Arnold Schwarzenegger
Governor

REAL-TIME GRID RELIABILITY MANAGEMENT

Prototype Phasor-Based Real-Time Monitoring Software Tool – User Guide

APPENDIX F

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Consortium for
Electric
Reliability
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CA ISO Real-Time Dynamics Monitoring System™ (RTDMS)

USER GUIDE

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Prepared by:

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for

CERTS
Consortium for Electric Reliability Technology Solutions

California ISO

Preface

Electric Power Group (EPG), under the auspices of Consortium for Electric Reliability Technology Solutions (CERTS), has developed the California Independent System Operator (California ISO) Real-Time Dynamics Monitoring System (RTDMS). RTDMS was built on the Grid-3P™ technology platform and uses high resolution synchronized data from Phasor Measurement Units (PMUs) for monitoring grid dynamics. The application is for the real time monitoring and tracking of phase angles between sources and sink buses within the Western Interconnection, local and system frequencies at a high resolution as well as MW and MVAR flows computed from the voltage and current phasor measurements.

The flow of real-time data and information from the substation PMUs to the utility Phasor Data Concentrator (PDC), through the WECC Wide-Area Network and into the California ISO's PDC and visualization monitor is depicted in Figure 1. The Real Time Dynamics Monitoring System is used to visualize phasor measurement data and provide the user with displays to monitor real-time dynamics and system events within the WECC grid.

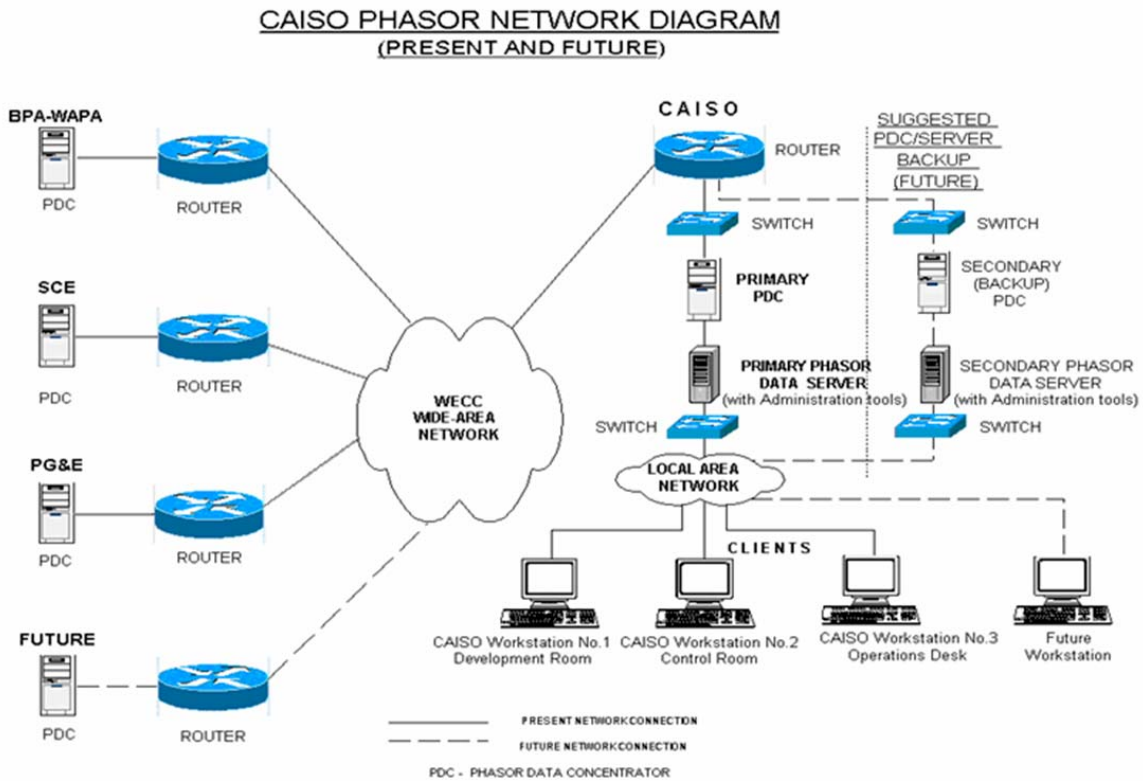

Figure 1: Data Flow for the Real-Time Dynamics Monitoring System Prototype

Source: CERTS

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The Real-Time Dynamics Monitoring System technology platform was developed by EPG under the auspices of CERTS and funded by the U.S. Department of Energy. Adaptation of RTDMS for California ISO, use was funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

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This application is for authorized users only subject to non-disclosure agreement between data providers and California ISO.

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1. EXECUTIVE SUMMARY

1.1. Purpose

The California ISO Real-Time Dynamics Monitoring System is designed to monitor the dynamics within the WECC grid and assess the system behavior during normal and disturbance conditions.

1.2. Intended Users

Operating authorities such as independent system operators (ISOs), regional transmission organizations (RTOs), reliability coordinators, and control area dispatchers in their management of grid reliability.

1.3. Functional Overview

- ***Real-Time Phasor Data Access in BPA's PDCStream Format*** – The California ISO RTDMS system reads phasor data in the BPA defined industry standard PDCStream format. Phasor data input for this prototype can originate from the Phasor Measurement Units (PMUs) directly or from collection devices such as Phasor Data Concentrators (PDCs) or data repositories. This includes synchronized, highly accurate and precisely time tagged measurements of voltage phase angle and magnitude, current phase angle and magnitude, frequencies and MWs and MVARs

- ***Information Dissemination from the Server to Client Over LAN*** - The system architecture relies on prevalent Microsoft technologies to disseminate the data cached in memory at the host RTDMS Server to multiple RTDMS client applications over a local area network (LAN).

  The flow of data is as follows:
  - The *PDCStream Data Reader* within the RTDMS Server reads the real-time data stream (Voltages, Currents, Frequency) and computes derived quantities (such as MW and MVAR flows).
  - The *RTDMS Server* archives both the raw and derived quantities in memory within a rolling cache, the most recent alarms, and permanently archives event files, and makes this data and information available to all the RTDMS client applications.
  - The *RTDMS clients are* the visualization applications that can access the phasor data and alarms from the Server over the LAN.

- ***Remote Client Monitoring Applications*** - The RTDMS clients are stand-alone monitoring applications that connect to the RTDMS server and acquire phasor data from the server.

- ***Multiple Visualization Displays*** – The application will have multiple displays such as the one shown in Figure 2 for monitoring:

  Interconnection Frequency
  - Identify approximate point of acceleration or deceleration (loss of load or generation) within the WECC system.
  - Assess system coherency and its dynamic stress under normal operating conditions.

  Voltage Magnitude and Relative Angles
  - Comprehensive profile of WECC voltage angles and magnitudes.
  - Identify the high and low voltage regions within the WECC grid.
  - Monitor angles relative to a specific location, utility or regions.
  - Operating organizations ability to set threshold limits.

  Angle Differences across Identified Transmission Paths

- Provides a bird's-eye view of the WECC sources and sinks of power.
- Monitor phase angle differences across key WECC paths.
- Operating organizations ability to set threshold limits.

Real and Reactive Power Flows Across Monitored Lines

- Monitor actual MW and MVAR flows at key paths.
- Track flows with respect to predefined thresholds.
- Operating organizations ability to set threshold limits.

- ***Configurability*** - A configuration tool provides a friendly graphic user interface to specify visualization subsets, and update the displays with new paths, thresholds etc, as new PMUs are added to the system. The defined configuration settings are portable and can be transferred with ease to other monitoring clients. This procedure with preserve display standardization across the Western Interconnection.

- ***Alarms*** - The application uses hard limits on monitoring metrics (frequency, angle difference pairs, MW, MVAR) and rate of change for visual alarming. The hard limits are defined by the users based on offline studies, simulation and operating experience. All relevant information pertaining to these alarms (such as the metric associated with the violation, the start time of violation, the end time of violation, the violation value and corresponding threshold, the violation type, etc) are continuously shown in the alarming display and are also logged into a 'txt' file.

- ***Event Files*** – In addition to alarming, event files consisting of all monitored data over specified time duration (default duration is five minutes) are automatically stored whenever a rate of change alarm is generated. These event files can be loaded into the application for offline analysis.

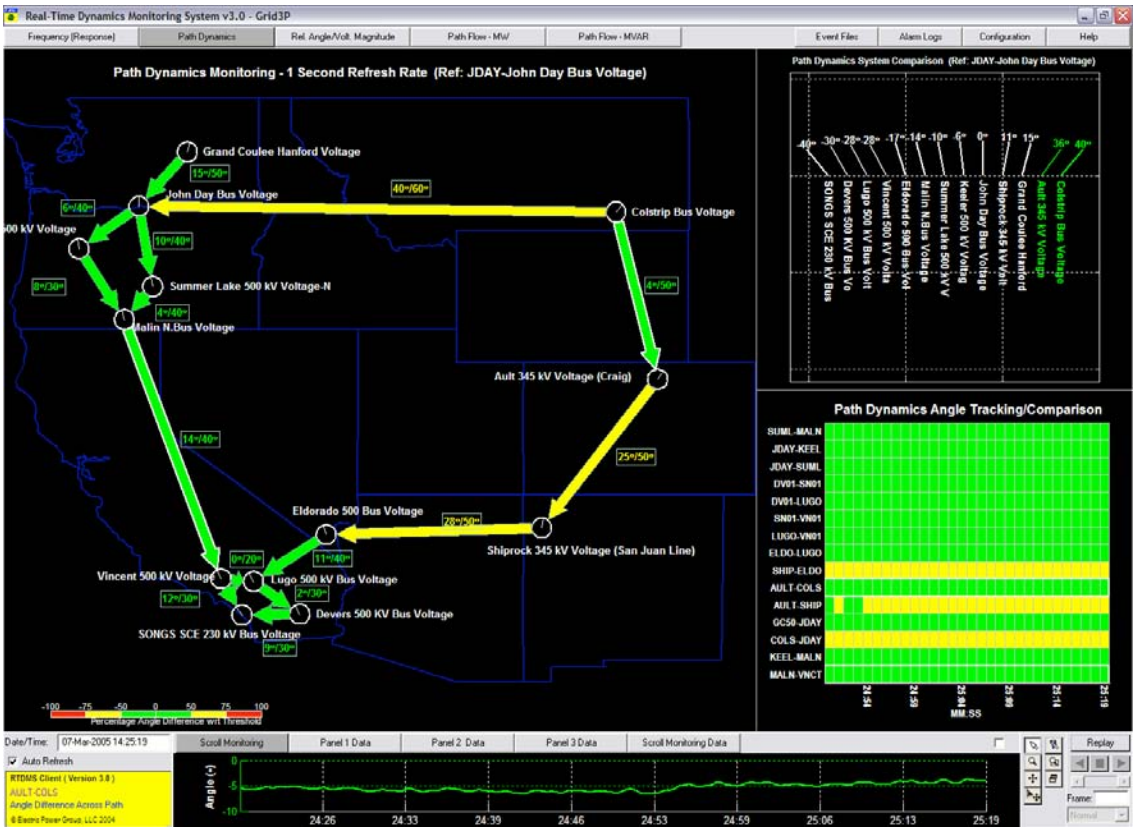


Figure 2: RTDMS Client Monitoring Application – Sample Display (Path Dynamics)

Source: CERTS

1.4. RTDMS Client Application Requirements

The user can install the RTDMS clients on a desktop computer and remotely connect to the RTDMS Server for accessing, displaying, and monitoring real-time phasor data (Figure 3).

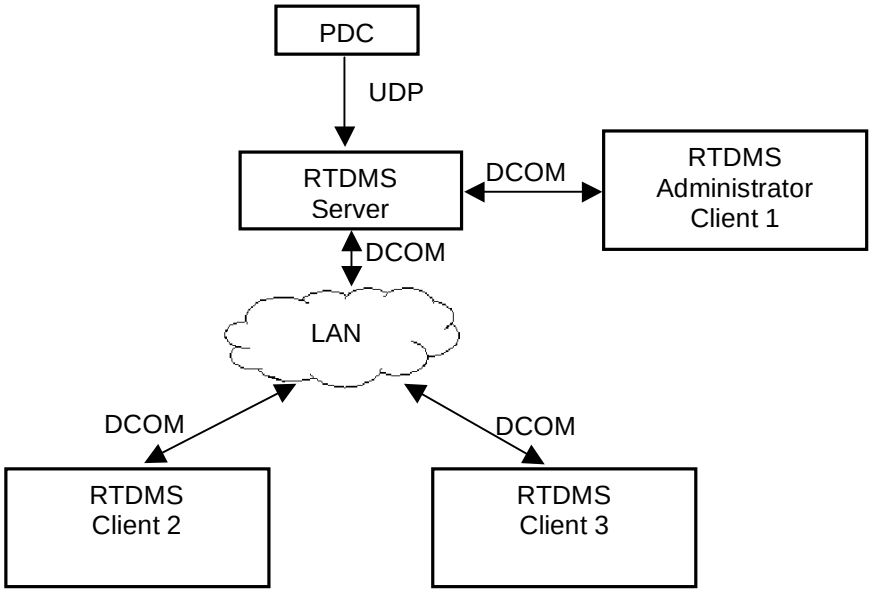


Figure 3: RTDMS Server/Client Setup

Source: CERTS

Requirements: The following is required to run the RTDMS Client application:

Table 1: RTDMS Visualization Client Application – Recommended Hardware Requirements

Memory	512 MB or greater
CPU	Pentium III processor or up (1.0 G Hz or higher)
Video	64 MB graphic memory AGP 8X or PCI express graphic card such as nVidia Quadro FX 3000 and up.
Storage	20 GB hard disk and up
Operating System	Windows 2000, Windows XP Professional
Display	1280 by 1024 Pixels or better

Source: CERTS

1.5. Monitoring Performance

The goal for the RTDMS system is to make information available to users in the shortest possible time. The performance of the application (such as refresh rates and resolution, replay time, etc) will be determined by the supporting system architecture. Some of the factors influencing system performance are:

- Data resolution at the source
- Communication latencies
- Number of PMUs to be included in the visualization displays

In this version of the application, users may experience a delay of a few seconds from the time the data is read by the measurement units and when it is displayed within the RTDMS client's visualization displays.

2. INTRODUCTION

2.1. Real-Time Wide-Area Performance Monitoring

Investigation of the August 14, 2003, blackout concluded the need for wide-area monitoring to maintain the integrity of the grid through continuous checking of important metrics during normal and emergency conditions. The RTDMS application provides a tool to meet these new monitoring requirements. It collects phasor data procured by Phasor Measurement Units (PMUs) in a synchronized manner to provide real time information about the status of the system. The high resolution data offers wide-area visibility of system dynamics and real-time grid reliability assessment by utilities, ISOs, RTOs and reliability coordinators during normal and disturbance conditions. Details on how this application will accomplish this goal are provided in this document.

2.2. RTDMS – Functional Overview

This "user guide" has been developed for the Real-Time Dynamics Monitoring System – a phasor monitoring system developed on the Grid-3P™ Platform, and designed to utilize the true potential of phasor technology to closely track grid dynamics and assess the health of the grid. In particular, the ability of phasor measurements to directly and accurately measure system states (voltages/current magnitudes and angles), and to have them available precisely time-tagged at a very high sub-second rate offers a wide-area snapshot of system dynamics in real time. This kind of observability isn't available with conventional SCADA data (i.e., SCADA data is not capable of capturing swing dynamics). Furthermore, algorithms within the system also use the precise timing information to continuously track phasor data and perform real-time estimates of crucial network parameters and selected metrics to provide the most accurate up-to-date assessment of the system limits.

The phasor measurement units at a substation collect a set of data at a sub-second rate (30 times a second, 60 times a second, etc). Included in this set are voltage phasor measurement(s), current phasor measurements on each of the lines connected to the substation, a local frequency measurement as well as an accurate time stamp of when this set of measurements was made. The data from each one of the PMUs is then sent to a local phasor data concentrator (PDC) where the received data is synchronized based on the time stamps and is forwarded to central data repository (California ISO PDC) as close to real time as possible (Figure 1). Currently, there are about 20 data collection locations as indicated in Table 2. In the future, additional data is expected from new PMU installations and from other utilities.

The RTDMS client applications, through their various geographic and graphic displays, provide operators and dispatchers both real-time and historical information, and alarms on:

- *Local and interconnection frequency*, as well as changes in frequency that can be mapped to precise generation-load imbalances within the interconnection. The local frequency measurements can be used to assess system coherency and its dynamic stress under normal operating conditions.
- *Phase angle differences* across different utilities with respect to their alarming thresholds to assess the static stress across the system and proximity to instability.
- *Comprehensive voltage angle and magnitude profiles* offer a birds-eye view of the sources and sinks of power and identify the high and low voltage regions within the grid.
- *The MW and MVAR flows*, computed from the voltage and current phasors, and track these flows with respect to predefined thresholds.

In addition to real-time monitoring capabilities, the application also stores short duration data files whenever transient events are detected, which can be loaded into the application for off-line post-disturbance analysis.

All the displays in the application have been designed bearing the end user in mind and the information presented in the displays is pertinent to what would be valuable to them. It has been demonstrated that the more effective operational displays are those that follow a hierarchical approach to presenting operational data. In this hierarchical approach, very critical data is presented at the high level on a very

simple system display. From the high-level system display the users can navigate to a lower level and more detailed displays.

Table 2: Current and Future PMUs to be Incorporated into the WECC Phasor Network

PMU Location	Owner
1. Slatt	BPA
2. Summer Lake	BPA
3. Captain Jack	BPA
4. Keeler	BPA
5. Maple Valley	BPA
6. Sylmar	BPA
7. Big Eddy 500 kV	BPA
8. Big Eddy 230 kV	BPA
9. Colstrip	BPA
10. Malin	BPA
11. John Day	BPA
12. Grand Coulee	BPA
13. McNary 230 kV	BPA
14. McNary 500kV	BPA
15. Ashe 500 kV	BPA
16. Ault	WAPA
17. Bears Ears	WAPA
18. PMOC UPS (Spare)	WAPA
19. Shiprock	WAPA
20. Vincent[1]	SCE
21. Devers 500 & 230kV	SCE
22. Mohave	SCE
23. Devers 115kV	SCE
24. Big Creek	SCE
25. Alamitos	SCE
26. San Onofre	SCE
27. Kramer	SCE
28. Valley	SCE
29. Antelope	SCE
30. Control	SCE
31. Lugo	SCE
32. Eldorado	SCE
33. Magunden	SCE
34. Midway	PG&E
35. Diablo Canyon	PG&E
36. Moss Landing	PG&E
37. Tesla	PG&E
38. Pittsburg	PG&E
39. Los Banos	PG&E
40. Metcalf	PG&E
41. Table Mountain	PG&E
42. Gates	PG&E

Source: CERTS

3. QUICK START

The RTDMS Server 3.0 must be installed and running on a PC machine to which the PDC is sending data to, and RTDMS Client 3.0 should be configured to receive data from the RTDMS Server 3.0, before the RTDMS Client 3.0 can be launched. Please refer to the 'RTDMS Installation and Support Guide' for detailed step-by-step instructions on the installation and setup process.

To start the RTDMS Client application, click on the "CA ISO RTDMS Client 3.0" shortcut icon located on the desktop (Figure 4).

Figure 4: RTDMS Client Start Icon

Clicking on the icon will launch the application. When the application starts, the default "Frequency (Response)" monitoring display is shown (Figure 5). The chart presented in this display is the interconnection frequency plot with up to a one second refresh rate with the most current time being to the right along the horizontal axis. The frequency range being graphed is shown along the vertical axis to the right of the plot.

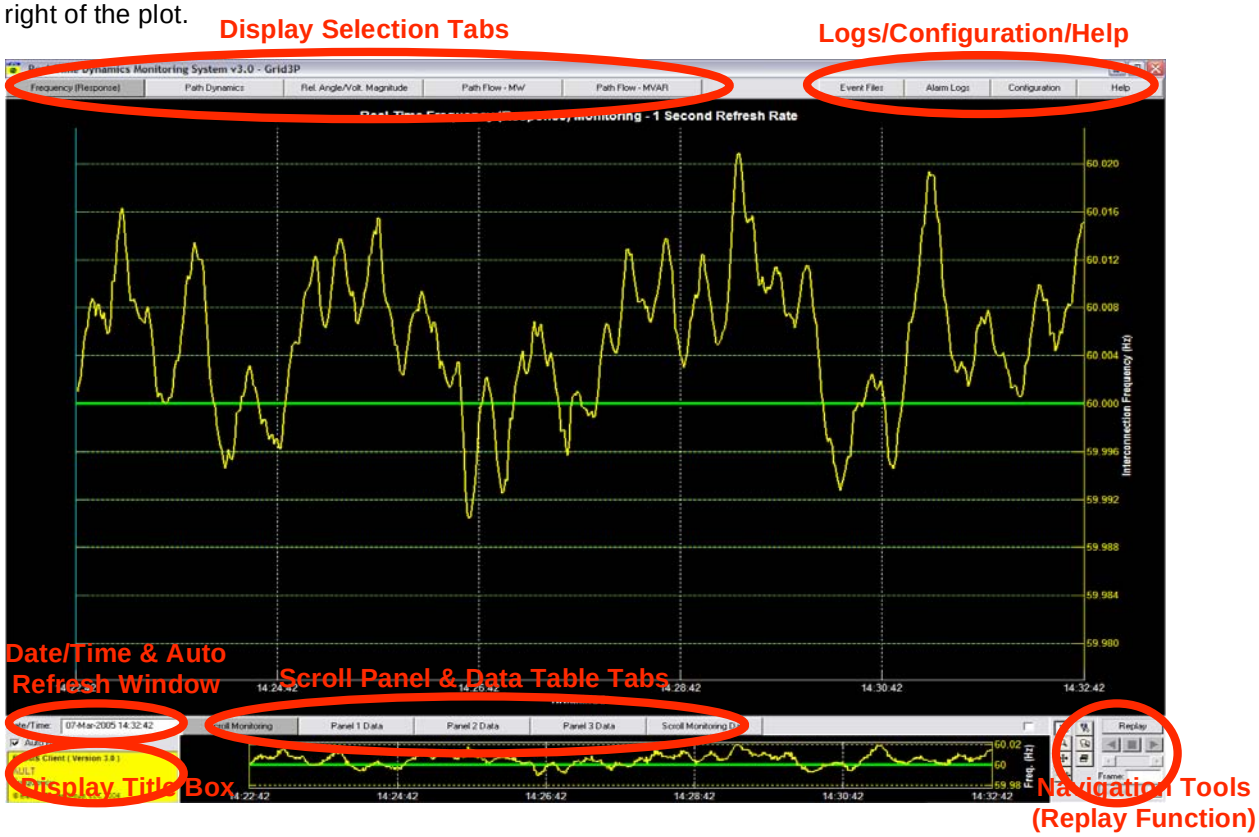


Figure 5: RTDMS Default Display – Frequency (Response) Monitoring

Source: CERTS

There are a total of five display selection tabs located at the top left corner of the application (Figure 6) corresponding to each of the five (5) different monitoring functions of the application: "Frequency (Response)", "Path Dynamics", "Relative Angle/Voltage Magnitude", "Path Flow-MW" and "Path Flow-MVAR". The user can use these tabs to navigate between various functional displays by clicking on the appropriate tab.

Figure 6: RTDMS Display Selection Tabs

Source: CERTS

4. REAL-TIME DYNAMICS MONITORING SYSTEM OVERVIEW

This section of the user's guide will include a brief view of the system architecture, a description of the navigational tools, and a detailed description of the individual monitoring tabs offered by the application.

4.1. Application Architecture

Figure 7 shows the architecture of the RTDMS system. The system adheres to a client/server architecture where the Server, connected to the host data source (California ISO Phasor Data Concentrator), will distribute the information to the multiple client monitoring applications over a secure LAN connection. This straightforward configuration will facilitate a seamless, open and flexible integration with the client for distribution and visualization of the data. Each of the different components of the application is described below:

4.1.1. Data Retrieving, Alarming, and Storage – RTDMS Server

The PDCStream data reader component within the server is designed to interface directly with the PDC over a local area network, and to read, in real-time, the complete phasor data stream. In addition to the data stream, the reader also reads all supplemental static information such as PMU, their coordinates, signal names, signal types, etc (Refer to Appendix 1). The phasor data read by PDCStream data reader from the PDC is pre-processed and cached at the RTDMS server and is available for real time visualization via the applications running on multiple client terminals. In addition, the data is also analyzed in real-time to detect any predefined threshold violations or transient events, which are both logged into text file as well provide real-time alarming at all RTDMS visualization clients. In the case of transient event detection, the disturbance data is also permanently stored into event files of pre-specified duration (default is 5 minutes) and can be loaded into the RTDMS visualization clients for post-disturbance analysis.

4.1.2. RTDMS Client Monitoring Visualization Application – RTDMS Clients

The RTDMS visualization displays, running on the client terminals, is delivered as a stand-alone application designed to connect to the RTDMS server over a LAN connection. It has the ability to acquire phasor data from the host, to process this data, and to display it in geo-graphic displays. The displays shall enable the user to monitor and track meaningful performance metrics with respect to predefined thresholds and will be alarmed whenever these thresholds are violated. These clients may also be used to load event file data saved into the local offline cache for post-disturbance analysis within the application. This user's guide elaborates on the use of the RTDMS client application.

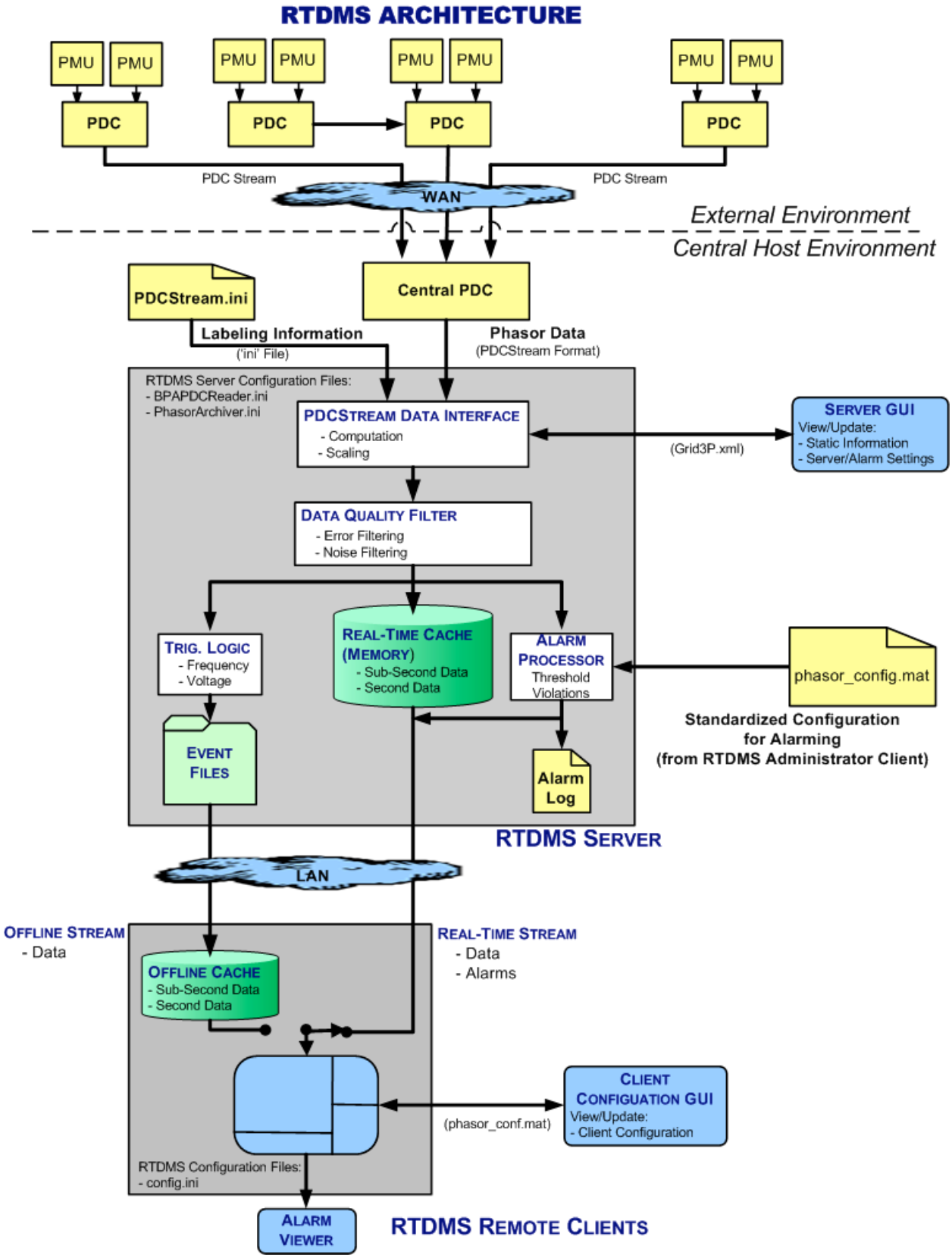


Figure 7: Real-Time Dynamics Monitoring System Architecture

Source: CERTS

4.2. Visualization Architecture

The visualization overview shown in Figure 8 lays out the displays available to the user. Whether in Real-Time (i.e., streaming data) or Offline (i.e. archived event files) monitoring modes, each of the following five displays: “Frequency (Response)”, “Path Dynamics” (Angle Differences Across Regions), “Relative Angle/Voltage Magnitude”, “Path Flow – MW’ and “Path Flow – MVAR” are available within the application and can be utilized by the user by selecting the applicable data visualization. The “Wide Area” and “Local Area” monitoring capabilities available for some of the displays present the data in different forms and therefore allow for better analysis of the data.

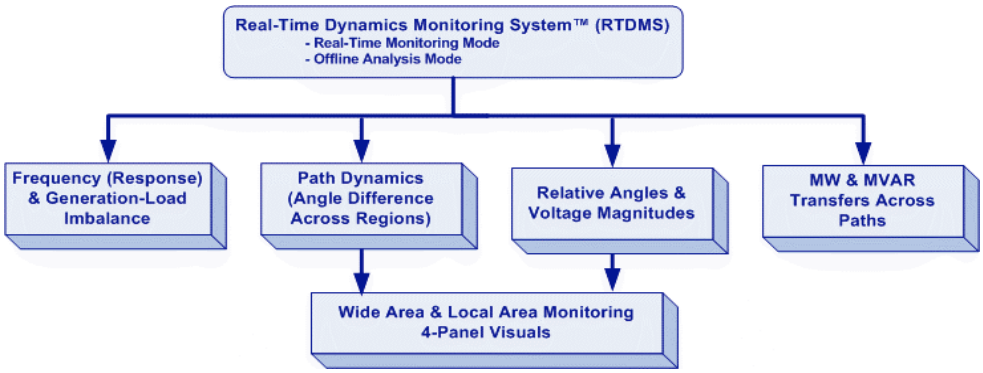


Figure 8: RTDMS Visualization Overview

Source: CERTS

In addition to the geo-graphical plots and multi-panel views (one-panel or four-panel) within the various displays, the displays (and the platform in general) offer configuration, alarming, and navigational capabilities, through control icons, selection tabs, and information windows located within the display.

4.2.1. Date/Time and Auto Refresh Window

In real-time operation, the date and time of the most recent data available for visualization within the application are displayed in a date/time window located in the lower left corner of the screen (Figure 9). The application uses the 24-hour clock and automatically refreshes with new data once every second and this date/time window is updated accordingly. In off-line mode, the date and time during the event capture is shown in the date/time window.

Figure 9: Date/Time and Auto Refresh

Note: During real-time operation, the automatic refreshing of the data can also be stopped by clicking off the “Auto Refresh” check box. This will freeze the data and hold the displays for closer interrogation.

Both, real-time and event data can be replayed with the application for close interrogation. When in Replay mode (Refer to Section 4.2.6), the user may manually alter the time within the Date/Time window and rewind to a desired point in time. To do this, either type in the desired time into the Date/Time window or right click within this window to launch the “Date Selection” graphic user interface (Figure 10).

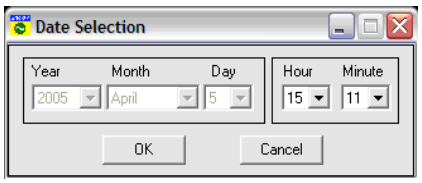


Figure 10: Date Selection Graphic User Interface for Replay

4.2.2. Configuration Utility

The "configuration utility" lets the user customize the functionality of the visualization application. With the utility, the user has the ability to select a subset of PMUs from those available to the application, and customize each of the displays based on signals belonging to the subset of PMUs. The configuration utility therefore allows the user to update the application as PMUs are added/removed from the phasor network. The details on how to use this feature are included in Section 12.

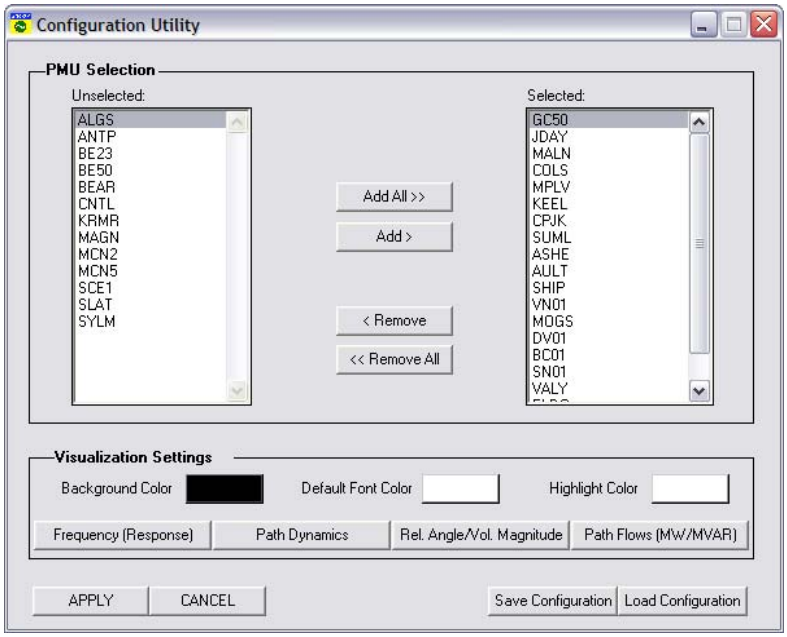


Figure 11: Configuration Utility Graphic User Interface

Source: CERTS

4.2.3. Alarm Logs

The "alarm log" pop-up box keeps track of the most recent violations under any/all of the following conditions:

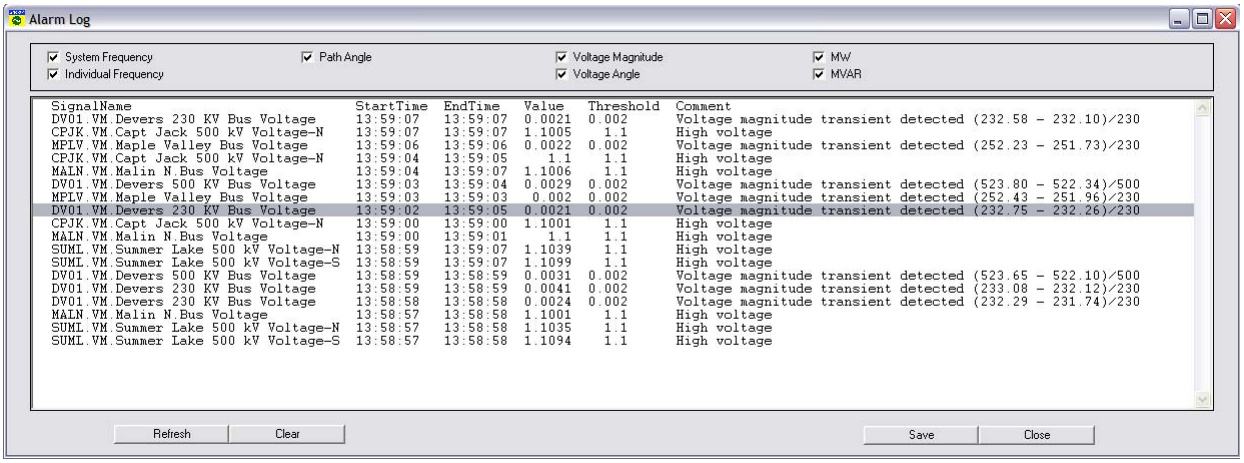
- System frequency exceeding specified threshold limits.
- Local frequency variations exceed specified thresholds limits.
- Sudden changes in system and local frequencies.
- Voltage magnitudes exceed minimum or maximum thresholds (i.e. low or high voltages).
- Sudden changes in voltage magnitudes.
- Relative voltage angles exceeding specified thresholds limits w-r-t chosen reference.
- Angle difference across specified paths exceed defined threshold limits.
- MW/MVAR flows across specified paths exceed defined threshold limits.

Note: When sudden changes in voltage magnitude or frequency signals are detected, the phasor data is stored into event files for offline post-disturbance analysis (Refer to Section 4.2.4).

Whenever an alarm occurs, the "alarm logs" tab located in the top right corner of the RTDMS clients is highlighted in red until the alarm is acknowledged by the user (Figure 12).

Figure 12: "Alarm Logs" Tab Highlighted in Red to Alert RTDMS User of New Alarm

To acknowledge the alarm, click on this tab and the "Alarm Log" box pops-up (Figure 13). Though all the alarms are logged at the RTDMS server as a text file, the user may be selective on the alarms he wishes to see at the RTDMS client. This is done by selecting/deselecting the appropriate alarm types within the "Alarm Log" box. For each alarm listed in the box, the alarm log provides information on the signal associated with the violation, the start time of the violation, the end time of the violation (or most current time during a violation), the violation value and corresponding threshold, and the nature of the violation (Refer to Section 10 for further details).



SignalName	StartTime	EndTime	Value	Threshold	Comment
DV01.VM.Devers 230 KV Bus Voltage	13:59:07	13:59:07	0.0021	0.002	Voltage magnitude transient detected (232.58 - 232.10)/230
CPJK.VM.Capt Jack 500 kV Voltage-N	13:59:07	13:59:07	1.1005	1.1	High voltage
MPLV.VM.Maple Valley Bus Voltage	13:59:06	13:59:06	0.0022	0.002	Voltage magnitude transient detected (252.23 - 251.73)/230
CPJK.VM.Capt Jack 500 kV Voltage-N	13:59:04	13:59:05	1.1	1.1	High voltage
MALN.VM.Malin N.Bus Voltage	13:59:04	13:59:07	1.1006	1.1	High voltage
DV01.VM.Devers 500 KV Bus Voltage	13:59:03	13:59:04	0.0029	0.002	Voltage magnitude transient detected (523.80 - 522.34)/500
MPLV.VM.Maple Valley Bus Voltage	13:59:03	13:59:03	0.002	0.002	Voltage magnitude transient detected (252.43 - 251.96)/230
DV01.VM.Devers 230 KV Bus Voltage	13:59:02	13:59:05	0.0021	0.002	Voltage magnitude transient detected (232.75 - 232.26)/230
CPJK.VM.Capt Jack 500 kV Voltage-N	13:59:00	13:59:00	1.1001	1.1	High voltage
MALN.VM.Malin N.Bus Voltage	13:59:00	13:59:01	1.1	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-N	13:58:59	13:59:07	1.1039	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-S	13:58:59	13:59:07	1.1099	1.1	High voltage
DV01.VM.Devers 500 KV Bus Voltage	13:58:59	13:58:59	0.0031	0.002	Voltage magnitude transient detected (523.65 - 522.10)/500
DV01.VM.Devers 230 KV Bus Voltage	13:58:59	13:58:59	0.0041	0.002	Voltage magnitude transient detected (233.08 - 232.12)/230
DV01.VM.Devers 230 KV Bus Voltage	13:58:58	13:58:58	0.0024	0.002	Voltage magnitude transient detected (232.29 - 231.74)/230
MALN.VM.Malin N.Bus Voltage	13:58:57	13:58:58	1.1001	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-N	13:58:57	13:58:58	1.1035	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-S	13:58:57	13:58:58	1.1094	1.1	High voltage

Figure 13: Alarm Log Pop-up Box

Source: CERTS

4.2.4. Event Files

Event detection logic built into the RTDMS server identifies sudden changes in both frequency and voltage magnitude measurements and triggers data and alarm storage into event files over predefined time duration (default duration of these event files is five minutes). These event files can be loaded into RTDMS clients for offline post-disturbance analysis (Figure 14). The details on loading these files and viewing them are provided in Section 11.

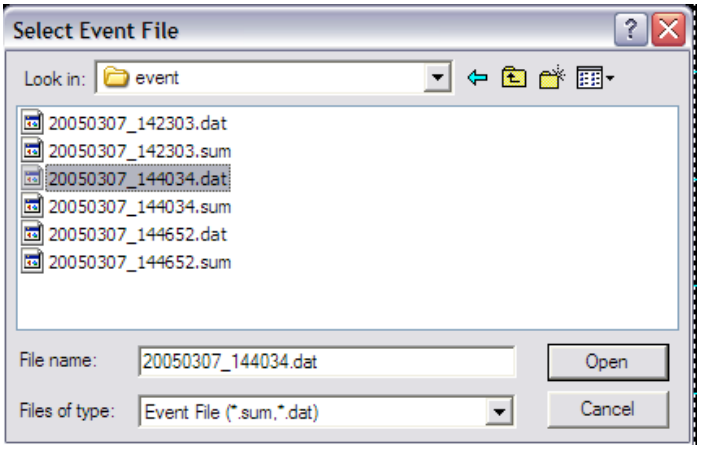


Figure 14: Navigation Window to Load Event Files

Source: CERTS

4.2.5. Navigational Tools

The navigation tools provided to the user can be selected by clicking on one of the seven mouse control icons shown in Figure 15 located in the bottom right corner of all the displays. The functionality of these icons is briefly described in Table 3.

Figure 15: Mouse Control Icons

Table 3: Navigation Tools

Function	Mouse Control Icon	What it does
Selection Arrow	- This is the default Navigation tool. Selecting this tool allows the user to click (either right or left) and move through the different plots and data tables.	Needs to be selected (clicked) prior to selecting the desired area to be viewed.
Zoom In/Out	- Click the magnifying glass to resize the image. With the mouse on the image, hold the button and slide the mouse down or to the left to reduce the size of the image or move the mouse up or to the right to increase the size of the image.	Zoom In – Enlarge the details of the selected area. Zoom Out – Provides an aerial view for a selected area.
Reposition	- Click the cross arrows, move the cursor to the viewing panel, click the left mouse and drag the object to the desired location in the panel	Allows the user to reposition or center objects being displayed in the panel.
Pick to Move Text	- Click on the cross arrows with the pointer, move the cursor to the text label, click the left mouse and drag the text label to the desired location in the panel.	Allows the user to reposition text labels being displayed in the panel.
Pick to Display Data	- Click on the arrow within the question mark to select data within the plot or diagram.	Brings hidden data associated with an object into view.
Rubber Band Zoom	- Click the magnifying glass with the box in the background to select the zoom desired.	Places a box around the desired part of an area or plot to be enlarged. When the right mouse bottom (RMB) is released the selected area will be enlarged.
Restore to Original Size	- Click on the double plot icon to restore the plot or diagram to its original size.	Restores a diagram to its default size when utilized.

Source: CERTS

4.2.6. Replay Function

During real-time operation, the Replay functionality (Figure 16) permits the user to switch from the real-time monitoring mode to the replay mode to view cached data for historical tracking and analyses. Once in the Replay mode, the auto-rewind/auto-forward buttons or the slider can be used to move back/ahead in time and recreate the various RTDMS displays with the cached data.

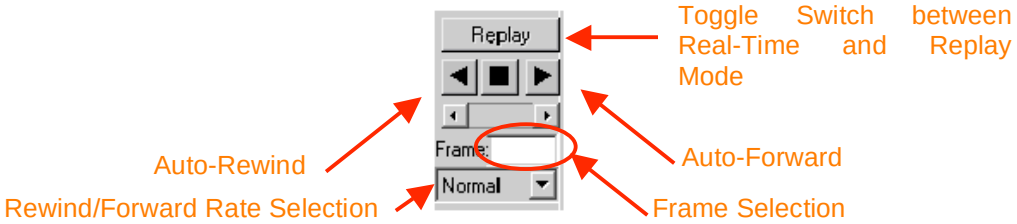


Figure 16: Replay Functions

Once in the Replay mode, the user can move back/ahead in time and recreate the various RTDMS displays using the cached data in one of the following ways:

- Use the Auto-Rewind/Auto-Forward[2] buttons to automatically step back or forth in time. The Rate Selection for the auto-rewind (auto-forward) feature is set though a pull-down menu where "Slow", "Normal", and "Fast" options correspond to a incremental step size of 1 second, 10 seconds and 60 seconds respectively between screen refreshes.
- Use the Slider to manually interrogate the data within the cache.
- Enter the frame number directly into "Frame" box. Each frame index corresponds to a particular slice in time (in seconds). Hence for a one hour long cache, there are 3600 frames with the 3600th frame being the most current set of data and the first frame corresponding to one hour old data.
- Manually enter the Date/Time window to rewind/forward to a desired point in time (Refer to Section 4.2.1).

The use of the replay capability as described above can also be used to interrogate event files when they are loaded into the RTDMS Client. Once in Offline mode, clicking on the "Replay" button brings the user back to the Real-Time operating mode.

Note: When in Replay mode, the screen refreshes are no longer in real-time – their execute times are dependent on the data retrieval times between the Server and the Client.
Whether in Replay or Offline mode, the "Alarm Log" box continues to automatically update with the most recent alarms detected at the RTDMS Server.

4.2.7. Display Title Box

The Title box (Figure 17) identifies the information that is currently being displayed in the "Scroll Monitoring" panel (i.e., the Panel 4 at the bottom of the displays). A Title box with a yellow background implies that the application is being used in a real-time mode for viewing real-time streaming data, while a blue background indicates that the application is being used in an Offline viewing mode for analysis of previously saved event files. These example indicate that the the MVAR flows on Path 75 are being viewed in the "Scroll Monitoring" panel.

Figure 17: Title Box

[2] When using the forward function with the slider positioned all the way to the right, the displays will automatically rewind to start of the cached data and progress forwards from that point onwards.

4.2.8. Data Tables

All the visuals in the application are generated from the input phasor data. This input data is also available in textual format in the Panel 4. In particular, the data associated with the graphics within a particular panel of a display can be examined by selecting the corresponding panel data tab within that display (Figure 18). These data tables can also be enlarged by clicking the box in the upper right hand corner of the data tables.

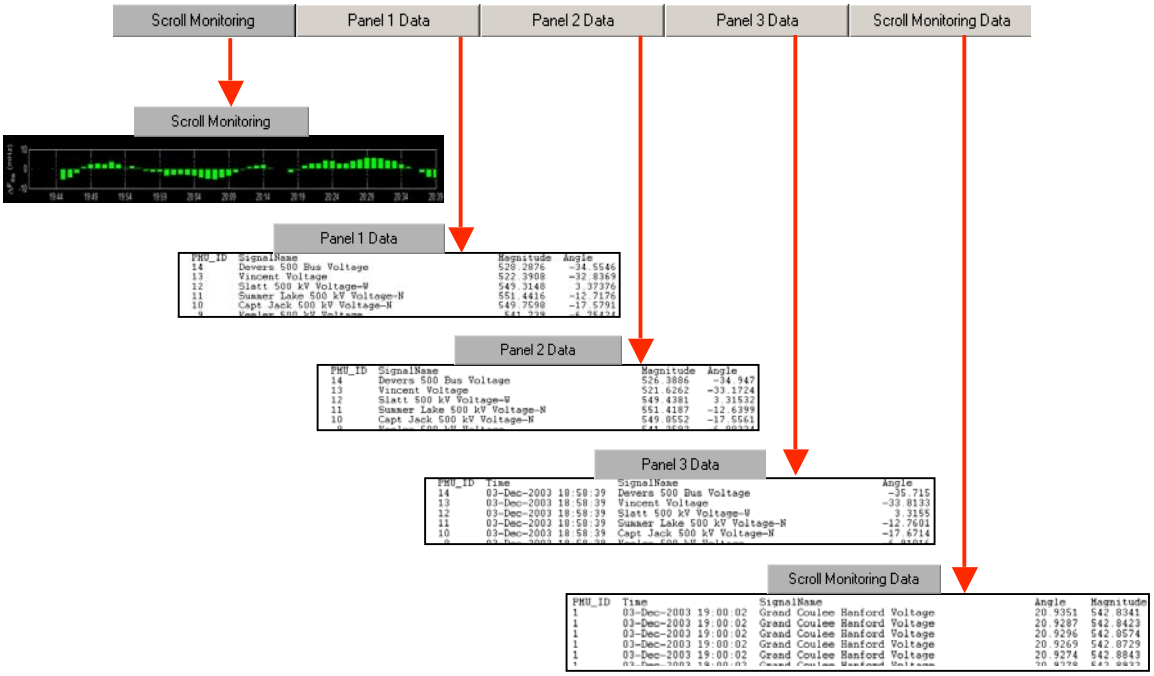


Figure 18: Data Table Overview

The textual information belonging to a particular panel can also be exported to any text editor and printed or saved as a text file. To do this, right click within a particular data panel of interest and the pop-up menu shown in (Figure 19) will appear.

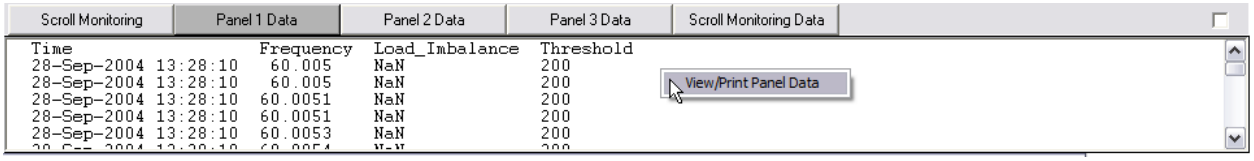


Figure 19: Data Table Print/Save Pop-Up

5. FREQUENCY (RESPONSE) MONITORING

5.1. Overview

Using phasor data, the application is capable of tracking the interconnection frequency in real time. In particular, the fine sub-second resolution associated with phasor technology enables the user to closely monitor and track the interconnection frequency during a disturbance. Furthermore, using a running window to dynamically track the change in interconnection frequency over a specified time interval (i.e., time scales associated with primary control); this frequency response can be accurately mapped to a generation-load imbalance in the system (in MW) through the natural frequency response coefficient for the interconnection.

Phasor data also has the capability of providing synchronized local frequency measurements across the interconnection. The application therefore can track the deviation in each of the local frequencies from the interconnection frequency as well. The maximum separation in local frequencies from the interconnection frequency is a measure of interconnection coherency at each instant in time. Moreover, in the event of a sudden generation-load imbalance, the local frequency having the greatest deviation during the transient timeframe provides a good estimate of the geographic location of the imbalance. All this information is conveyed through the various panels of the “Frequency (Response)” monitoring display.

The “Frequency (Response)” monitoring graphics are shown in Figure 20. In this configuration, the default graphics can be changed in two ways: the corresponding “Generation-Load Imbalance” graphic can be added or the user may go to a “Four-Panel” display where additional information is available. Here, each of the panels in the four-panel display can also be enlarged by double clicking with the left mouse button on the desired panel.

Double clicking in the “Frequency (Response) Monitoring” main panel will take the user to the four-panel display as seen in Figure 20. The four panels can either be viewed together or any one of them can be enlarged individually for easier viewing and analyzing. The user also has the ability to change the time duration in either of these panels. Below is a description of the four panels:

- Panel 1 – “Frequency (Response) Monitoring”, default display.
- Panel 2 – Is the upper right display “Local Frequency Coherence Comparison”.
- Panel 3 – Is the lower right graph “Interconnection Frequency & Imbalance Duration Curves.”
- Panel 4 – Is the bottom panel showing frequency change bar chart or local frequency trend plots.

Panels 2, 3, and 4 can be enlarged by double clicking within the desired panel with the left mouse button. To return to the four-panel display, double left click on the enlarged panel and the four-panel display will be restored.

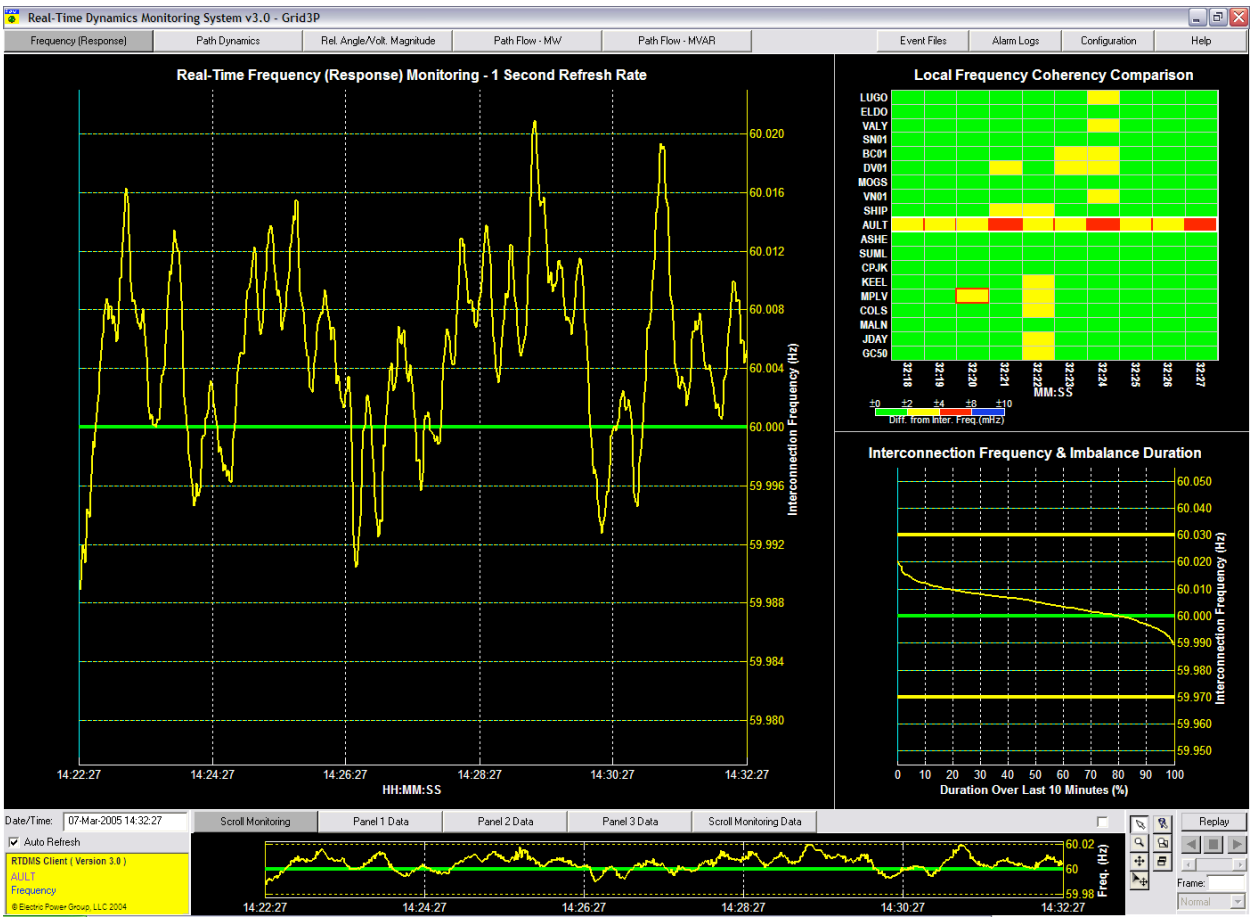


Figure 20: Four-Panel Frequency Monitoring

Source: CERTS

5.2. Frequency (Response) Monitoring One-Panel Display

The "Real-Time Frequency (Response) Monitoring" graph refreshes every second to give the user a real time view of the interconnection frequency[3] at a default one second resolution[4]. However, the resolution may be changed to the higher sub-second resolution to accurately view the interconnection frequency changes in the event of a system disturbance. An additional graph (the "Generation-Load Imbalance (MW)" graph), which maps changes in Interconnection frequency to associated generation-load imbalances within the system, can be overlaid over the interconnection frequency graph.

To have the "Generation-Load Imbalance" graph displayed, right mouse click in the "Real-Time Frequency (Response) Monitoring" default panel. The Display/Duration pop-up box will appear as seen in Figure 21. Select "Generation-Load Imbalance" and this graph will be added to the Interconnection frequency graph.

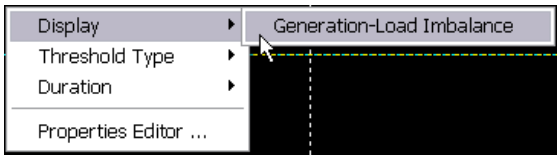


Figure 21: Generation-Load Imbalance Display/Duration Pop-Up

[3] The interconnection frequency is calculated by averaging the local frequencies at each of phasor monitoring points

[4] The one-second resolution data is computed by averaging the sub-second resolution data over the second time interval.

The generation-load imbalance computation is based on the frequency change between the present time and 10 seconds in the past (time scale associated with primary control responsible for the system frequency response), and is appropriately scaled by the "Natural Frequency Response Coefficient" of the Interconnection and displayed as the "Generation-Load Imbalance". During a frequency excursion this graphic will identify both the amount of imbalance (MW) that caused the deviation as well as the recovery of the Interconnection. The "Natural Frequency Response Coefficient" for the Western Interconnection is 1500 MW/0.1 Hz and for the Eastern Interconnection is 3200 MW/0.1 Hz. Both the time duration over which the frequency change is calculated and the imbalance mapping coefficient applied to this change are user configurable through the configuration utility (Refer to Section 10).

In Figure 22, the main display shows both Interconnection frequency and generation-load imbalance. The right axis, in yellow, demonstrates the "Interconnection Frequency (Hz)". The left axis, in cyan, gives the "generation-load imbalance (MW)". Fixed monitoring thresholds for the interconnection frequency appear as bold yellow lines across the chart if the Interconnection frequency approaches the threshold. The default threshold values are set to 59.97 Hz and 60.03 Hz as outlined in the NERC Policy-9 frequency monitoring criteria for reliability coordinators. "...*Take remedial actions when interconnection frequency error is in excess of 0.07 Hz for more than 20 minutes*...", but may be changed by the user through the configuration utility. Alternately, using an option in the pull-down menu (Figure 23), the user may replace the fixed thresholds by soft thresholds defined as a set number standard deviation of the mean value calculated from the Interconnection frequency data over the specified time duration within the chart (Refer to Section 10).

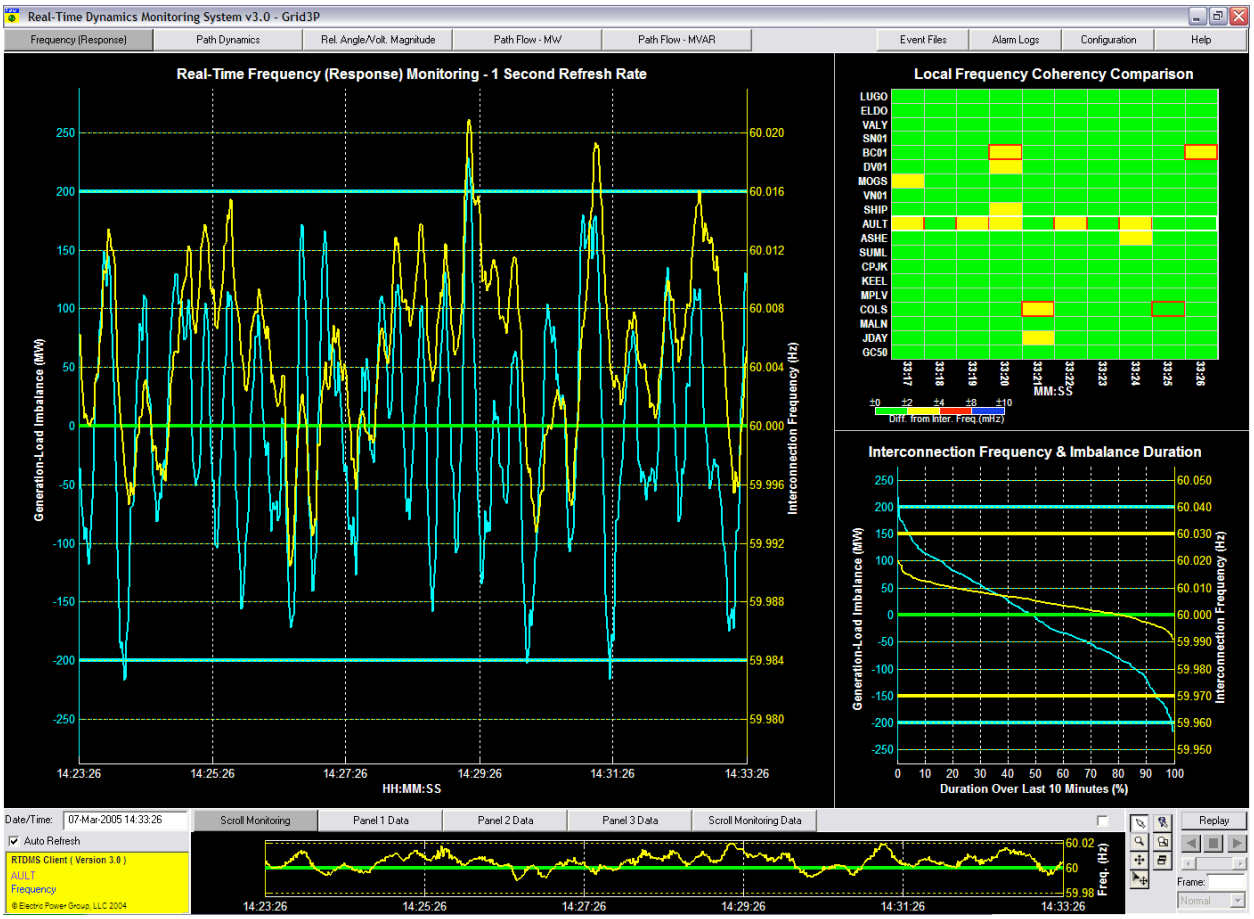


Figure 22: Four-Panel Frequency/Generation-Load Imbalance Monitoring

Source: CERTS

The “generation-load imbalance” threshold lines (cyan) also appear when this plot is displayed. While the default thresholds for the generation-load imbalance (cyan) value are ±200 MW, it can be changed through the configuration utility as well (Refer to Section 10).

Figure 23: Soft/Hard Threshold Selection Pop-Up

The default duration time for the “Real-Time Frequency (Response) Monitoring” graph is 10 minutes. This duration can be changed by clicking the right mouse button within the panel; the Display/Duration pop-up box will appear as seen in Figure 24. The time duration desired can then be selected for the panel[5].

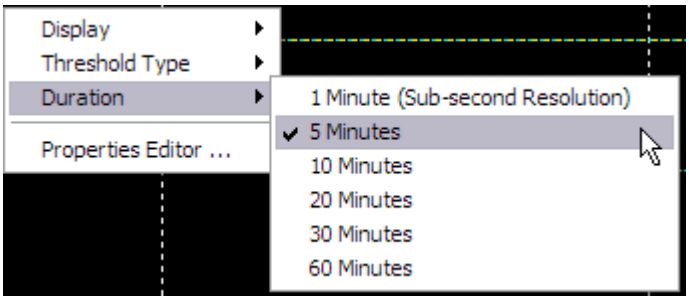


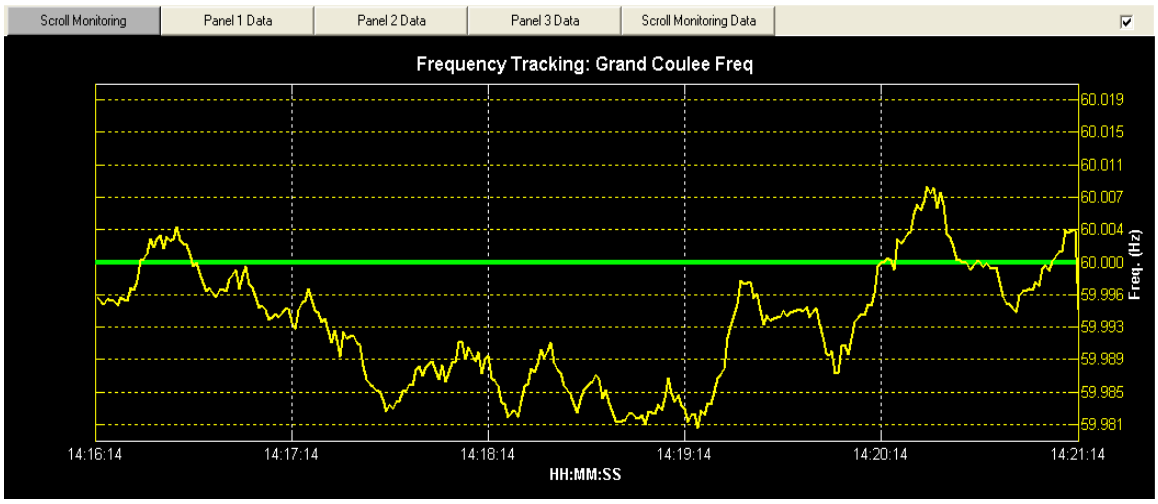
Figure 24: Frequency /Imbalance Duration Selection Pop-Up

The “Scroll Monitoring” panel button, highlighted in Figure 25, is one of five selections for the window beneath the main panel. As a default, here the change in frequency over the specified time duration is displayed on a bar chart. Alternately, through a pull-down menu option, this plot can be replaced by a trend plot of local frequency measurements at any of the available PMU locations. The PMU whose frequency measurements are to be displayed in this panel is chosen by clicking within the row corresponding to this PMU in the “Local Frequency Coherence Comparison” plot shown in panel 2 (see Section 5.3). In either case, time duration for these plot matches the duration set for the frequency monitoring display in panel 1.

The remaining four tabs “Panel 1 Data”, “Panel 2 Data”, “Panel 3 Data” and “Scroll Monitoring Data” provide data in tabular and textual format for the plots in each of the corresponding panels of the four-panel display. Each of the five selections can also be enlarged by either clicking in the upper right hand corner box or double clicking on the display. Remove the check in the box or double click within the display to return the bottom panel to its default display.

[5] If a one-minute duration is selected, then the data used in the plot for the frequency and the imbalance data are at its highest sub-second resolution that is needed for detailed visibility of transient frequency responses

(a)



(b)

Figure 25: Scroll Monitoring Graph (Enlarged) – (a) Delta Interconnection Frequency (b) Local Frequency Trend Plot at PMU Location.

5.3. Frequency (Response) Monitoring Four-Panel Display

In the four-panel view, the "Real-Time Frequency (Response) Monitoring" graph described in section 5.2 is displayed as Panel 1. Panel 2 is the upper right display "Local Frequency Coherence Comparison" and Panel 3 is the lower right graph "Interconnection Frequency and Imbalance Duration Curves." Panel 4 is the "Scroll Monitoring" frequency change bar chart explained in the previous section. Panels 2 and 3 can be enlarged by double clicking within the desired panel with the left mouse button. To return to the four-panel display, double left click on the enlarged panel and the four-panel display will be restored. Panel 4 can be enlarged or reduced by clicking on the upper right hand corner box.

In Panel 2, the objective of the "Local Frequency Coherence Comparison" display (Figure 26) is to provide the operating staff with a quick source of information on the spread in local frequencies as a measure of dynamic stress being exerted on the system under normal conditions. Furthermore, in the event of an outage, it will help identify which area of the Interconnection experienced a loss of load or generation causing a noticeable local frequency deviation over the transient timeframe.

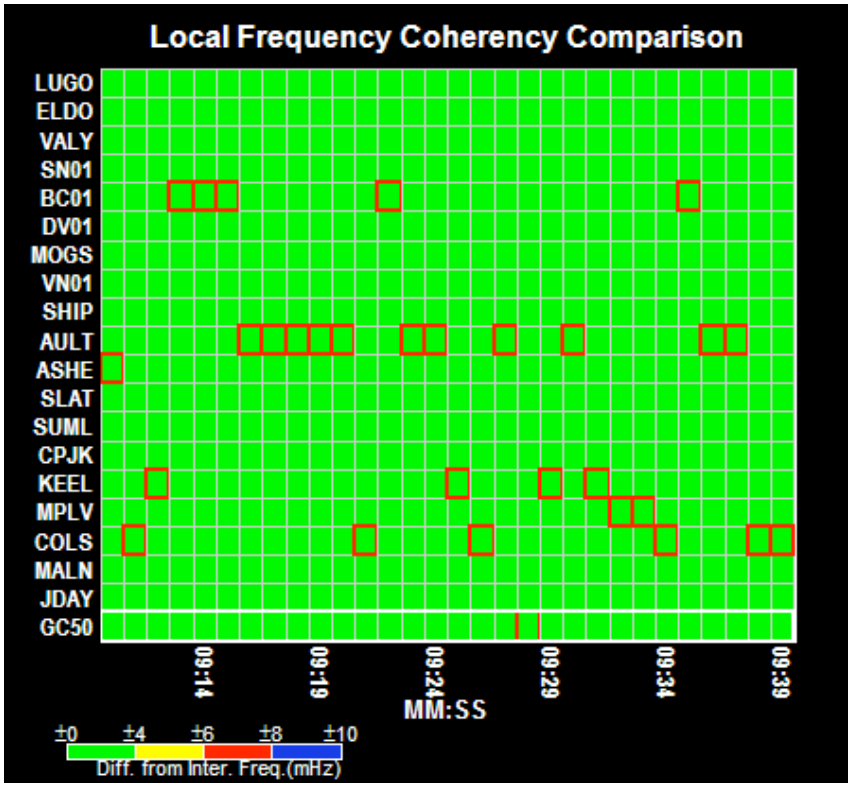


Figure 26: Local Frequency Coherence Comparison (Panel 2)[6]

Source: CERTS

The x-axis of the plot is the time in minutes and seconds (MM:SS). The duration time for the plot can be changed by the user. To change the time (x-axis), right click in Panel 2. Figure 27 will appear and it lists the selectable time periods available for the panel.

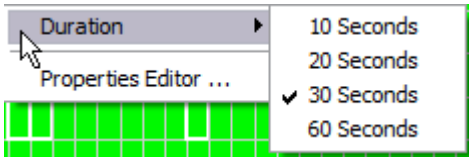


Figure 27: Local Frequency Coherence Comparison Duration Selection Pop-Up

The color legend represents the four (4) levels of deviation from the Interconnection frequency (Figure 28).

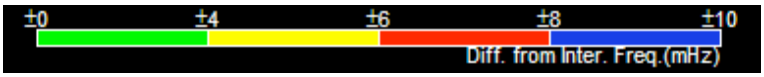


Figure 28: Local Frequency Coherence Comparison Legend

The y-axis lists the PMU locations where local frequency data is available for comparison. To the right of each PMU is a series of rectangles along the time axis that will indicate (using color) its frequency deviation from the system frequency at a particular instance in time.

In addition, at each slice in time, the one cell associated with the PMU measuring the largest local frequency deviation for that time instance will be highlighted with a border around it as well. In the event

[6] Any black (blank) cells in the plot indicate absent phasor data.

of a major frequency excursion, the PMU reporting this greatest frequency deviation is most likely to be in the close proximity of the area that experienced the problem.

The “Interconnection Frequency and Imbalance Duration Curves” in Panel 3 (Figure 29) presents a statistical distribution of the interconnection frequency as the default graph.

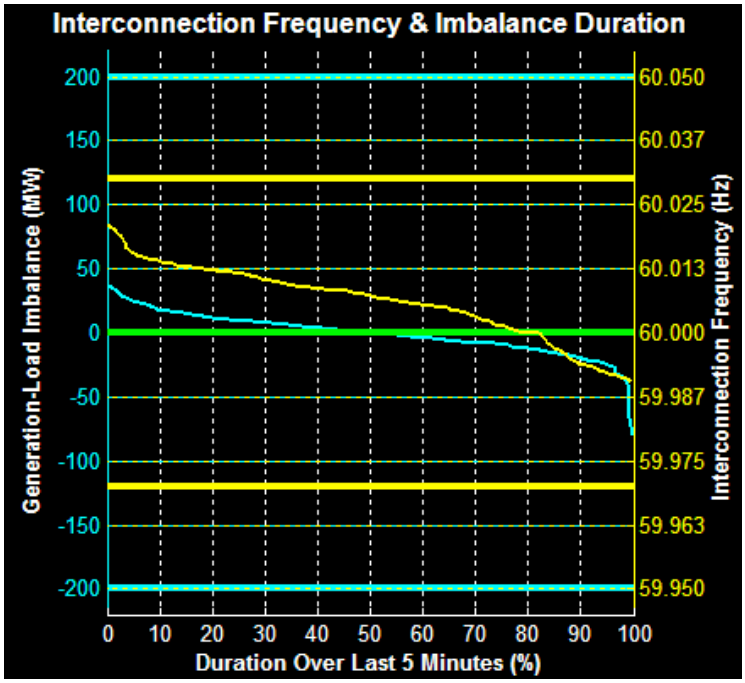


Figure 29: Interconnection Frequency & Imbalance Duration Curves (Panel 3)

Source: CERTS

The statistical distribution for the generation-load imbalance graph can be added by right clicking in the panel and selecting “Generation-Load Imbalance” (Figure 30). The thresholds and the y-axis are the same as for Panel 1. The x-axis shows the percentage of the time that the interconnection frequency was above/below nominal frequency. The generation-load imbalance line demonstrates the percentage of time that the interconnection imbalance was above/below zero. As with other graphs, the duration over which the distribution is computed can be changed through a pull-down menu made available through a right click within the panel (Figure 31).

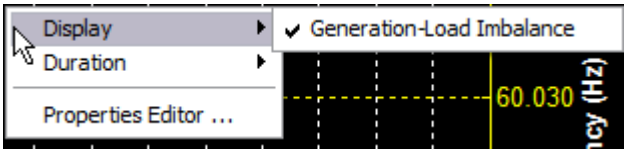


Figure 30: Interconnection Frequency and Imbalance Duration Curves Display Pop-Up

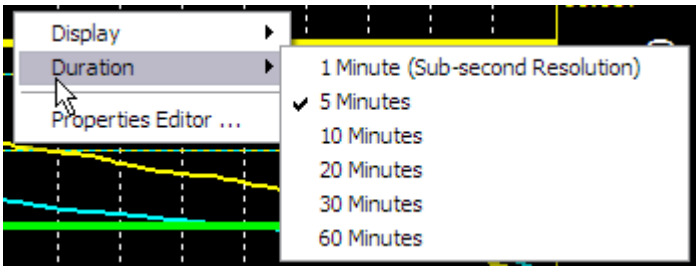


Figure 31: Interconnection Frequency and Imbalance Duration Curves Duration Selection Pop-Up

6. PATH DYNAMICS MONITORING

6.1. Overview

The "Path Dynamics" monitoring display will allow the dispatcher to monitor voltage angle differences between key monitoring points in the power system and track associated dynamics in real time with respect to predetermined thresholds. The identified "paths" (i.e., voltage phase angle differences between the two points in the system for which phasor measurements are available) and their corresponding thresholds are user-defined and shall be obtained from offline stability studies. The application continuously tracks these angle differences across all the identified paths and displays them as colored arrows between the points defining the paths in the display. A change in the angle differences would be an indication of a change in the power transfer across the path or a change in system configuration, while the size of the angle difference would indicate the stress or lack of stress the transmission system is undergoing.

The "Path Dynamics" tab function is similar to the "Frequency (Response)" tab with the exception that it offers the ability to visualize the data and graphics in two views: a "Wide Area" view (Figure 32) and a "Local Area" view (Figure 33).

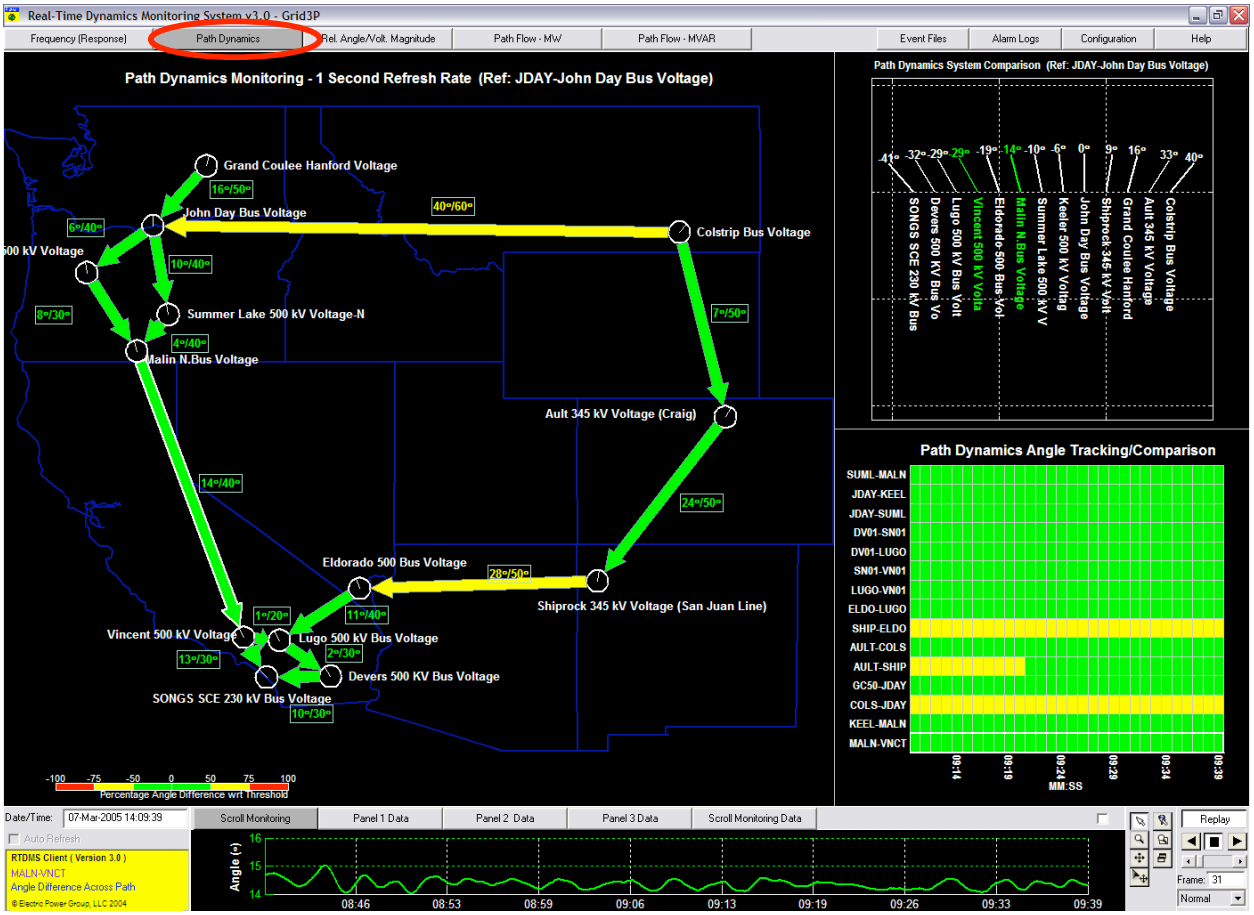


Figure 32: Four-Panel Path Dynamics Monitoring (Wide Area)

Source: CERTS

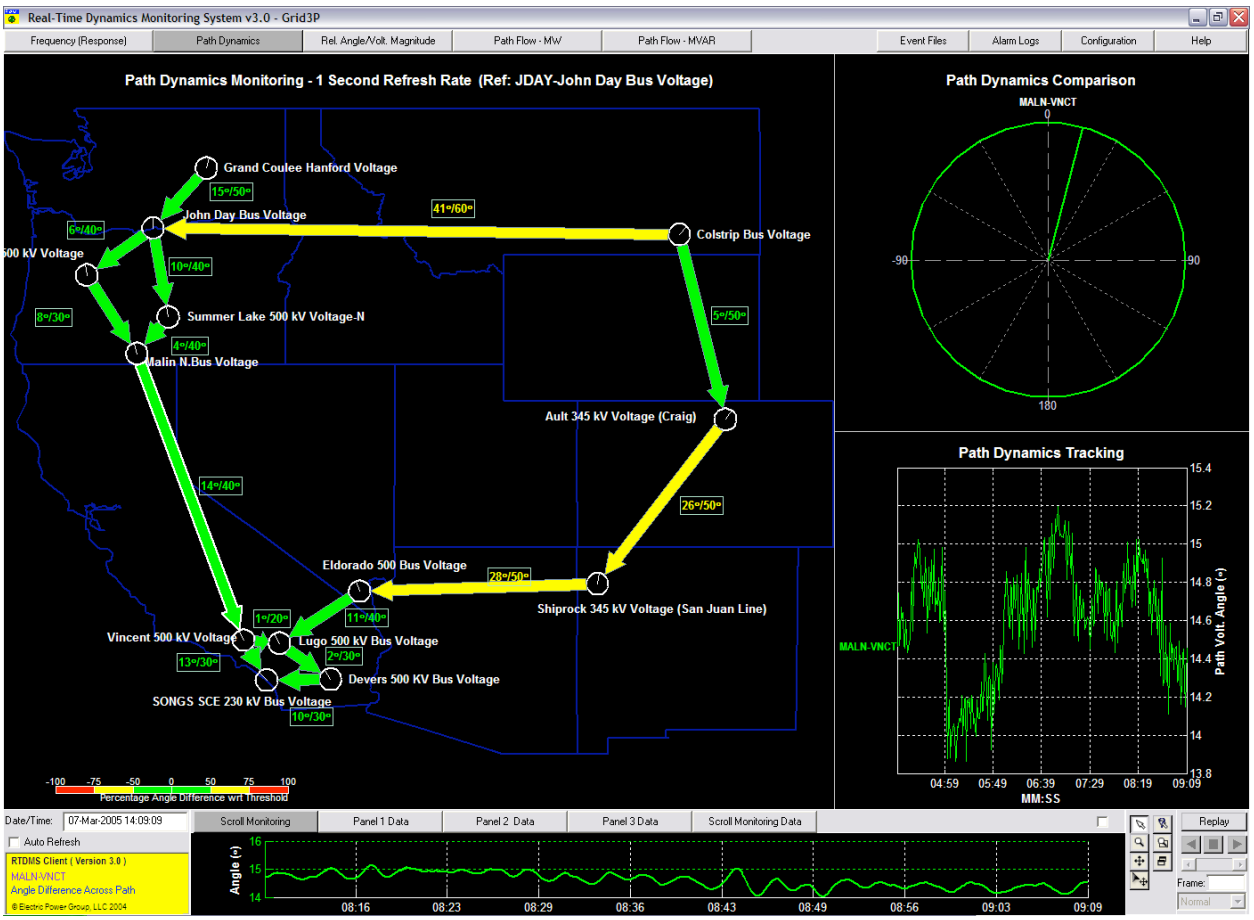


Figure 33: Four-Panel Path Dynamics Monitoring (Local Area)

6.2. Path Dynamics Monitoring One-Panel Display

The "Path Dynamics" one-panel display is selected by clicking on the "Path Dynamics" tab (red circle in Figure 32). The angle difference across a path is displayed as a color-coded arrow connecting the two phasor monitoring points that define the path. The direction of arrow is defined such that it points from the larger of the two angles to the smaller one to demonstrate the direction of the power flow and can therefore change under varying system and market conditions.

The color of the arrow is based on a legend located in the bottom left hand corner of the display (Figure 34). Its colors indicate the proximity (in percentage) of the actual phase angle difference across the path to the predefined alarming threshold defined for it. This actual angle value (the number on the left) and the alarming threshold (the number on the right) are shown in a box adjacent to the colored arrow as well.

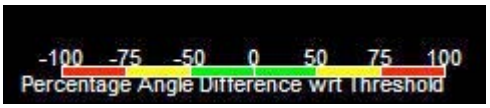


Figure 34: Path Dynamics Legend

Note: While the arrow and the adjoining text indicates the angle difference between the two monitoring points, the dials at the two ends of the arrow represent the measured angles at each of these points where the dial's needle orientation with respect to the vertical is representative of the angle being measured at that location with respect to a common reference angle (Refer to Section 7).

Example: In Figure 33, the Malin-Vincent path has been selected and it has an actual voltage angle difference of 14° (i.e., the difference between the voltage angle measured by the Malin PMU and the voltage angle measured by the Vincent PMU is 14 °). This angle difference must not exceed a preset threshold value of 40°. The correct threshold limit for this path is derived by offline engineering studies, and updated into the application through the configuration utility (Refer to Section 10). An actual angle difference of 14° implies that this angle is 35% of its 40° threshold limit. From the color legend (Figure 34), the Malin-Vincent path is shown as a green arrow since this percentage value falls below 50%.

The default setting for the "Path Dynamics Monitoring" panel is to display the actual angle difference values, station names, and thresholds next to the path arrow. The names and angle difference associated with the paths can be removed from the display, if desired. To do this, right mouse click in the "Path Dynamics Monitoring" panel and the pop-up menu box shown in Figure 35 will appear. Deselect the "Station Name" and "Path Angle Value" and the name and values will disappear.

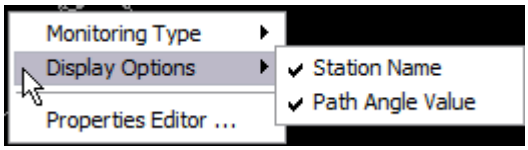


Figure 35: Path Dynamics Display Pop-Up

Under the "Scroll Monitoring" display, located below the main path display (display is enlarged by clicking check box in upper right corner) user will find the phase angle difference for the last selected path (Figure 36). To select a specific path to be displayed on the scroll monitoring panel, first make sure you have clicked on the "Selection Arrow" (bottom right), and then point and click on the desired path to be tracked. The outline of the path arrow will turn white indicating it was selected. The path name on the scroll monitoring display should reflect the line selected. In this view the Malin-Vincent path has been selected. The y-axis on the left of the plot is the angle difference (in degrees), while the x-axis is time in minutes and seconds (MM:SS) with the most current time to the right of the axis. This plot allows the user to track the angle difference across the path over the past minute at the highest sub-second resolution.

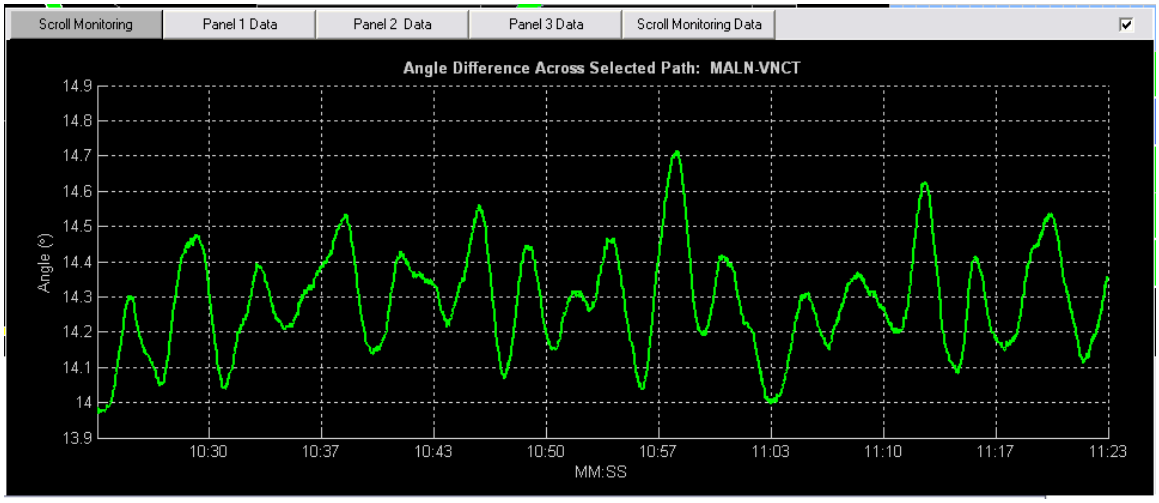


Figure 36: Selected Path Angle Difference Tracking (Enlarged)

Source: CERTS

6.3. Path Dynamics Monitoring Four-Panel Display

A double left mouse click in the default one-panel will take the user to the four-panel display. This may also be done using a right mouse click within the one-panel display to show the pop-up menu box and to select the desired four-panel view ("Wide Area Monitoring/Tracking" or "Local Area Monitoring/Tracking") from the menu (Figure 37).

Figure 37: Path Dynamics Monitoring Type Pop-Up

6.3.1. Path Dynamics – Wide Area Monitoring/Tracking

Select the "Wide Area Monitoring/Tracking," and the view shown in Figure 38 will be presented. Each of the three panels (panel 1, panel 2 and panel 3) can be enlarged by double clicking with the left mouse button within the panel.

In this view, the "Path Dynamics Monitoring" display described in Section 6.2 is shown in Panel 1 of the four-panel display. Panel 2 in the upper right corner is the "Path Dynamics System Comparison" display and panel 3 in the lower right corner is the "Path Dynamics Angle Tracking/Comparison" display. Panel 4 is the "Scroll Monitoring" plot that was explained in the previous section.

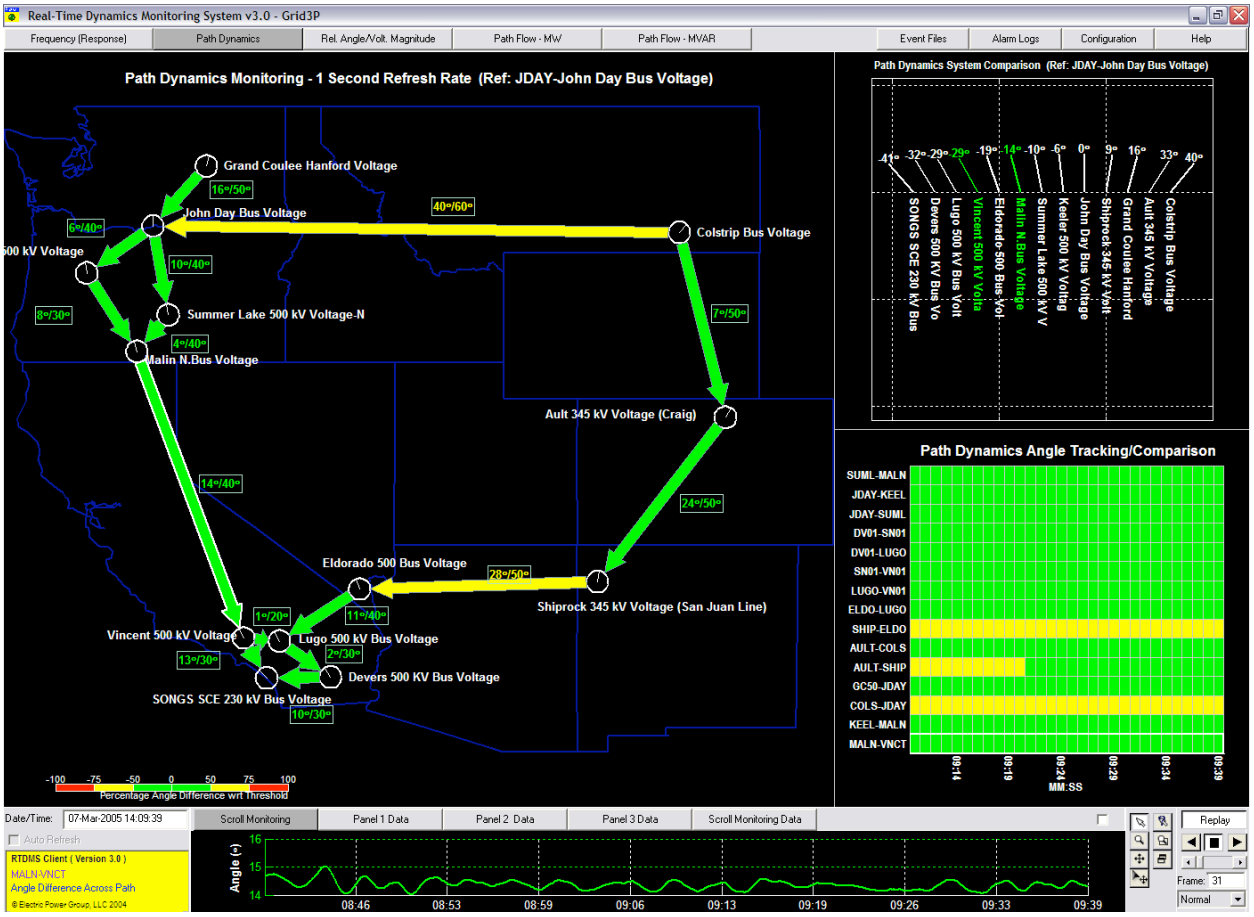


Figure 38: Four-Panel Path Dynamics – Wide Area Monitoring/Tracking

Source: CERTS

The “Path Dynamics System Comparison” display uses a feather plot to let the user analyze the phase angle behavior at the source and sink of a selected path with respect to the angles at the sources/sinks of all the identified dynamics paths shown in Panel 1. Each vector of this plot corresponds to a monitoring location, and the orientation of this vector with respect to the vertical represents the voltage angle being measured at that point with respect to a common reference[7] (Note: Increase in angles corresponds to a clockwise rotation with respect to the vertical). In the display above (Figure 38), John Day is the reference and will be displayed as a vertical vector (i.e., 0 degrees). Furthermore, the vectors in the feather plot are ordered such that the points to the right of reference will have a leading angle and the points to the left will have a lagging angle (Figure 39). As power flows from larger angles to smaller angles, this sorted plot offers a wide-area view of the power flows within the system. Finally, the two vectors representing the source and sink of the selected path are color-coded based on the legend in Figure 34.

Example: In the display below (Figure 39), the Malin-Vincent path has been selected. The path is shown by a solid yellow arrow in the geographic display (Figure 38, panel 1). In the feather plot, the vectors corresponding to the source and sink of this path (i.e., Malin and Vincent) also appear in the color of the path arrow (green in this example).

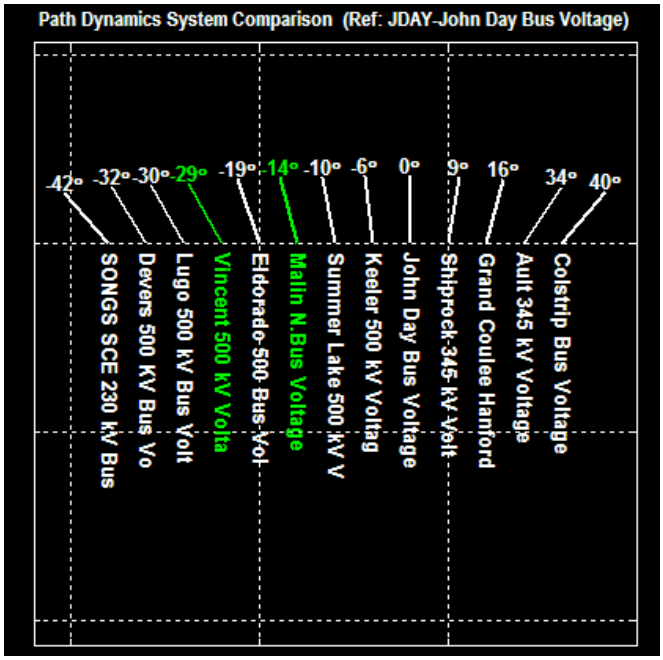


Figure 39: Path Dynamics System Comparison (Panel 2)

Source: CERTS

The graphics in the “Path Dynamics Tracking/Comparison” panel provides a birds-eye view of the phase angle difference across all the identified paths for tracking and comparison purposes (Figure 40). The x-axis of the plot is time in minutes and seconds (MM:SS) and the y-axis lists the identified paths. Hence, each cell in the plot corresponds to a particular path and time, and the color coding of the cell, which represents the phase angle difference across the path, can be cross-referenced to the color legend at the bottom of the geographic display in Panel 1 (Figure 38). The default time duration for the plot is 30 seconds and may be changed by the user.

[7] The reference may be changed and is described in Section 7.2.

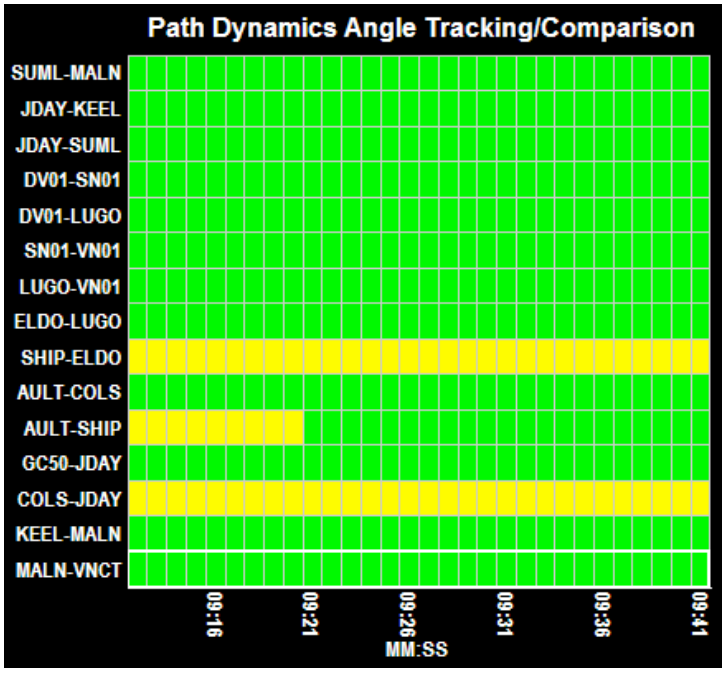


Figure 40: Path Dynamics Tracking Comparison (Panel 3)

To set the desired time duration, left click in the "Path Dynamics Tracking/Comparison" panel and the pull-down menu shown in Figure 41 will appear. Select the desired duration from the available options.

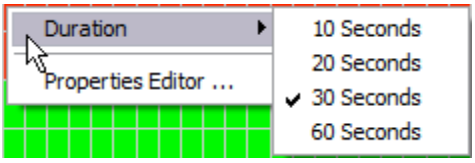


Figure 41: Path Dynamics Tracking Comparison Duration Pop-Up

6.3.2. Path Dynamics – Local Area Monitoring/Tracking

While the "Wide Area Monitoring/Tracking" view provided a macroscopic understanding of the angle differences across identified paths in relation to the overall system behavior, the purpose of "Local Area Monitoring/Tracking" view is to let the user get more specific data and information about specific selected paths.

Selecting "Local Monitoring/Tracking" option from the menu in Figure 37 will present the four-panel display as seen in Figure 42. Double left clicking either in Panel 1, Panel 2, or Panel 3 of the display will enlarge the corresponding panel.

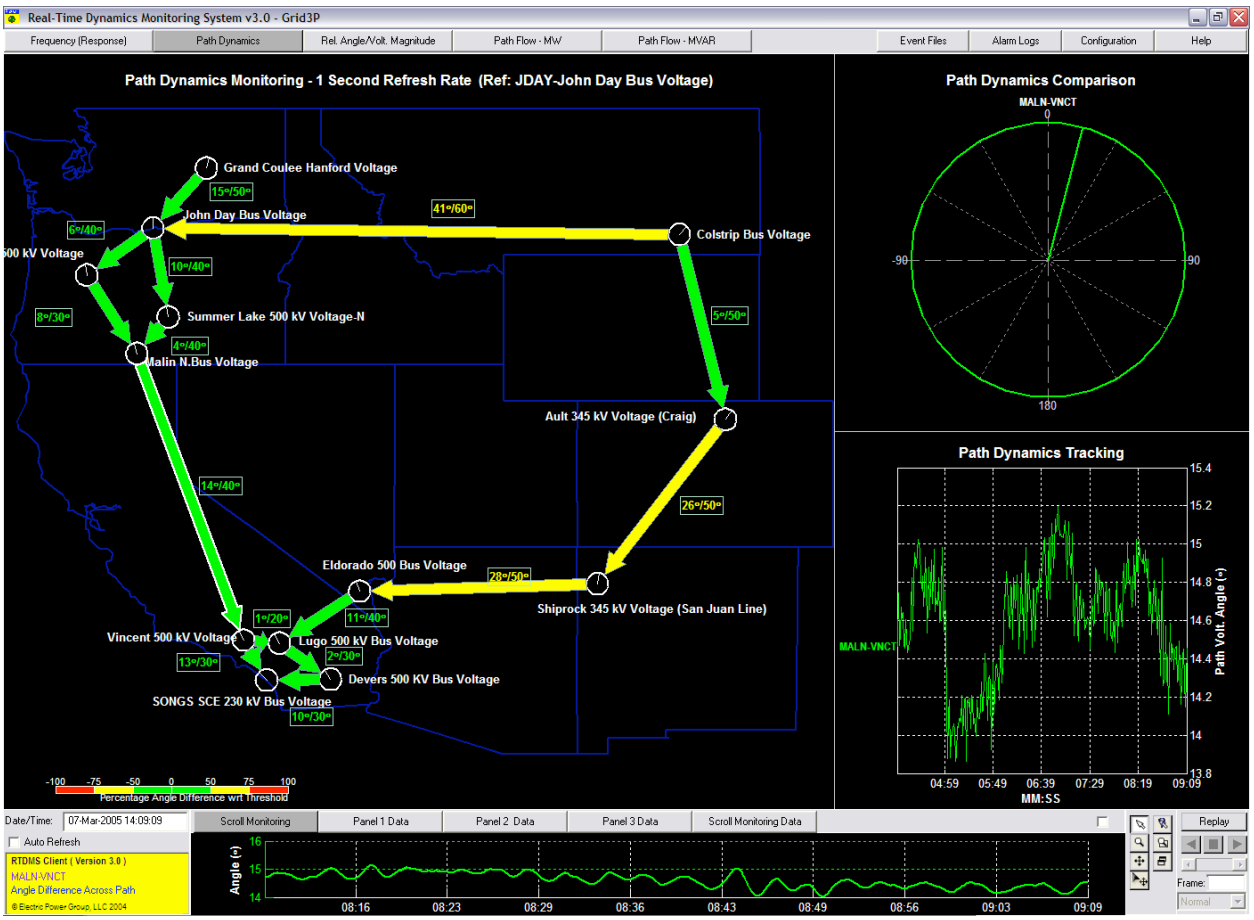


Figure 42: Four-Panel Path Dynamics - Local Area Monitoring/Tracking

Source: CERTS

The "Path Dynamics Comparison" in Panel 2 allows the user to compare the phase angle differences across a set of selected paths. The user may left mouse click on any of the arrows shown in Panel 1 to select/deselect a path and the phase angle difference across the path is added to Panel 2 as a dial where the orientation of the dial with respect to the vertical is indicative of the angle. The color of the dial matches the color of the path arrow selected, both of which are determined by the color legend in the geographic panel (Figure 34).

The "Path Dynamics Tracking" in Panel 3 provides a historical profile of the phase angle differences across the set of selected paths at the second resolution. The x-axis of the plot is time in minutes and seconds (MM:SS) and the y-axis is the angle difference in degrees. As with all other plots, the time duration of the plot may be altered via a pull-down menu made available by using the right mouse click within the panel.

<u>Example</u>: In Figure 42, the Malin-Vincent path has been selected and shows the corresponding graphics in Panel 2 and Panel 3 of the display. In Panel 2, the angle across the path is shown as a dial where the needle of the dial makes a 14° angle with the vertical axis in the clockwise direction to indicate the angle difference across the path. In Panel 3, the time history for the angle across the path is shown over the past five minute interval (default time duration) and at a second resolution.

Multiple paths (maximum 6) can be selected and displayed in the "Path Dynamics Comparison" and the "Path Dynamics Tracking" graphics. The selected paths will appear as seen in Figure 43. Note that each selected path arrow is outlined in white.

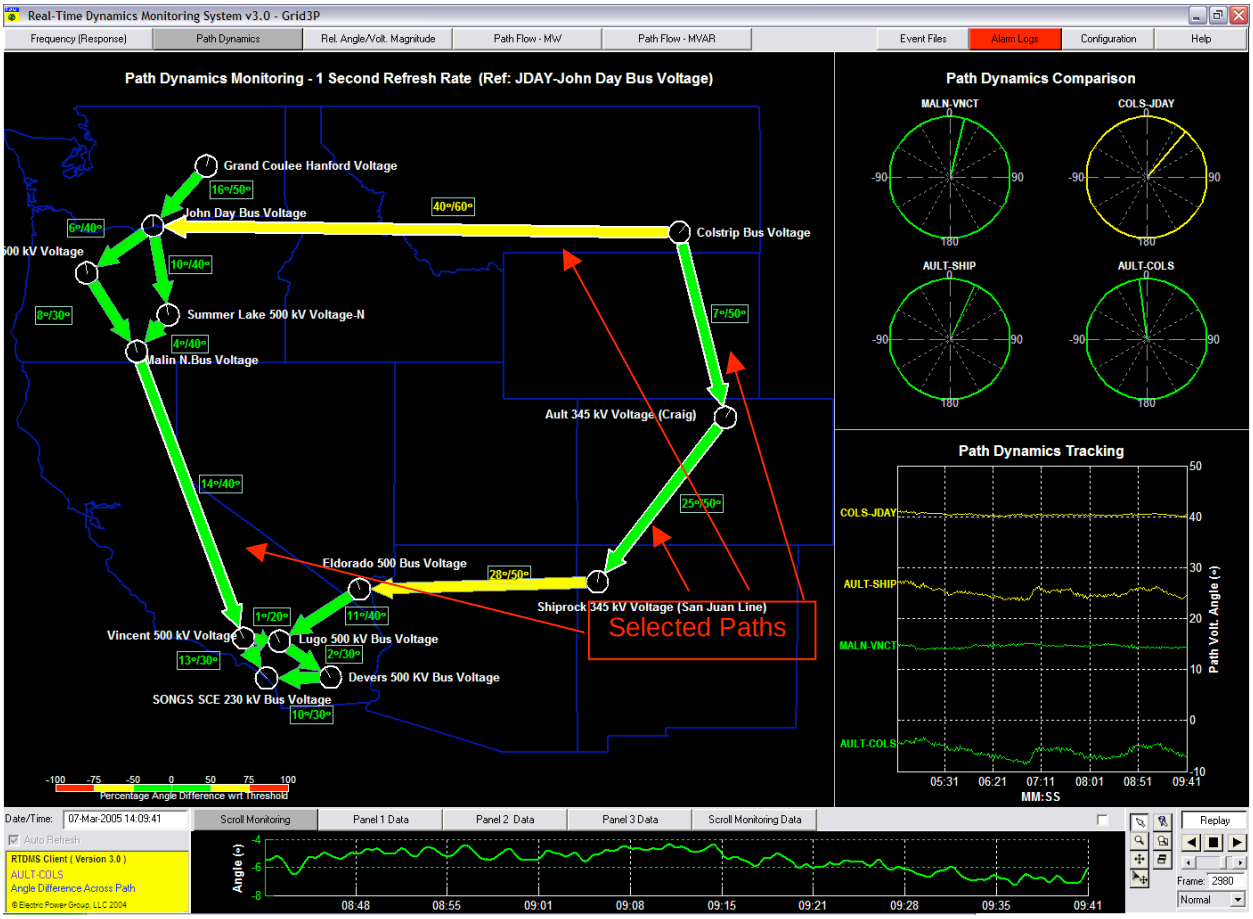


Figure 43: Four-Panel Path Dynamics - Local Area Monitoring/Tracking (Four Paths Selected)

Source: CERTS

7. RELATIVE ANGLE\VOLTAGE MAGNITUDE MONITORING

7.1. Overview

The value of phasor technology lies in its capability to precisely and simultaneously measure voltage phasors (i.e., voltage angles and voltage magnitudes) at various points across the power system at a high rate and to provide accurate timing information along with these measurements. This display shows the voltage angle and voltage magnitude measured at each of the phasor monitoring points on a geographical map. The voltage angles are measured relative to a common selectable reference for the grid (i.e., the angle difference between a monitoring point and the reference point). Such a geographic angle and voltage magnitude profile provides a bird's-eye view of the sources and sinks of power across the grid, the high- and low-voltage regions within the system, as well as helps identify regions that may be operating under stressed conditions.

Like the "Path Dynamics" monitoring display, the "Relative Angle/Voltage Magnitude" monitoring display also offers a "Wide Area" (Figure 44) and a "Local Area" (Figure 45) view, and the user can select between the two views using options available within a pull-down menu.

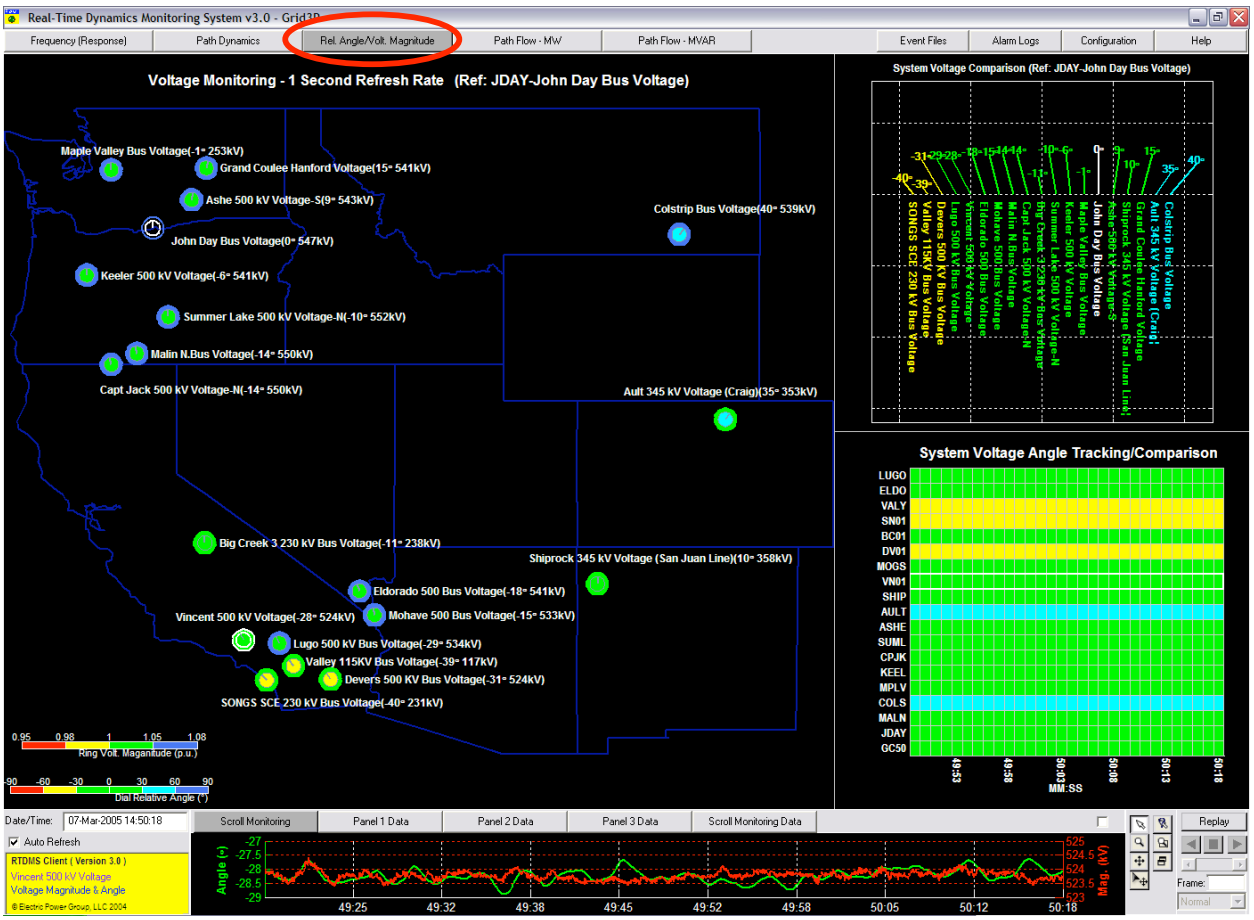


Figure 44: Four-Panel Relative Angle/Voltage Magnitude Monitoring (Wide Area)

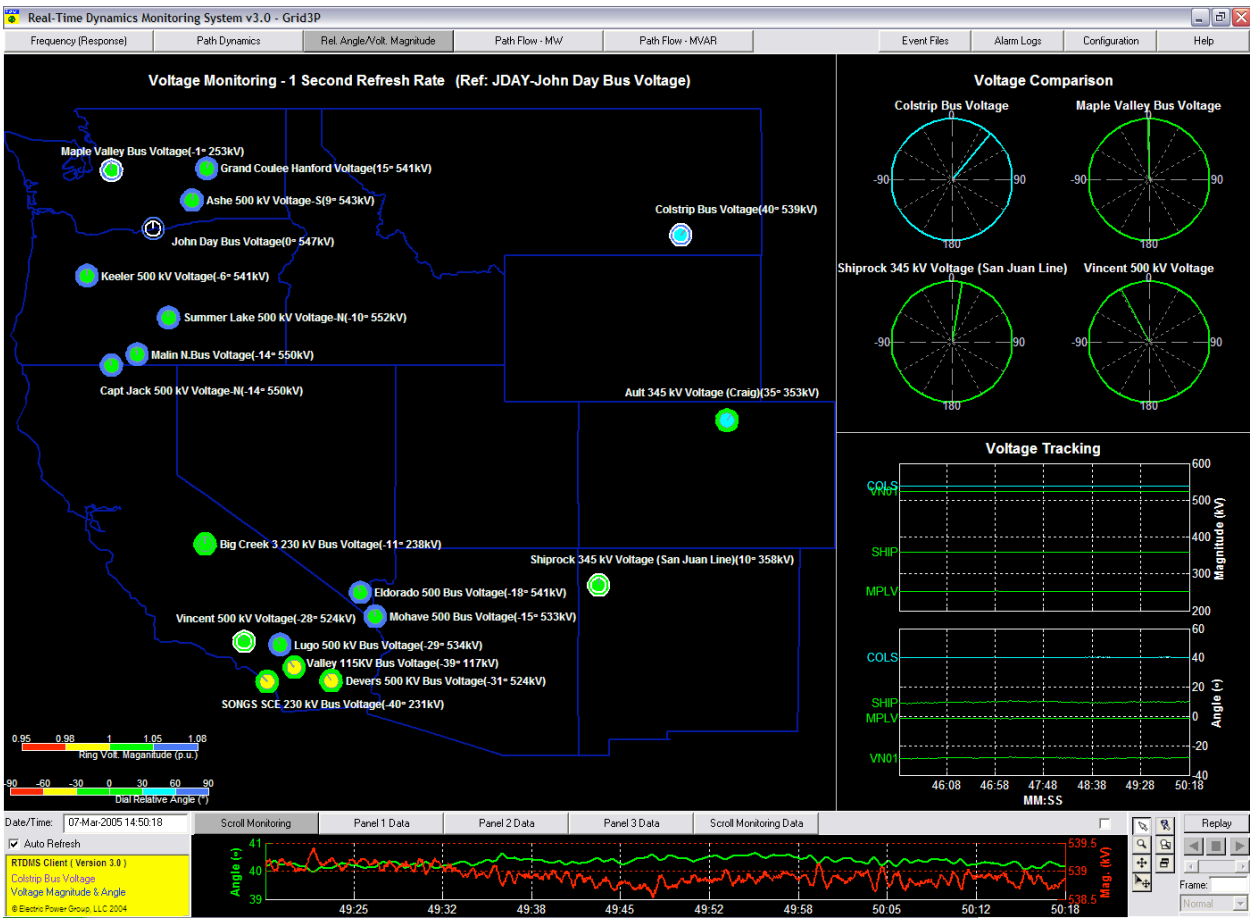


Figure 45: Four-Panel Relative Angle/Voltage Magnitude Monitoring (Local Area)

7.2. Relative Angle/Voltage Magnitude One-Panel Display

Selecting the "Relative Angle/Voltage Magnitude" tab at the top of any of the displays will bring up just Panel 1, the left panel in Figure 44. In Panel 1, the voltage angles with respect to a common reference are displayed as a dial at the corresponding monitoring location in a geographic display, while the voltage magnitudes are indicated by a color-coded ring around the corresponding dial within the geographic display. Both the orientation of the dial's needle with respect to the vertical and its color are representative of the angle being measured at that location (Note: Increase in angles corresponds to a clockwise rotation with respect to the vertical). The legends used this color-coding are located at the bottom left of the display (see Figure 44). The voltage angle and voltage magnitude legend is also color-coded based on "per-unit" values (Figure 46).

Figure 46: Relative Angle/Voltage Magnitude – Relative Angle and Voltage Magnitude Legends

Example: In Figure 49, the Vincent voltage is 524 kV (outer ring is green), which is between 1.00 p.u. and 1.05 p.u. This second ring allows the user to visually scan for abnormal voltages both above and below the nominal values.

The reference for all the angles in the display is the one dial that is not colored (Grand Coulee in Figure 44). This reference can be changed by the user.

To change the reference for the system angles, right mouse click on the monitoring location that is to set as the reference and the pop-up menu box shown in Figure 47 will appear. Select the “Set as Reference” option and the appropriate voltage from those available for that particular monitoring location.

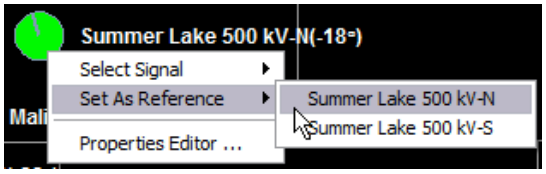


Figure 47: Voltage Monitoring Reference Selector

In addition to the angle information, the user may also choose to view the voltage magnitude information at each of the monitoring locations. This is done by right mouse clicking within the geographic display and selecting the “Include Volt. Magnitude” option in the pull-down menu box. The same menu can be used to display the “Station Name” or “Signal Value” next to the monitoring location within the geographic display (Figure 48).

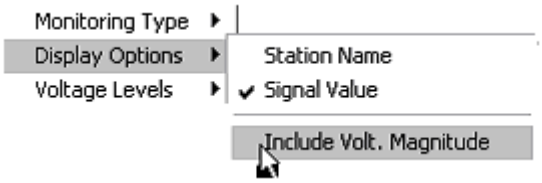


Figure 48: Relative Angle/Voltage Magnitude Display Options Pop-Up

When the voltage magnitude information is chosen, it is displayed along with angle information as a ring around the dials where the color and the size of the ring are indicative of the voltage magnitude (Figure 49). The voltage magnitude legend is color-coded based on “per-unit” values (Figure 46).

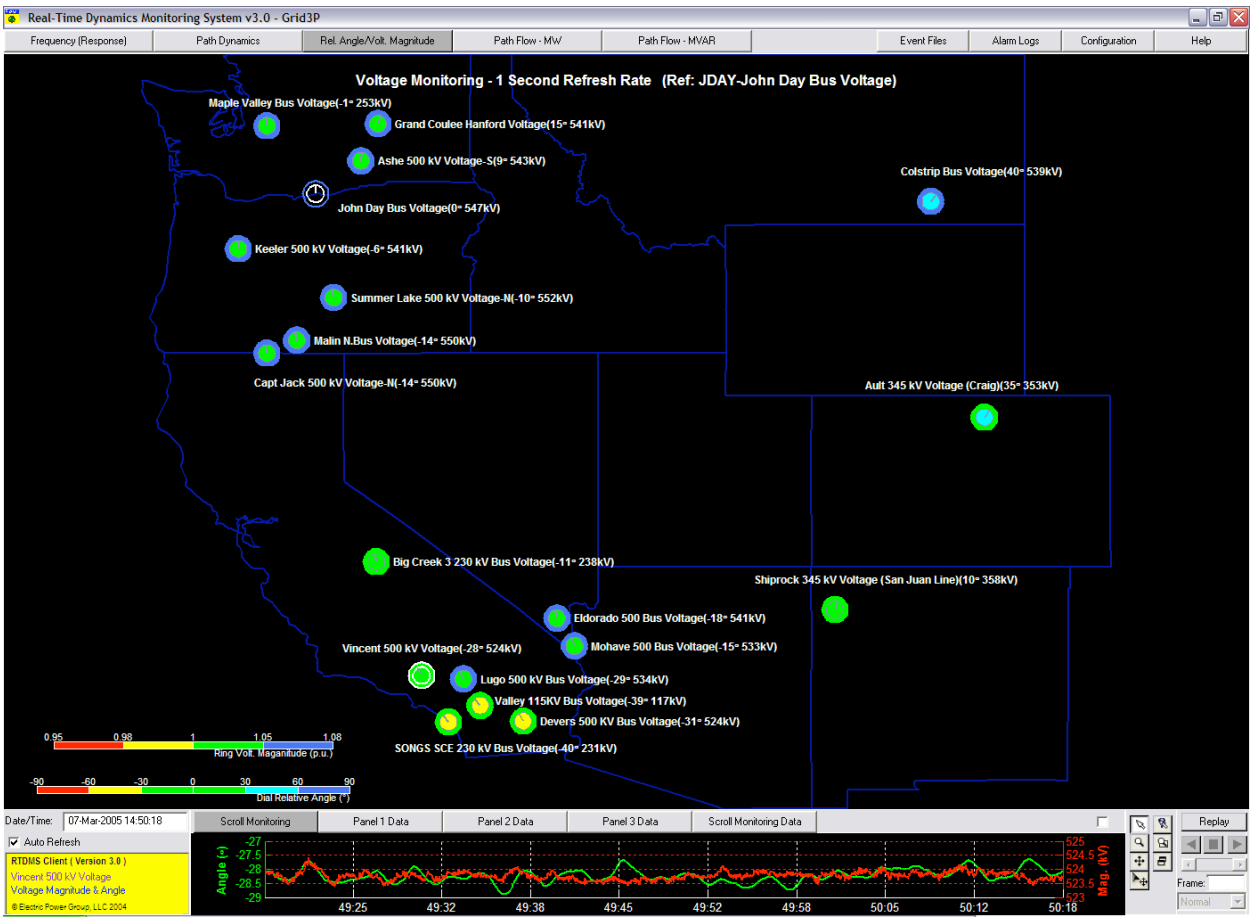


Figure 49: One-Panel Relative Angle/Voltage Magnitude with Voltage Magnitude Information

Source: CERTS

The display also allows the user to be selective in viewing the angles and voltage magnitudes being displayed based on their voltage levels. This is done via a right mouse click within the geographic display to show the pop-up menu box in Figure 50. The default setting is "All" for the "Voltage Levels". To change to a specific voltage level, right click on the desired voltage. In doing so, only those monitoring points whose voltages belong to the selected voltage level will appear in the geographic panel.

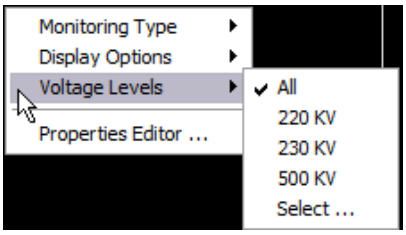


Figure 50: Relative Angle/Voltage Magnitude Voltage Levels Pop-Up

The "Scroll Monitoring" at the bottom of Panel 1 tracks the relative angle of the last selected monitoring location at the highest sub-second resolution over the past one minute (Figure 51). Furthermore, if the "Include Volt. Magnitude" option has been selected (Figure 48), then the voltage magnitude at this monitoring location is also shown here.

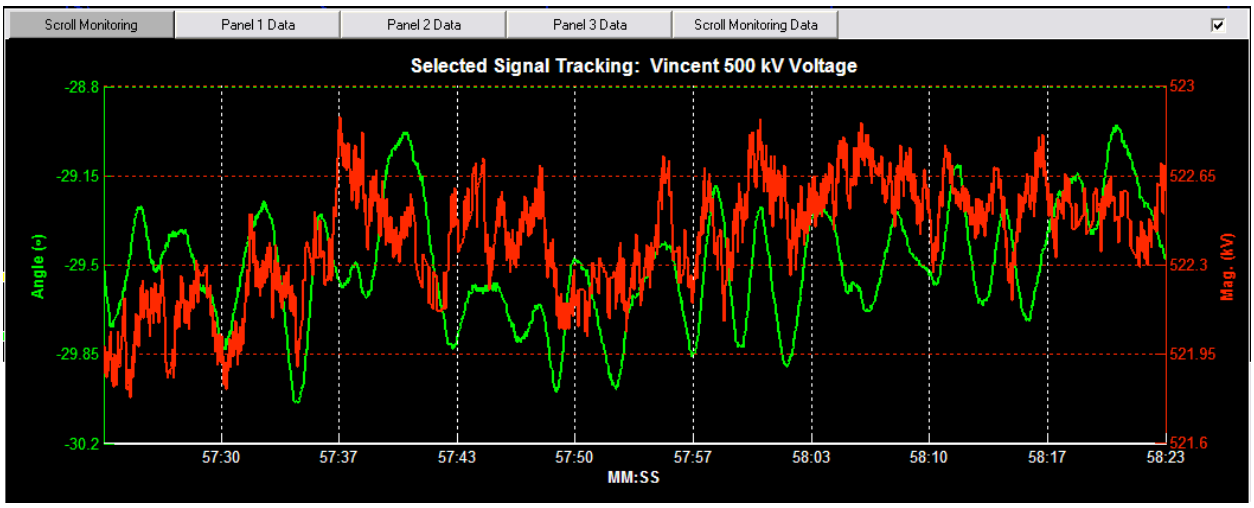


Figure 51: Selected Relative Angle/Voltage Magnitude Tracking

7.3. Relative Angle/Voltage Magnitude Four-Panel Display

As with all other displays, a double left mouse click in Panel 1 display will take the user to the corresponding four-panel display. This may also be done using a right mouse click within the one-panel display to show the pop-up menu box and to select the desired four-panel view ("Wide Area Monitoring/Tracking" or "Local Area Monitoring/Tracking") from the menu (Figure 54).

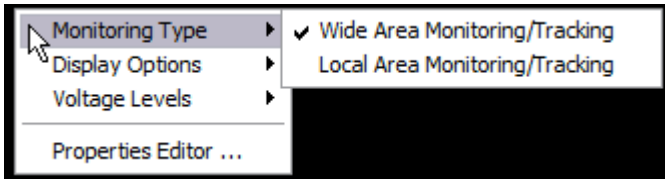


Figure 52: Relative Angle/Voltage Magnitude Monitoring Type Pop-Up

7.3.1. Relative Angle/Voltage Magnitude – Wide Area Monitoring/Tracking

The four panels within the "Wide Area Monitoring/Tracking" view are the "Voltage Monitoring – One Second Refresh Rate" display in Panel 1 which was described earlier. The "System Voltage Comparison" is displayed in Panel 2, and the "System Voltage Angle Tracking/Comparison" is shown in Panel 3. The "Scroll Monitoring" Panel which is located at the bottom of the four-panel display was also described earlier.

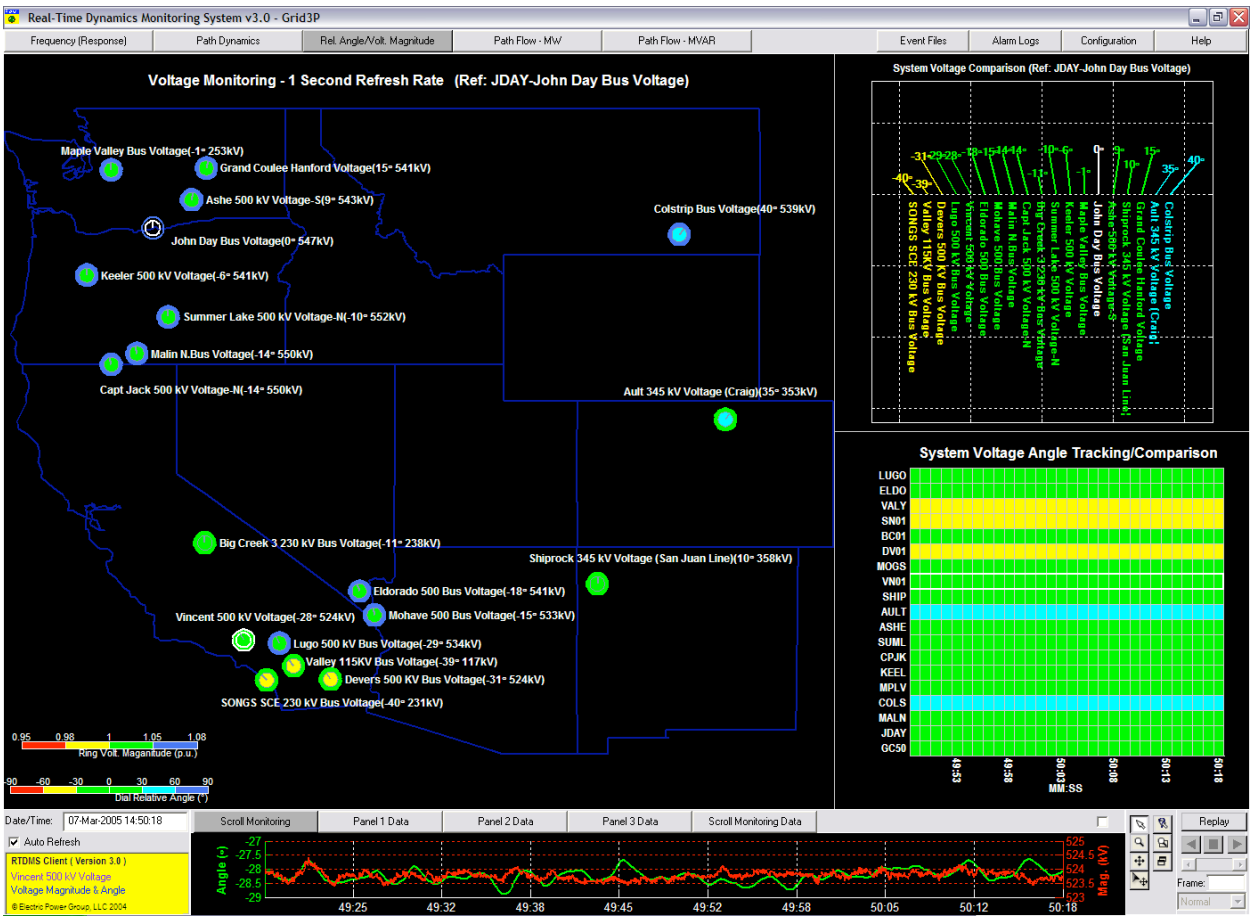


Figure 53: Four-Panel Relative Angle/Voltage Magnitude - Wide Area Monitoring/Tracking

Source: CERTS

The "System Voltage Comparison" panel uses a feather plot to compare all the voltage angles and magnitudes across the power grid (top right of Figure 53). Each vector of this plot corresponds to a monitoring location and the length and the orientation of this vector with respect to the vertical is indicative of the relative angle at that monitoring location. The reference for the angles is always a vertical vector (i.e., 0 degrees) and is shown in white (i.e., Grand Coulee). The vectors are also color-coded according to the legend in the bottom left of Figure 53.

In the "System Voltage Angle Tracking Comparison" panel, the time history of all the relative angles is provided for tracking and comparison purposes (bottom right of Figure 49). The x-axis of the plot is time in minutes and seconds (MM:SS), and the y-axis lists the monitoring locations. Each cell in the plot, therefore, corresponds to a particular monitoring location and time, and the color-coding of the cell, which represents the relative angle, can be cross-referenced to the color legend at the bottom of the geographic display in panel 1 (Figure 49). The time duration for the plot is selectable.

To select a desired time, right click in the "System Voltage Angle Tracking/Comparison" panel. Figure 54 presents the selectable time available.

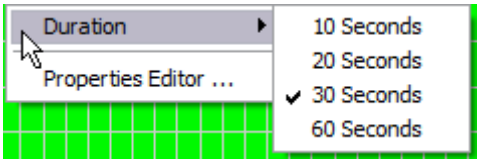


Figure 54: System Voltage Angle Tracking/Comparison Duration Pop-Up

7.3.2. Relative Angle/Voltage Magnitude – Local Area Monitoring/Tracking

Figure 55 shows the four-panel graphics for the "Local Area Monitoring/Tracking" view. Each of panels can be enlarged by double left clicking on the desired panel.

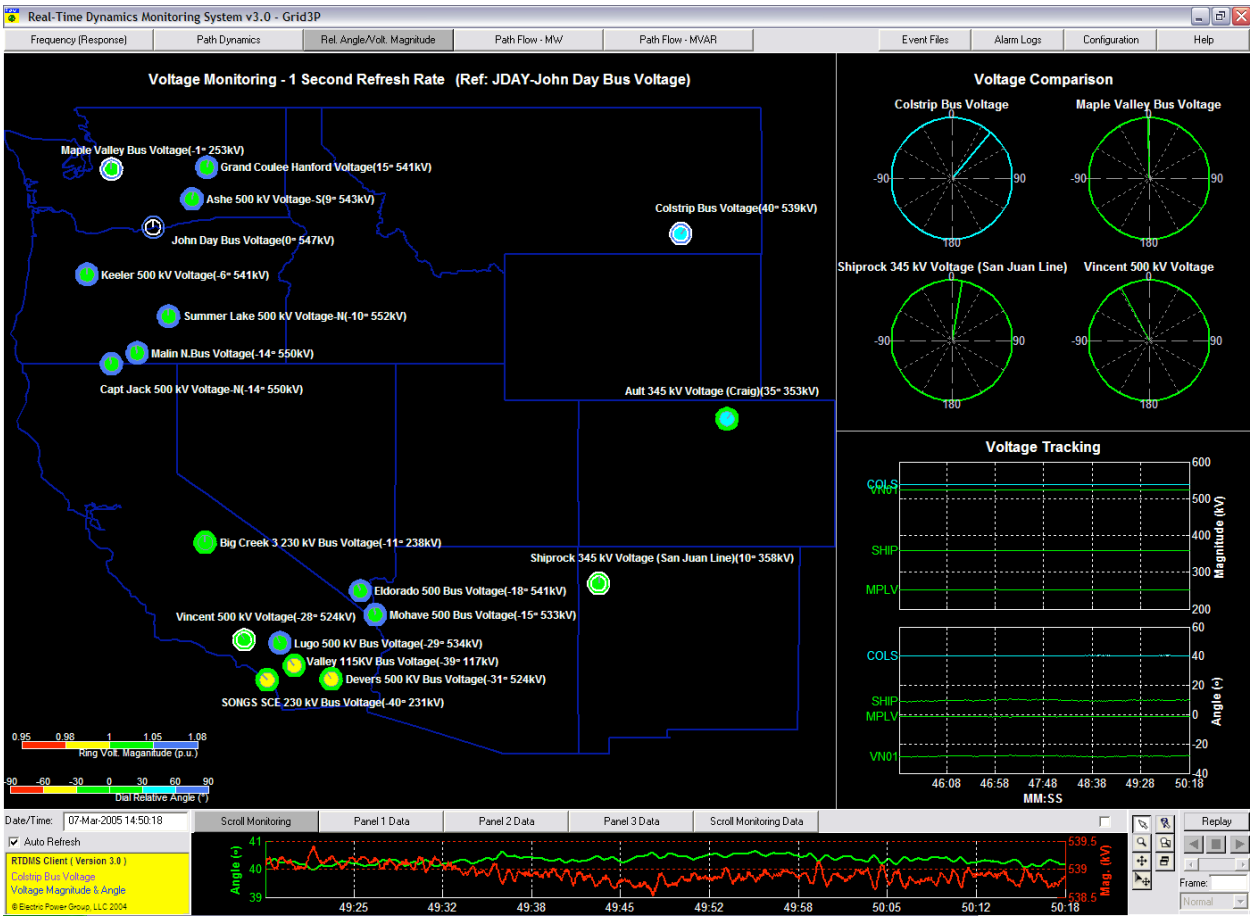


Figure 55: Four-Panel Relative Angle/Voltage Magnitude – Local Area Monitoring/Tracking

In Figure 55 displays, in the top right panel, the voltage angles for Grand Coulee, Colstrip, Vincent and Ault are viewed as dials on the "Voltage Comparison" panel. In this display, the angles for up to six monitoring locations may be added by left clicking on the corresponding dials in the geographic display. A selected location in the geographic panel will have a white border around it as an indicator of its selection. To deselect it, simply left click on it again and it will be removed from the "Voltage Comparison" panel.

The "Voltage Tracking" panel is shown in the bottom right of Figure 55. It provides a time history for the relative angles at the selected monitoring locations and the second resolution. The x-axis of the plot is time in minutes and seconds (MM:SS), and the y-axis is the angle in degrees. The time duration of the plot may be altered via a pop-up menu made available using the right mouse click within the panel (Figure 56).

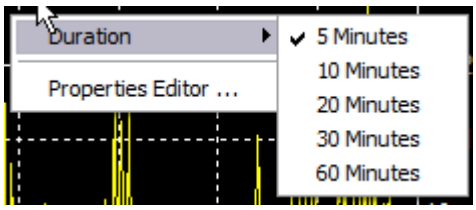


Figure 56: Voltage Tracking Duration Pop-Up

Finally, if the "Include Volt. Magnitude" option has been selected (Figure 48), then the time history for the voltage magnitudes at the selected monitoring location and the second resolution is shown as well (Figure 57). The upper plot tracks the voltage (in kV), and the lower tracks the relative angle (in degrees).

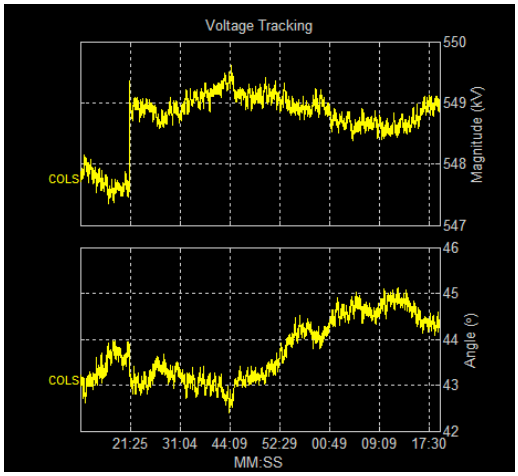


Figure 57: Voltage Tracking Including Voltage Magnitude (Panel 3)

8. PATH FLOW (MW) MONITORING

8.1. Overview

The application receives voltage phasor measurements at each of the monitoring locations as well as current phasor measurement on lines connected to the monitoring location. These measurements are used to calculate the real and reactive power flows on the monitored line. The "Path Flow – MW" monitoring display tracks the real power flows across monitored transmission lines or paths (set of monitored lines for which limits have been defined) with respect to their predefined flow limits. Furthermore, as these values are obtained solely from phasor measurements, they offer redundancy to the existing SCADA system. Figure 58 outlines the graphics available within the "Path Flow – MW" monitoring display.

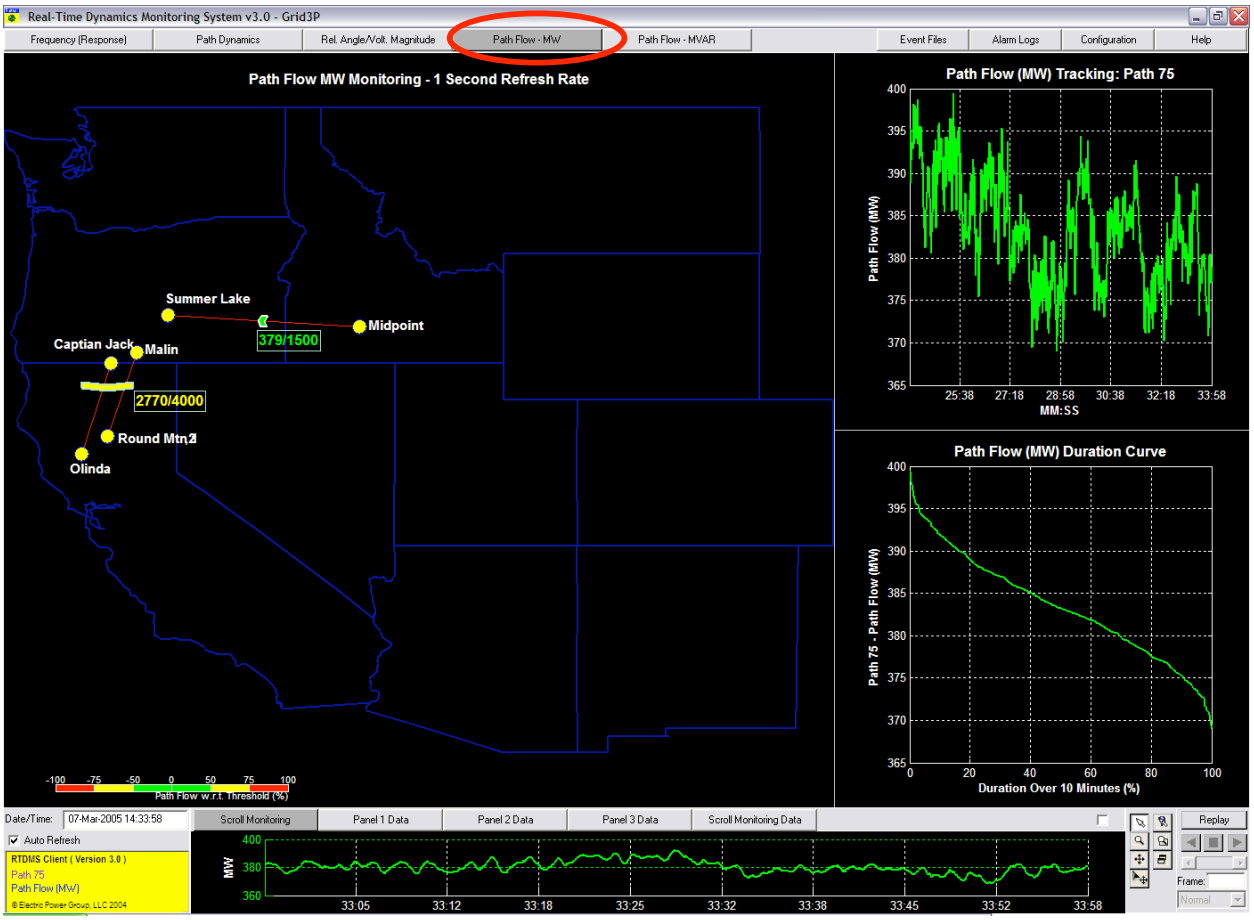


Figure 58: Four-Panel Path Flow – MW Monitoring

Source: CERTS

8.2. Path Flow (MW) One-Panel Display

Selecting the "Path Flow -MW" tab at the top of any of the displays will bring up just Panel 1, the left panel in Figure 58, where the various transmission paths are plotted on a geographical map in the "Path Flow – MW Monitoring" panel of the display. The real flows through that path are shown as an arrowhead across all the lines that define the path. While the color of the arrowhead represents the proximity (in percentage) of the MW flows to their alarming thresholds (bottom left on Figure 58), the arrowhead indicates the directionality of these flows.

Under the default settings, the actual MW flows and their corresponding limits are shown next to the arrowhead. The actual flows are listed to the left, and the thresholds are listed to the right. The station

names at both ends of the monitored line are also shown. To remove the station names from the displays, right click within the panel and the pop-up menu will appear (Figure 59). Click on the "Station Name" and the names will be removed. The same pop-up menu can be used to eliminate the "Path Flow Value" from the displays.

Figure 59: Path Flow – MW – Display Options Pop-Up

Figure 60 presents an enlarged view of Panel 4 "Scroll Monitoring" and the actual MW flow across the single selected path. A path is selected with a left mouse click on the arrowhead in the geographic display for the path and will be indicated by a white border around the arrowhead. The y-axis to the left of the plot is the MW flow and the x-axis is time in minutes and seconds (MM:SS). This plot allows the user to track the MW flows across the selected path over the past minute at the highest sub-second resolution.

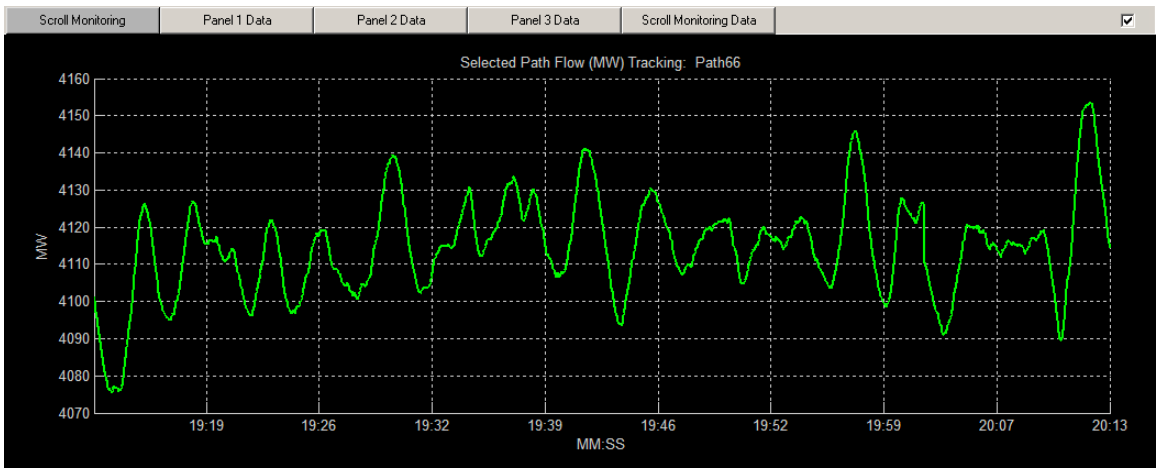


Figure 60: Selected Path Flow (MW) Tracking (Enlarged)

8.3. Path Flow (MW) Four-Panel Display

Left double clicks within Panel 1 will bring up the corresponding four-panel display (Figure 58). To enlarge any of the panels, double click with the left mouse button within the desired panel.

Panel 2 – the "Path Flow (MW) Tracking" – shows the actual MW flow over a specific path when selected (Figure 61). The panel provides a time history of the MW flows across the selected path at the second resolution. The x-axis of the plot is time in minutes and seconds (MM:SS), and the y-axis is the MW flow. A path is selected with a left mouse click on the arrowhead in the geographic display for the path and will be indicated by a white border around the arrowhead. The time duration of the plot may be altered via a pop-up menu made available using the right click within the panel.

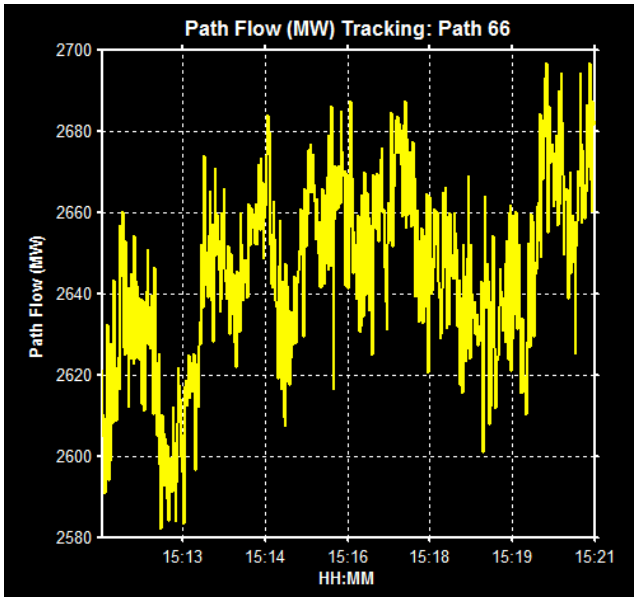


Figure 61: Path Flow (MW) Tracking (Panel 2)

Panel 3 – the "Path Flow (MW) Duration Curve" – displays a statistical distribution of the MW flows across the selected path (Figure 62). For each MW value along the y-axis, the corresponding x-axis along the curve shows the percentage time that the MW flows were above the value. In Figure 62, the Path 66 had over 2665 MW flowing for 20% of the time. The duration over which the distribution is computed is also selectable through a pull-down menu displayed via a right click within the panel.

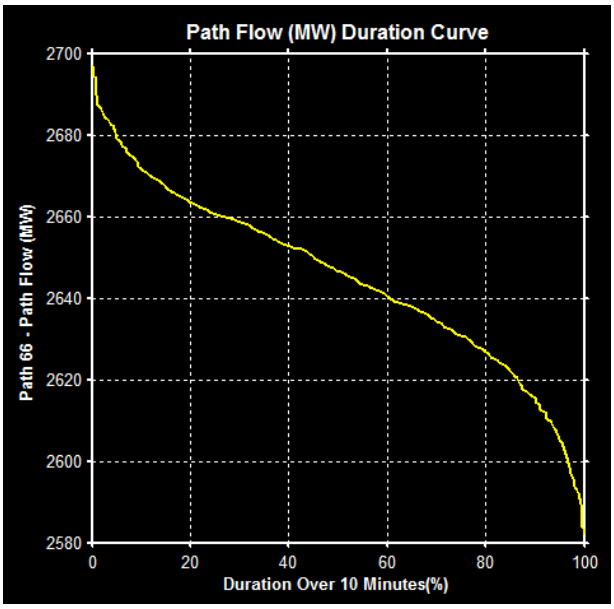


Figure 62: Path Flow (MW) Duration Curve (Panel 3)

Source: CERTS

9. PATH FLOW (MVAR) MONITORING

9.1. Overview

The "Path Flow – MVAR" monitoring display tracks the reactive power flows across monitored lines or transmission paths (set of monitored lines for which limits have been defined) with respect to their predefined flow limits. Figure 63 outlines the graphics available within the "Path Flow – MVAR" monitoring display.

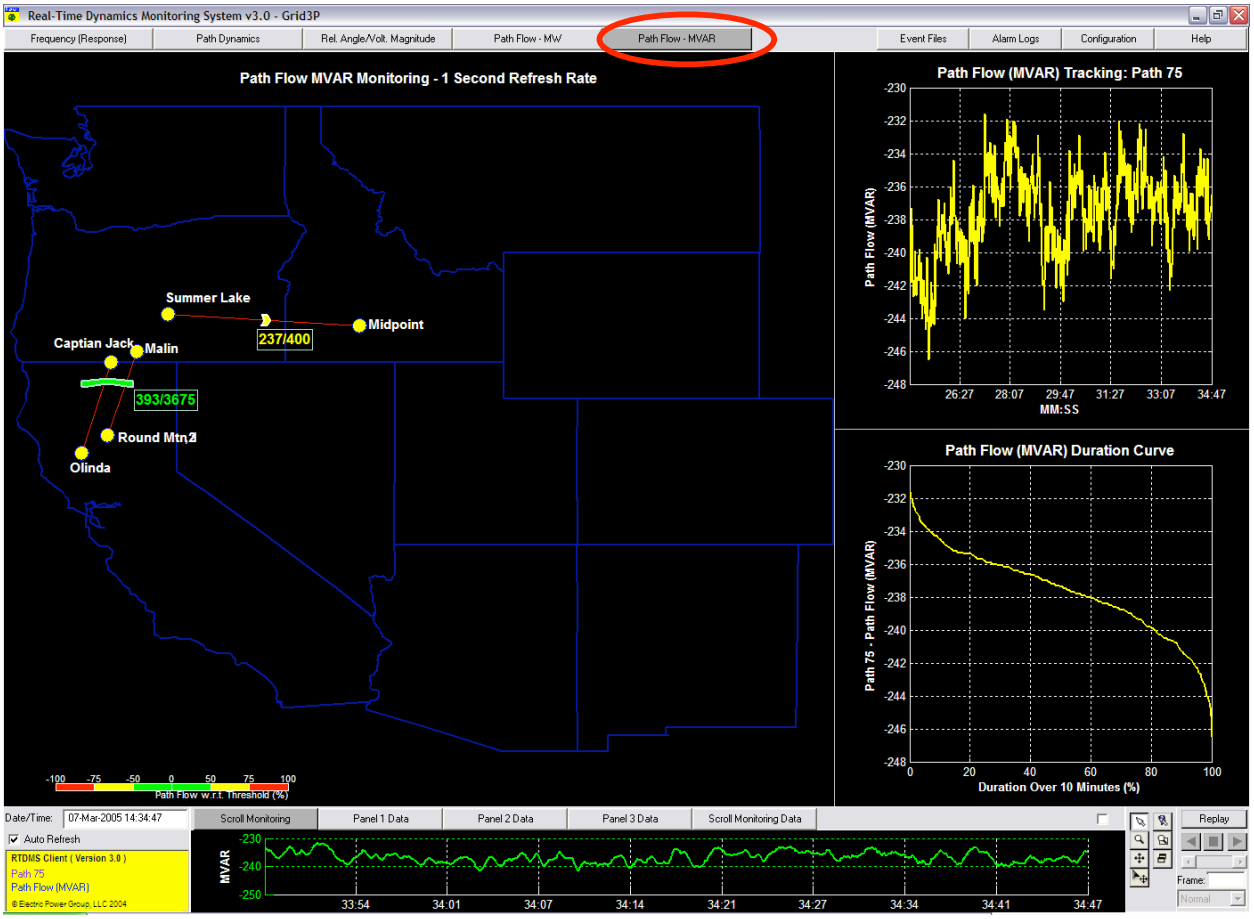


Figure 63: Four-Panel Path Flow – MVAR Monitoring

Source: CERTS

9.2. Path Flow (MVAR) One-Panel Display

Selecting the "Path Flow – MVAR" tab at the top of any of the displays will bring up just Panel 1, the left panel in Figure 63, where the various transmission paths are plotted on a geographical map in the "Path Flow – MVAR Monitoring" panel of the display. The reactive flows through that path are shown as an arrowhead across all the lines that define the path. While the color of the arrowhead represents the proximity (in percentage) of the MVAR flows to their alarming thresholds (bottom left on Figure 63), the arrowhead indicates the directionality of these flows.

Like the MW display, the actual MVAR flows and their corresponding limits are shown next to the arrowhead. The actual flows are listed to the left and the thresholds are listed to the right. The station names at both ends of the monitored line are also shown. To remove the station names from the display, right click within the panel and the pop-up menu will appear (Figure 64). Click on the "Station Name" and

the names will be removed. The same pop-up menu can be used to add/remove the “Path Flow Value” and/or “Station Name”.

Figure 64: Path Flow – MVAR – Display Options Pop-Up

Figure 65 presents an enlarged view of the actual MVAR flow across the single selected path. As with the MW display, the path is selected with a left mouse click on the arrowhead in the geographic display for the path and will be indicated by a white border around the arrowhead. The y-axis to the left of the plot is the MVAR flow and the x-axis is time in minutes and seconds (MM:SS). This plot allows the user to track the MVAR flows across the selected path over the past minute at the highest sub-second resolution.

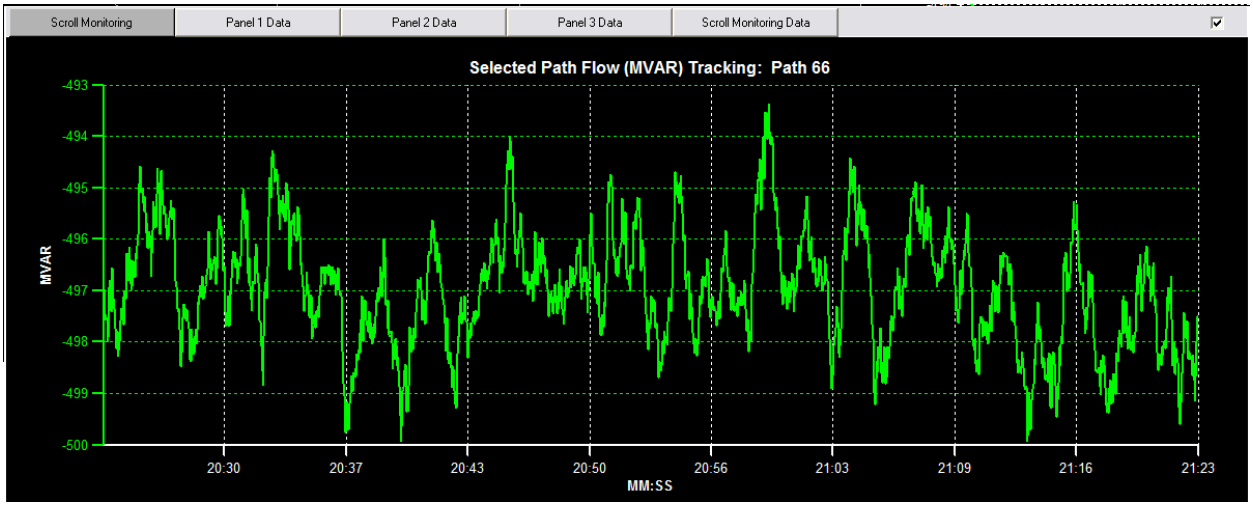


Figure 65: Selected Path Flow (MVAR) Tracking (Enlarged)

9.3. Path Flow (MVAR) Four-Panel Display

A left double click within panel 1 will bring up the corresponding four-panel display (Figure 63). To enlarge any of the panels, double click with the left mouse button within the desired panel.

Panel 2, the top right of Figure 63, is a view of the “Path Flow (MVAR) Tracking” plot where the time history of the MVAR flows on the selected path (Path 66) are being tracked. The panel provides a time history of the MVAR flows across the selected path at the second resolution (Figure 66). The x-axis of the plot is time in minutes and seconds (MM:SS), and the y-axis is the MW flow. The time duration of the plot may be altered via a pull-down menu made available using the right click within the panel.

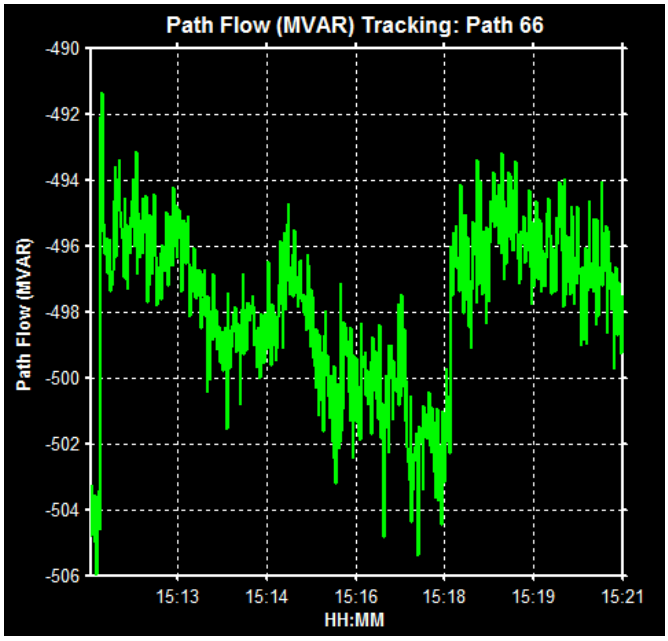


Figure 66: Path Flow (MVAR) Tracking (Panel 2)

Panel 3, the bottom right of Figure 63, is a view of the "Path Flow (MVAR) Duration Curve". Panel 3 displays a statistical distribution of the MVAR flows across the selected path (Figure 67). For each MVAR value along the y-axis, the corresponding x-axis along the curve shows the percentage time that the MW flows were above the value. In the figure, Path 66 had over 70 MVAR flowing from Cordova for 20% of the time. The duration over which the distribution is computed is also selectable through a pull-down menu displayed via a right click within the panel.

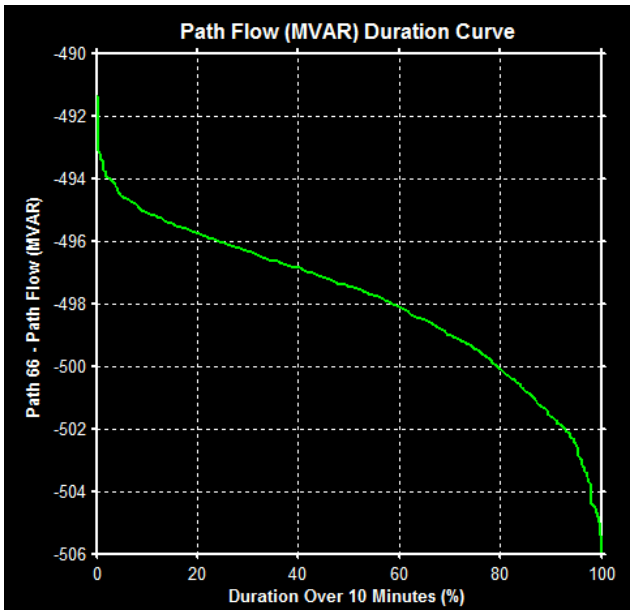


Figure 67: Path Flow (MVAR) Duration Curve (Panel 3)

10. ALARMS

Alarming logic built into the RTDMS server has the ability to analyze the streaming real-time data to detect and alarm on either threshold violations or significant changes (i.e. change within a second interval exceeding a specified threshold) on certain identified signals and metrics. In particular, the types of alarming logic within the RTDMS server include:

- System frequency exceeding specified threshold limits.
- Local frequency variations exceeding specified thresholds limits.
- Sudden changes in system and local frequencies.
- Voltage magnitudes exceeding minimum or maximum thresholds (i.e. low or high voltages).
- Sudden changes in voltage magnitudes.
- Relative voltage angles exceeding specified thresholds limits w-r-t chosen reference.
- Angle difference across specified paths exceed defined threshold limits.
- MW/MVAR flows across specified paths exceed defined threshold limits.

Note: When sudden changes in voltage magnitude or frequency signals are detected, the phasor data is stored into event files for offline post-disturbance analysis (Refer to Section 11).

The threshold parameters and signals/metrics used for alarming are specified in the "PhasorArchiver.ini" file at the RTDMS server (i.e. file resides within the 'RTDMS Server 3.0' directory). Having these alarming parameter definitions and the detection capability at the central RTDMS server ensures consistency in the alarming process across all RTDMS clients even when each RTDMS client may differ in its particular configuration as defined through its "Configuration Utility" (Refer to Section 12).

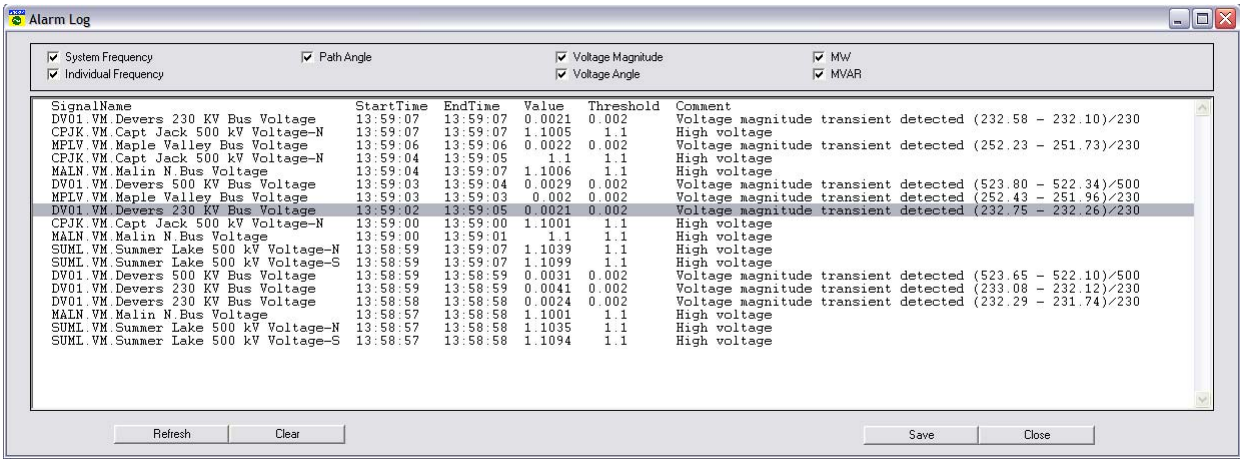
(Note: The central alarming parameters may be changed by manually editing the 'PhasorArchiver.ini'. Alternately, the parameter settings within any RTDMS configuration file that can be created on the RTDMS client using its "Configuration Utility", may be imported into the RTDMS server to automatically update the parameters in the 'PhasorArchiver.ini' with the settings as defined within the imported configuration file. Please refer to the *RTDMS Installation and Support Guide* for further details on the RTDMS server configurability).

Whenever a violation is detected in real time, it is automatically logged into text files at the RTDMS server. For convenience, these alarm log files are named by the starting date and time of the alarm logging process into the file (e.g. '20050307_135259alarm.log' indicates that this file contains alarm logs beginning at 13:52:59 on the 7th of March, 2005). All alarm logs at the server are stored in the in an 'alarm' folder within the 'RTDMS Server 3.0' directory (when the RTDMS server is installed in the default installation directory, these files reside in the 'C:\Program Files\CERTS-EPG Grid 3P\RTDMS Server 3.0\alarm\' directory).

Not only are the generated alarms permanently logged at the server, these alarms are immediately made visible on all RTDMS clients that are connected to the server at the time. Whenever, a new violation is detected at the server, the "Alarm Logs" tab located in the top right corner of all RTDMS clients is highlighted in red to indicate the occurrence of a new alarm (Figure 68). This "Alarm Logs" tab remains red until the alarm is acknowledged by the user.

Figure 68: "Alarm Logs" Tab Highlighted in Red to Alert RTDMS User of New Alarm

To acknowledge the alarm, click on this tab and the "Alarm Log" box pops up (Figure 69). Though all the alarms are logged at the RTDMS server as a text file, the user may be selective on the alarms he wishes to see at the RTDMS client. This is done by selecting/deselecting the appropriate alarm types within the "Alarm Log" box. For each alarm listed in the box, the alarm log provides information on the signal associated with the violation, the start time of the violation, the end time of the violation (or most current time during a violation), the violation value and corresponding threshold, and the nature of the violation.



SignalName	StartTime	EndTime	Value	Threshold	Comment
DV01.VM.Devers 230 KV Bus Voltage	13:59:07	13:59:07	0.0021	0.002	Voltage magnitude transient detected (232.58 - 232.10)/230
CPJK.VM.Capt Jack 500 kV Voltage-N	13:59:07	13:59:07	1.1005	1.1	High voltage
MPLV.VM.Maple Valley Bus Voltage	13:59:06	13:59:06	0.0022	0.002	Voltage magnitude transient detected (252.23 - 251.73)/230
CPJK.VM.Capt Jack 500 kV Voltage-N	13:59:04	13:59:05	1.1	1.1	High voltage
MALN.VM.Malin N.Bus Voltage	13:59:04	13:59:07	1.1006	1.1	High voltage
DV01.VM.Devers 500 KV Bus Voltage	13:59:03	13:59:04	0.0029	0.002	Voltage magnitude transient detected (523.80 - 522.34)/500
MPLV.VM.Maple Valley Bus Voltage	13:59:03	13:59:03	0.002	0.002	Voltage magnitude transient detected (252.43 - 251.96)/230
DV01.VM.Devers 230 KV Bus Voltage	13:59:02	13:59:05	0.0021	0.002	Voltage magnitude transient detected (232.75 - 232.26)/230
CPJK.VM.Capt Jack 500 kV Voltage-N	13:59:00	13:59:00	1.1001	1.1	High voltage
MALN.VM.Malin N.Bus Voltage	13:59:00	13:59:01	1.1	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-N	13:58:59	13:59:07	1.1039	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-S	13:58:59	13:59:07	1.1099	1.1	High voltage
DV01.VM.Devers 500 KV Bus Voltage	13:58:59	13:58:59	0.0031	0.002	Voltage magnitude transient detected (523.65 - 522.10)/500
DV01.VM.Devers 230 KV Bus Voltage	13:58:59	13:58:59	0.0041	0.002	Voltage magnitude transient detected (233.08 - 232.12)/230
DV01.VM.Devers 230 KV Bus Voltage	13:58:58	13:58:58	0.0024	0.002	Voltage magnitude transient detected (232.29 - 231.74)/230
MALN.VM.Malin N.Bus Voltage	13:58:57	13:58:58	1.1001	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-N	13:58:57	13:58:58	1.1035	1.1	High voltage
SUML.VM.Summer Lake 500 kV Voltage-S	13:58:57	13:58:58	1.1094	1.1	High voltage

Figure 69: Alarm Log Pop-up Box

Example: Figure 70 shows an alarm logged into the "Alarm Log" box when a sudden changed in "Devers 230kV Bus Voltage" voltage signal occurred on March 7, 2005 at 13:59:02 that triggered the alarm. The voltage magnitude change within the first second was 0.0221 p.u. (i.e. 11kV at a 500kV base) which exceeded the alarming rate of change voltage threshold as specified in "PhasorArchiver.ini" file at the RTDMS Server (i.e. 0.002 p.u. in this example), and this violation persisted though the next few seconds (i.e., 13:59:05).

SignalName	StartTime	EndTime	Value	Threshold	Comment
DV01.VM.Devers 230 KV Bus Voltage	13:59:02	13:59:05	0.0021	0.002	Voltage magnitude transient detected (232.75 - 232.26)/230

Figure 70: Alarm Log Example

If a new alarm occurs while viewing the alarm log, the "Alarm Logs" tab again switches color to red. Clicking on the "Refresh" button serves to acknowledge the alarm and updates the current list of alarms shown in the alarm log with the new alarms. Furthermore, the violations observed in the "Alarm Log" box can also be saved into a text file for future viewing by clicking on the "Save" button and specifying the save location. Alternately, the current list of alarms may be removed fom the box by clicking on the "Clear" button.

Note: Whether in Replay or Offline mode, the "Alarm Log" box continues to keep track of the most recent alarms detected at the RTDMS Server.

11. EVENT FILES AND OFFLINE ANALYSIS

Whenever a rate of change alarm either in frequency or voltage magnitude measurements is encountered, all the streaming data and the subsequent alarm logs over a predefined time duration (default duration is 5 minutes of post-event data) are automatically stored at the RTDMS server. In particular, for each captured event, a '.dat'. and a '.sum' file is created in the "event" folder within the "RTDMS Server 3.0" directory that stores the data and the alarm summary respectively (when the RTDMS Server is installed in the default installation directory, these files reside in the 'C:\Program Files\CERTS-EPG Grid 3P\RTDMS Server 3.0\event\' directory). Both the data and the alarm summary files are named by the event start times (e.g. '20050307_144034.dat' and '20050307_144034.sum' files contain the data and the alarm summary for an event that was captured on March 7, 2005 at 14:40:34). As with alarming parameters, the event capture time duration and the rate of change thresholds can be modified by manually editing the 'PhasorArchiver.ini' file residing at the RTDMS server. Please refer to the *RTDMS Installation and Support Guide* for further details on the RTDMS server configurability.

Event files stored at the RTDMS server are available for viewing by all RTDMS clients that are connected to the RTDMS server over a local area network. These event files can be loaded into RTDMS clients for off-line post-disturbance analysis. When a sudden change in frequency or voltage magnitude is detected, the corresponding alarm triggers the 'Alarm Logs' tab in the RTDMS clients to turn red indicating the occurrence of a new alarm (Figure 68) and this alarm is automatically registered in the "Alarm Log" box (Figure 69).

To switch out of real-time monitoring mode and to load a captured event file into the RTDMS client, click on the "Event Files" tab located on the top right corner of the client application.

Figure 71: "Event Files" Tab for Loading Disturbance Files

When the "Event Files" tab is clicked, the navigation window pops up allowing the user to find and select the event file of interest (Figure 72). By default, these files are stored in the 'event' folder within the 'RTDMS Server 3.0' directory. Select the file of interest as labeled by the start date/time of the event (select '.dat' file to load both the data and the alarm summary for the event or '.sum' file to only load the alarm summary for the event), and click on "Open" to being loading the file into the RTDMS client for offline analysis. As an example, in Figure 72, the event captured on March 7, 2005 at 14:40:34 is being loaded into the application.

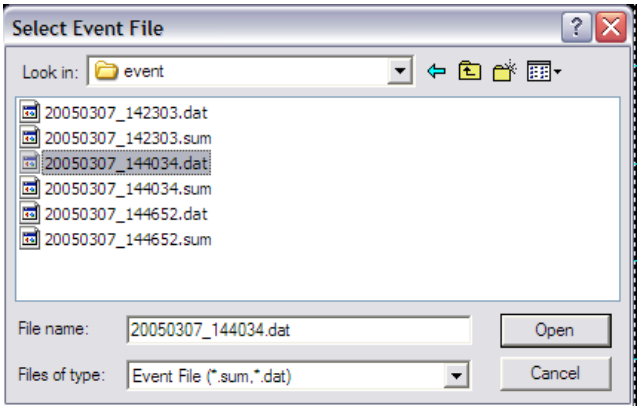


Figure 72: Navigation Window to Load Event File

All the functionality offered in the real-time monitoring mode (i.e., multi-panel displays, navigational tools, replay, data tables etc) is available to the user in this Offline mode. Hence, with the event file loaded into the RTDMS client, the user can utilize these capabilities for a post-disturbance analysis of the event file.

Example: An event that was captured on March 7, 2005 at 14:40:34 has been selected (Figure 72) and loaded into the RTDMS visualization client (Figure 73). When the application completes loading the data, it automatically switches into the off-line mode which is indicated by a switch in the Title box's background color from yellow to blue (Figure 17). Additionally, the alarm summary pop-up box also appears listing all the violations during the course of the event. In the example, one of the violations listed in the alarm summary for the event file is a sudden frequency change of 41.8mHz within a second as measured by the 'Slatt' PMU on March 7, 2005 at 14:41:11. To further investigate this event alarm, the "Frequency (Response)" monitoring four-panel display was selected and the replay capability was used to rewind to the time in question within the event file. The time duration for the trend plot in Panel 1 was set to 1 minute to allow viewing of this data at the sub-second resolution. Additionally, the 'Slatt' frequency was selected within the "Local Frequency Coherency Comparison" mesh plot and automatically displayed in Panel 4. A look at the different panels of this display (Figure 73) confirms sudden transients in the 'Slat' frequency between 14:41:11 and 14:41:13 resulting in it having the biggest deviation from the interconnection frequency during the time in question.

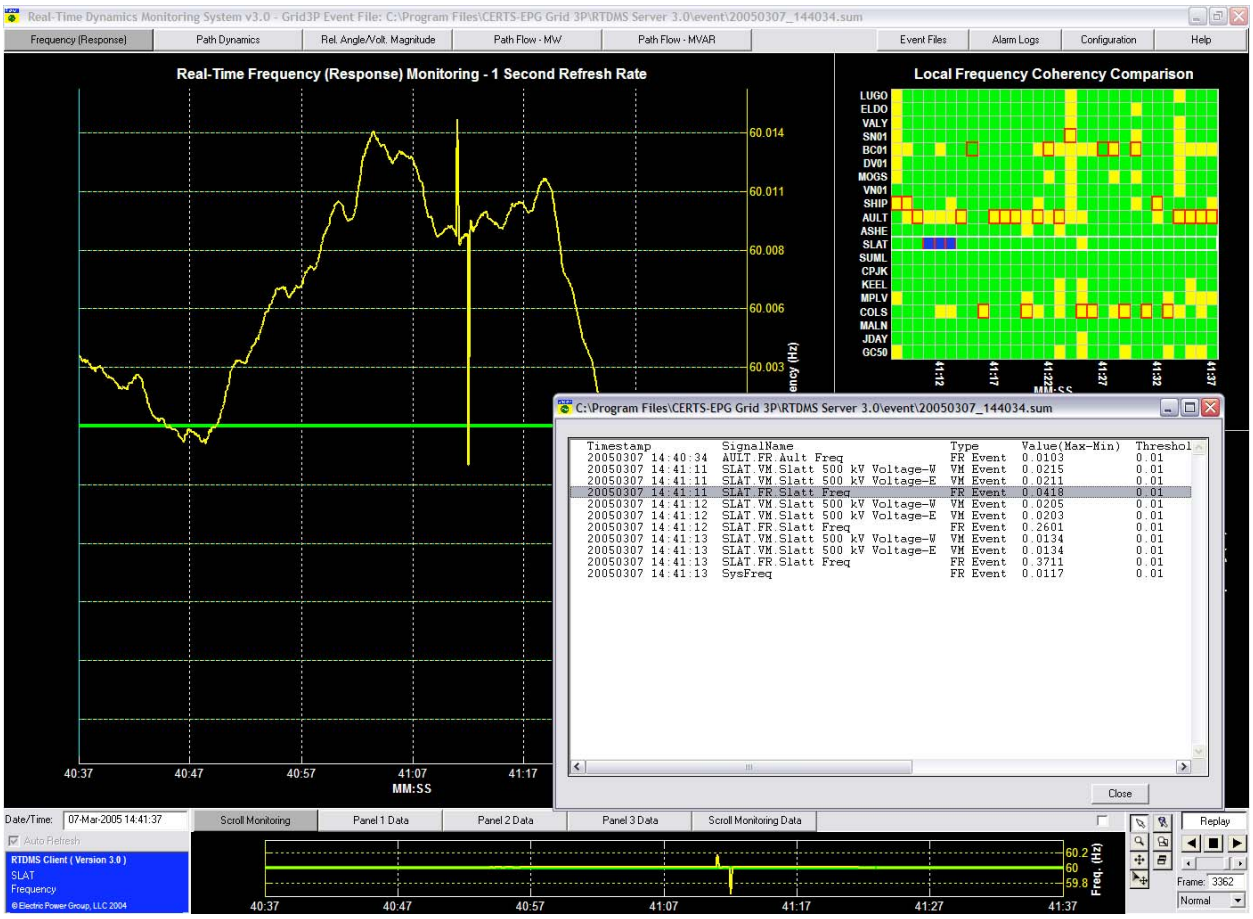


Figure 73: RTDMS in Offline Mode for Post-Disturbance Analysis

Once the offline analysis is complete, the user can switch back to "Real-Time" mode by clicking on the "Replay" button.

(Note: It is recommended that the user wait the predefined recording duration after the event has been detected before loading the event file to allow for the event recording completion. Attempting to load an event file that hasn't completed recording will only load partial data into the application).

12. CONFIGURABILITY

The RTDMS server communicates both the phasor data and static information to all the remote monitoring RTDMS clients (Refer to Appendix 1). If there is a change in the static information (reflecting changes in the system configuration such as the addition or removal of PMUs), it is detected by each of the remote client applications, and the configuration utility window automatically pops up with the latest signal information. The user can utilize this utility to update the visualization displays. Alternately, the user may manually launch the utility by clicking on the "Configuration" tab located on the top right corner of the display and reconfigure the display visuals. All the configuration settings are saved in a single file for easy portability. These configuration files have a '.mat' extension (e.g. 'phasor_conf_default.mat') and can be loaded in any RTDMS client application. These settings include the newly defined set of monitoring preferences such as the monitoring points, paths, alarming thresholds as well as the visualization properties such as color schemes, font types and sizes, labels etc. The configuration details are described in this and the following section (Section 13).

(Note: RTDMS configuration files can not only be shared across different RTDMS clients, they can also be imported into the RTDMS server to specify alarming signals/metrics and threshold parameters).

12.1. Client Configuration Utility

The configuration utility graphic user interface (GUI) is shown in Figure 74. Under the "PMU Selection" section of the GUI, the most current set of PMUs which are available to the system fall either under the "Unselected" list or the "Selected" list (PMUs identified by a four letter PMU code – Refer to Appendix 1). The "Selected" list is the subset of PMUs whose monitored signals are to be used within the visualization. The "Unselected" list is the remaining set of PMUs.

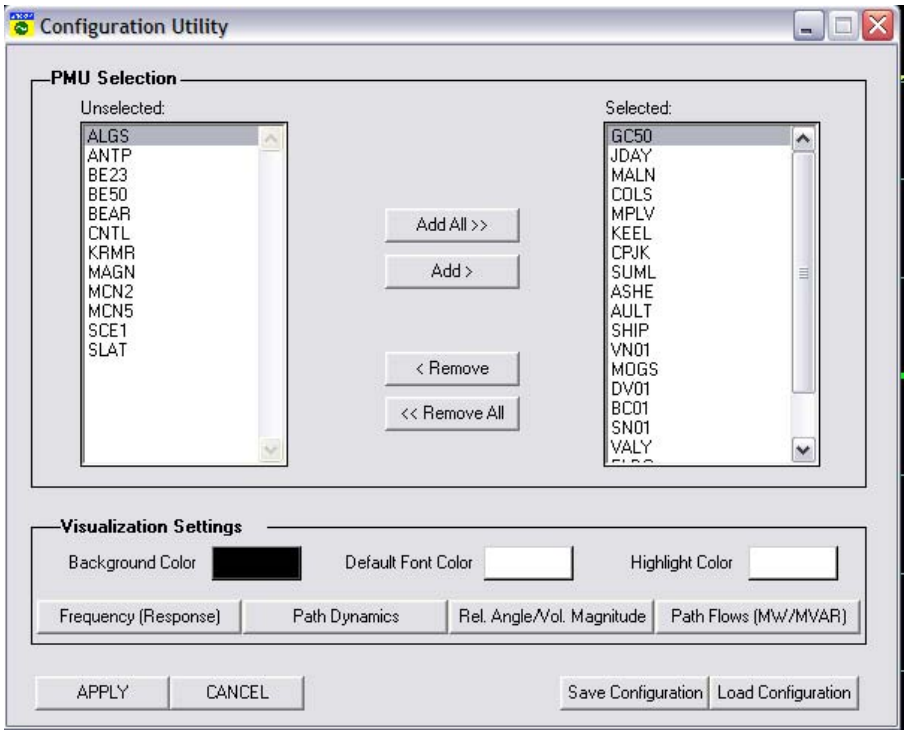


Figure 74: Configuration Utility Master Graphic User Interface

When a new PMU is installed and connected to the system and the corresponding static information is updated at the server, the change is detected by all the monitoring client applications and it is automatically added to the "Unselected" list. The user may now choose to include the information being

monitored by the new PMU by selecting it under the “Unselected” list and clicking on the “Add” button. The new PMU is moved from the “Unselected” list into the “Selected” list.

The user can also remove PMU(s) by highlighting them in the “Selected” list and clicking on the “Remove” button. If the monitored signals from a PMU that are being removed are used in path definitions (either angle difference paths or MW/MVAR paths), then a warning box pops up to alert the user (Figure 75).

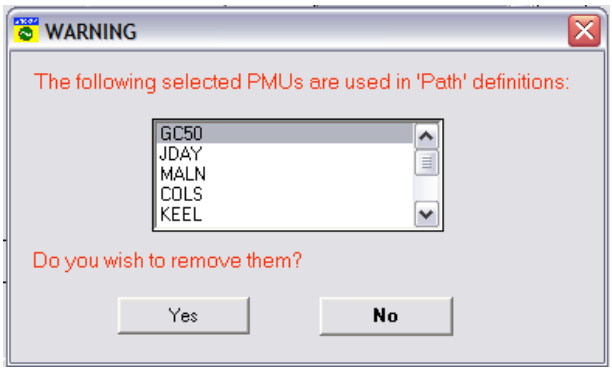


Figure 75: Warning Pop-Up during PMU Removal

If the user still wishes to remove the PMU(s), then the user can acknowledge the warning by clicking “Yes”, in which case, the PMU(s) are removed from the “Selected” list and moved to the “Unselected” list. Any path definitions that utilized signals monitored by those deselected PMUs are removed from the displays.

The “Visualization Settings” within the configuration GUI let the user configure the application displays based on the “PMU Selection“ (shown under the “Selected” list) through the procedure outlined above. The user can change the background color of all the displays. To do this, click on the rectangular color box and the color palette is launched (Figure 76). The user can either choose from the available color selection by clicking on the color or define a customized color using the R-G-B sliders. The selected/defined color is shown in the rectangular box. Once a background color is selected, click on “OK” button. The user can also change the text and graphic highlight colors in a similar fashion.

Figure 76: Color Palette Pop-Up

Within the “Visualization Settings” are four buttons corresponding to each of the monitoring functions and displays: “Frequency (Response)”, “Path Dynamics”, “Rel. Angle / Vol. Magnitude”, Path Flows (MW/MVAR). Clicking on a button launches a configuration GUI for the corresponding display that lets the user configure the display. Once these configuration GUIs have been used to modify the display parameters, click on the “APPLY” button for the changes to take effect. The user can also save these latest set of configuration settings as a new configuration file. To do this click on “Save Configuration” and the user will be prompted to assign a name to the file. The user can later load this file or a previously saved configuration file by clicking on the “Load Configuration” and selecting it from the appropriate file list shown. Alternately, the user may click on the “CANCEL” button to revert to the earlier configuration (Note: The default configuration setting file is labeled as ‘phasor_conf_default.mat’).

12.1.1. Frequency (Response) Configuration

Click on the “Frequency (Response)” button within the Configuration Utility, and the Frequency (Response) configuration GUI will pop-up (Figure 77). The user can use this GUI to update the frequency and the frequency response monitoring settings. For frequency monitoring, the user can set the scheduled frequency (shown as a solid horizontal green line in the frequency monitoring displays) and associated soft/hard alarming limits (shown as a solid yellow line in the frequency monitoring displays). While the hard limits are fixed upper and lower frequency limits with respect to the scheduled frequency, the soft limits are variable statistical limits determined by the set number of standard deviations from the mean as computed from the frequency data available within the frequency monitoring display.

For frequency response monitoring, the user can also change the “Natural Frequency Response Coefficient” that maps Interconnection frequency changes to generation-load imbalances within the system, by entering the new coefficient (in MW/0.1Hz) under the “Imbalance Coefficient” field, the time duration (in seconds) over which the frequency change is calculated under the “Response Interval” field, as well as the alarming limits (shown as a solid cyan line in the frequency monitoring displays). Click on the “OK” button once the two fields have been updated (and the “APPLY” button within the Configuration Utility in Figure 74), and the changes are registered. The generation-load imbalance is calculated by multiplying the Interconnection frequency change over the specified time duration multiplied by the imbalance coefficient.

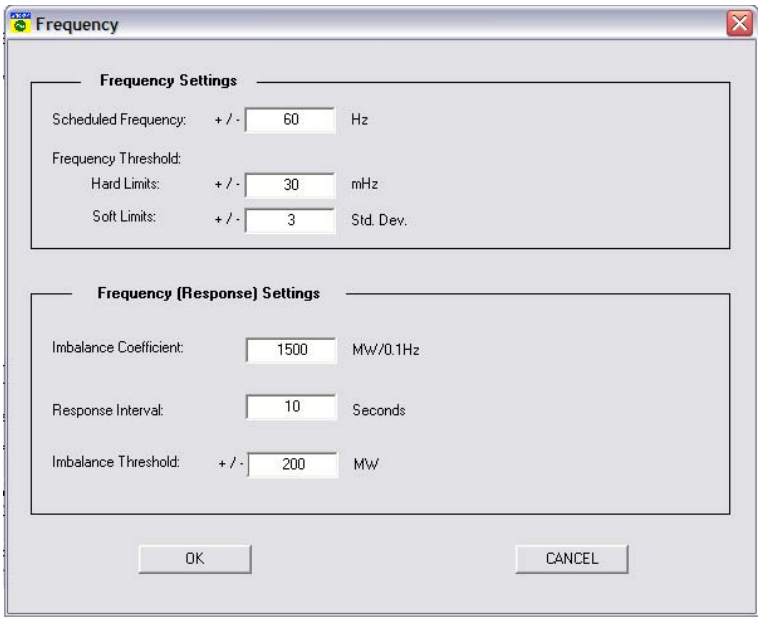


Figure 77: Frequency (Response) Configuration Graphic User Interface

12.1.2. Path Dynamics Configuration

Click on the “Path Dynamics” button within the Configuration Utility and the Path Dynamics configuration GUI will pop-up (Figure 78). The user can use this GUI to define a new path and corresponding alarming thresholds, remove a existing path, or modify the path name or thresholds on an existing path.

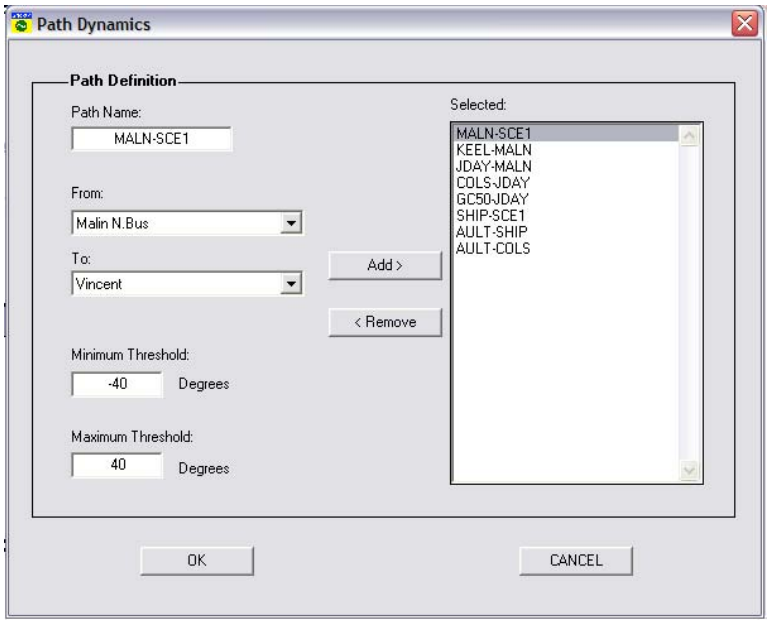


Figure 78: Path Dynamics Configuration Graphic User Interface

To add a new path to the “Path Dynamics” display, select the “from” voltage and the “to” voltage from those available in the pull-down list (these set of voltages are being monitored by the selected subset of PMUs defined in Section 12.1). The new path is then defined as the voltage angle difference between the “from” voltage angle and the “to” voltage angle and will be shown within the “Path Dynamics” display as an arrow between the two locations (the arrow in the display points from the larger voltage angle to the smaller voltage angle and therefore reflects the directionality of power flow from the source to the sink). The “Path Name” field is automatically filled according to the PMUs associated with the “from” and “to” voltages but can be altered by the user. The minimum and maximum alarming thresholds for the new path are entered under the “Minimum Threshold” and “Maximum Threshold” fields respectively. Once all the fields have been specified, click on the “Add” button and the new path is added to the set of existing paths shown under the “Selected” list.

To remove an existing path from the “Path Dynamics” display, choose the desired path from the “Selected” list and click on the “Remove” button.

To update the fields of an existing path within the “Path Dynamics” display, choose the desired path from the “Selected” list, modify the “Path Name”, “Minimum Threshold” and “Maximum Threshold” fields, and click on the “Add” button.

Once the desired changes have been made, click on the “OK” button (and the “APPLY” button within the Configuration Utility in Figure 74) for the changes to take effect[8].

[8] Once the a new path is added, use the “Pick to Move Text” icon under the navigation tools to reposition the associated text information within the display and avoid overlap.

12.1.3. Relative Angle/Voltage Magnitude Configuration

Click on the “Rel. Angle / Volt. Magnitude” button within the Configuration Utility, and the Relative Angle / Voltage Magnitude configuration GUI will pop up (Figure 79). The user can use this GUI to modify the reference PMU, to adjust a PMU’s coordinates within the geographic displays, and to set a voltage signal from PMU as the default monitoring voltage for that PMU.

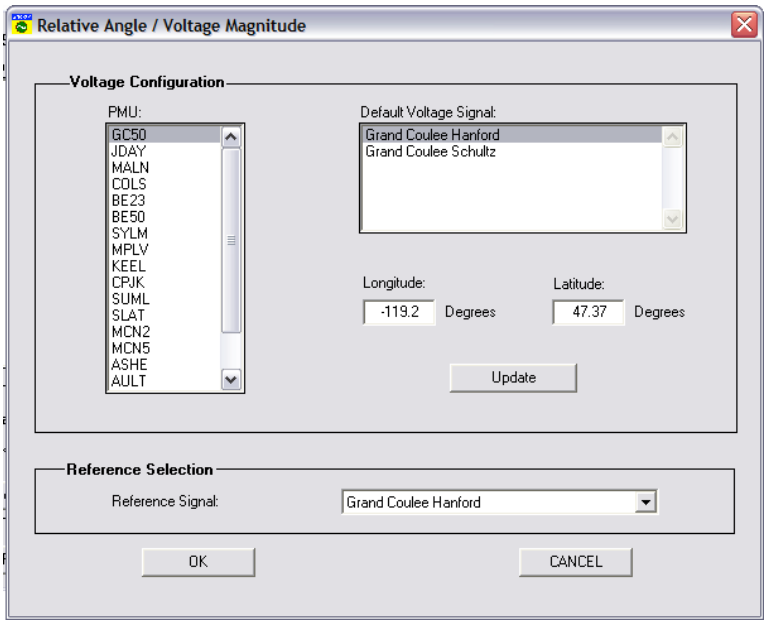


Figure 79: Rel. Angle / Volt. Magnitude Configuration Graphic User Interface

Some PMUs are configured to measure multiple voltages available at the PMU location (such as the high or low sides of transformers and series elements). Under such situations, the configuration utility allows the user to set one of these voltage signals as the default voltage to be shown within the “Rel. Angle / Volt. Magnitude” display. To do this, select a PMU from the “PMU” list and all its monitored voltages are shown in the “Default Voltage Signal” list. Select one of the available voltage signals from the list to set as the default voltage signal. Additionally, update the coordinates of the PMU in the “Longitude” and “Latitude” fields if desired. Click on the “Update” button to register the changes.

To change the reference used to compute the relative angles for the display, select the new “Reference Signal” from the list of available signals in the pull-down list.

Once the desired changes have been made, click on the “OK” button (and the “APPLY” button within the Configuration Utility in Figure 74) for the changes to take effect.

12.1.4. Path Flow (MW/MVAR) Configuration

Click on the “Path Flow (MW/MVAR)” button within the Configuration Utility and the MW/MVAR path configuration GUI will pop-up (Figure 80). The user can use this GUI to define new MW/MVAR paths or flowgates (a single line or set of lines across which the current flows are being measured and the power flows can therefore be computed), remove existing MW/MVAR paths, or modify the thresholds on existing MW/MVAR paths.

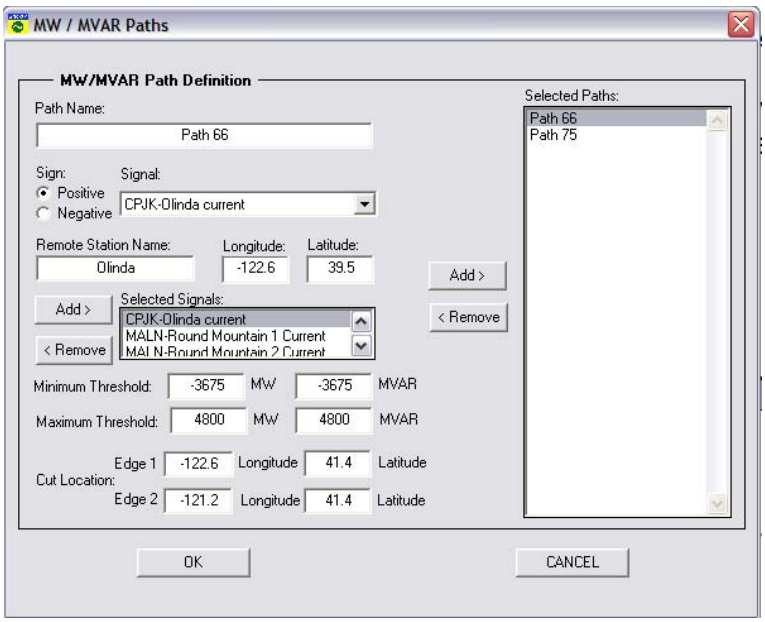


Figure 80: MW / MVAR Path Configuration Graphic User Interface

To add a new MW/MVAR path to the "Path Flow – MW (MVAR)" displays, enter its name under the "Path Name" field. Select the first "Signal" to be included in the path or flowgate definition from those available in the pull-down list – these are lines across which the MW and MVAR flows have been computed. Choose the "Sign" to be associated with the line flow to define the directionality of the flow (i.e., is the monitored power away from the PMU [positive sign] or towards the PMU [negative sign]). While the PMU information (such as its station name, latitude and longitude) is available to the client applications and within the configuration utility from the host site, this information may not be available for the remote station (i.e., the station at the other end of the selected line). If this remote station information is available at the host site, the "Remote Station Name", "Longitude" and "Latitude" fields are automatically populated, else the user can manually enter them. Once the information has been entered, click on the "Add" button located to the left of the GUI, and the signal is added to the "Selected Signals" list. Repeat the above process to add any additional line flows. The net flows through the set of signals within the "Selected Signals" list will define the path. Next, specify the net "Minimum Threshold" and "Maximum Threshold" fields for the real and reactive flows across the defined path. Finally, the "Edge1" and "Edge2" fields define the corners of the arrowhead associated with this new path and will be shown within the display. These fields are automatically filled such that the arrowhead is appropriately centered and oriented across the first line in the "Selected Signals" list. The user may change these coordinates to rescale the arrowhead. Once the information is entered, click on the "Add" button located in the center of the GUI and the new MW/MVAR path is added to the set of existing paths shown under the "Selected Paths" list.

To remove an existing path from the "Path Flow – MW (MVAR)" displays, choose the desired MW/MVAR path from the "Selected Paths" list and click on the "Remove" button located in the center of the GUI.

To update the fields of an existing path within the "Path Flow – MW (MVAR)" displays, choose the desired MW/MVAR path from the "Selected Paths" list, modify the appropriate fields, and click on the "Add" button located in the center of the GUI.

Once the desired changes have been made, click on the "OK" button (and the "APPLY" button within the Configuration Utility in Figure 74) for the changes to take effect[9].

[9] Use the "Pick to Move Text" icon under navigation tools to reposition associated text and avoid clutter.

13. PROPERTY EDITOR

The visual properties of each of the panels within all five displays can be customized by the user through a property editor GUI for that particular panel. A sample GUI is shown in Figure 81. Some of the capabilities of the property editor GUIs are:

- Change the maps in geographic displays.
- Modify font settings of titles, axis labels, legend labels, identifiers, text values etc.
- Change properties of graphics such as the dials and arrows.
- Adjust legends – their thresholds and associated colors.

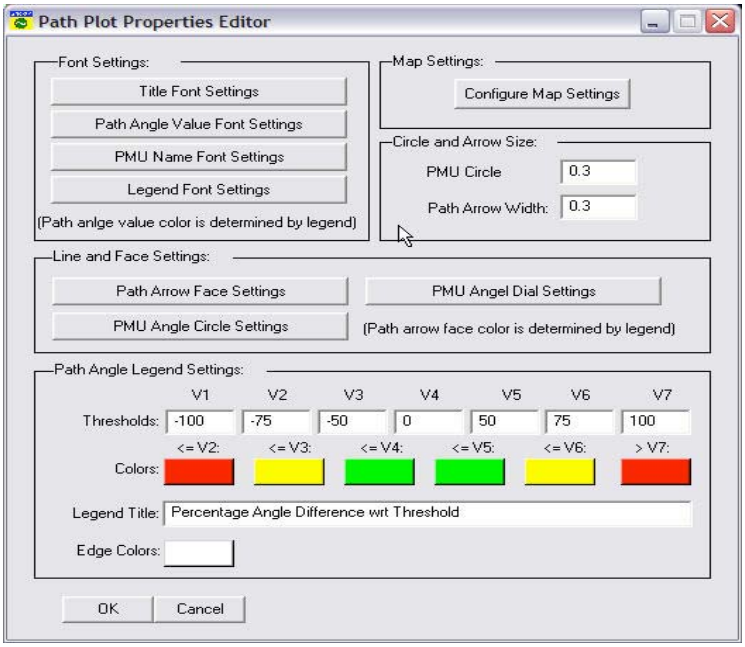


Figure 81: Property Editor Sample Graphic User Interface (Path Dynamics – Panel 1)

To open the property editor for a panel, right click within the panel and the pop-up menu shown in Figure 82 will appear. Select the "Property Editor…" option to launch the editor in for the particular panel.

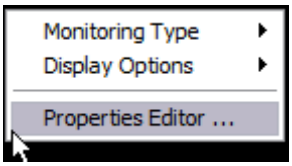


Figure 82: Property Editor Pop-Up

Note: The modifications made through the property editor for a panel are limited to the particular panel and do not affect the other panels.

14. HELP TAB

This tab, located on the top right corner, brings the RTDMS help directory listing information about the application categorized by major topics and sub-topics along with search capability based in key words (Figure 83).

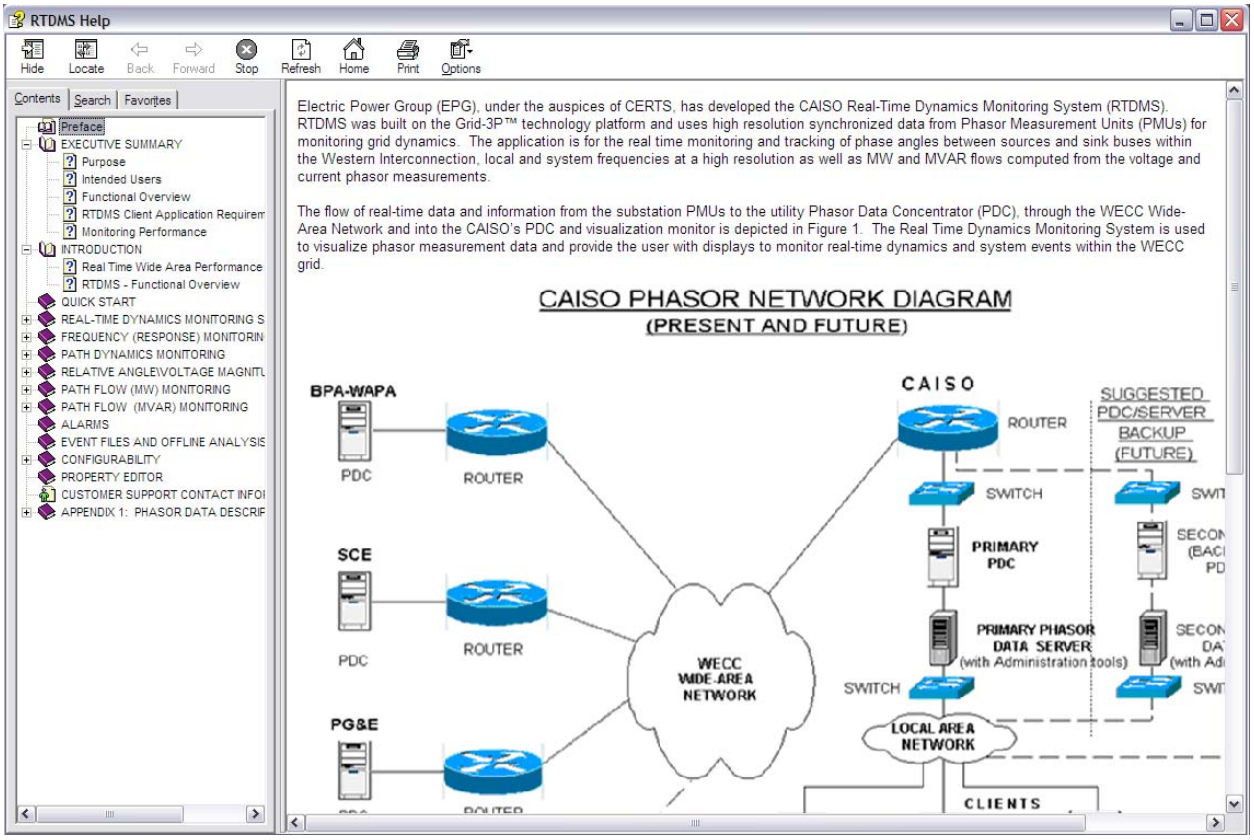


Figure 83: RTDMS Help Directory

CUSTOMER SUPPORT CONTACT INFORMATION

Electric Power Group support information:

Manu Parashar
201 South Lake Avenue, Suite 400
Pasadena, California 91101
E-mail parashar@electricpowergroup.com
Tel. 626-685-2015 Ext. 130

Simon Mo
201 South Lake Avenue, Suite 400
Pasadena, California 91101
E-mail mo@electricpowergroup.com
Tel. 626-685-2015 Ext. 123

APPENDIX 1: PHASOR DATA DESCRIPTION

Two types of data constitute the real-time phasor stream: static information about the PMU and the signal descriptions associated with each of its channels, and dynamic phasor values with timestamp information. This section outlines the data structure used within the RTDMS application.

1. Static Data

Version Information **–** Stores version and update information for static data.

Version: major and minor version information.
Update Date: the date the static information is updated.

Example
Version: 1.0
Update Date: 22-Aug-2004 16:07:44

PMU Description – Stores the static information of every PMU in the system to be monitored.

PMU ID: an integer to identify the PMU, unique.
PMU Code: short name, 4 characters string.
PMU Name: long name.
Longitude: location of PMU.
Latitude: location of PMU.
Vendor: Vendor of the PMU.

Example
PMU ID: 2
PMU Code: JDAY
PMU Name: John Day
Longitude: -119.2
Latitude: 47.37
Vendor: Macrodyne

Signal Description – Stores the static information signals provided by PMUs.

Signal ID: an integer to identify the signal, unique.
Signal Name: the description of the signal.
Signal Type: the code to describe the signal type such as
- VA: voltage angle
- VM: voltage magnitude
- IA: current angle
- IM: current magnitude
- FR: frequency
- PP: MW
- PQ: MVAR
- ##: Others

PMU ID: indicate the PMU with which the signal associates.
Base kV: an integer to present the voltage level of the signal (–1 if not applicable).
Item Name: the corresponding tag name in OPC/PI Server for this signal.
Remote Longitude: location of line current endpoint (optional, only applies to current type signal).
Remote Latitude: location of line current endpoint (optional, only applies to current type signal).
Remote Name: remote station name at the other end of this signal.

Example
Signal ID: 5
Signal Name: John Day-Big Eddy Current
Signal Type: IA

PMU ID: 2
Base kV: 500
Item Name: JDAY.IA.johnday- Big Eddy Current
Remote Longitude:
Remote Latitude:
Remote Name:

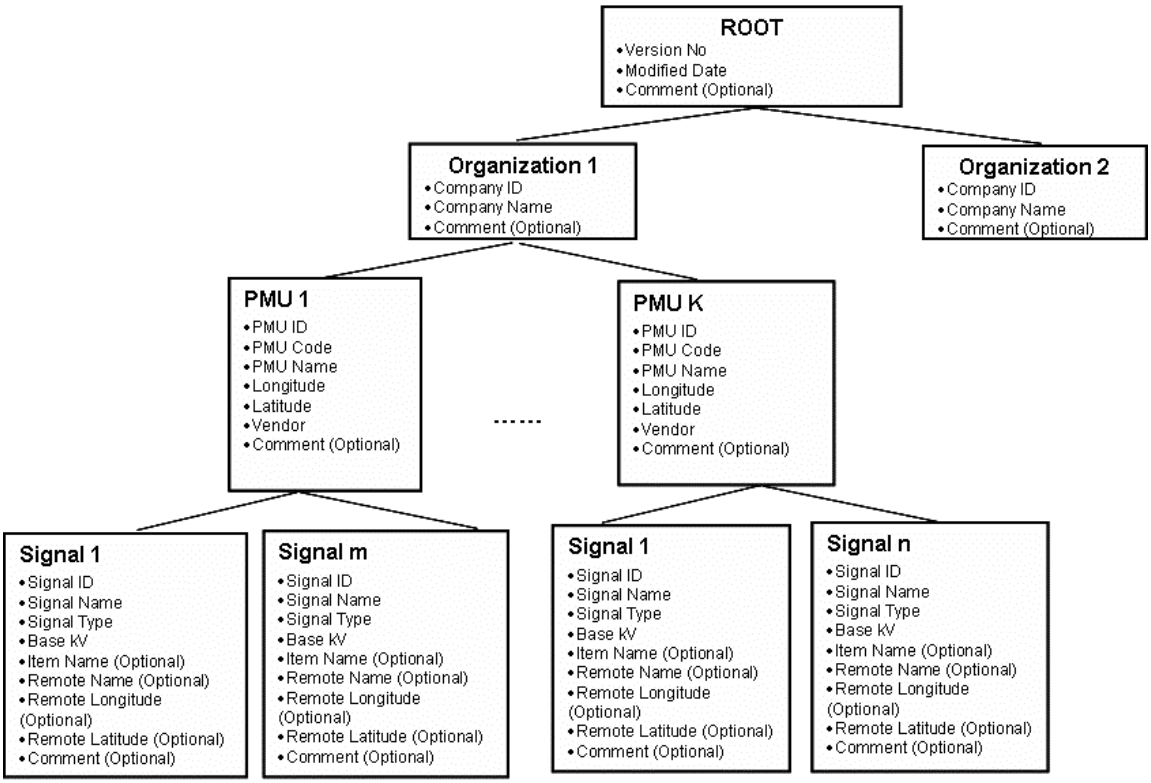
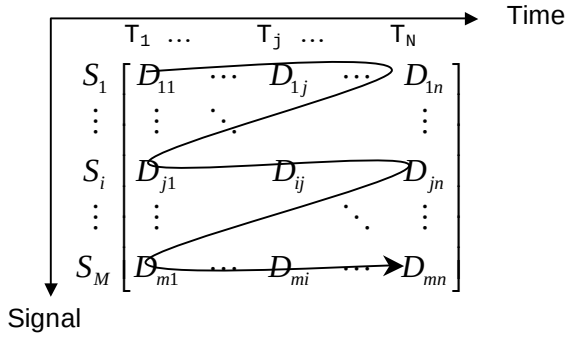


Figure 84: Static Information Hierarchical Structure

Source: CERTS

2. Dynamic Data

Time-stamped dynamic data of all signals are available for access. Dynamic data includes real-time data and historical data. Dynamic data can be accessed according to the provided signal ids and the timestamp. This data in the application is maintained as a two-dimensional array where the rows correspond to the signals and the signals correspond to different time instances.