynamics and validate accuracy of system models.

ERCOT
PGDA User Training
September 17, 2014

Electric Power Group

PGDA Training Objective

- Purpose of Event Analysis
- Use of PGDA in Operations and Planning
- How to Use PGDA
  - PGDA – Getting Started and Navigation
  - Working with Data – Data Sources, PGDA Functions
  - Oscillation Analysis in PGDA e.g. Modal
  - Automated Event Analysis – Locate start of event and Identify source of event, Estimate Frequency Response, Dynamic Performance
  - Model Validation
  - PGDA Reports - Summarize Results for Management
- Appendix

Purpose of Event Analysis

- Detailed understanding of the power system behavior and performance.
- Event Analysis enables engineers and operators to analyze events and assess system performance issues
  - **Frequency Response**
  - **Oscillations** from renewable resources, excitation systems, SVCs, etc.
  - **Setting Alarm limits**
  - **Diagnosing event root causes** e.g Blackouts
  - **Validate Models –** Comparing event signatures from simulation and real field data

PGDA – Expert System for Event Analysis

- ISOs and utilities are **investing** in synchrophasor networks
- Terra-bytes of synchrophasor data are **being collected** (time-synchronized and high-resolution at 30 to 120 samples per second)
- The Phasor Grid Dynamics Analyzer (PGDA) is an expert system used to analyze historical data

Advantages of PGDA

- **Simplifies workflow** by providing menu driven user data selection and analysis options
- **Provides** Comprehensive processing options to analyze **oscillations**
- **Enables Frequency Response** assessment
- **Enables** Wide area **root cause** analysis
- **Provides** Best **calculation techniques** to find first responder
- **Generates** Summary reports of events- create event libraries for use in operations and planning analyses and training
- **Eliminates** time consuming, expensive **manual processes** for event analysis
- **Reproduces analysis** to shift engineers and operators in one click

Key Questions Answered by PGDA

- What happened?
- What was the sequence of events?
- What was the severity of event?
- Did the system respond as expected?
  - Frequency Response
  - Dynamic Performance
  - Oscillatory Behavior
  - Renewables Performance and Grid Impacts
- Are the models valid?
- How does generation mix affect grid performance?
- What are grid vulnerabilities?
- Where should capital be invested to reduce vulnerabilities?
- Are the alarm settings and operating guides appropriate?

PGDA Features and Capabilities

Data Sources

- Databases
- Data Files

Data Engine

- Data Availability Statistics
- Pseudo Signal creation
- Time Zone Conversion
- Save and Re-produce analysis

Oscillation Analysis Tools

- Modal analysis
- Ringdown analysis
- Spectral analysis

Use Cases

- First Responder
- Frequency Response
- Oscillation Detection
- Validate Models

Plot Analysis

- Plot metrics over time
- Signal manipulation i.e. Normalize voltage by basekV
- Variability of the grid metrics across time intervals measured at different locations

Spectral Analysis

- Significant peaks signify oscillatory modes
- Identify & group location with similar oscillation patterns
- Identify Nature of Oscillations

Ringdown Analysis

- Oscillation Detection Tool under system dynamic conditions
- Provides Modal Frequency & Damping
- Provides Magnitude of Modes and Nature of Oscillations

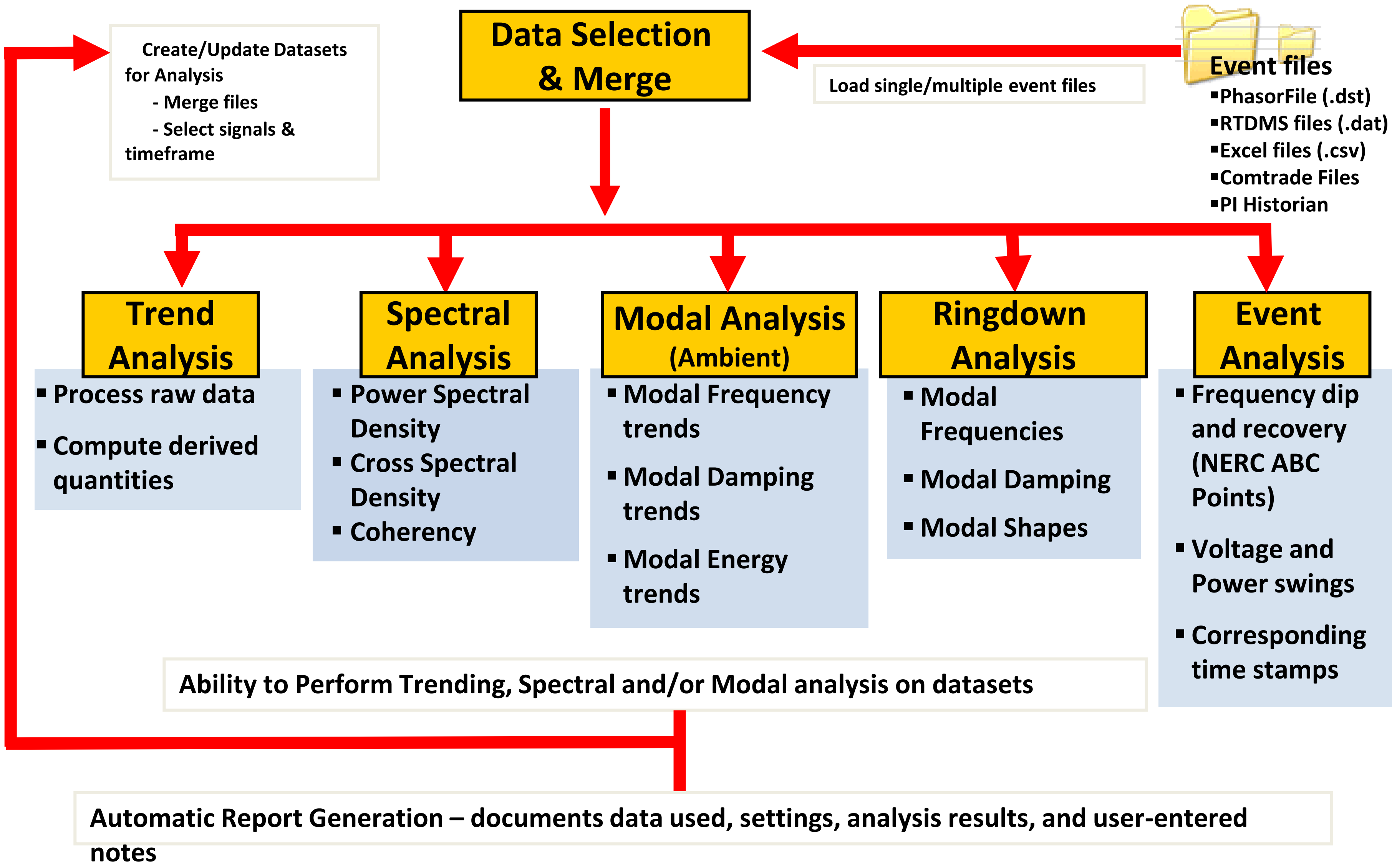
Ambient Modal Analysis

- Sustained Oscillation Detection Tool
- Provides Modal Frequency
- Provides Damping
- Provides Energy

PGDA Report

- Automated Report Generator
- Word, PDF

Analysis Tools In PGDA – Function Tabs



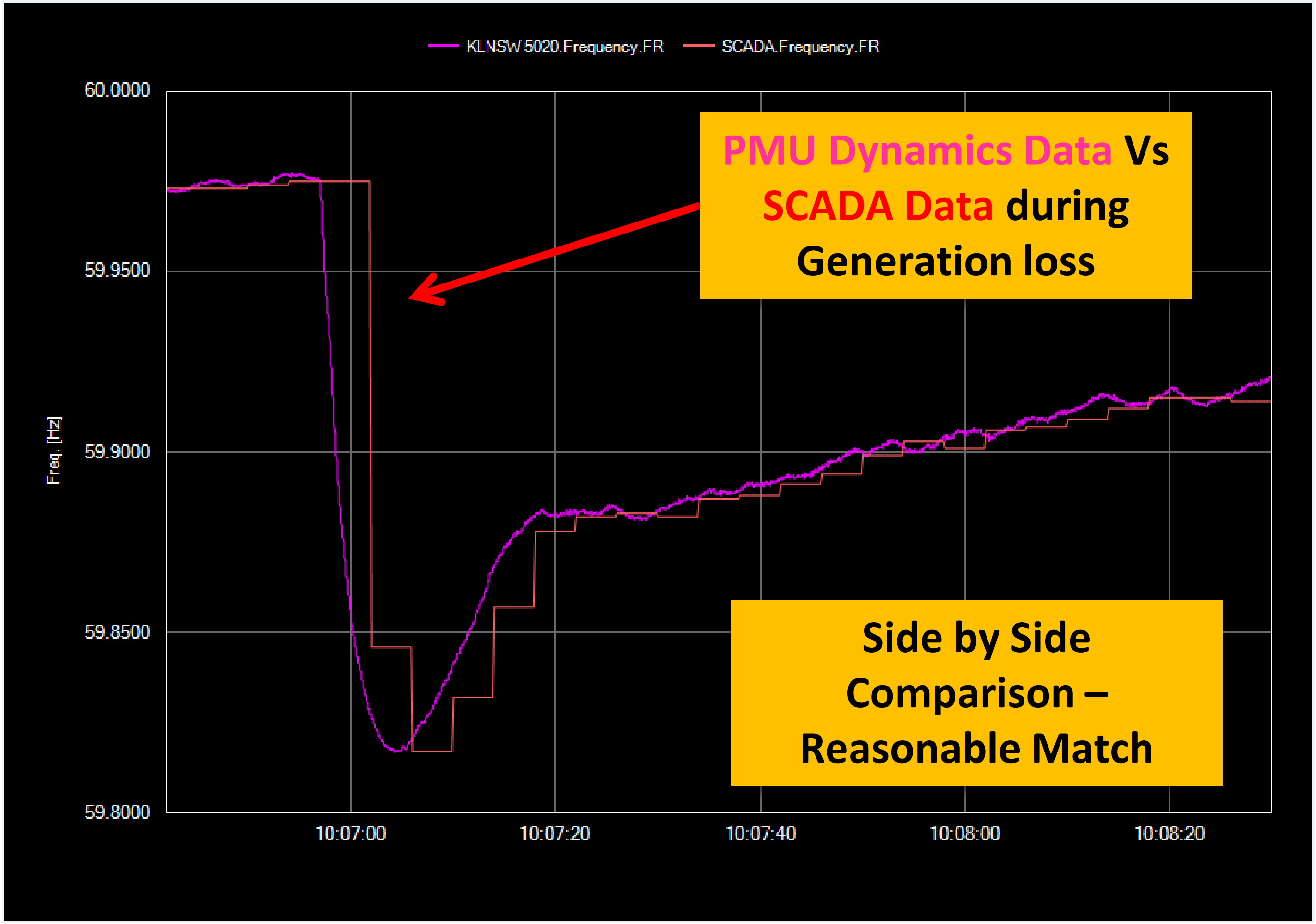
Illustrative Applications of PGDA

Event and Disturbance Analysis	• Quickly determine the causes and effects of power system events like generation trips , line trips, generation-load imbalances, and other dynamic events
Dynamic Model Validation	• Verify and improve dynamic models used in power system simulations to aid in planning and engineering studies
Dynamic stability and damping analysis	• Identifies oscillatory modes, characterizes the stability of oscillatory modes, and evaluates damping level to assess power grid stability.

PGDA Success Stories

- **Estimation of Inertia** - Calculation of Frequency Response for Frequency Events
- **Baselining Oscillations** – Determine type of Oscillations such as inter-area, local and control system driven oscillations from wind farms.
- Determining **Source of system events** such as generation trips, line trips & load trips
- Identifying **Change in Control System Settings** – Locates the start and end of oscillations to correlate with changes in settings
- **Model Validation** – Oscillations from Real Event Vs. Simulated Data

Measurement Validation



Why is Model Validation Critical?

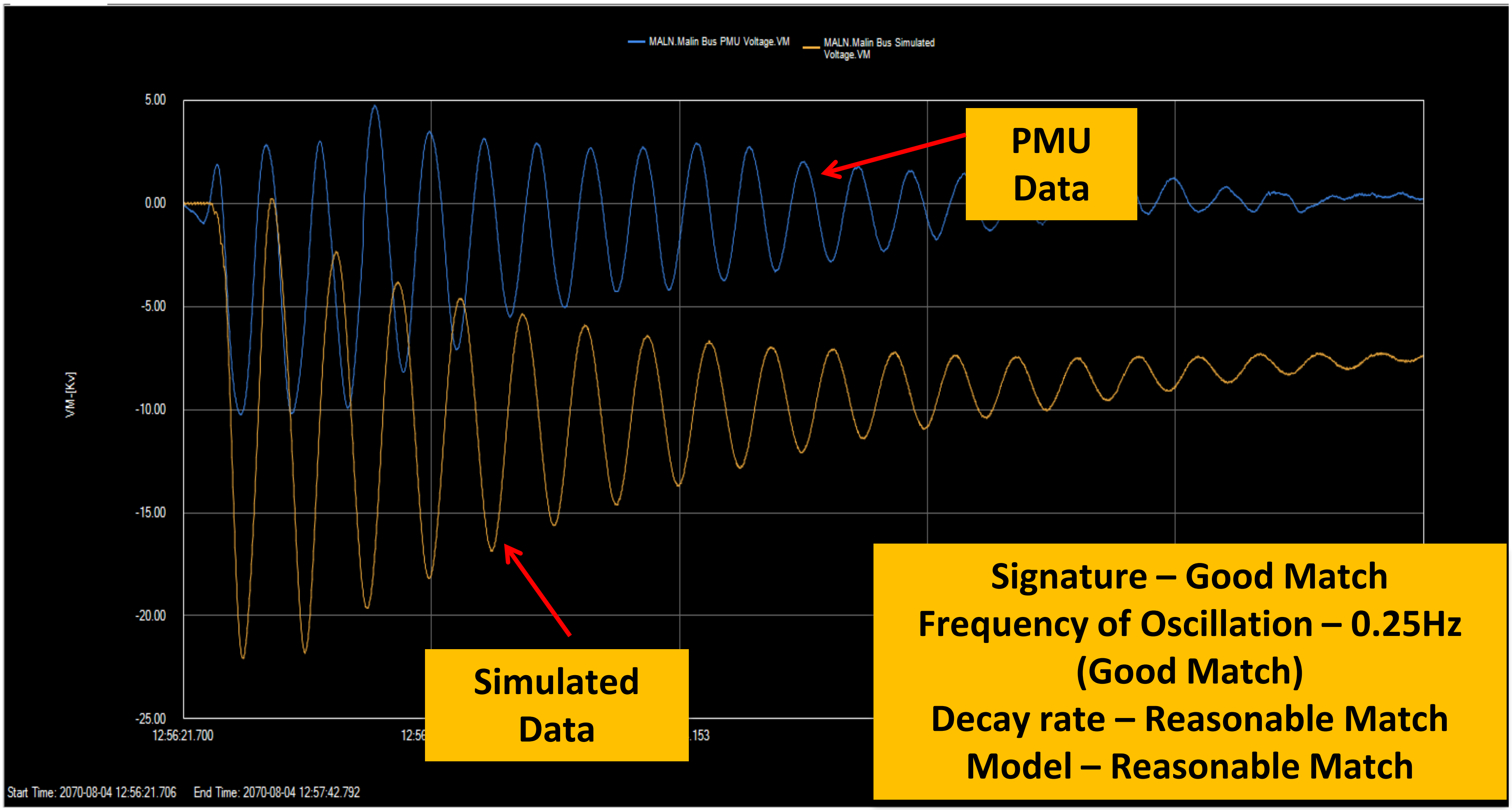
- Model is a system representation that includes Generator, Load and Other devices with Parameters.
- Model are being used to simulate a dynamic event scenarios to foretell Grid behavior and prepare for contingencies
- Model are being used to estimate state of the system
- The Model has to be accurate and tuned properly to match field parameters

What to Validate in Model?

- Metrics that can be used for Model Validation are
  - Voltage Phasor
  - Real and Reactive power
- Characteristics that assess over accuracy of model are
  - Signature or Shape of Signal
  - Modal Characteristics such as
    - Oscillation Frequency
    - Oscillation Damping
  - Absolute Values

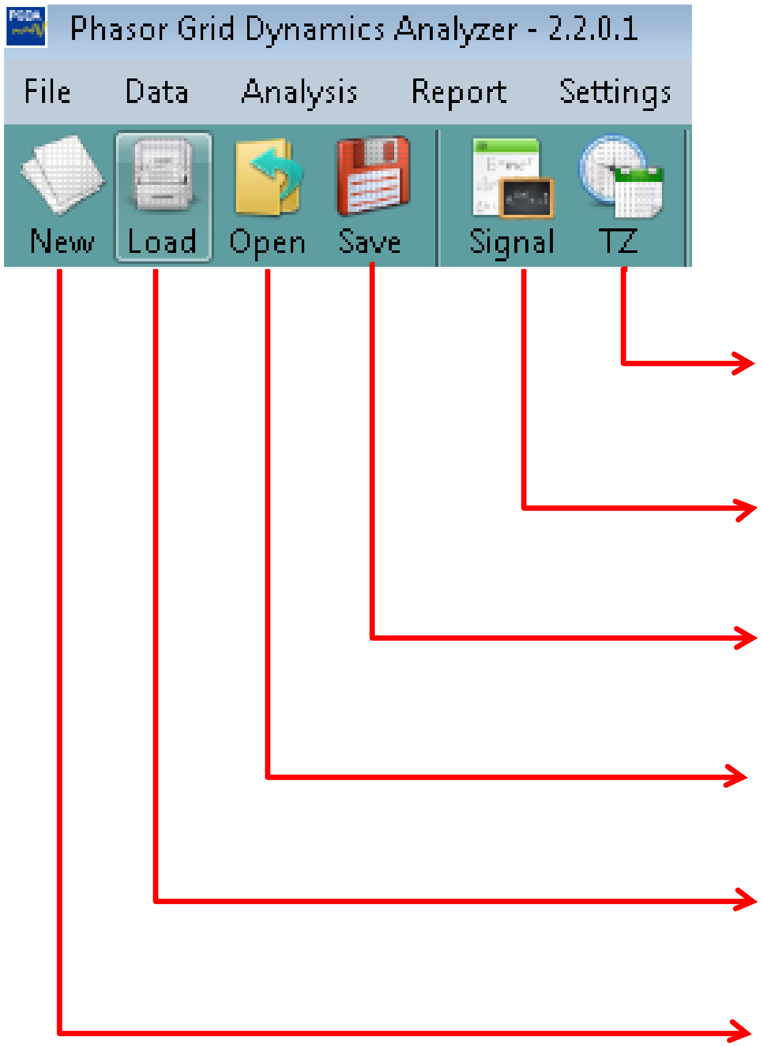
Model Validation – WECC Aug 4, 2000

Voltage Magnitude Plot Analysis - De-trend by First Value



Overview of PGDA – Menu, Toolbar, Windows

Using Toolbars



Time Zone – Change time zone during analysis

Signal – Create pseudo signals using signals from data sources

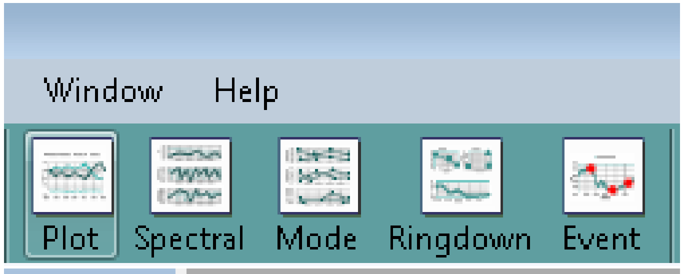
Save – One Click Toolbar to save project work

Open – Toolbar to open saved project work

Load – Toolbar to load data source

New – Toolbar to clean existing analysis

Using Toolbars



Event Analysis – Frequency Response

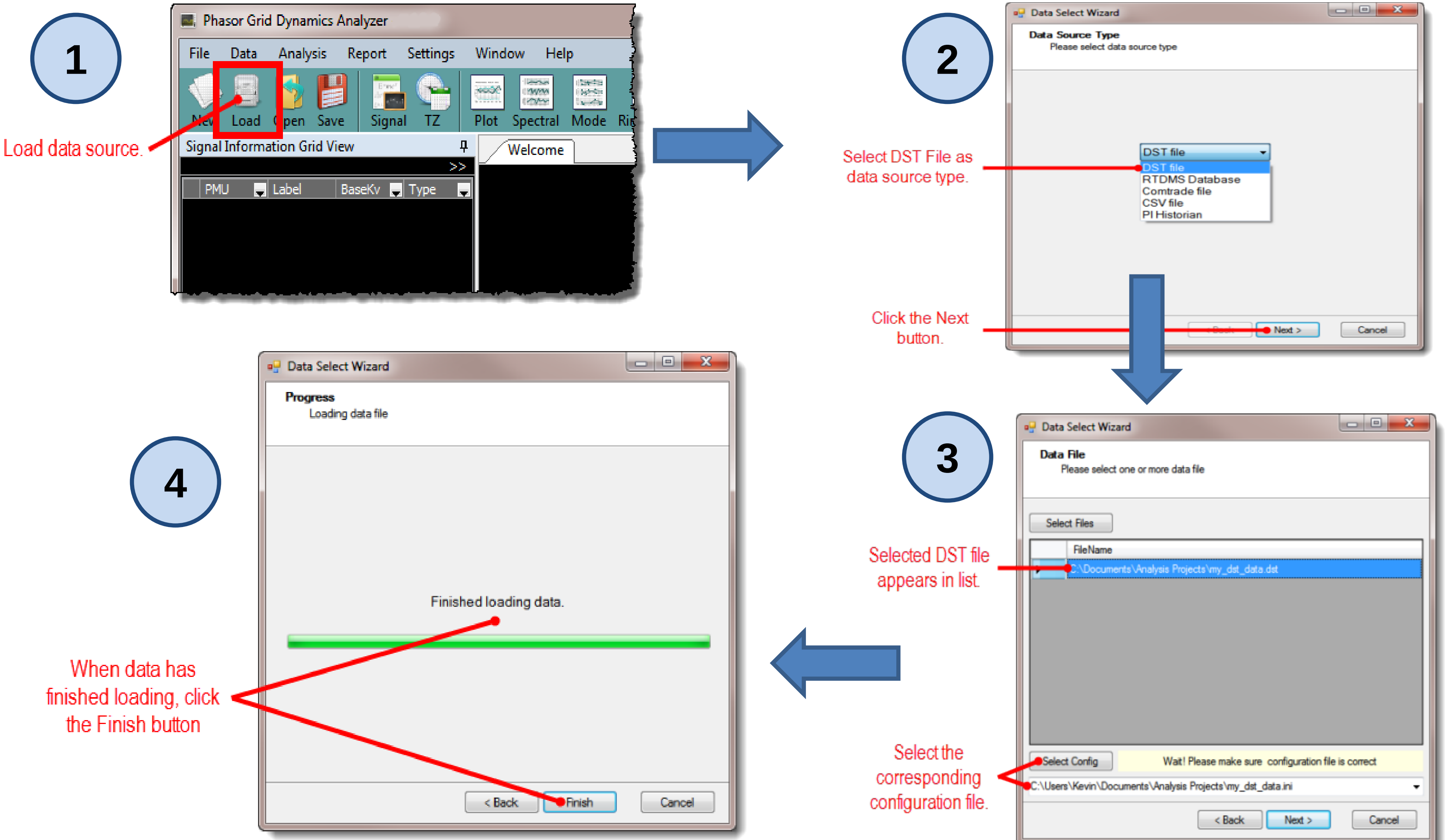
Ringdown Analysis – Oscillation Detection

Modal Analysis – Frequency, Damping & Energy

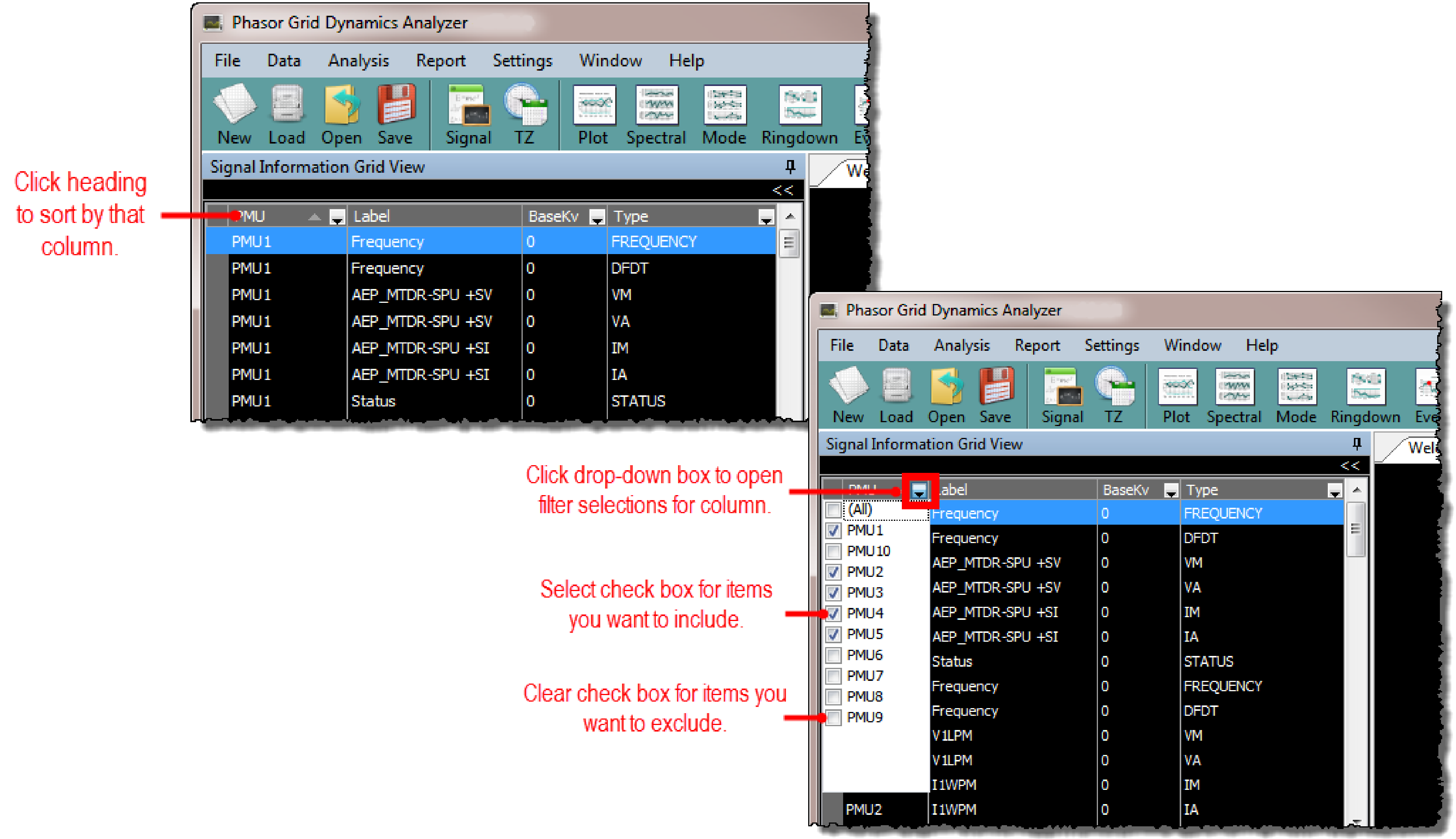
Spectral Analysis – Frequency Domain Analysis

Plot Analysis – Time Aligned Statistical Analysis

How to Use Load Toolbar - Files



How to Sort & Filter Signals



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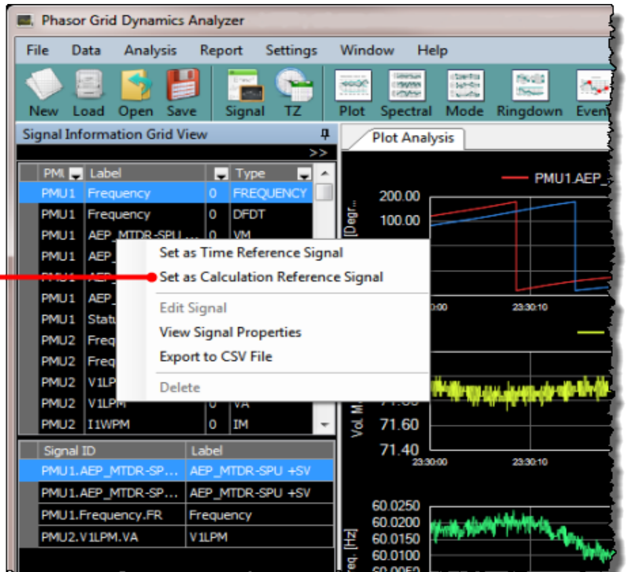
How to Set a Signal as Calculation Reference Signal

Right Click on signal

Set calculation reference signal on pop-up menu.

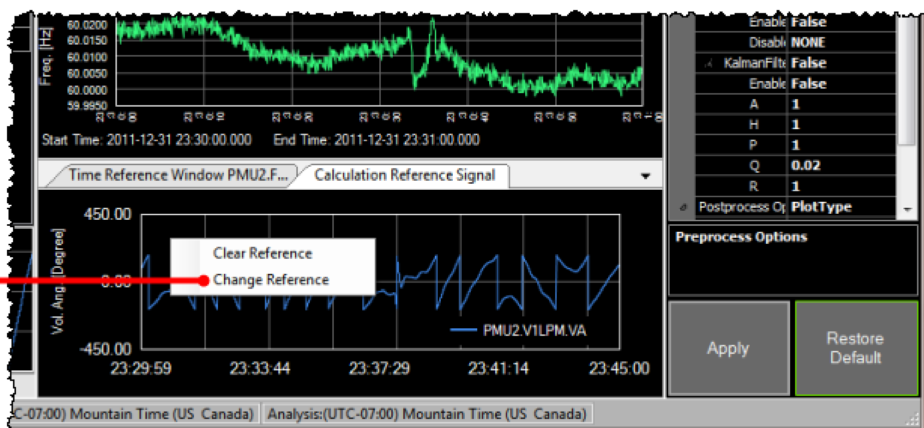


OR

1

Right Click on window

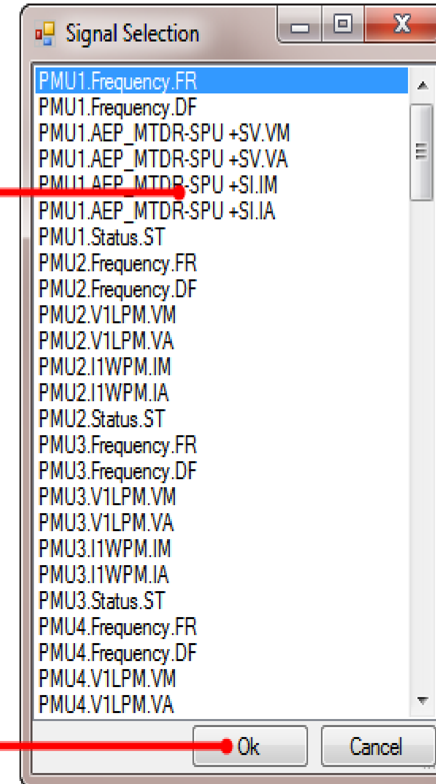
Change signal on pop-up menu.



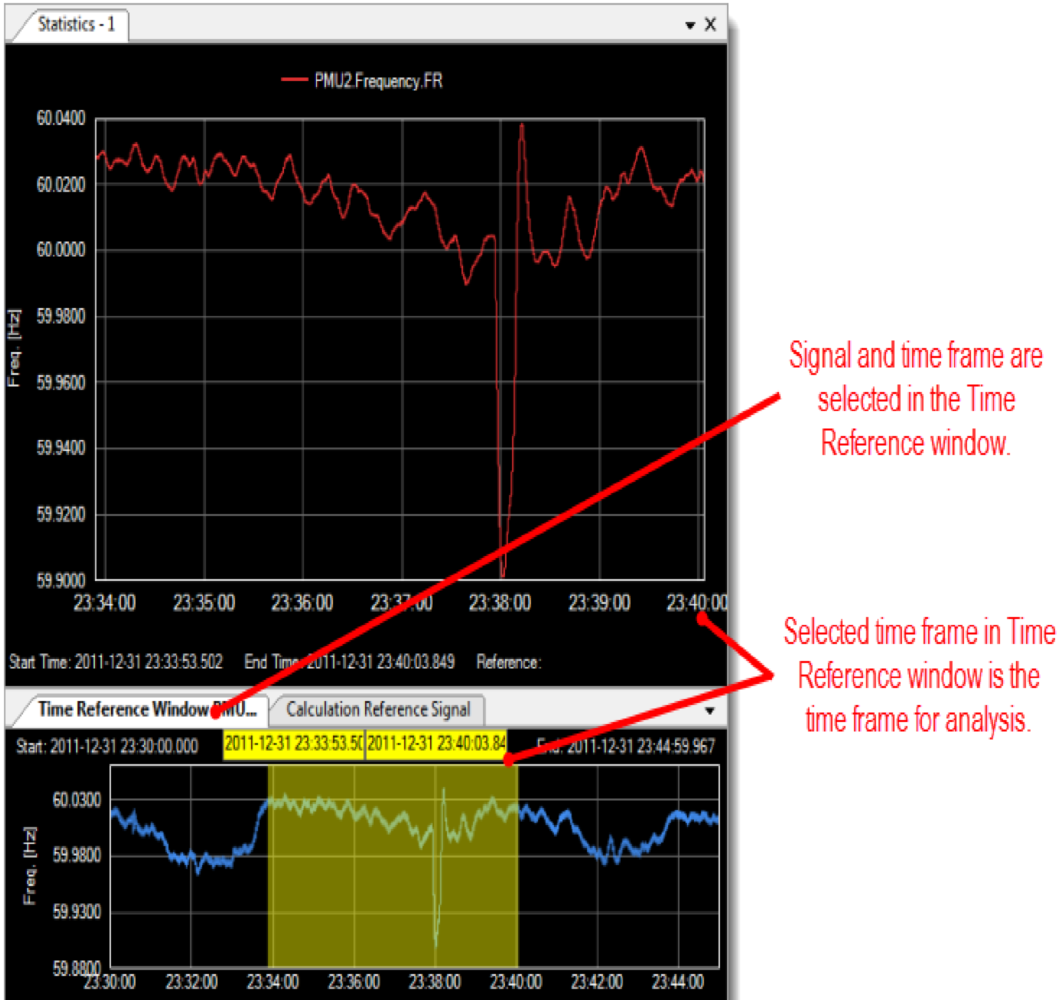
2

Select a signal.

Click the OK button.



How to Change Time Reference Window – 3 ways

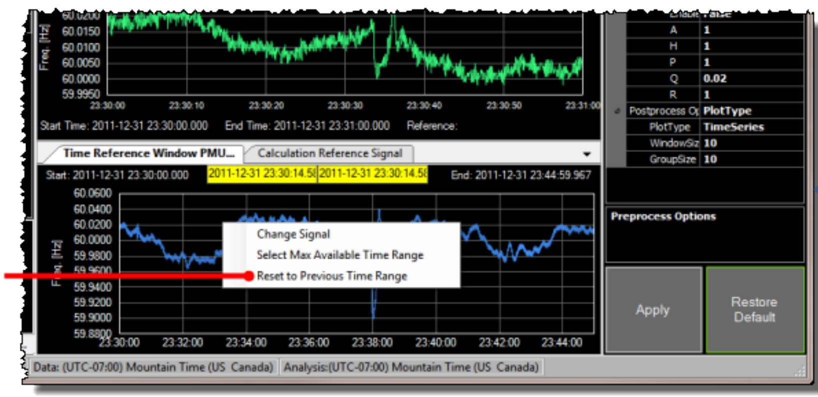


You can change the time frame in three different ways:

- Highlight the time frame (Left click and drag) in the **Time Reference** window.
- Manually enter the start and end time in the **Time Reference** yellow bar.
- Extend or shrink the start and end time by left click and drag.

How to Use Time Reference Window Properties

Select previous time frame on pop-up menu.



- Right Click on Time Reference Window
- Use Previous Time Range - Reset the time period to previous selected in the **Time Reference** window.
- Use Maximum Time Range - Select the maximum available time frame.

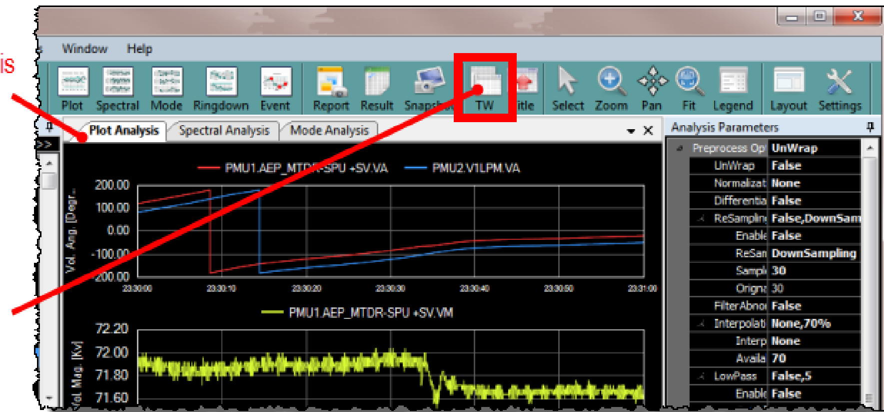
How to Use Time Reference Window Properties

Use Time Range From Previous Analysis

- Replicate the time frame from another analysis window.

Select analysis you want to change.

Click TW button.

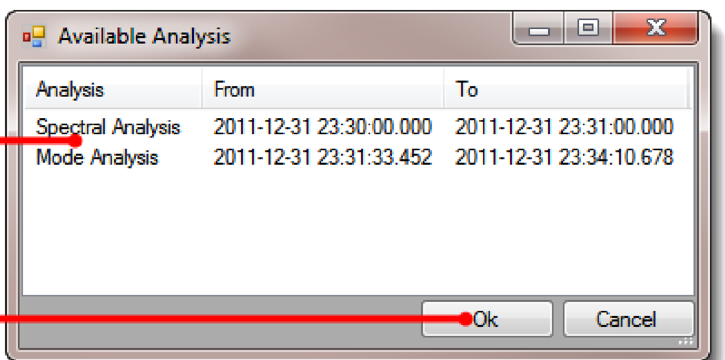


1

2

Select an analysis.

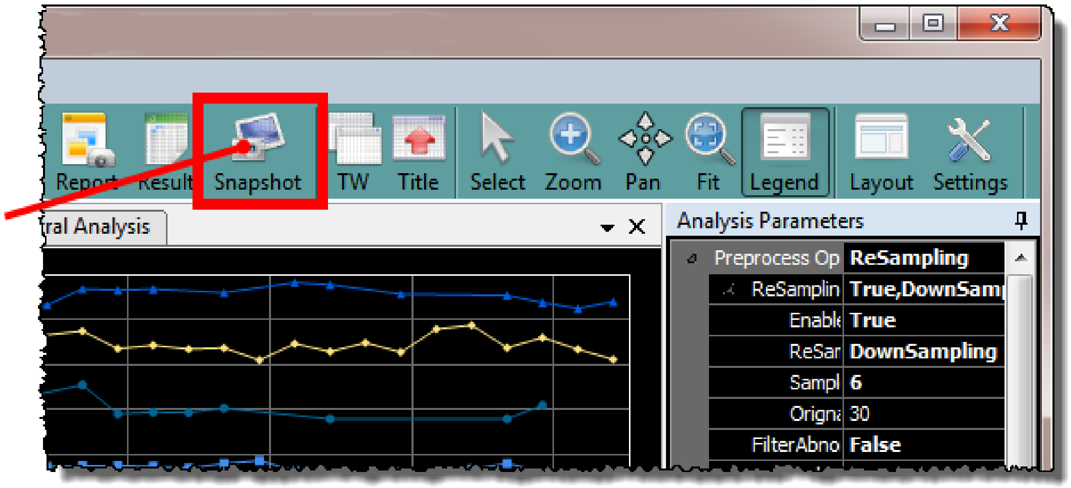
Click the OK button.



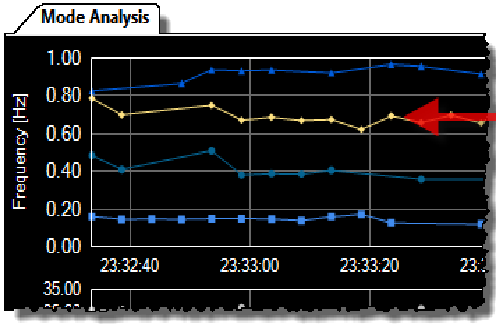
How to Capture Screen Shot of a Chart

Select the analysis window with the chart you want to copy, and then click the Snapshot button on the toolbar. The screen shot is copied to your operating system clipboard, allowing you to paste it to into other applications such as word processors or presentation tools.

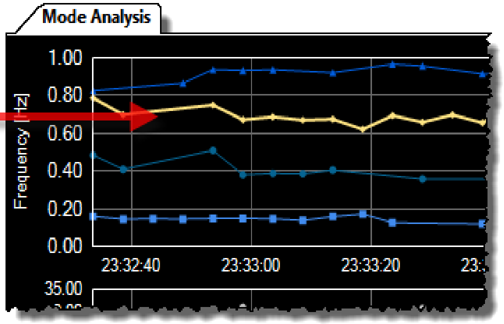
Capture screen shot of chart



How to Highlight and Hide Signal

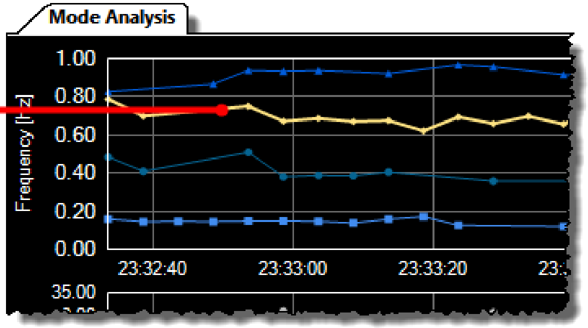


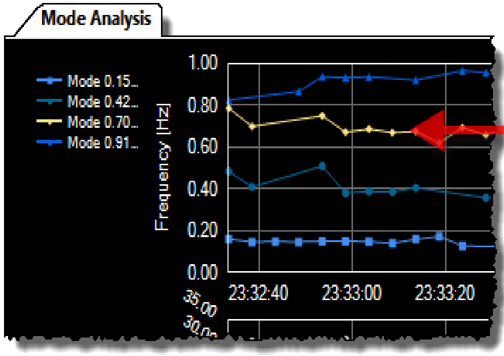
Signal without highlight.



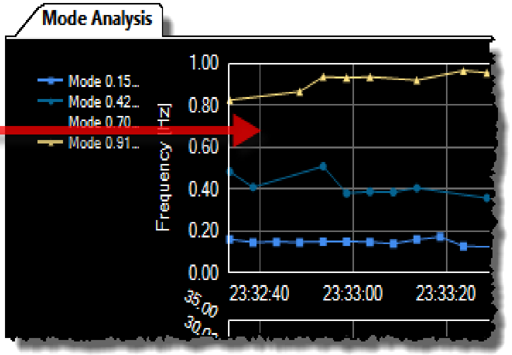
Highlighted signal.

Click signal to highlight it.



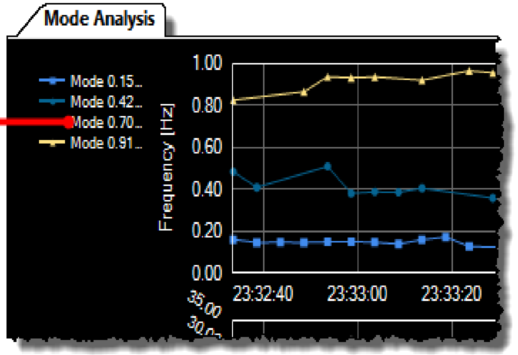


Visible signal.



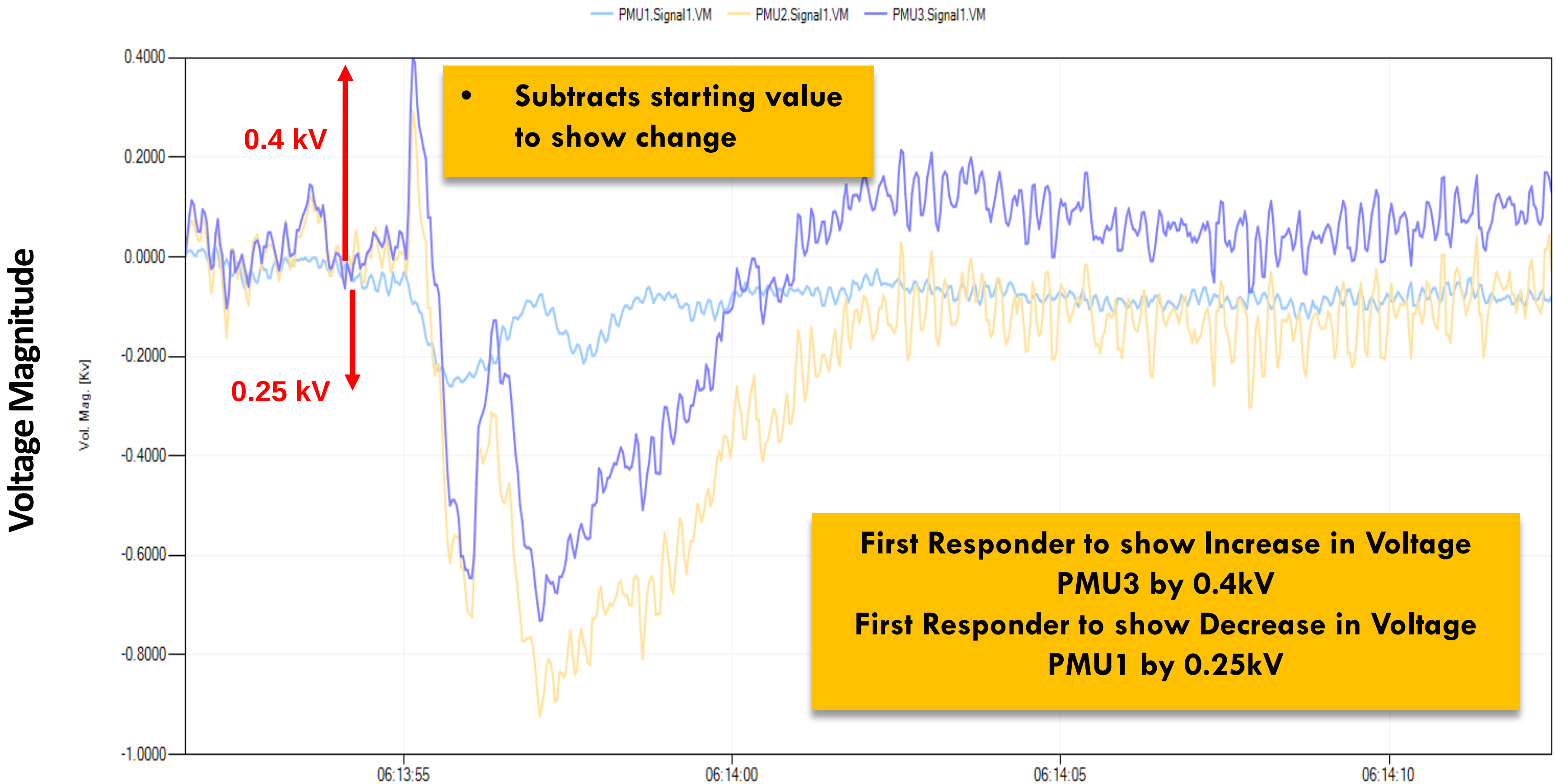
Hidden signal.

Right-click signal in legend to show it.



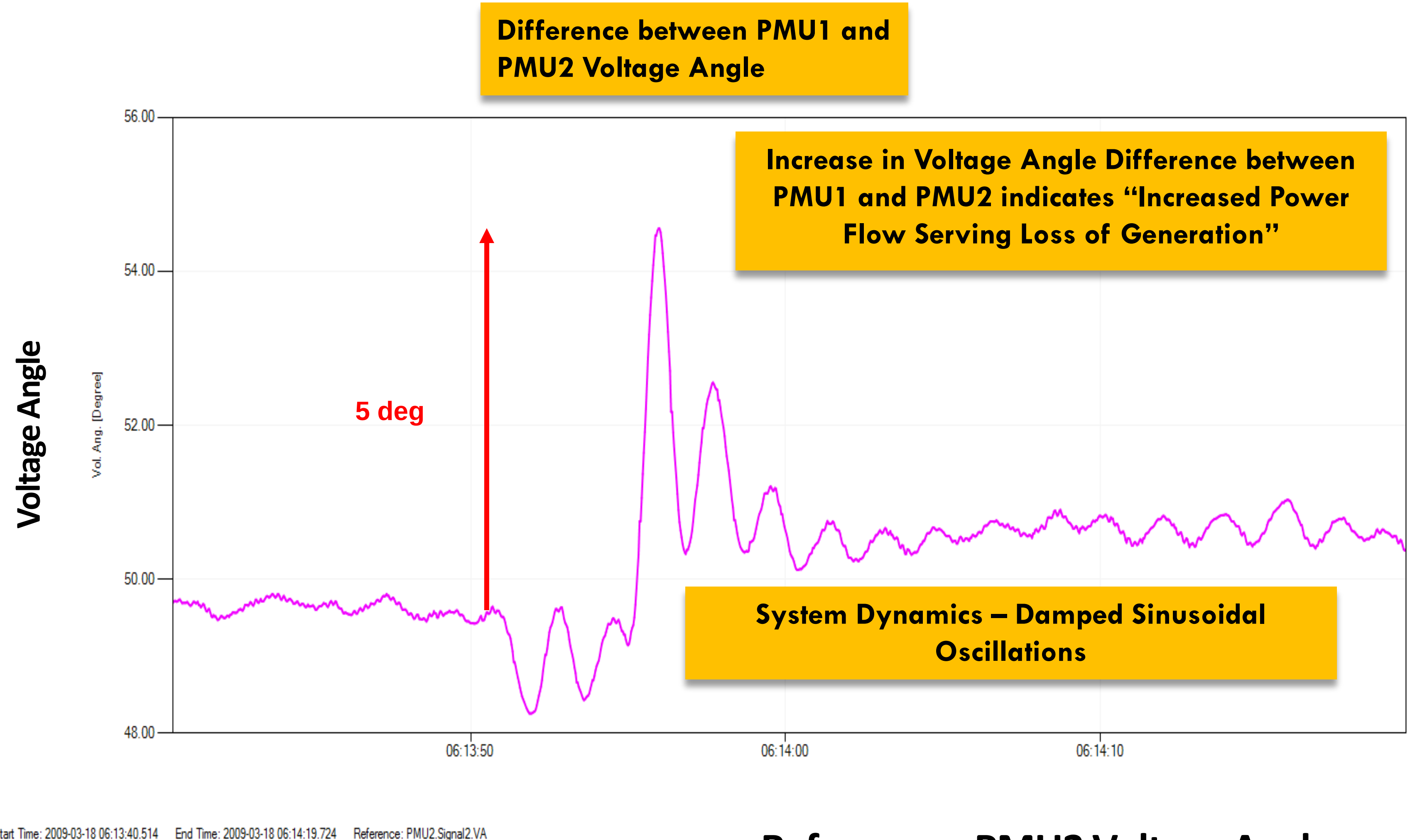
PGDA Voltage Analysis – First Responder

Plot Analysis - De-trend by First Value



Start Time: 2009-03-18 06:13:51.653 End Time: 2009-03-18 06:14:12.495 Reference:

PGDA Voltage Angle Analysis – System Impact & Dynamics following Generation Trip



Reference – PMU2 Voltage Angle

What is Automated Event Analysis?

- Identifies the time stamps and associated NERC-defined A, B and C frequencies for a generator drop event (or a load drop event)

- Computes the estimated frequency response represented in MW/0.1Hz (Loss of resource every 100 mHz) using:
  - Frequency Swing in Hz
  - Generation Loss in MW

How to Use Event Analysis Tab

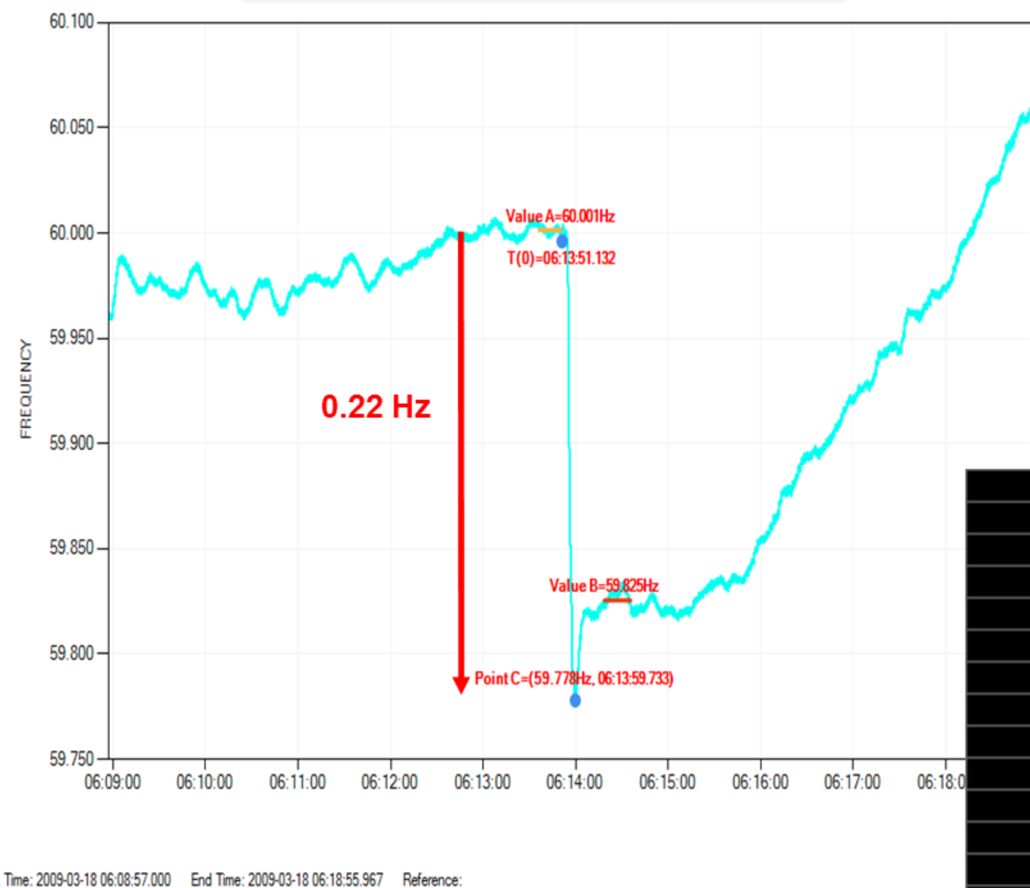
- Selecting a frequency signal near the source of the event, and a Time Reference Window which encompasses the frequency event, this tab will automatically locate the
  - Starting time of the event T(0)
  - Timestamps and value of Pre-event NERC defined A Frequency,
  - Timestamps and value of C Frequency (Minimum Frequency prior to governor response)
  - Timestamps and value of NERC defined B (Stabilizing Frequency after governor action)

Benefit of Event Analysis

- Selecting multiple Voltage, Angle and power signals near the source of the event, and a Time Reference Window which encompasses the frequency event, this tab will automatically locate the
  - Greatest Voltage Swing and Sustained Deviation
  - Greatest Voltage Angle Dynamic Swing and Steady State Separation
  - Greatest Power Swing and Sustained Power Deviation

PGDA Event Analysis – Frequency Response Estimation

Generation Trip



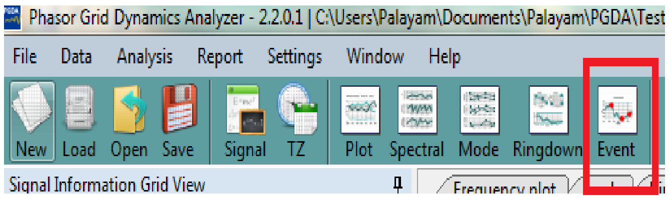
NERC-defined A, B and C Frequency
A – 60.001 Hz
B – 59.825 Hz
C – 59.778 Hz
Generation Loss = 800MW
Inertial Frequency Response = 358 MW/0.1Hz
Primary Frequency Response = 454 MW/0.1Hz

Analysis Results

PointC	59.778, 2009-03-18 06:13:59.733
ValueA	60.001
ValueB	59.825
T0	2009-03-18 06:13:51.132
PreEventFrequency	60.001
PrimaryControlActionRecoveryFrequency	59.825
NadirFrequency	59.778
FrequencySwing	0.223
TimeToStabilization	18.867
RecoveryTimeStamp	2009-03-18 06:18:16.500
TimeTo60Hz	255.1
LowestFrequencyPMU	PMU1.Signal3.FR
FirstRespondingPMUSignal	PMU1.Signal3.FR
TotalGenerationLoss	800
EstFreqRspUsingAB	454.845
EstFreqRspUsingAC	358.744

How to Use Event Analysis

1



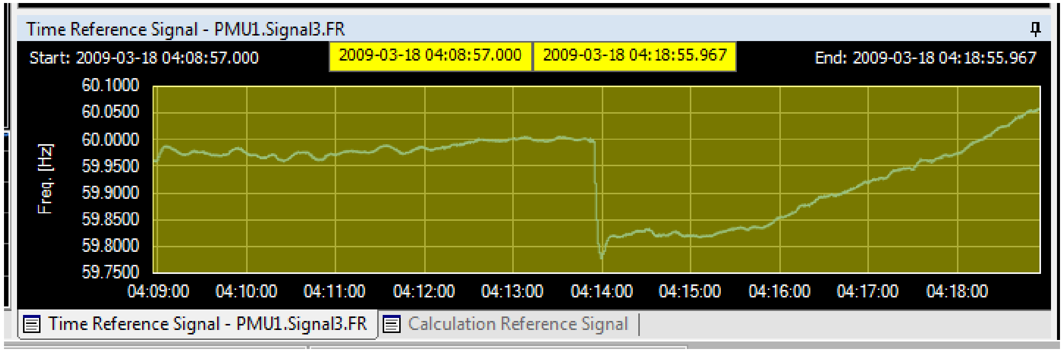
Click Event Tab

2

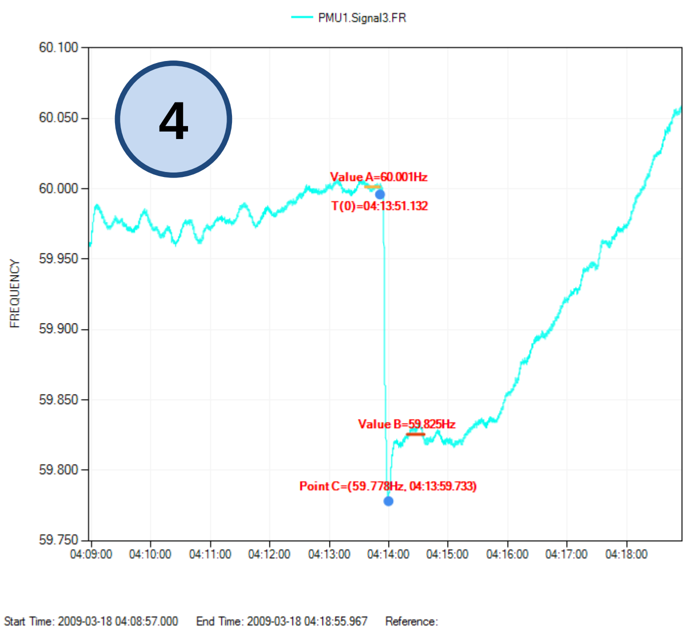
Select Frequency Signal

3

Select Time Window



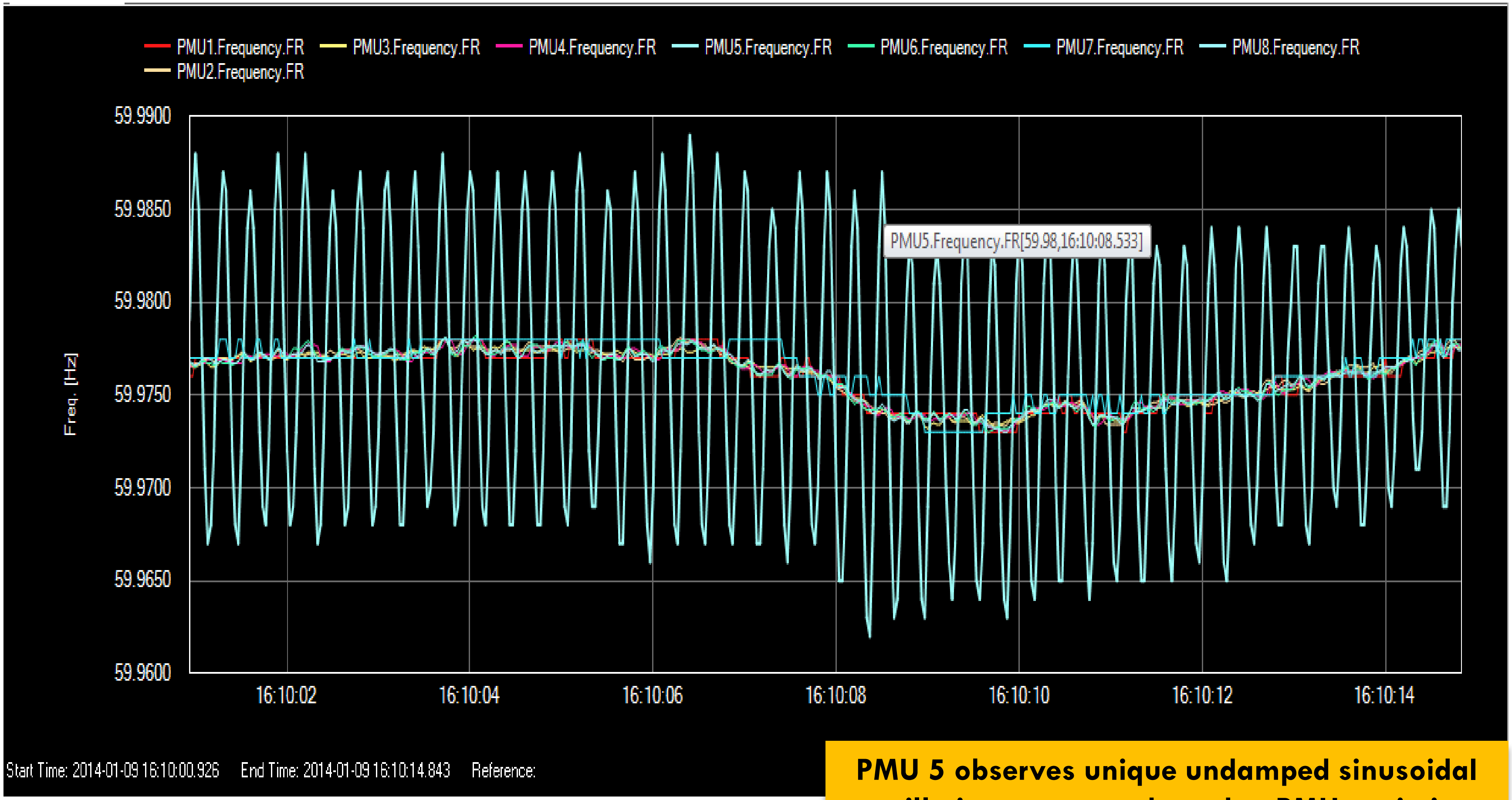
4



PGDA Frequency Analysis – Oscillation Source

Plot Analysis – Zoom & Identify

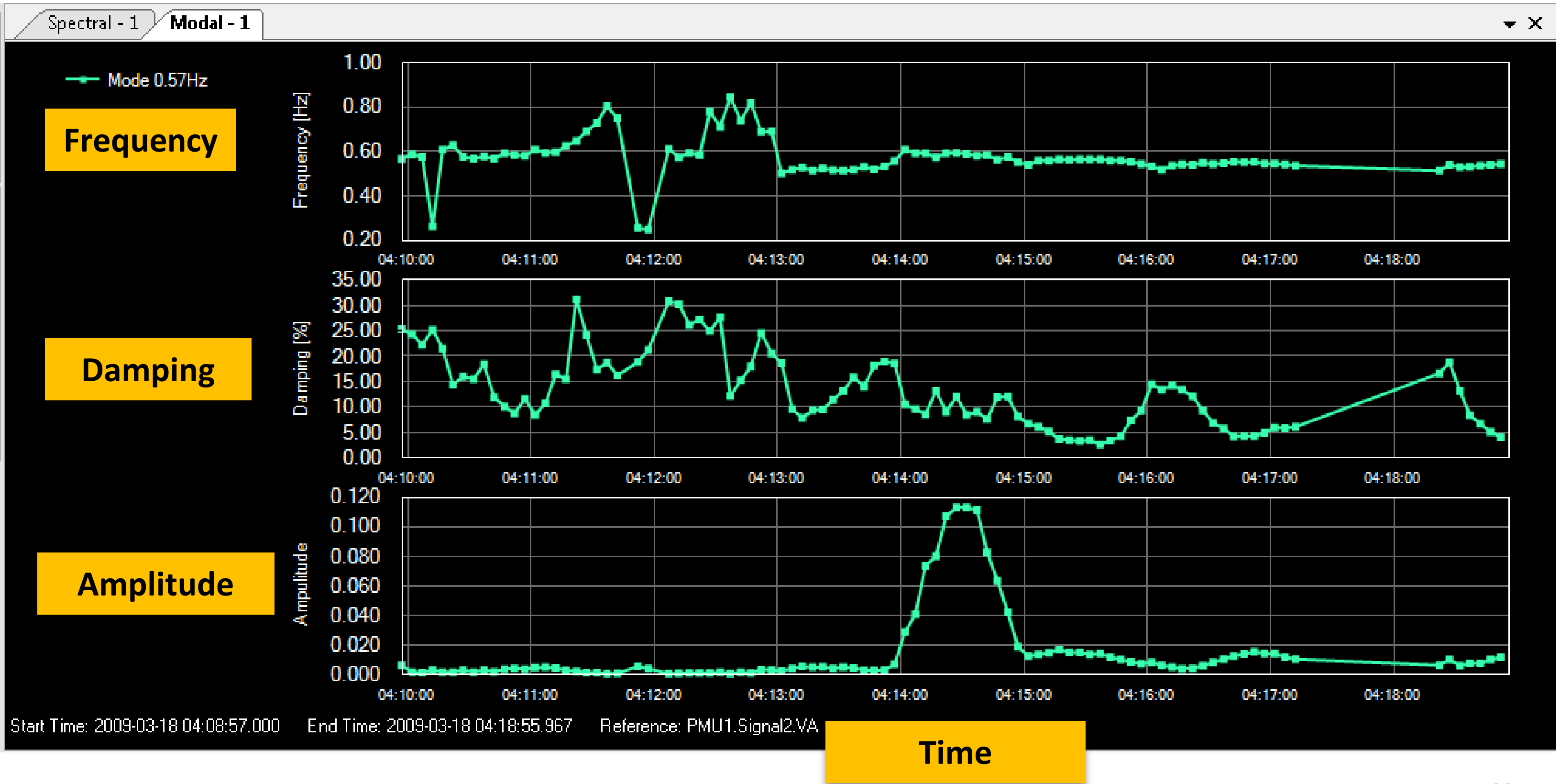
Frequency (Hz)



PMU 5 observes unique undamped sinusoidal oscillations compared to other PMUs pointing nearby location for source of oscillation

Using Modal Analysis

- Modal Analysis is performed under ambient conditions to observe oscillatory behavior i.e. event free conditions
- Modal Analysis provides the trend of **Modal Frequency, Modal Damping and Modal Energy** over a period of time. These 3 are represented as 3 separate charts on the display screen of the Modal Ambient Analysis
- Modal Analysis typically requires 5 minutes or more of data for analysis. Analysis of shorter time samples can be accomplished by adjusting the Algorithm Parameters.



Using Modal Analysis

The analysis screen of Modal Analysis consists of the following 3 sub charts:

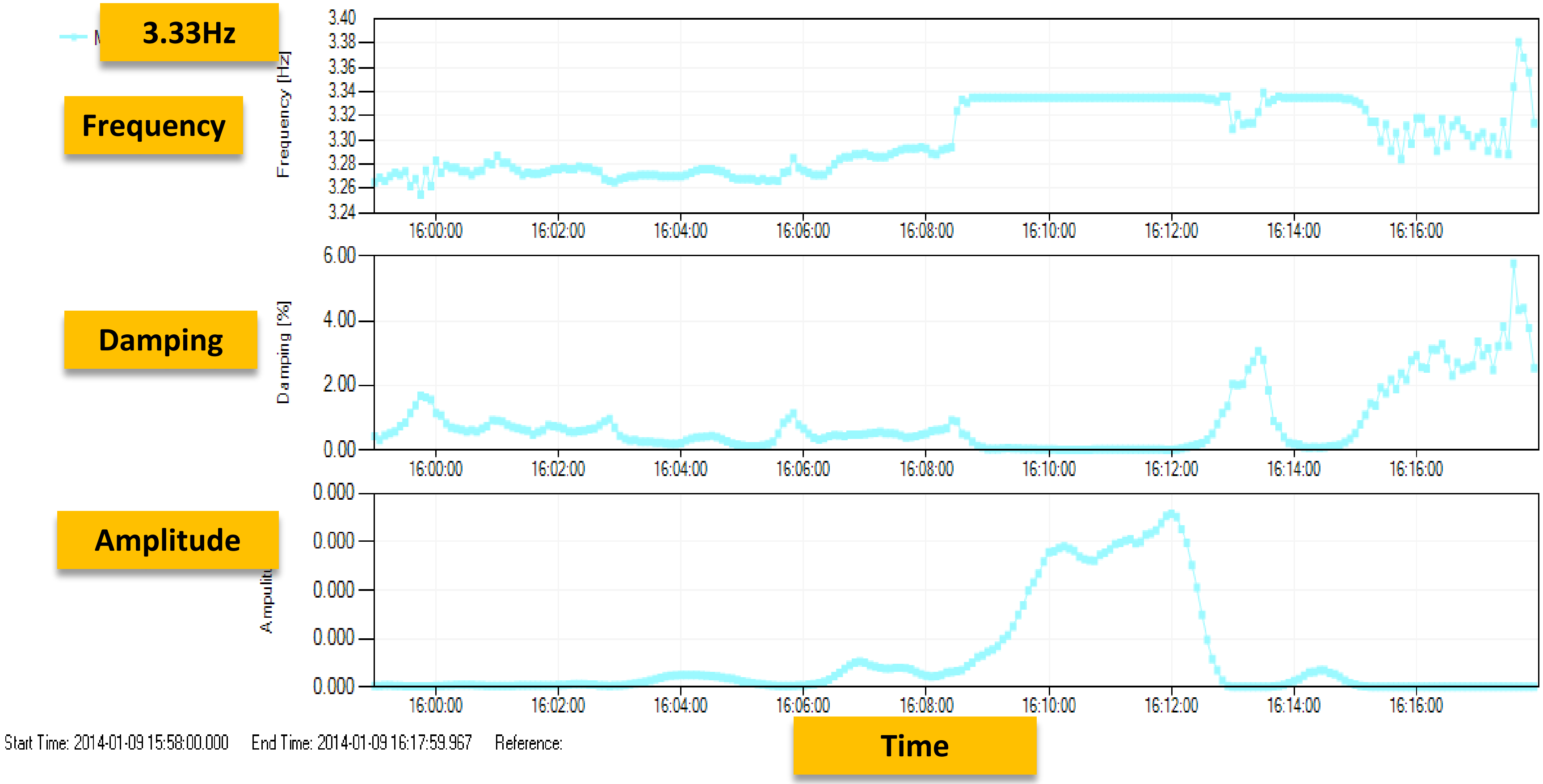
- **Frequency (Hz):**
  This subplot displays the trend of mode over the selected time

- **Damping (%):**
  This subplot displays the corresponding trend of damping values for each mode in the same color

- **Cross Spectrum Chart**
  This subplot displays the modal energy trend for corresponding frequency and damping values in their respective colors

Wind Farm Oscillation Driven by Control Systems

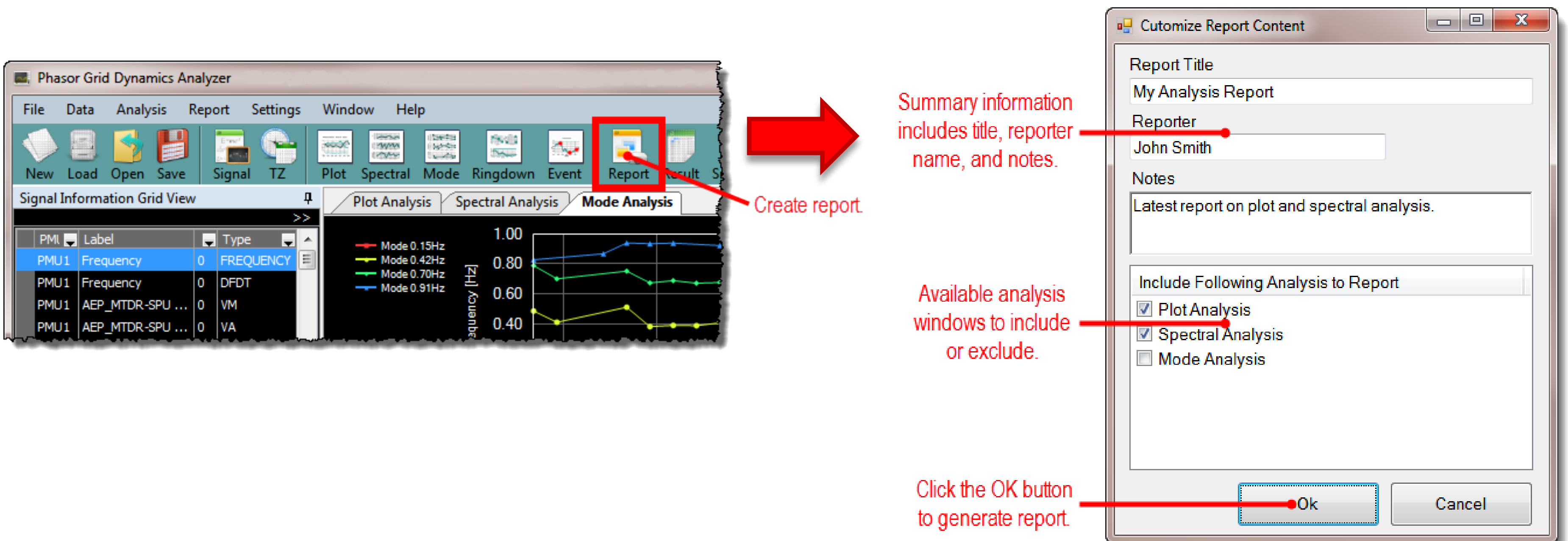
Modal Analysis – Mode, Damping & Energy



How to Generate Report Using Toolbar

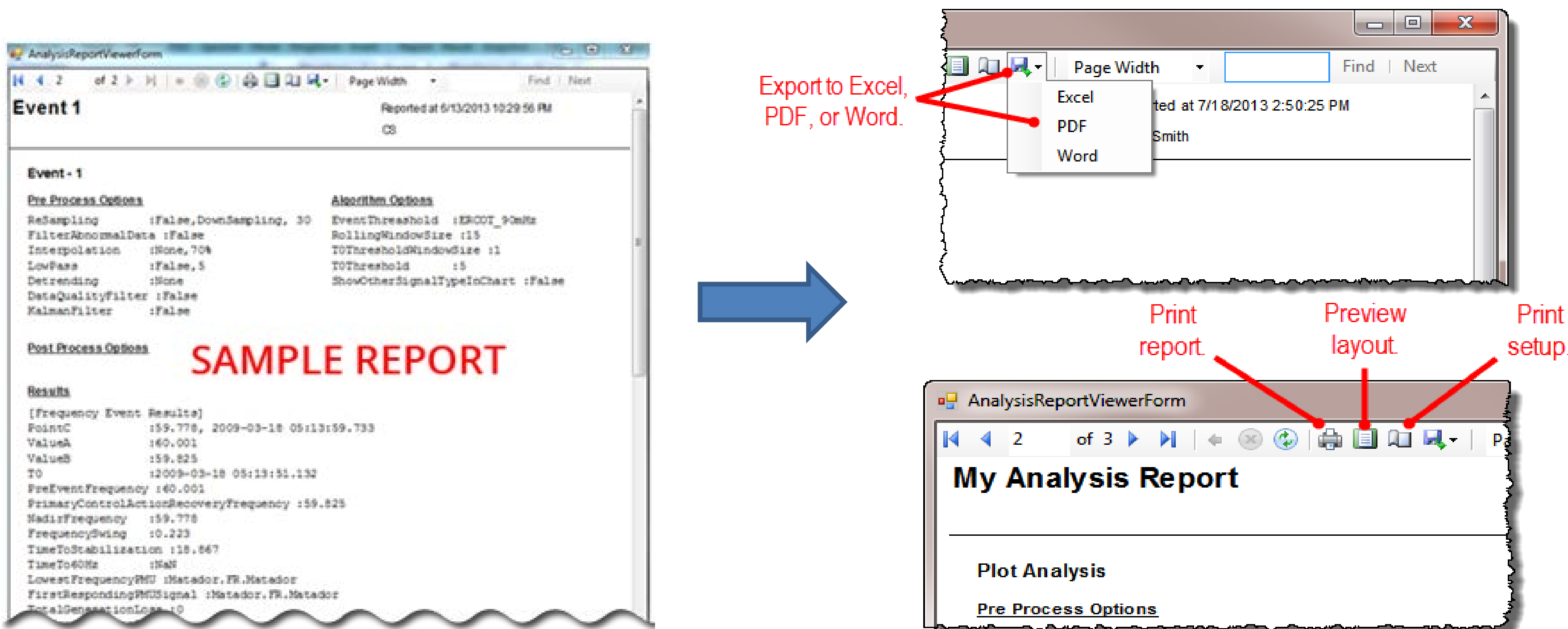
The Report Tab allows the user to quickly assemble selected plots representing the analysis of the phasor data into a concise, formatted report suitable for distribution. After completing all required analysis, click the **Report** button to create a summary analysis report of the phasor data.

When the button is clicked, the user is able to enter report title and reporter name and select the analyses to include in the report (from among the various analyses which the user has already performed). Additional descriptive notes may be entered in the Notes field.

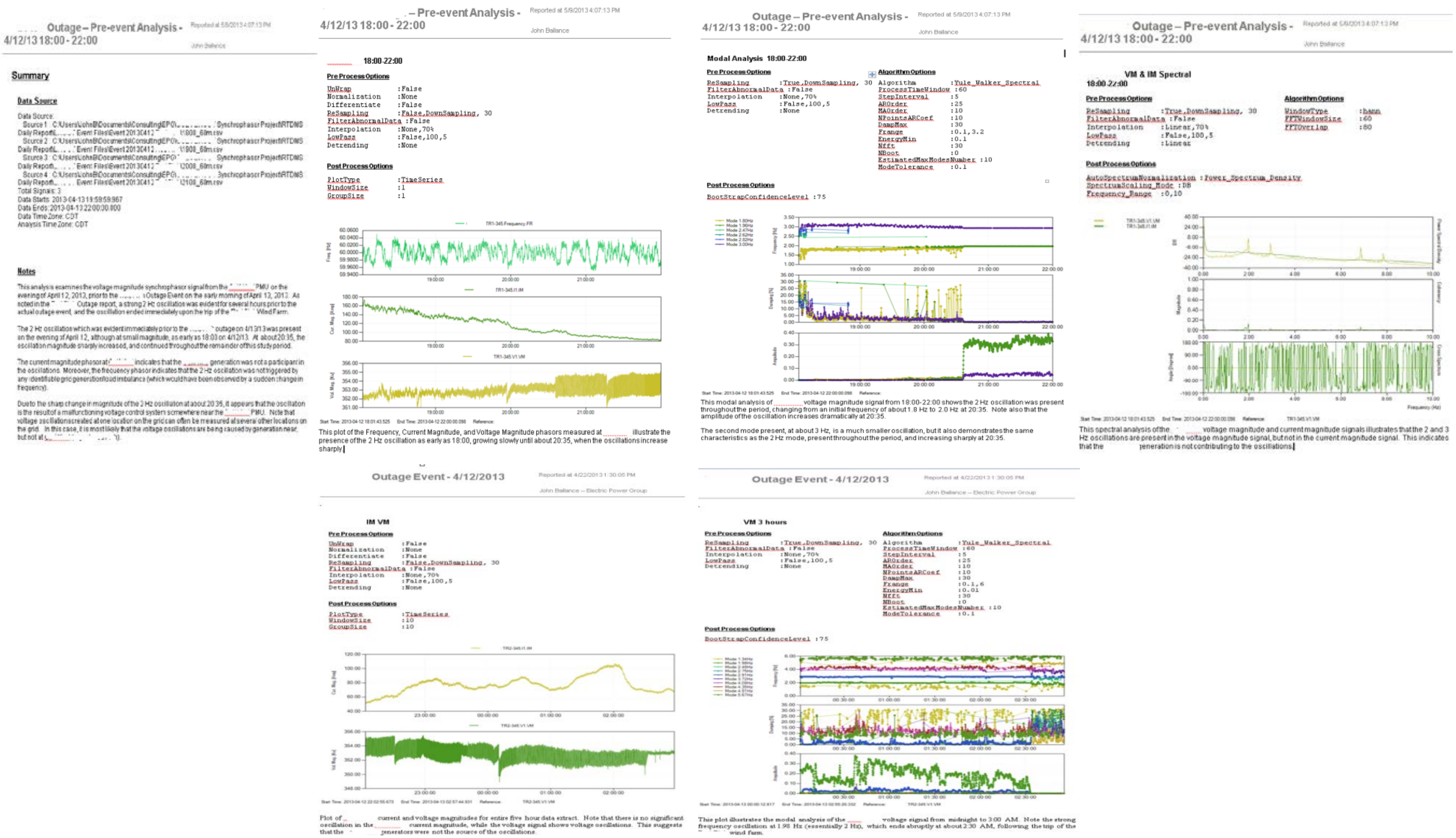


How to Save and Print PGDA Report

- The automatically generated report may now be saved in Excel, PDF, or Word
- The report automatically documents the name and location of the data file selected for analysis, the number of PMUs and time interval reflected in the data, and the time zones of both the data and the analysis
- Additionally, all the specific details of each graphical analysis performed (e.g. Plot, Spectral, Modal, Ringdown, or Event), together with notes and associated graphics will be saved



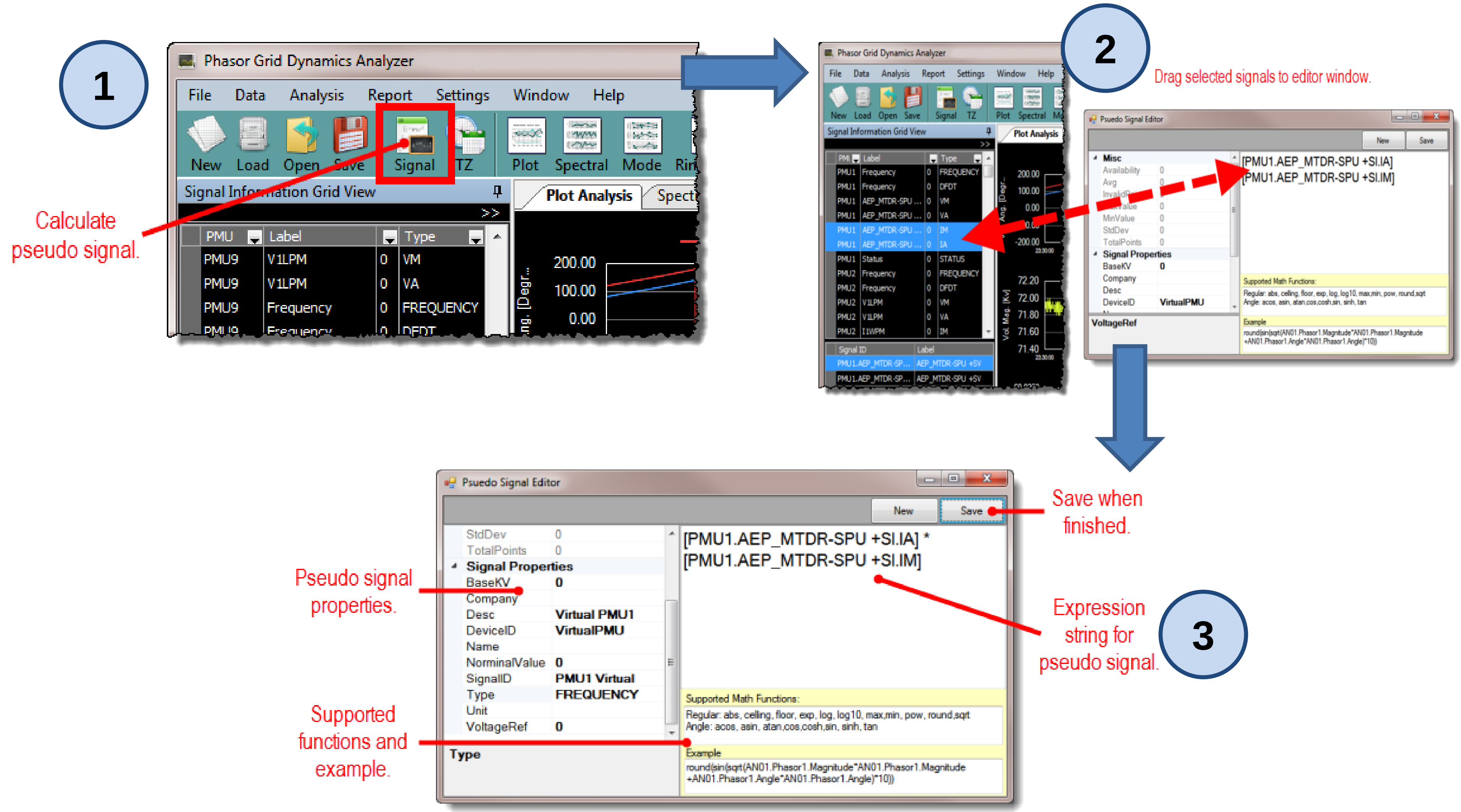
PGDA Report Generation



What is Pseudo Signal?

- Synchrophasor Measurements include the following metrics
  - Frequency & DF/DT
  - Voltage Magnitude & Angle (Voltage Phasor)
  - Current Magnitude & Angle (Current Phasor)
  - STATUS
- Pseudo Signal - PGDA provides capability to calculate a new metric using the above metrics
- Example:
- Real Power = sqrt(3)*Vm*Im*cos(Va-Ia), where
  - Vm is the line to Line voltage (kilo Volts)
  - Im is the line Current (Amperes)
  - Va is Voltage Angle (Degrees)
  - Ia is Current Angle (Degrees)

How to Create a Pseudo Signal



Thank You.

Any questions ?

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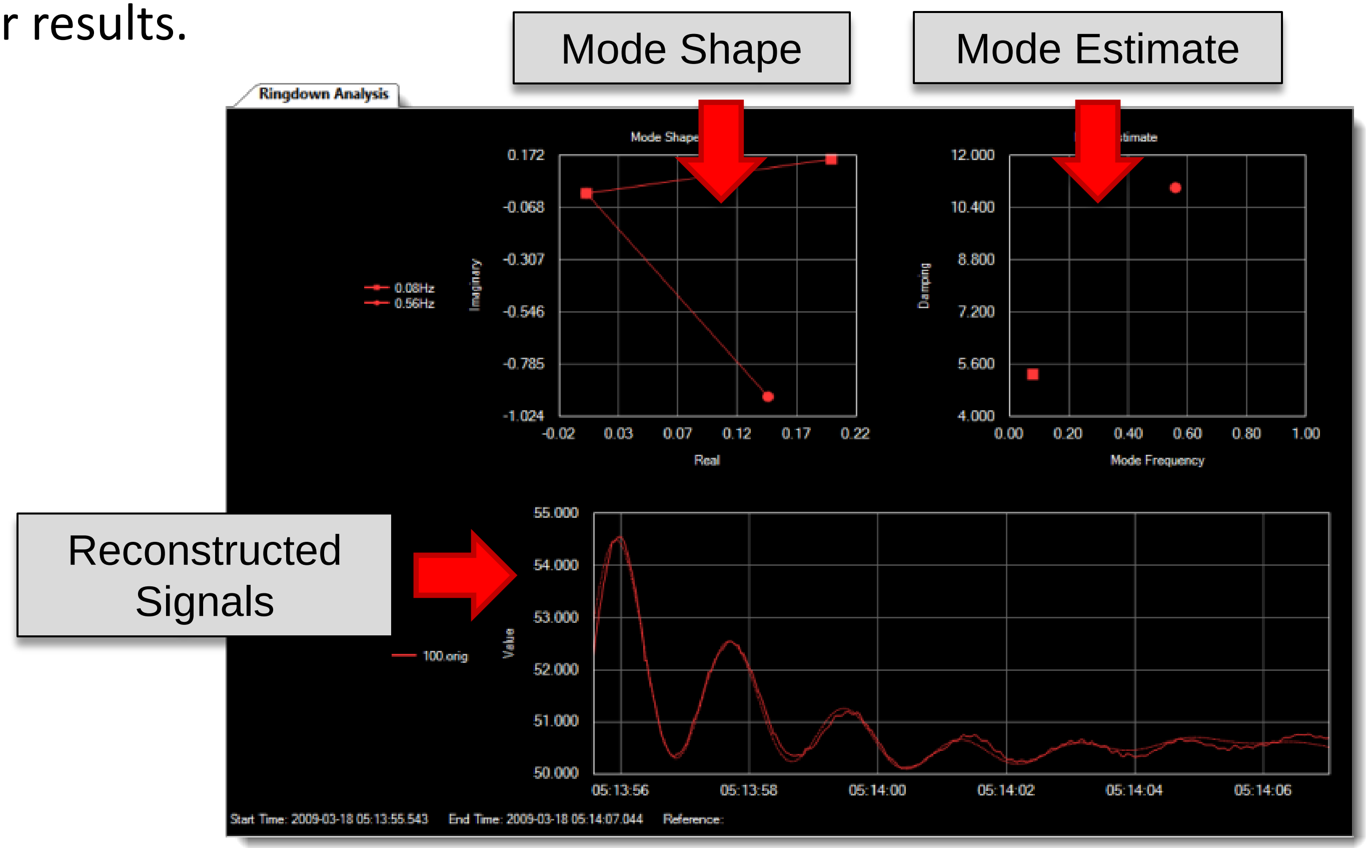
626.685.2015

Backup Slides

Using Ringdown Analysis

Ringdown analysis is a modal analysis that you can perform after an event to determine the modal estimates (frequency and damping), determine mode shape, and compare the original signal with the re-constructed signal to obtain better results.



Using Ringdown Analysis

The display screens of the Ringdown Analysis consist of the following sub charts:

- **Modal Estimates:** The Modal Estimate provides Modal Frequency and its corresponding Percentage Damping

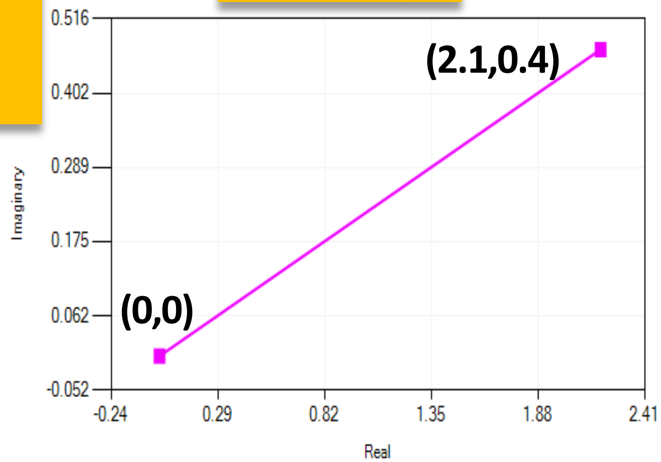
- **Modal Shape:** For each oscillatory mode, the Mode Shape provides information about the magnitude (i.e. 'where' is the oscillatory mode observable) and angular phasing relationship (i.e. 'what' locations are oscillating in phase or against each other) at the multiple signal locations.

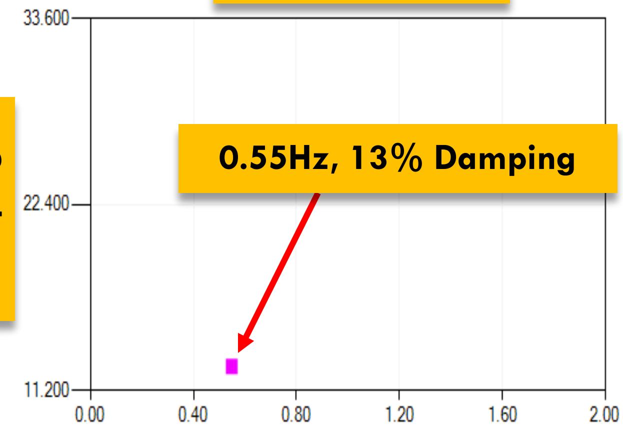
- **Original Reconstructed Signal:** Displayed as dotted line traces overlaid on the original signal

PGDA Ringdown Analysis – System Impact & Dynamics Following Generation Trip

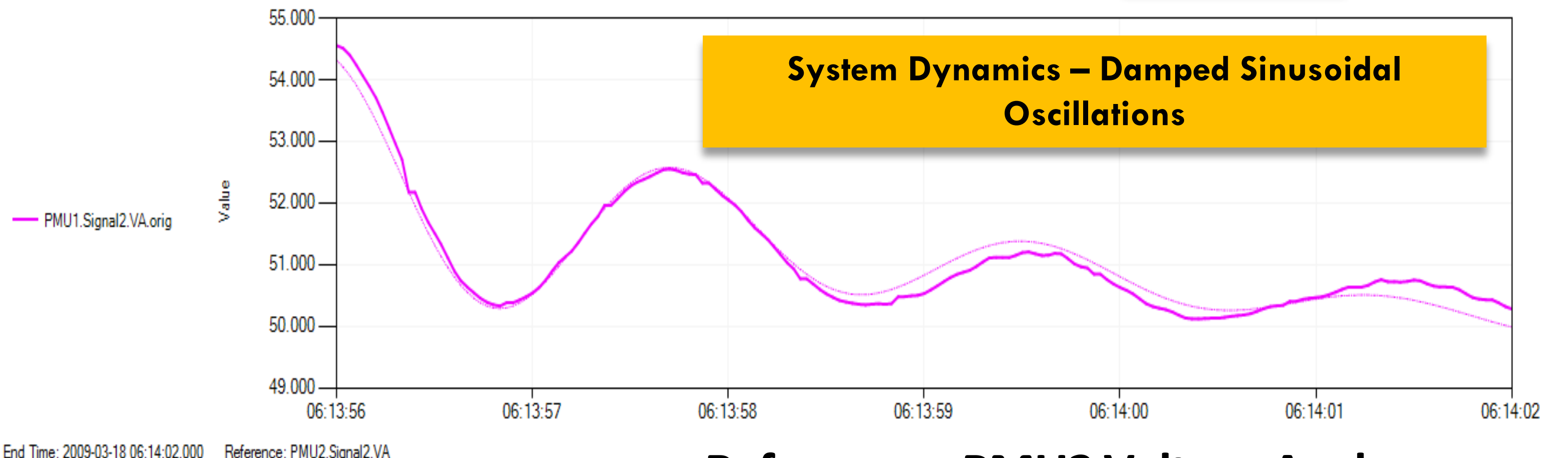
Mode Shape
Magnitude = 2.2
Phase Angle = 12.1 deg

0.55 Hz





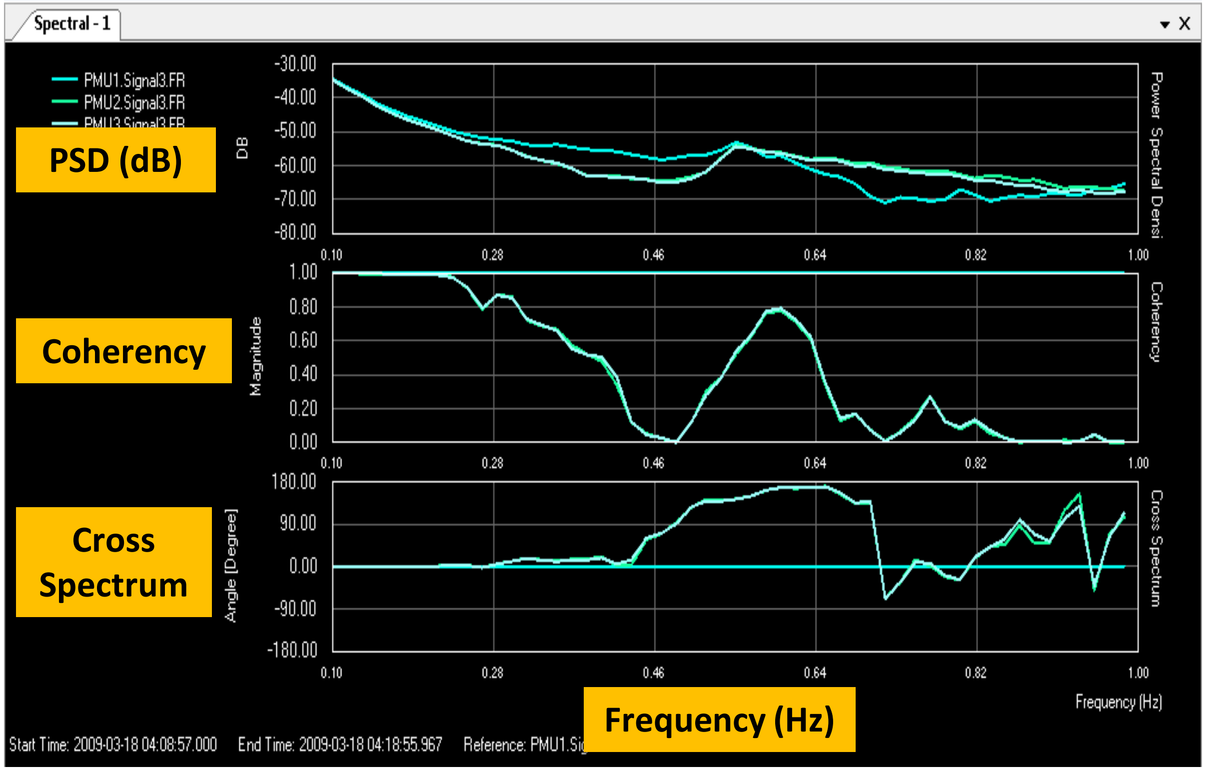
Voltage Angle



Reference – PMU2 Voltage Angle

Using Spectral Analysis

The Spectral Analysis is performed to observe Oscillatory Modal characteristics. This is performed to get a good indication of the mode present in the signals selected.



Note:

- The common X-axis for all the **three charts** is frequency.
- Spectral Analysis can be performed for event-free periods, and across events.
- The **time period** must be greater than 1 minute.
- However, we recommend using 7-10 minutes of data for better results.

Using Spectral Analysis

The analysis screen of Spectral Analysis consists of the following 3 sub charts:

- **Power spectral density (PSD) Chart**
  This subplot estimates the power spectral density of the input signal. This method splits the data into overlapping segments, computes modified periodograms of the overlapping segments, and averages the resulting periodograms to produce the power spectral density estimate. **The peaks in the chart signify oscillatory modes.**

- **Coherency Chart**
  This subplot estimates the coherence as a function of values between 0 and 1 indicating how well an input signal corresponds to a reference signal at each frequency. **A high coherency (usually >= 0.7) represents the participation of signals in the same oscillatory mode.**

- **Cross Spectrum Chart**
  The Cross Spectral Analysis provides **Phase Information of the signals** used in the analysis