Arnold Schwarzenegger
Governor

REAL-TIME GRID RELIABILITY MANAGEMENT

Prototype Phasor-Based Real-Time Monitoring Software Tool – Training Presentation

APPENDIX E

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Lawrence Berkeley National Laboratory
Consortium for Electric Reliability
Technology Solutions

October 2008
CEC-500-2008-049-APE

Prepared By:
Lawrence Berkeley National Laboratory
Joe Eto, Manu Parashar, Bernard Lesieutre, and
Nancy Jo Lewis
Berkeley, CA

Administered by University of California, California Institute for Energy and Environment under 500-99-013, BOA-138.
Jim Cole, Larry Miller
Oakland, California 94612
Commission Contract No. 500-02-004
Commission Work Authorization No: MR-036

Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

Beth Chambers
Contract Manager

Jamie Patterson
Program Area Lead
Transmission Research Program

Martha Krebs, Ph.D.
PIER Director

Thom Kelly, Ph.D.
Deputy Director
ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

RTDMS

CA ISO TRAINING SESSION

January 31, 2006

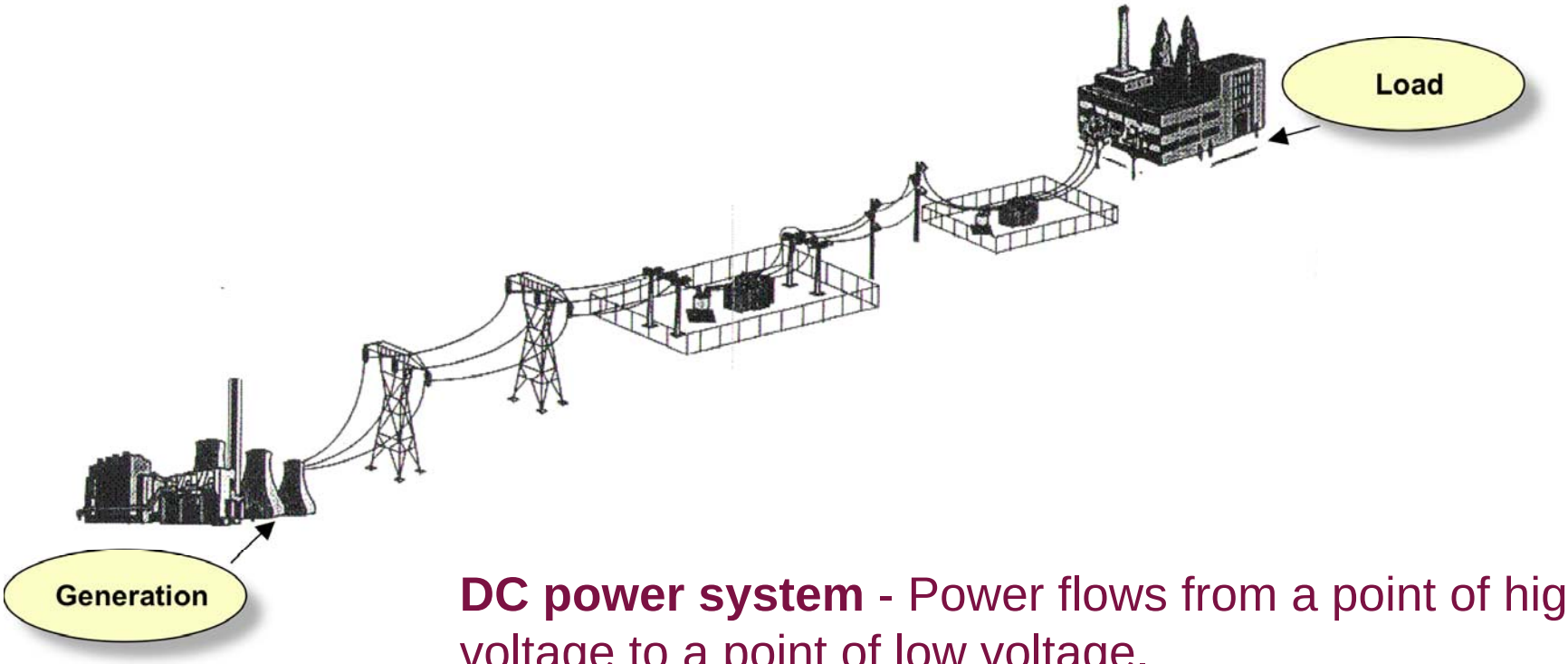
Manu Parashar & Jim Dyer
Electric Power Group (EPG)

Agenda

- Phasor Technology – Overview
- The Importance of Using Synchronized Data
- Review of Some WECC Events
- CA ISO Real-Time Dynamics Monitoring System
  - Project Objectives
  - System Architecture
  - What the System Operator Will See
- RTDMS Visualization
  - Architecture
  - Navigation Within RTDMS
  - Displays
  - Client Support
- RTDMS Application Demo

Phasor Technology Overview

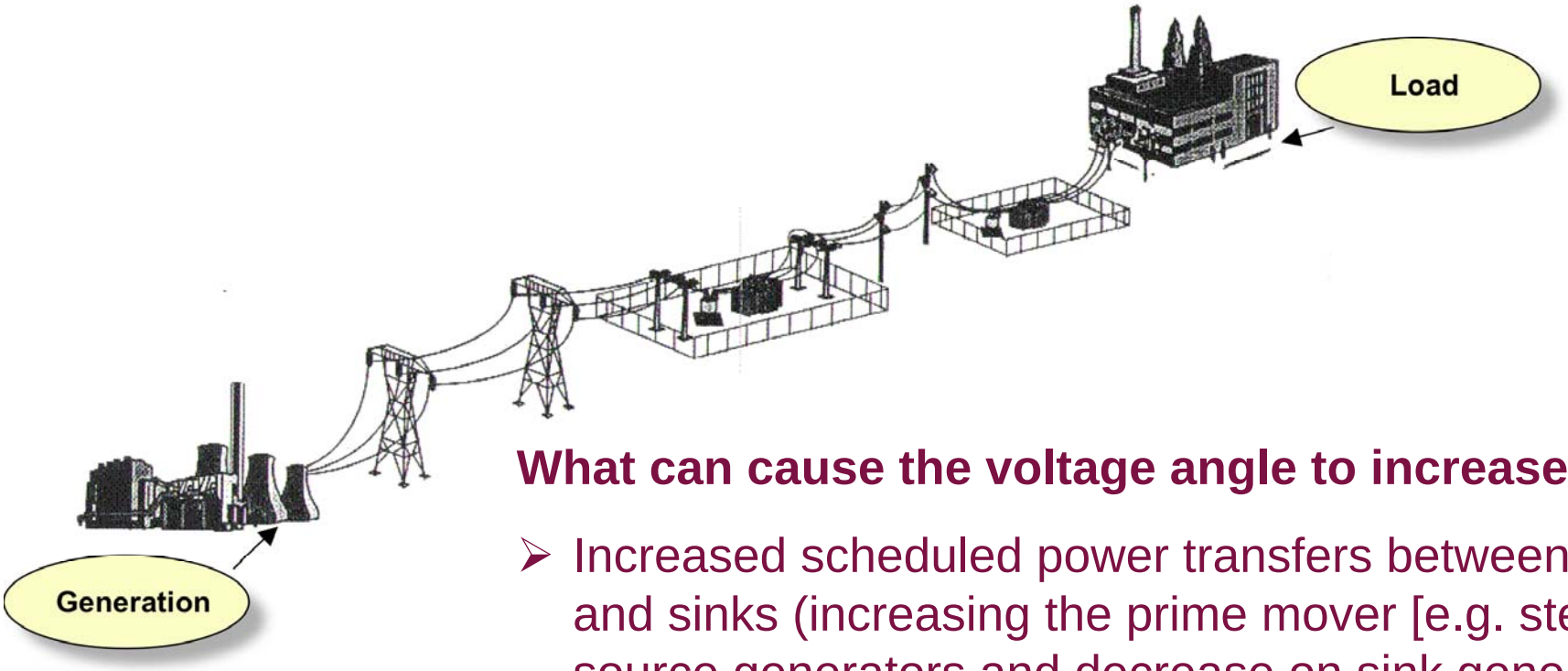
What Causes Power to Flow on the Grid



DC power system - Power flows from a point of high voltage to a point of low voltage.

AC power system - Power flows from a point of high voltage angle to a point of low voltage angle. The higher the angle the greater the power flow.

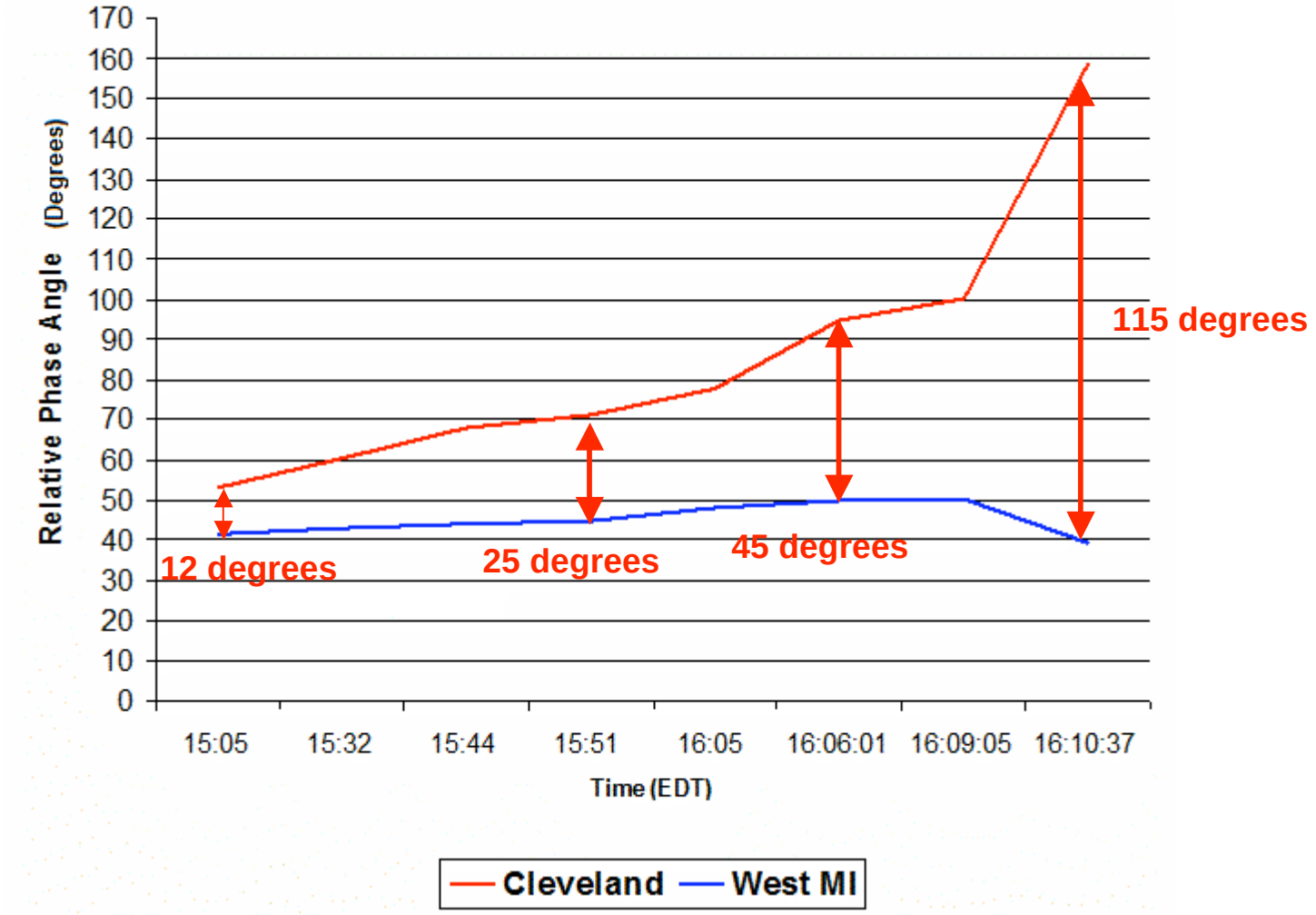
What Causes Voltage Angle to Increase



What can cause the voltage angle to increase?

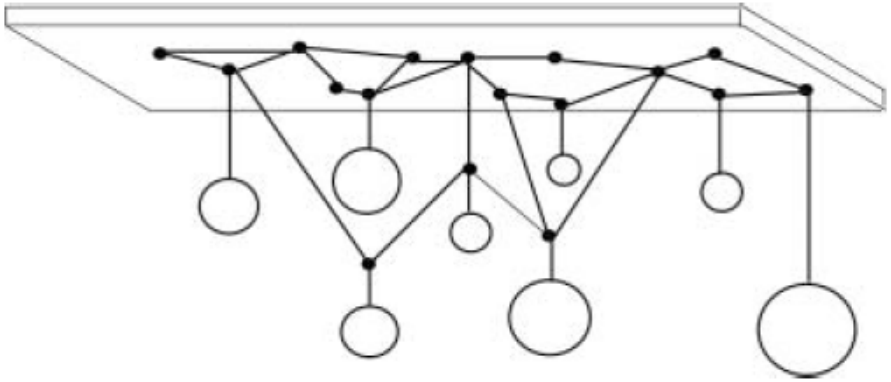
- Increased scheduled power transfers between source and sinks (increasing the prime mover [e.g. steam] in source generators and decrease on sink generators).
- Transmission lines removed (forced or scheduled) from service between source and sink, without adjusting schedules.
- Loss of generation in the sink area.

Eastern Interconnection - Angle Separation on 8-14-03

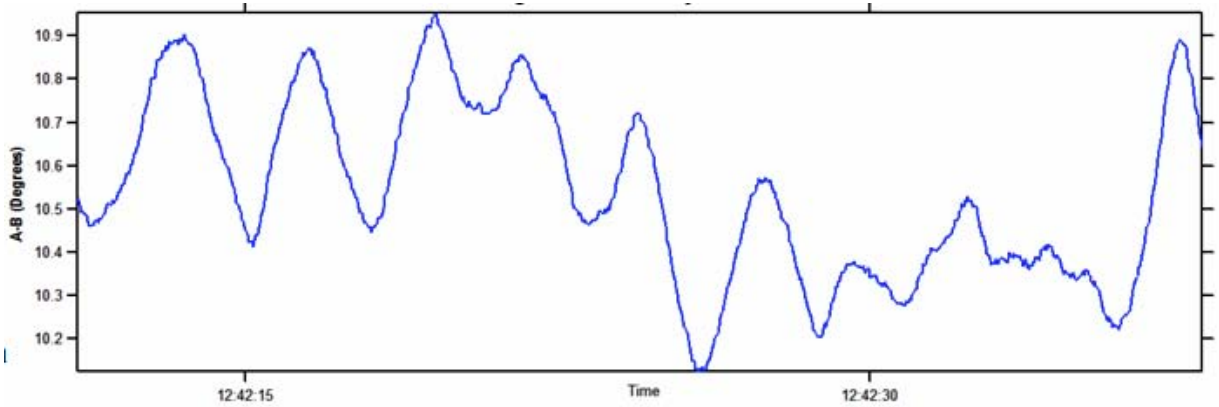


Power System Dynamics

Mechanical Analogy for Power System Dynamics

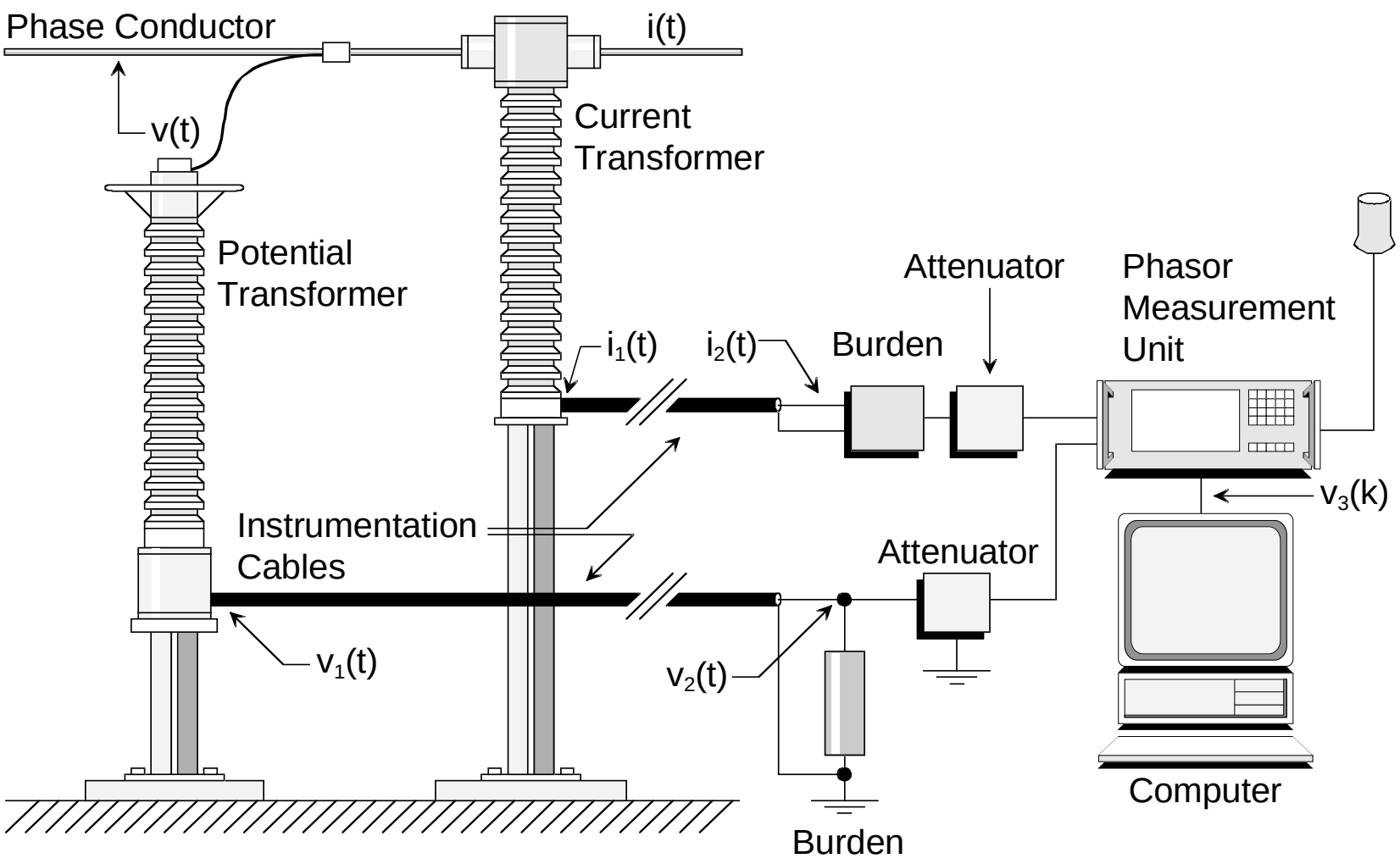


- Balls analogous to generators with different inertia
- Strings analogous to the physical power grid



- Pendulum swings analogous low-frequency oscillations observed by Phasor Measurement Units (PMUs)
- Oscillations may either decay or grow implying stability or instability respectively

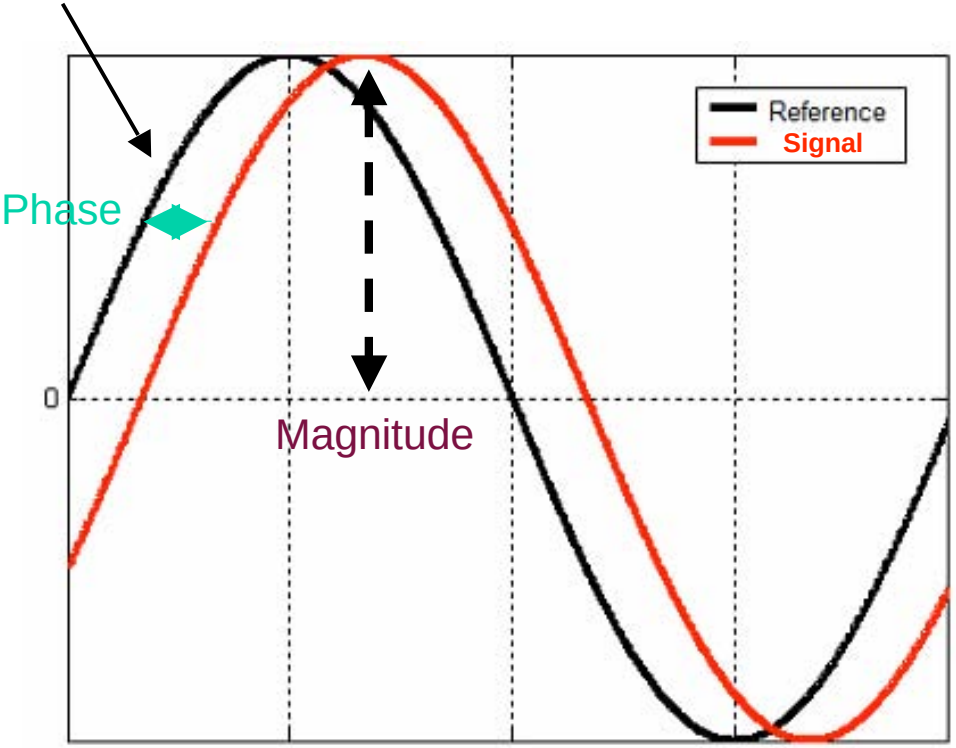
Source of Phasor Measurements

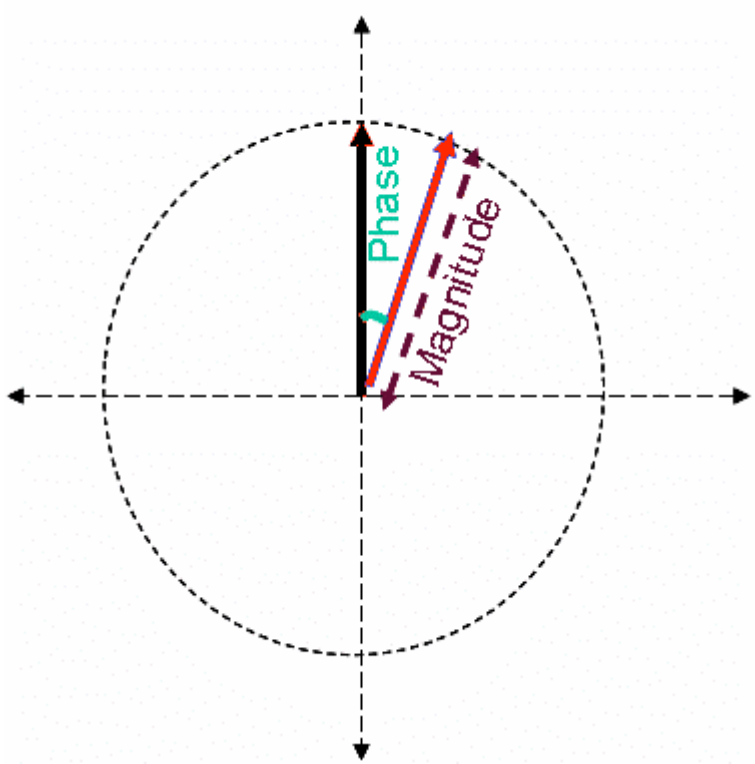


What Phasor Measurements are all about

Phasor Overview

"Reference 60Hz Signal using GPS time signal"

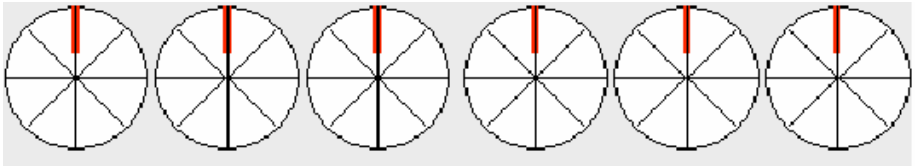




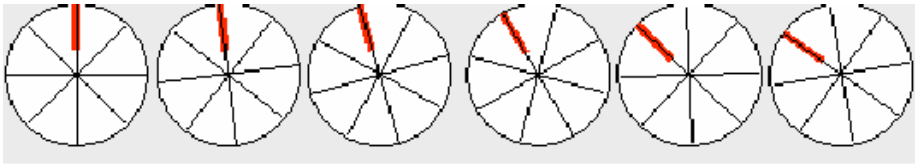
What Phasor Measurements are all about (cont.)

Strobe Light Analogy

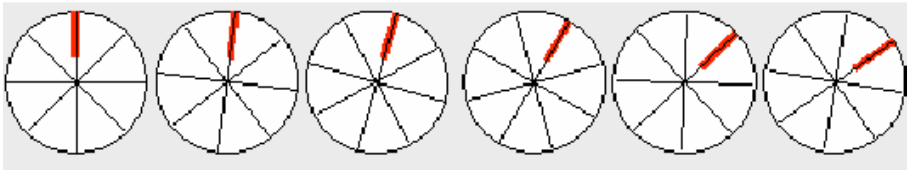
Pure 60Hz Signal



Decelerating System

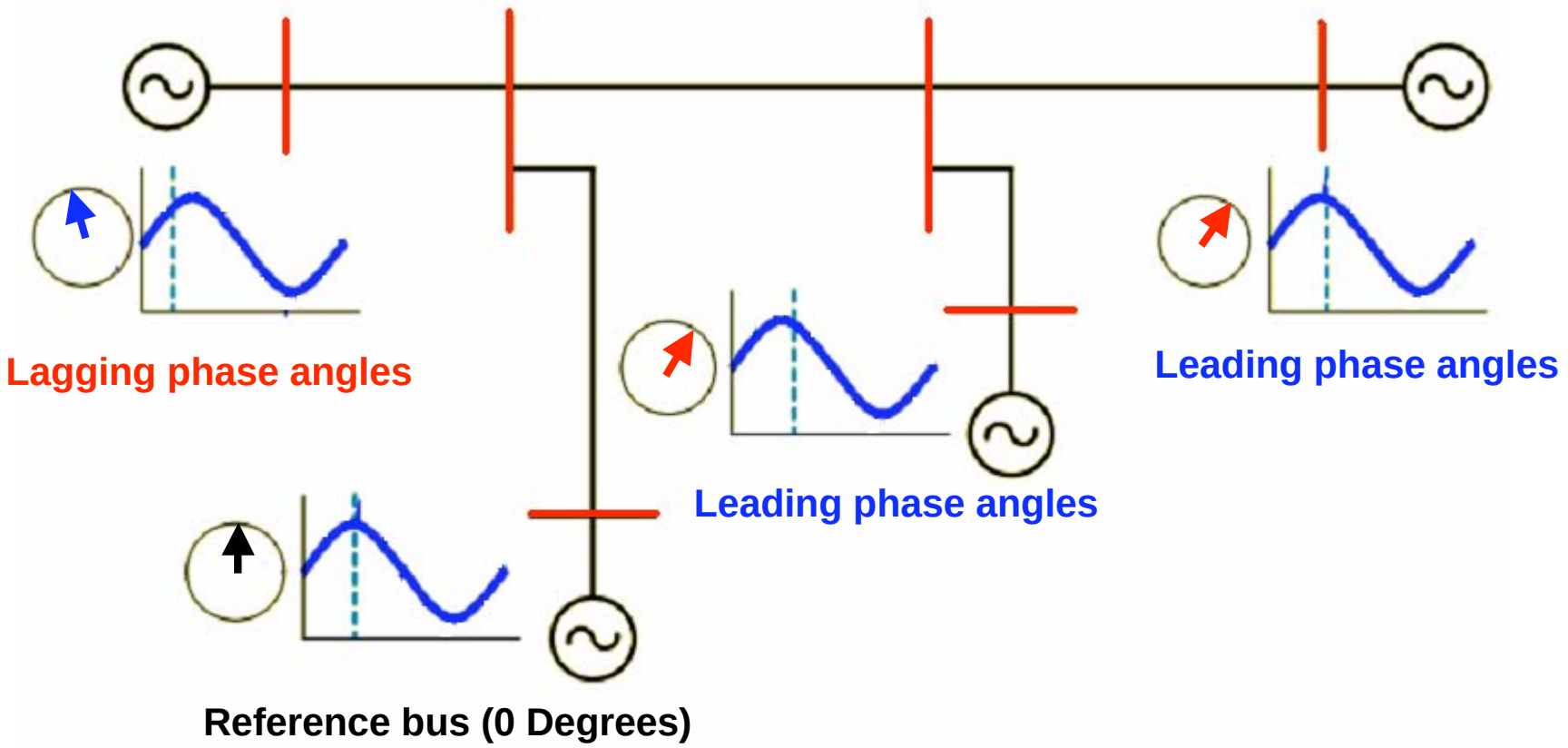


Accelerating System



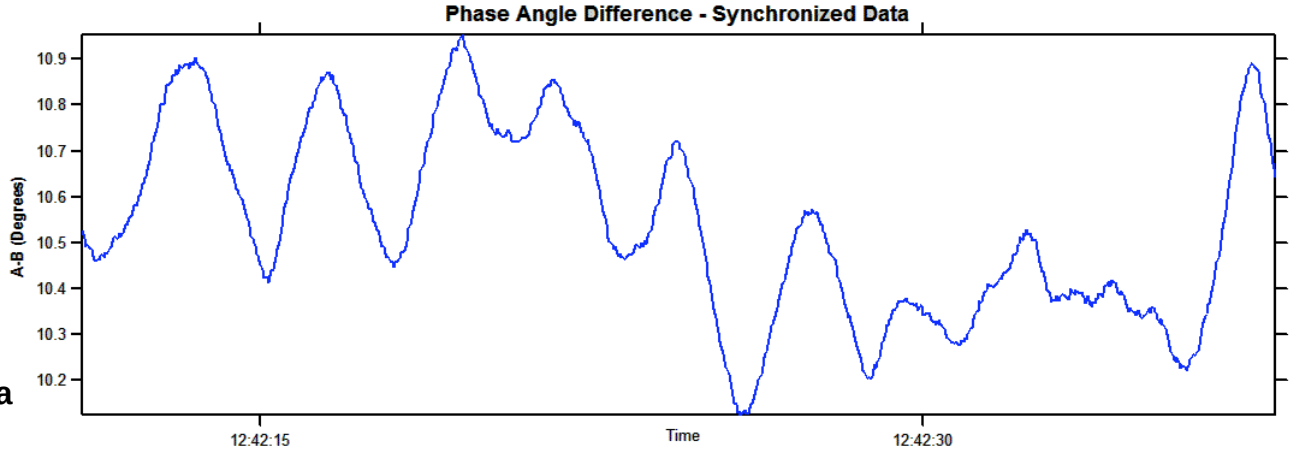
What Phasor Measurements are all about (cont.)

System Wide "Snapshot" Across Power Grid

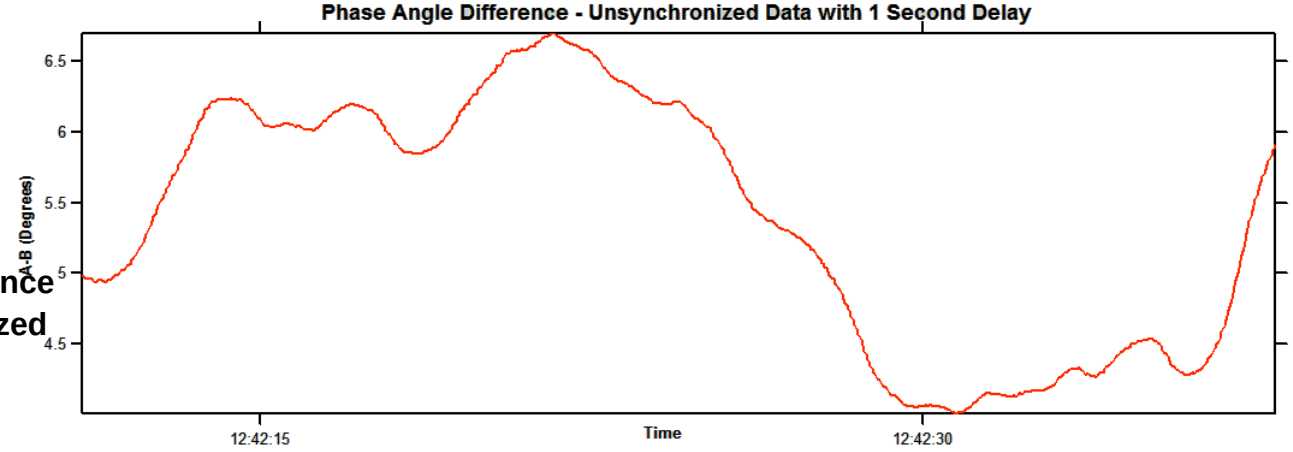


Importance of PMU Data Synchronization

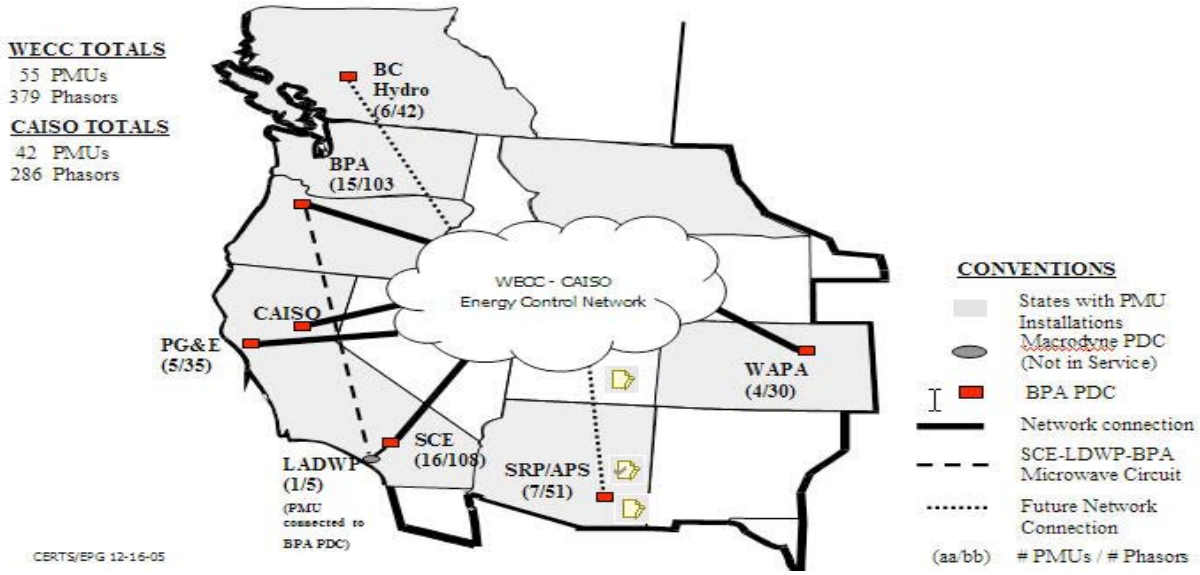
phase angle difference using synchronized data



phase angle difference using unsynchronized data with 1 second mismatch



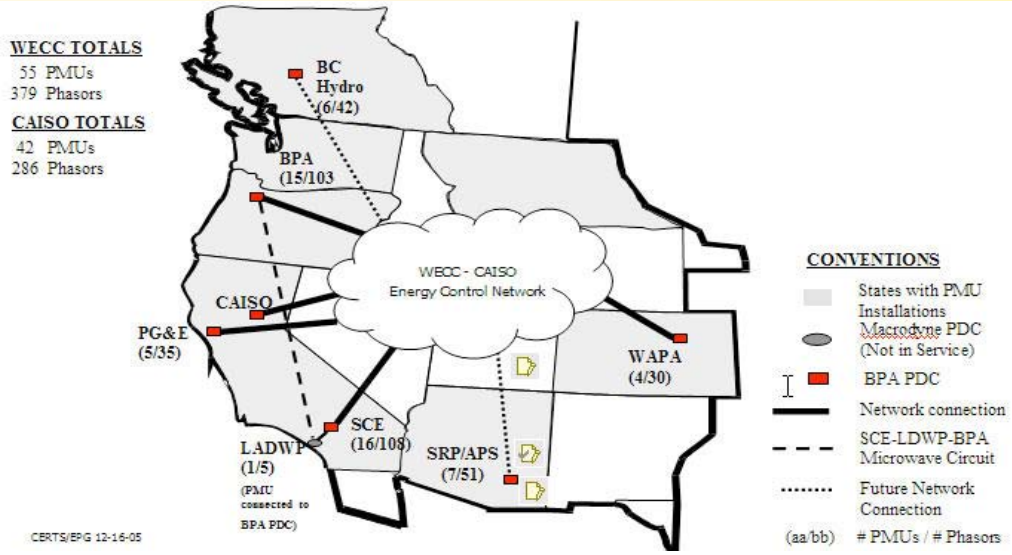
What Phasor Measurements are all about (cont.)



Networking - Most stability events, involve a widespread area, and involve oscillations and control interactions between neighboring utilities and geographic operational regions. This dictates the need for multiple recording devices across the transmission grid.

Time Synchronization - Phasor measurements are time-stamped using the global satellite positioning system so that measurements from across the interconnection can be precisely aligned for comparison against one another.

What Phasor Measurements are all about (cont)



The Primary Hardware Elements in a Phasor Network are:

Phasor Measurement Unit (PMU) – PMUs are located at key substations and measures and are capable of gathering better data at higher sampling rates than analog monitoring devices. The PMU time stamps the local frequency, voltage and line currents at a rate of 30 to 60 times per second. The voltage and current data is used to calculate MW and MVAR flows on key lines. Substation PMU phasor data is transmitted to a PDC at a central location..

Phasor Data Concentrator (PDC) – Receives, integrates, and stores phasor signals from remote PMUs. Can also exchange records with PDCs at other locations. One of the primary functions of the PDC is to perform data synchronization.

Phasor Technology – Industry Uses

- The use of phasor technology allows the industry to take high resolution "snapshots" of what is happening throughout the Western Interconnection grid and evaluate the grids performance during system events.

- System operators and planners can use data gathered by PMUs for a host of applications, including:

  - State estimation
  - Real-time wide area monitoring
  - Validation of power system models
  - Transient instability protection and fault location systems

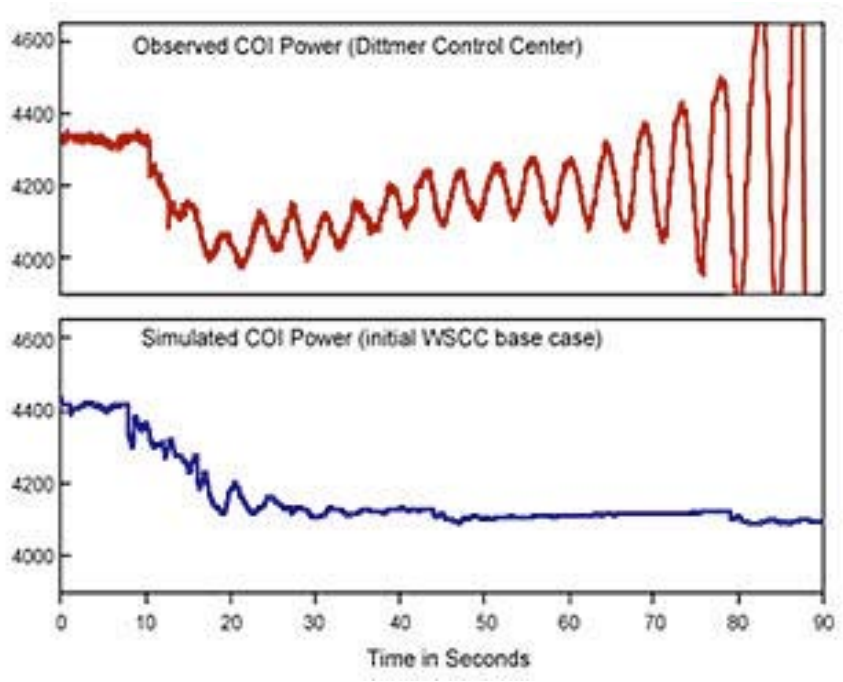
Value of Phasor Technologies - Example

WECC's Experience

Comparison of model simulation system performance predictions prior to the WECC's August 10, 1996 blackout (lower panel) and conditions actually recorded by phasor technologies (upper panel) showed that the planning models were not able to accurately capture underlying causes of the blackout

The WECC has since modified their simulation models to better represent actual system performance.

Actual System Performance



Model Simulation - Predicted System Performance

Actual WECC Phasor Data Events

WECC Event - # 1

- Location: Western Interconnection
- Date/Time: Friday, August 4, 2000, 7:56PM
- High Static Stress and Low Dynamic Stress

- System Conditions:

1) System was operating with an angle greater than 90 degrees between Devers Substation (Palm Springs, Ca.) and Grand Coulee Power Plant (near Spokane, Wa.), a distance of over 1,000 miles

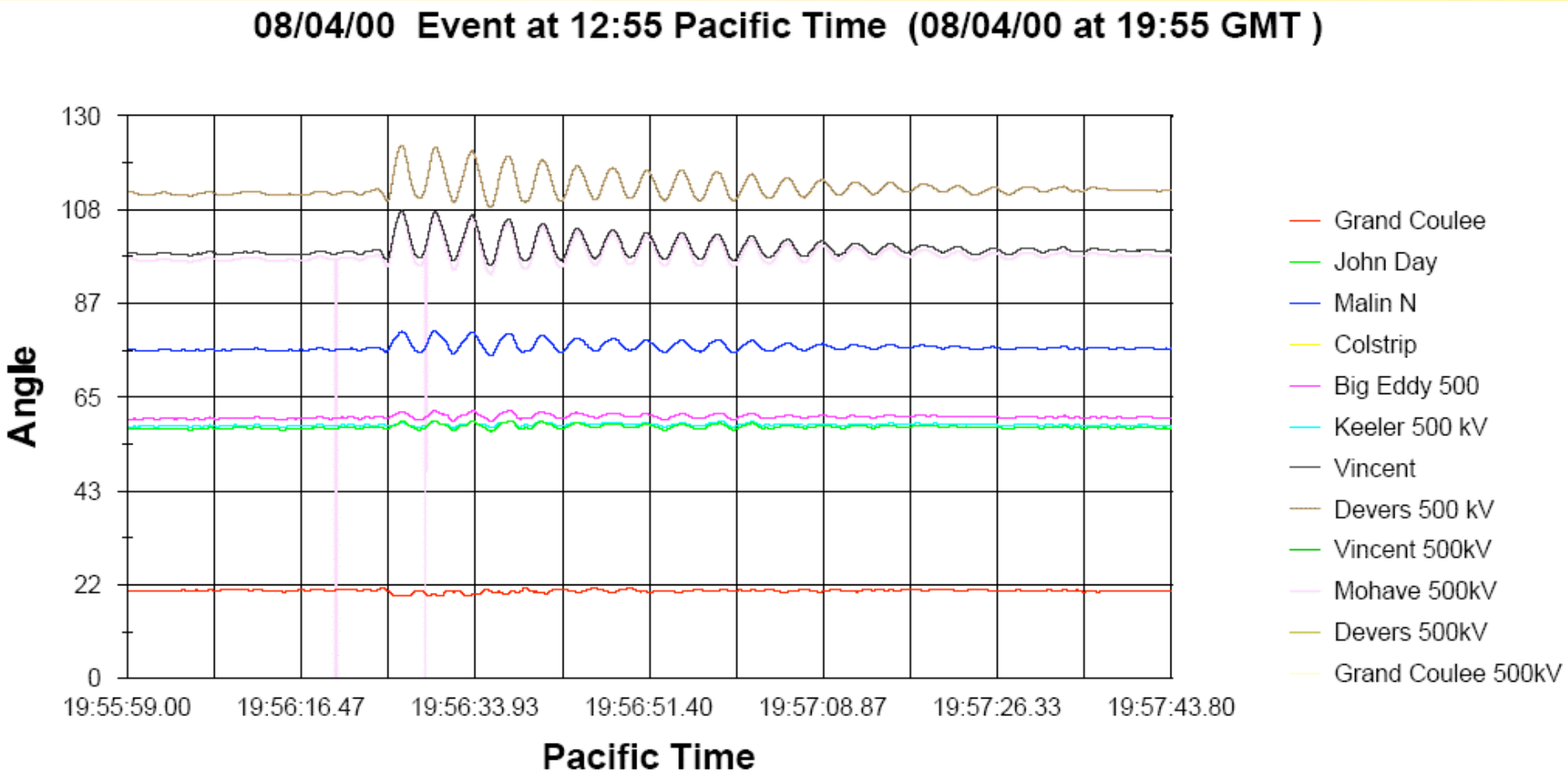
2) A 500 kV tie-line exporting power from British Columbia to Alberta, Canada tripped

3) Loss of line resulted in increased flows by 450 MW

4) The dynamic stress between Devers and Grand Coulee increased to 108 degrees (an 18 degree increase)

5) System oscillated for about 60 seconds showing low damping

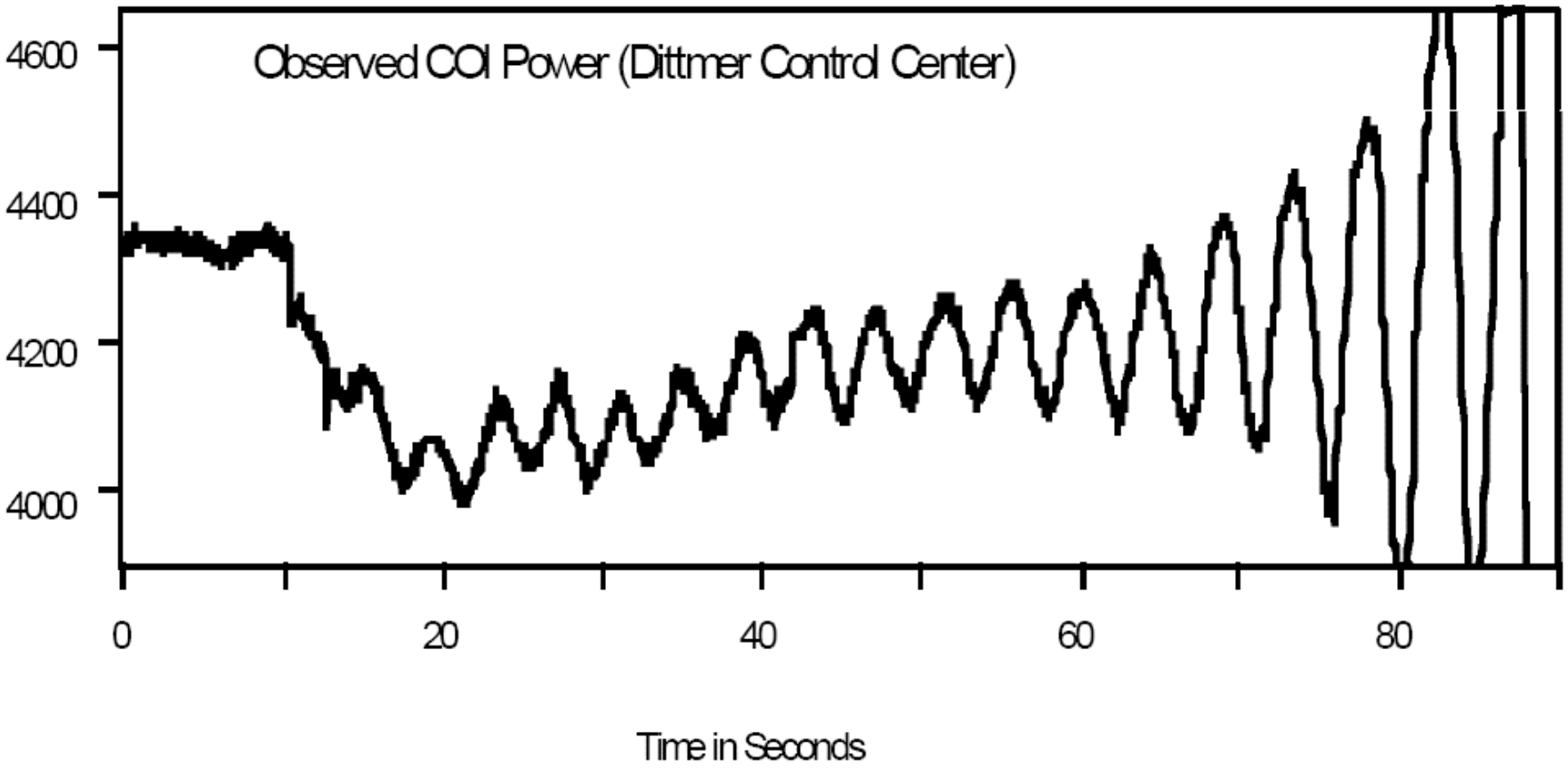
WECC Event - # 1



Angle Reference is Colstrip

J. Balance, B. Bhargava, G.D. Rodriquez, “Use of Phasor Measurement System for Enhancing AC-DC Power System Transmission Reliability and Capacity.”

Comparison with August 10th 1996



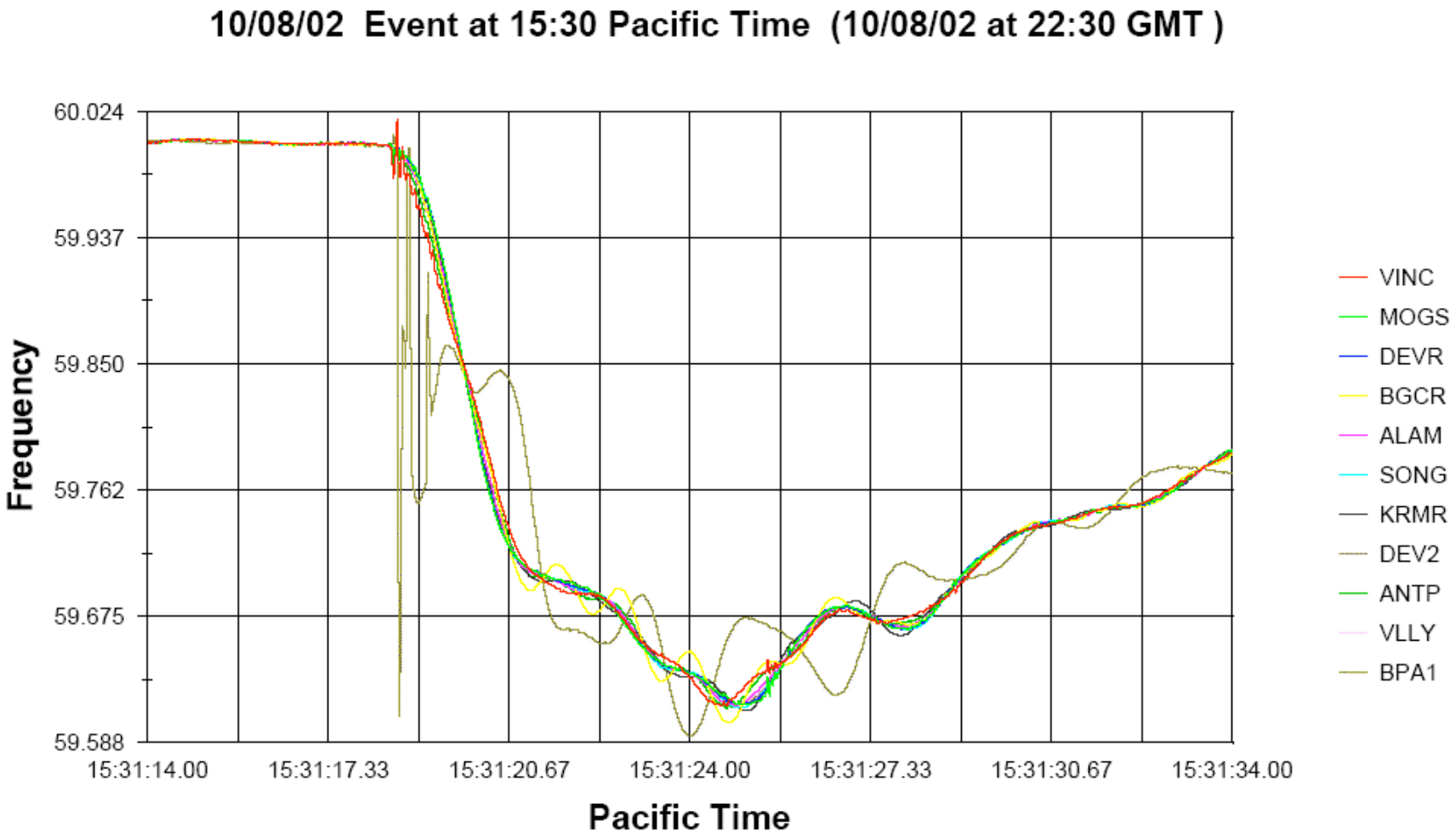
WECC Event # 2

- Location: Western Interconnection
- Date/Time: Tuesday, October 8, 2002, 3:38PM
- Abnormal Interconnection Frequency: 59.62 Hz (380 mHz)

- System Conditions:

1) An AC line fault occurred in the northwest tripping three 500 kV lines
2) SPS operated by applying the 1400 MW Chief Joseph break and tripping 2800 MW of generation in northern WECC system.
3) The frequency dropped to 59.620 Hz.

WECC Event #2


10/08/02 Event at 15:30 Pacific Time (10/08/02 at 22:30 GMT)
Frequency
60.024
59.937
59.850
59.762
59.675
59.588
15:31:14.00
15:31:17.33
15:31:20.67
15:31:24.00
15:31:27.33
15:31:30.67
15:31:34.00
Pacific Time
VINC
MOGS
DEVR
BGCR
ALAM
SONG
KRMR
DEV2
ANTP
VLLY
BPA1

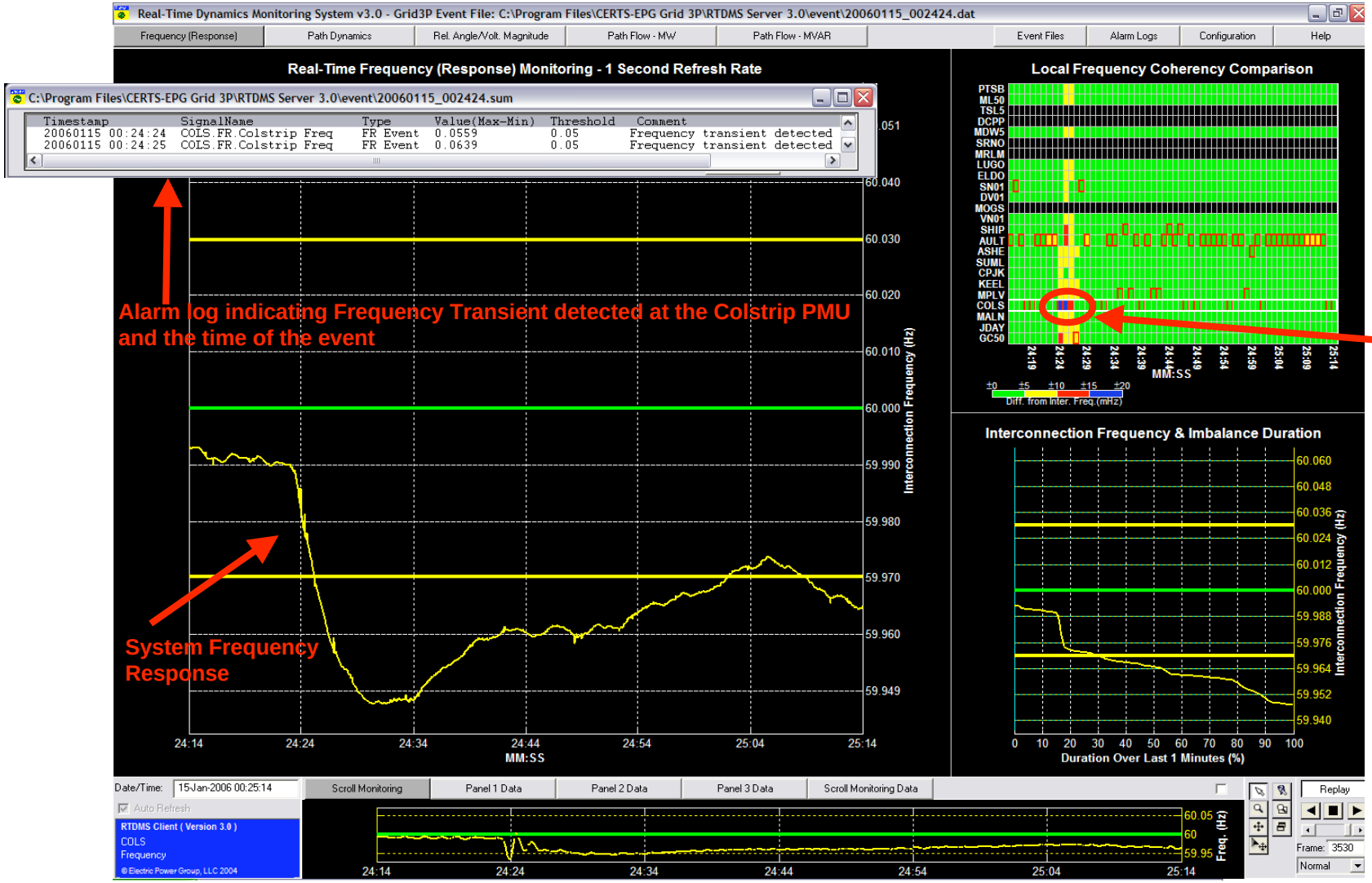
WECC Event # 3

- Location: Western Interconnection
- Date/Time: Sunday, January 15, 2006, 00:24AM
- Generator Trip (System Frequency Response Captured by RTDMS)

- System Conditions:
  1) NEW Colstrip Unit 1 relayed while carrying 240 MW
  2) System frequency deviated from 59.995Hz to 59.947Hz
  3) Recovered to 59.961Hz by governor action
  4) Returned to pre-disturbance level at 00:29

WECC Event #3

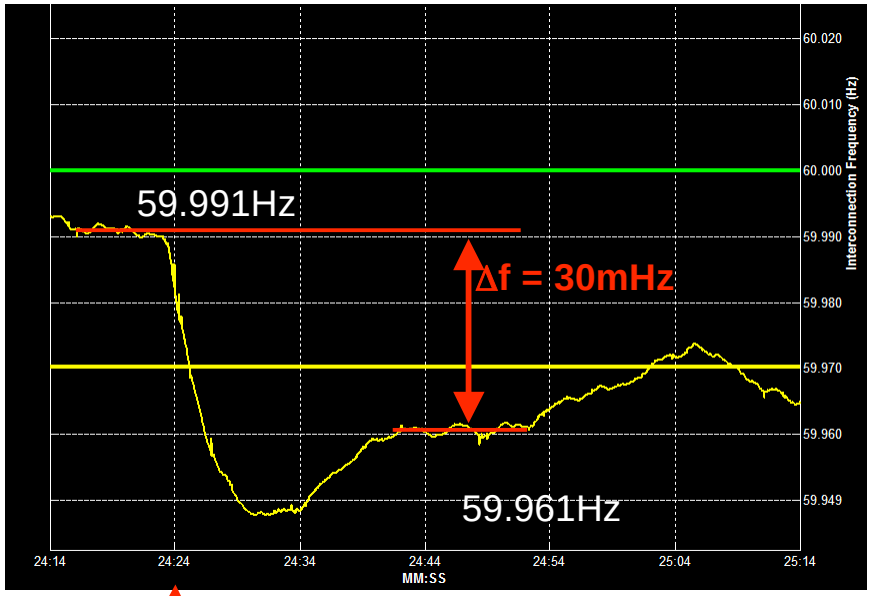
RTDMS Event File Name "20060115_002424"

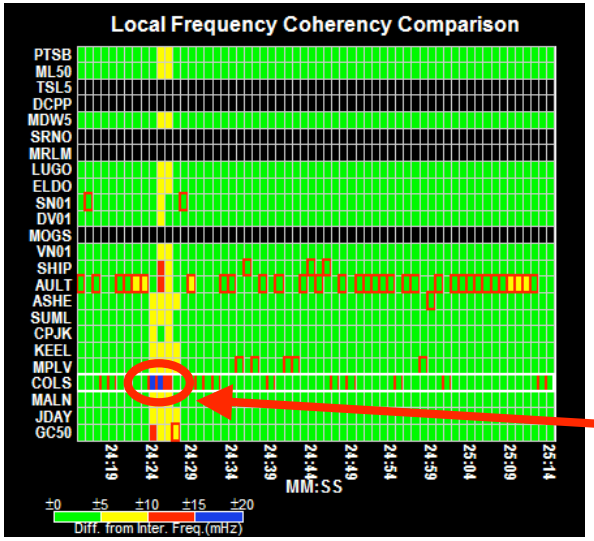


WECC Event #3 (Frequency Response)

January 15, 2006 (CA ISO Log)

01/15/2006 - **00:24** System frequency deviated from **59.995Hz** to 59.947Hz and recovered to 59.961Hz by governor action when NWE **Colstrip Unit** 1 relayed while carrying **240 MW**. System frequency returned to pre-disturbance level at 00:29.

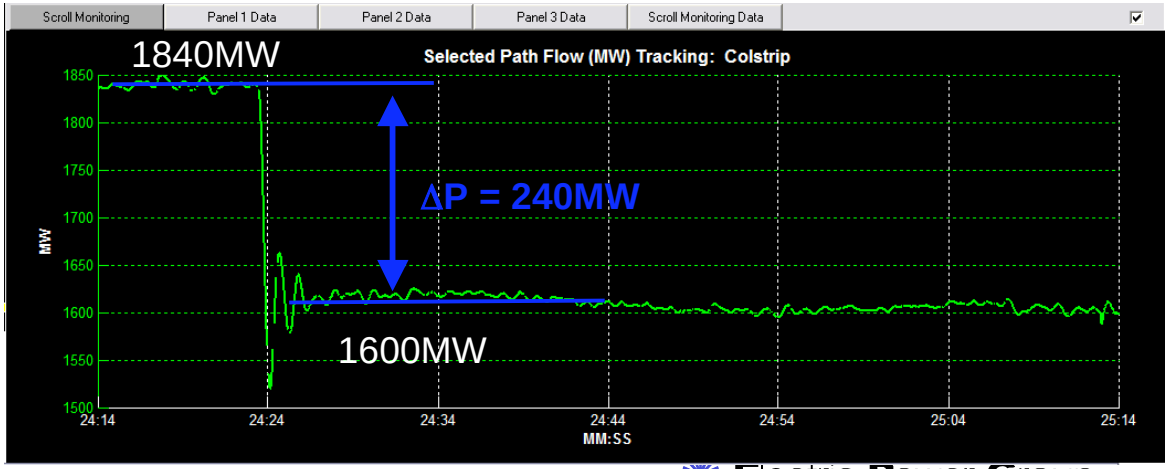




Identify Trip near Colstrip PMU

Jan 15, 2005 00:24:24 AM

$\beta = \Delta P/\Delta f = 800 MW/0.1Hz$



CERTS Consortium for Electric Reliability Technology Solutions

Electric Power Group

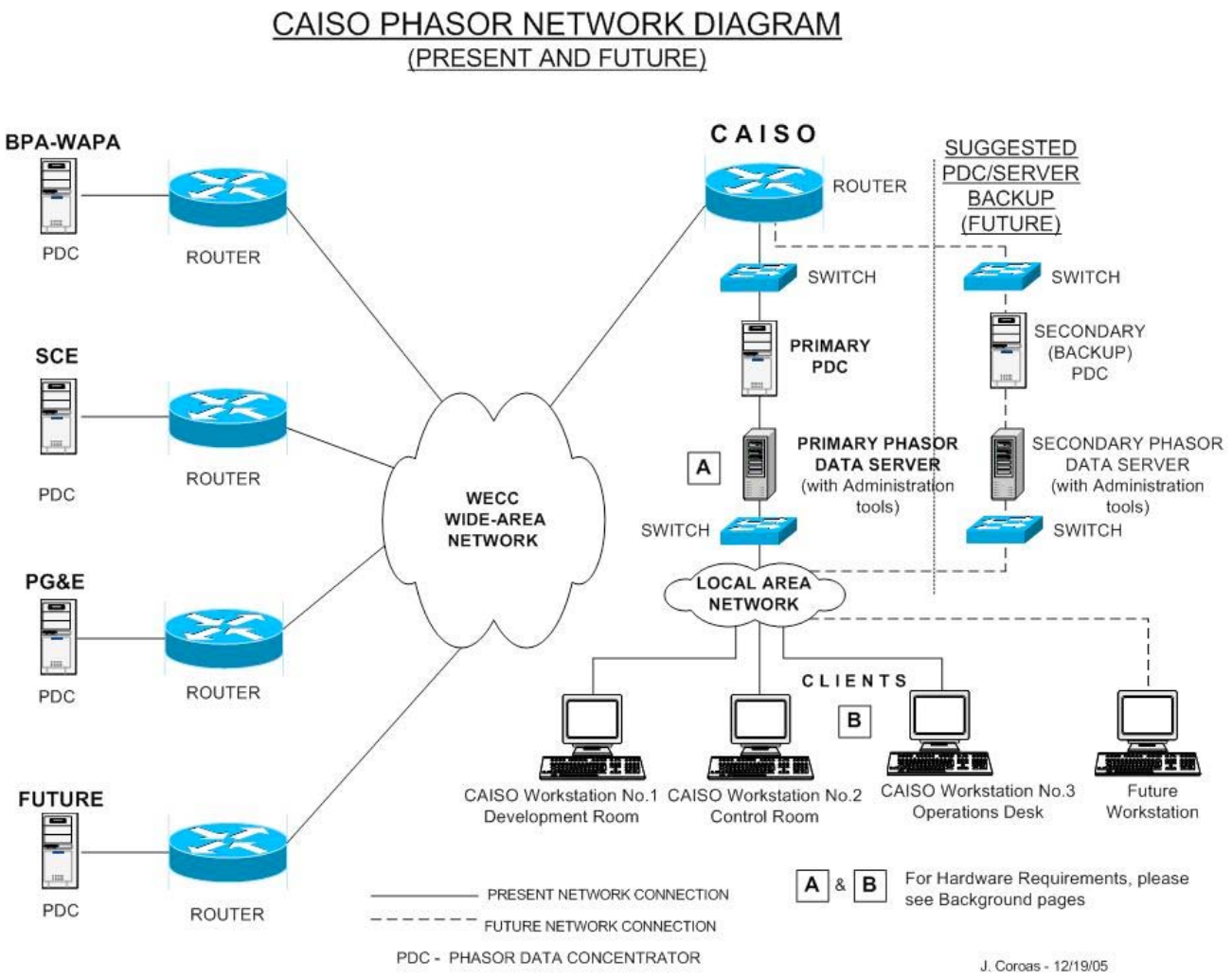
Any Questions About Phasor Technology?

Real-Time Dynamics Monitoring System (RTDMS)

Project Objectives for RTDMS Applications

- Develop a Real-Time Phasor Monitoring Prototype System for use by system operators at utilities, ISOs and reliability coordination centers.
- Enable system operators to gain familiarity with phasor technology for reliability monitoring and real-time operations.
- Learn to utilize phasor data to recognize normal and abnormal conditions, and assess grid stress.
- Provide system operators with real-time wide area information to increase situational awareness to avoid August 10, 1996 type blackouts.
- Monitor across the entire Western Interconnection (WI) for reliability, stability, system dynamics, and other key metrics using time synchronized phasor data.
- Enable system operators to evaluate and provide feedback on metrics monitored, visualization formats, functionality and displays.

CA ISO RTDMS System Architecture

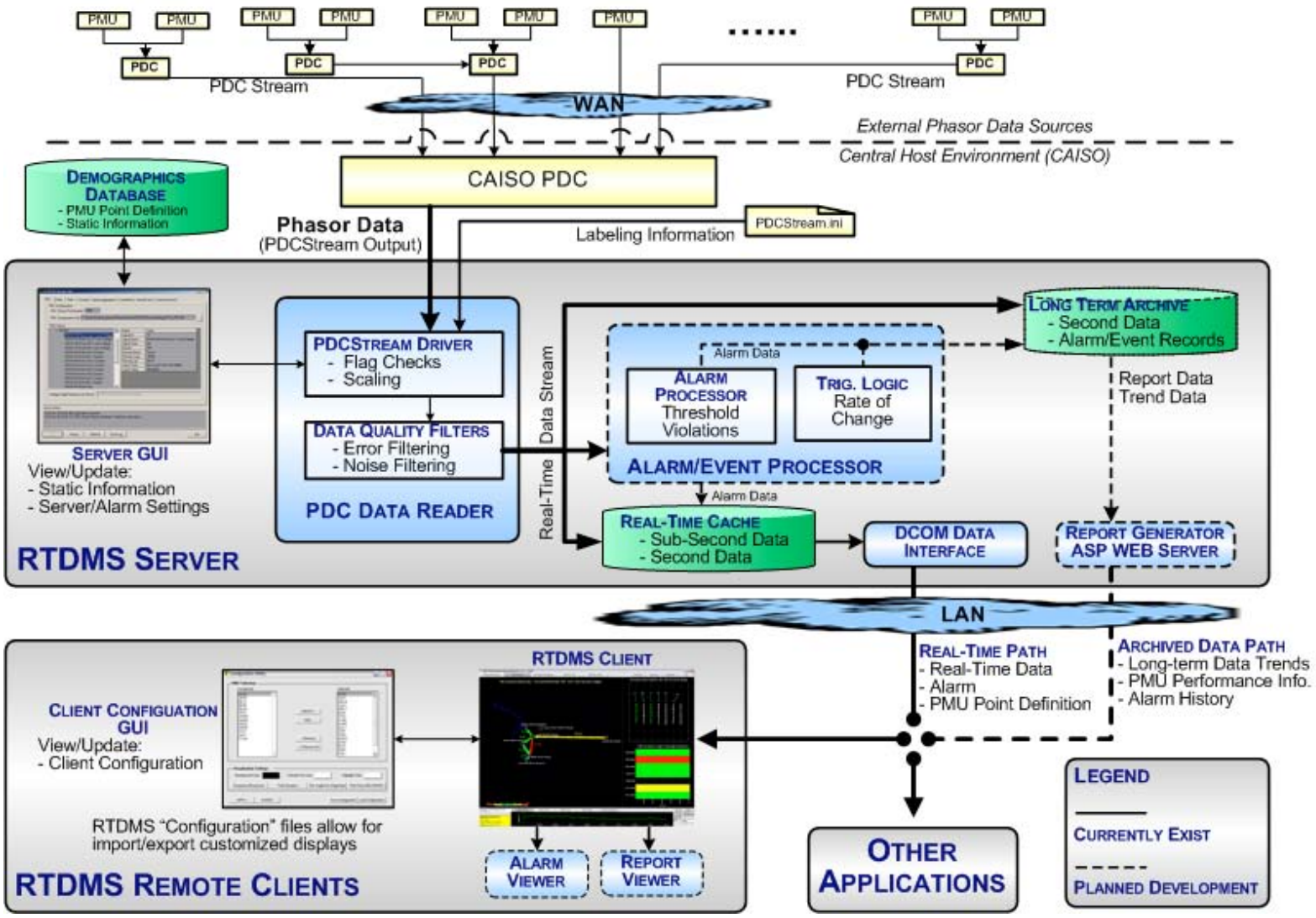


CA ISO RTDMS System Architecture

Data Acquisition
- Data Reading
- Data Cleansing
- Data Processing

Data Management
- Short-Term Buffer for RT Monitoring and Alarming
- Historical Data for Trending/Reporting

Remote Monitoring Clients
- Data Retrieval
- RT Monitoring & Alarming
- Trending & Reporting



CERTS

Electric Power Group

RTDMS – What will the System Operator See?

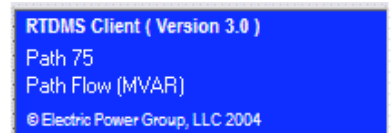
- Wide Area View of WECC – Key metrics at selected locations and transmission corridors.
- Key Metrics Include – System frequency, voltages, phase angles and angle differences between major sources and sinks
- Violation of Key Thresholds (defined limits) – Visual alarming (color coded)
- Rapid Changes in Metrics - Visual alarming
- Identify System Anomalies

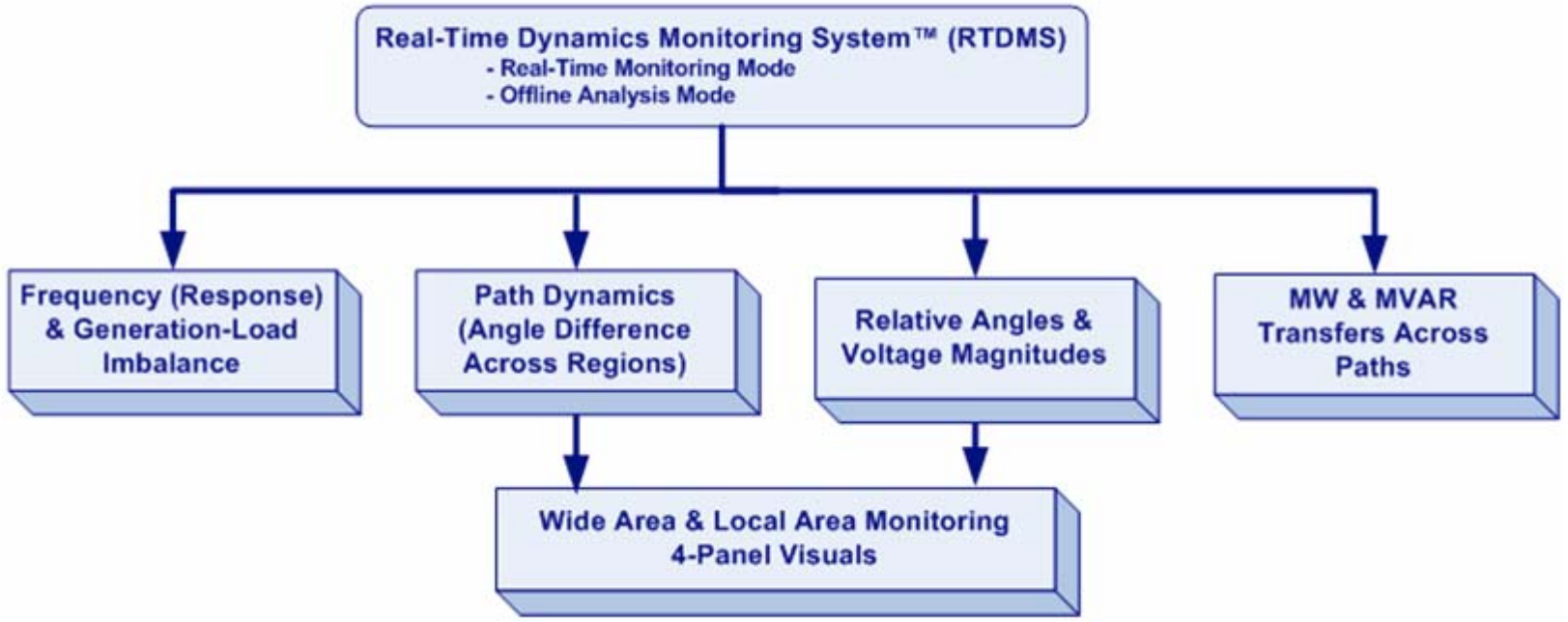
How To Navigate Around The RTDMS Screens

RTDMS Visualization Architecture

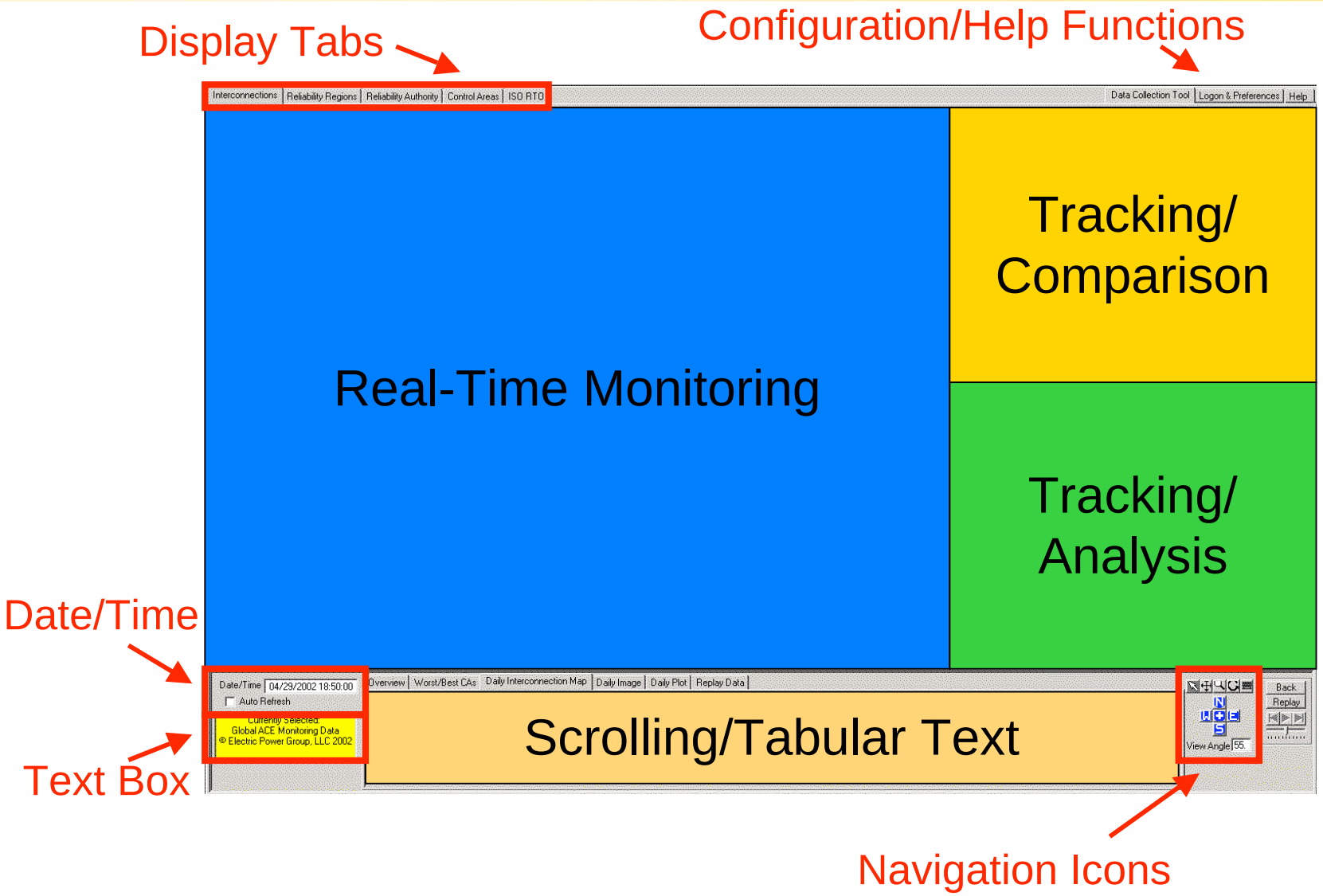
Real-Time Monitoring Mode

Offline Analysis Mode



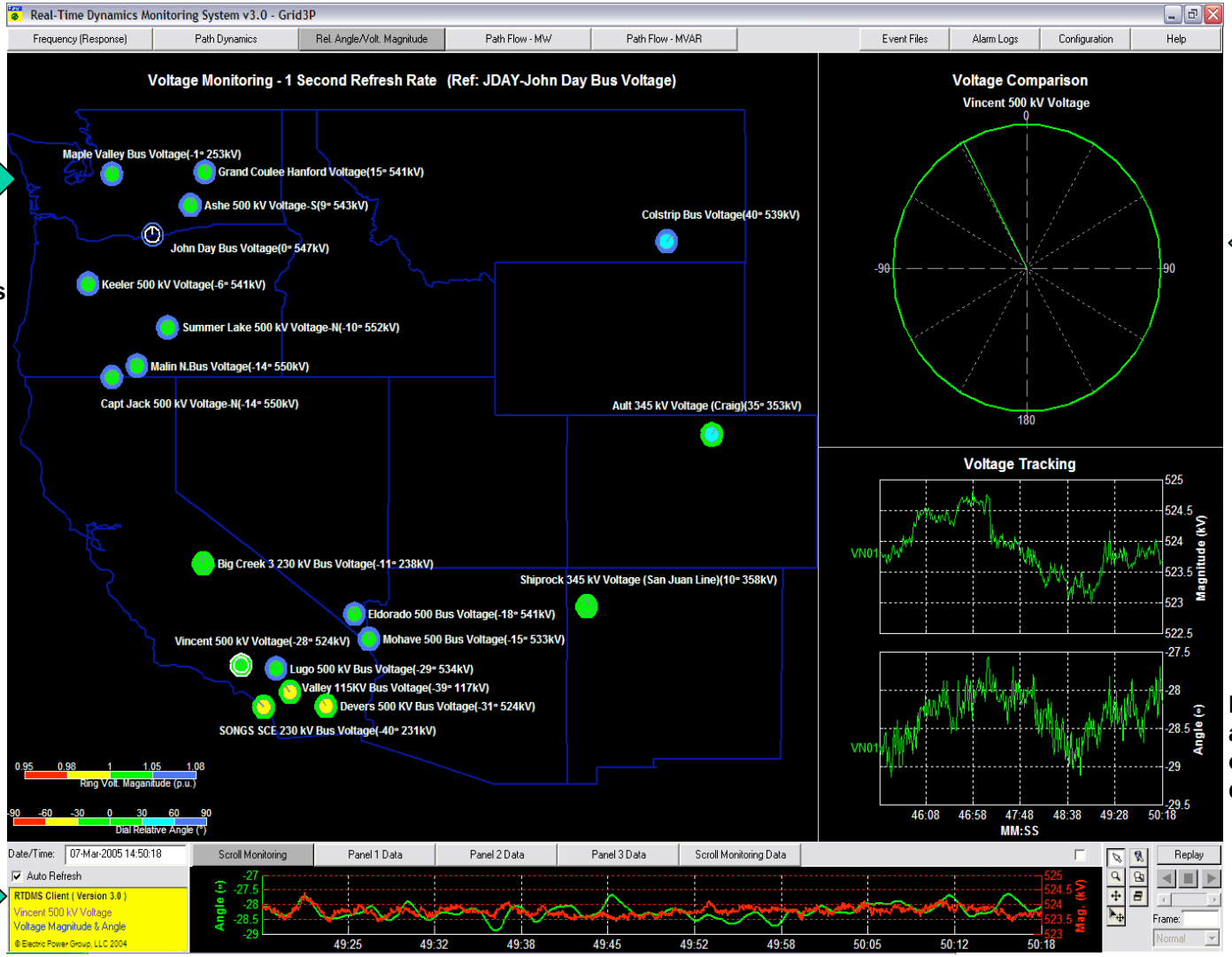


Four-Panel Display Major Functions



Sample Four-Panel Display

Monitor :
- voltage angles and magnitudes
- color coded
- quickly identify low or high voltage regions

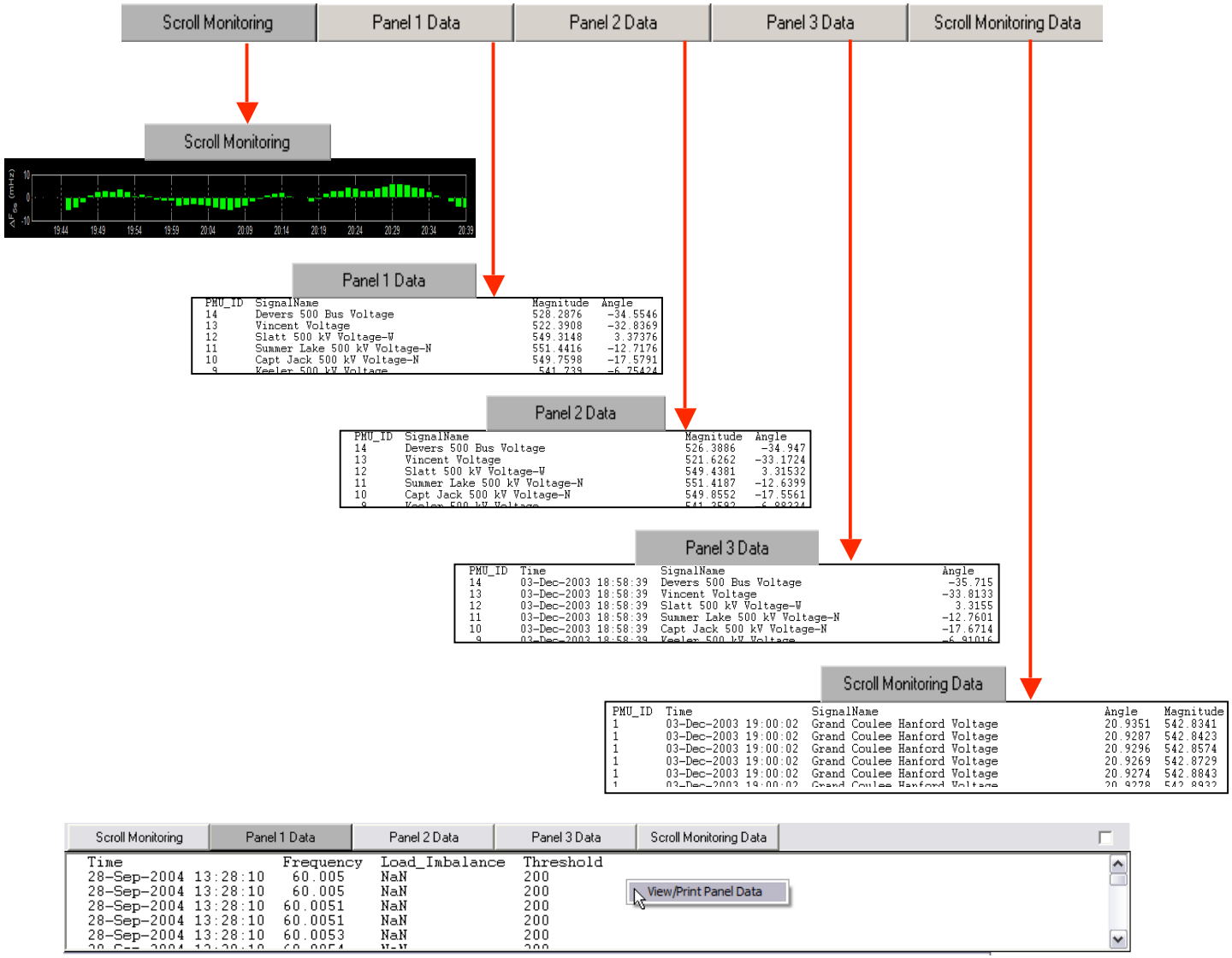


compare angles selected

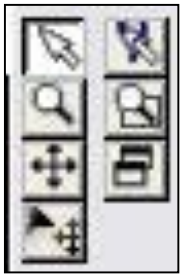
historical tracking and comparison over specified time duration

System Status

Tabular Table



Navigation Tools



Selection Arrow

This is the default Navigation tool. Selecting this tool allows the user to click and move through the different plots and data tables

Zoom In/Out

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.

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

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

Pick to Display Data

Click on the arrow within the question mark to select data within the plot or diagram

Rubber Band Zoom

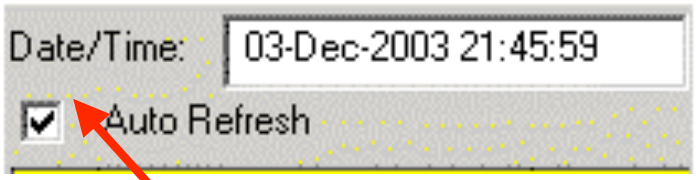
Click the magnifying glass with the box in the background, place mouse within the plot or diagram and left click to select the zoom desired

Restore to Original Size

Click on the double plot icon and click on the appropriate panel to restore the plot or diagram to its original size

Auto Refresh, Freeze and Replay

Real-Time Streaming Data (Auto Refresh)

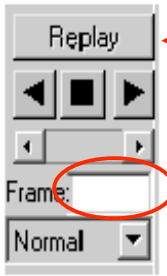


Click to remove “check” mark

Freeze Data

When “check” mark is removed the current data is held

Replay Data



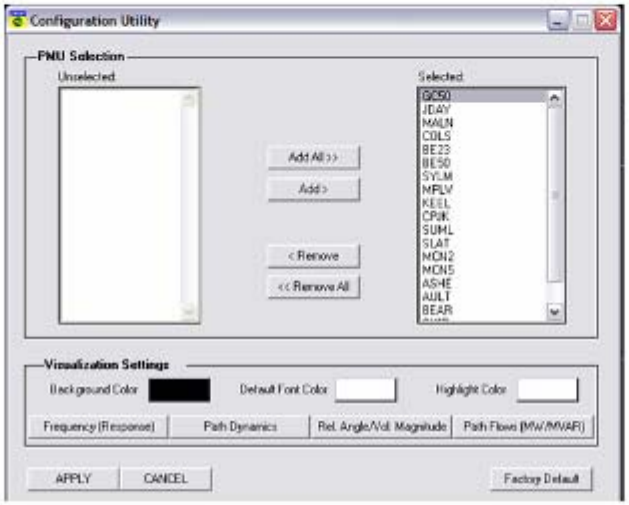
Toggle Switch between Real-Time and Replay Mode

Auto-Rewind

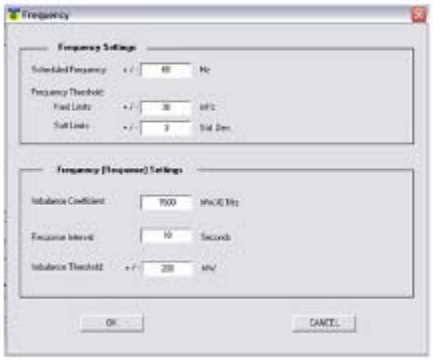
Auto-Forward

RTDMS Client Configuration Utility

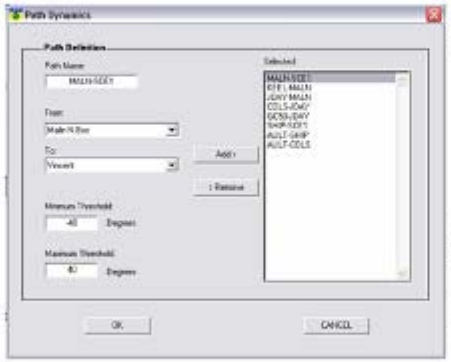
Configuration menus allow easy scalability as new monitoring devices are added to the system



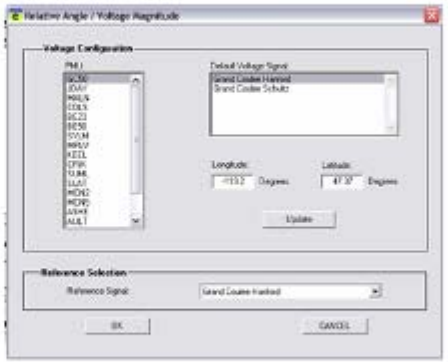
User-Defined Clusters



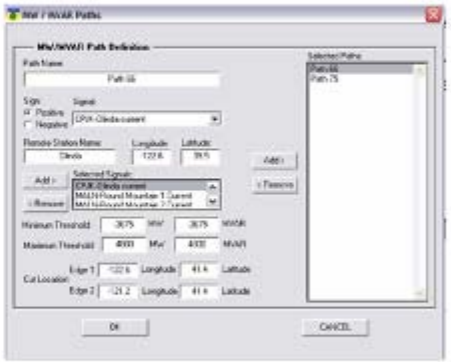
Frequency Monitoring Display



Path Dynamics Display



Relative Angle / Voltage Magnitude Display



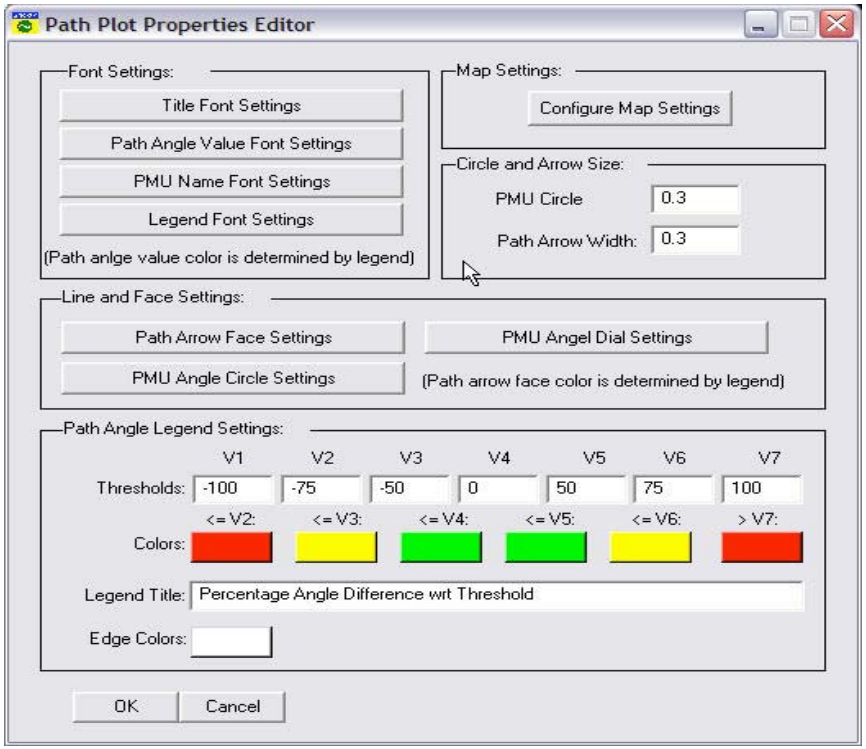
MW / MVAR Path Monitoring Display

CERTS
Consortium for Electric Reliability Technology Solutions

Electric Power Group

RTDMS Property Editor

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



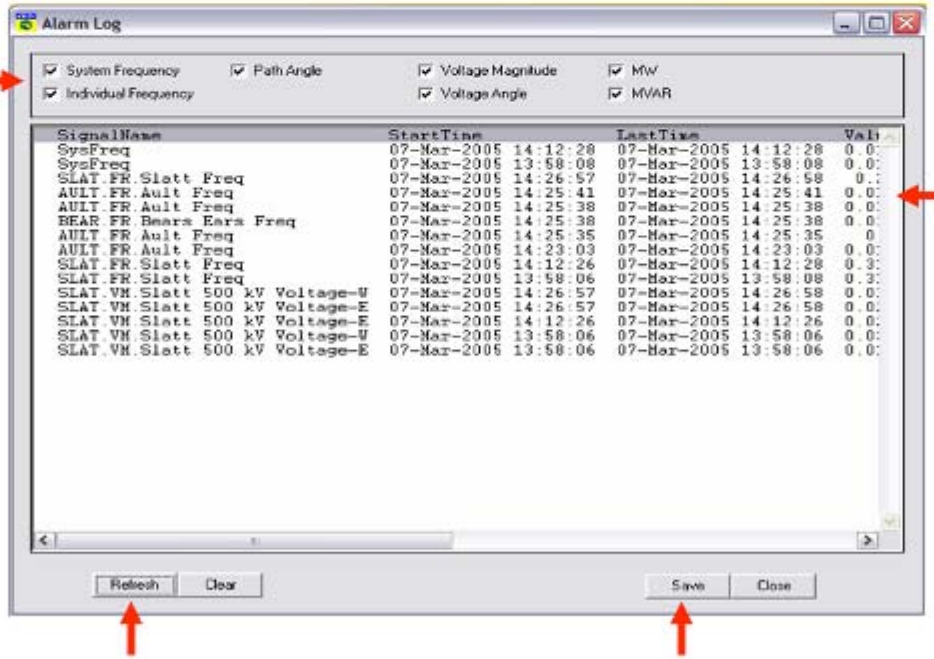
Alarm Logs

Whenever there are any preset threshold violations (i.e., a new alarm), the "Alarm Logs" tab is highlighted in Red until the alarm in acknowledged – reappears in Red if a new alarm occurs

Clicking on the "Alarm Logs" tab acknowledges the alarm and the Alarm Log pop-up box appears

Alarm Log Pop-up Box

Click check box to show/eliminate the alarms on different types of monitored metrics from being displayed



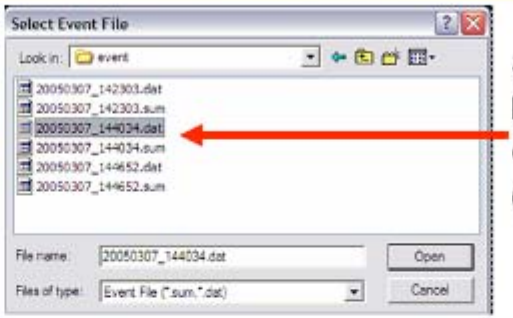
List the various alarms and relevant information (e.g. violation type, violation start time, violation end time, violation threshold, etc)

Click in "Refresh" to update alarm list during viewing

Click in "Save" to save current list of alarms into a text file

Event Files (RTDMS Offline Analysis)

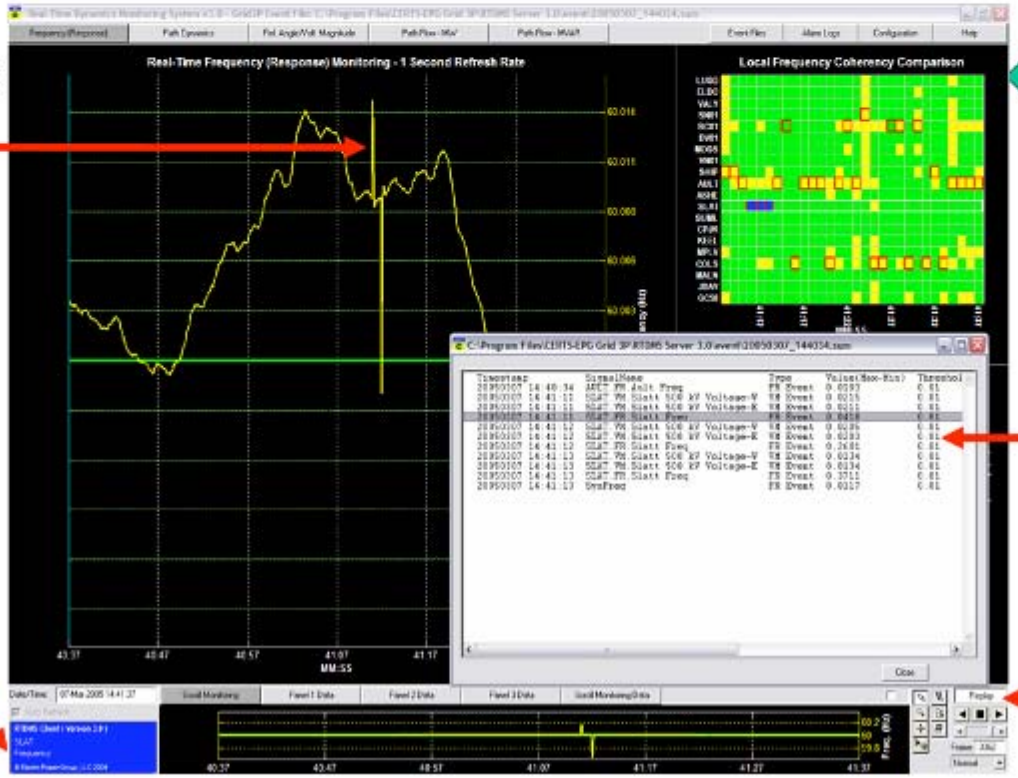
Click on "Event Files" tab to load an archived event file into the RTDMS application



Select an Event File to load into RTDMS for offline analysis (files labeled by date/time)

RTDMS in Offline Mode

Transient in frequency measurements triggered event capture



User-Defined Clusters

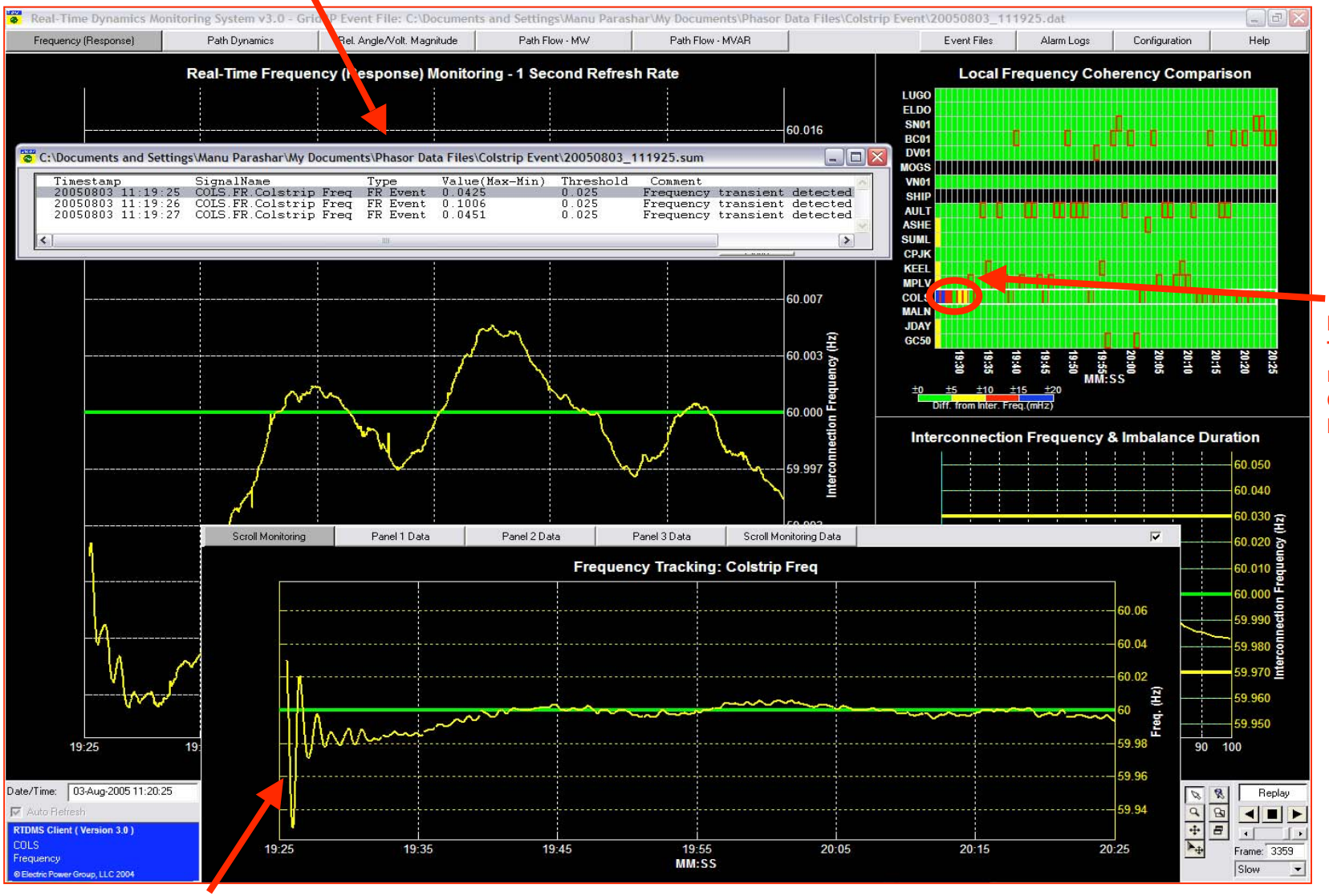
Alarm Summary box listing all violations during event capture

Title Box with blue background implies RTDMS is running in offline mode

Click on "Replay" button to switch back to real-time monitoring mode

RTDMS – Frequency Transient Example

Alarm log indicating Frequency Transient detected at the Colstrip PMU and the time of the event



Identify Trip near Colstrip PMU

Frequency response at Colstrip PMU

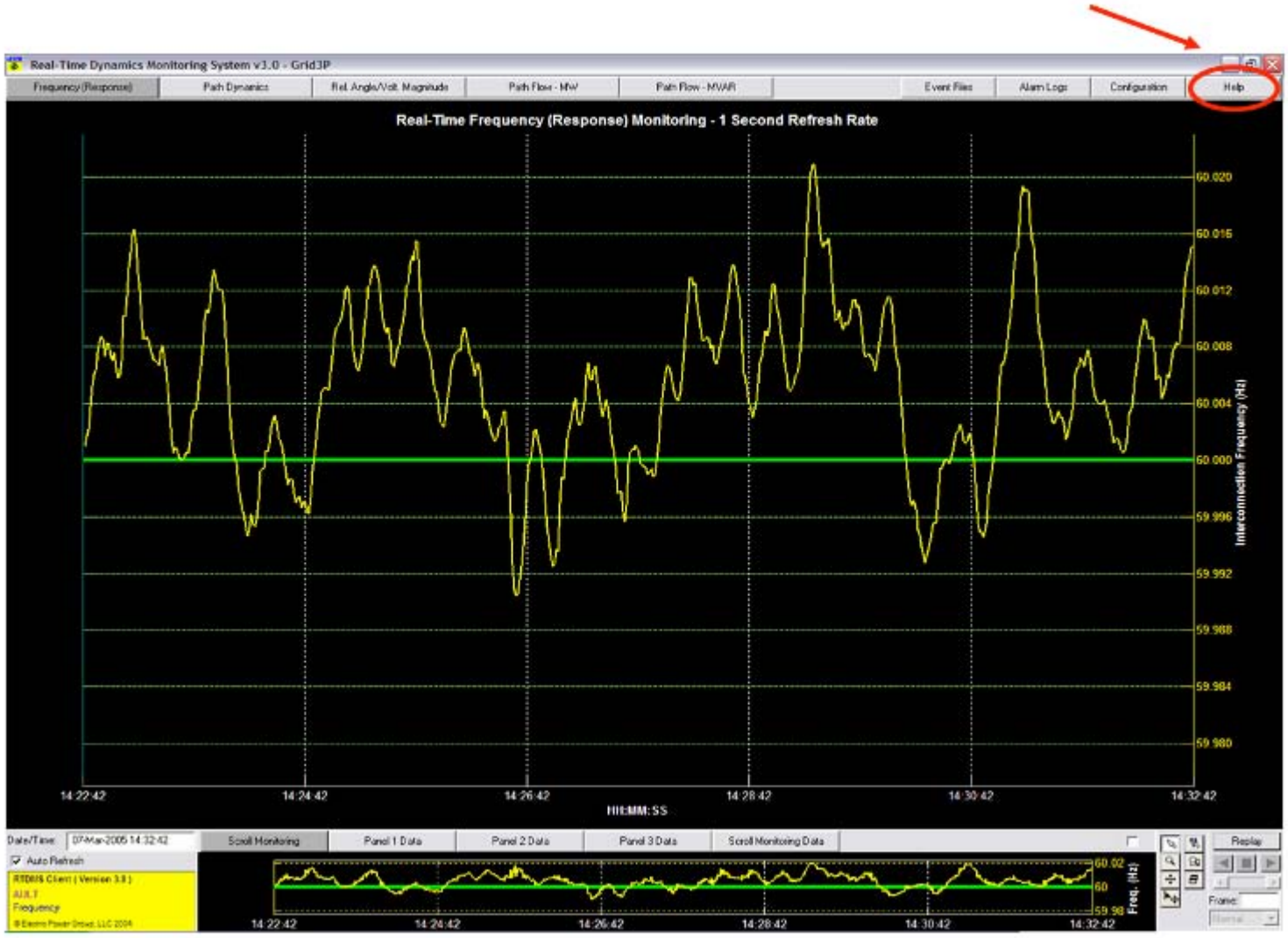
CA ISO RTDMS Functionalities Summary

RTDMS Functionalities at CA ISO:

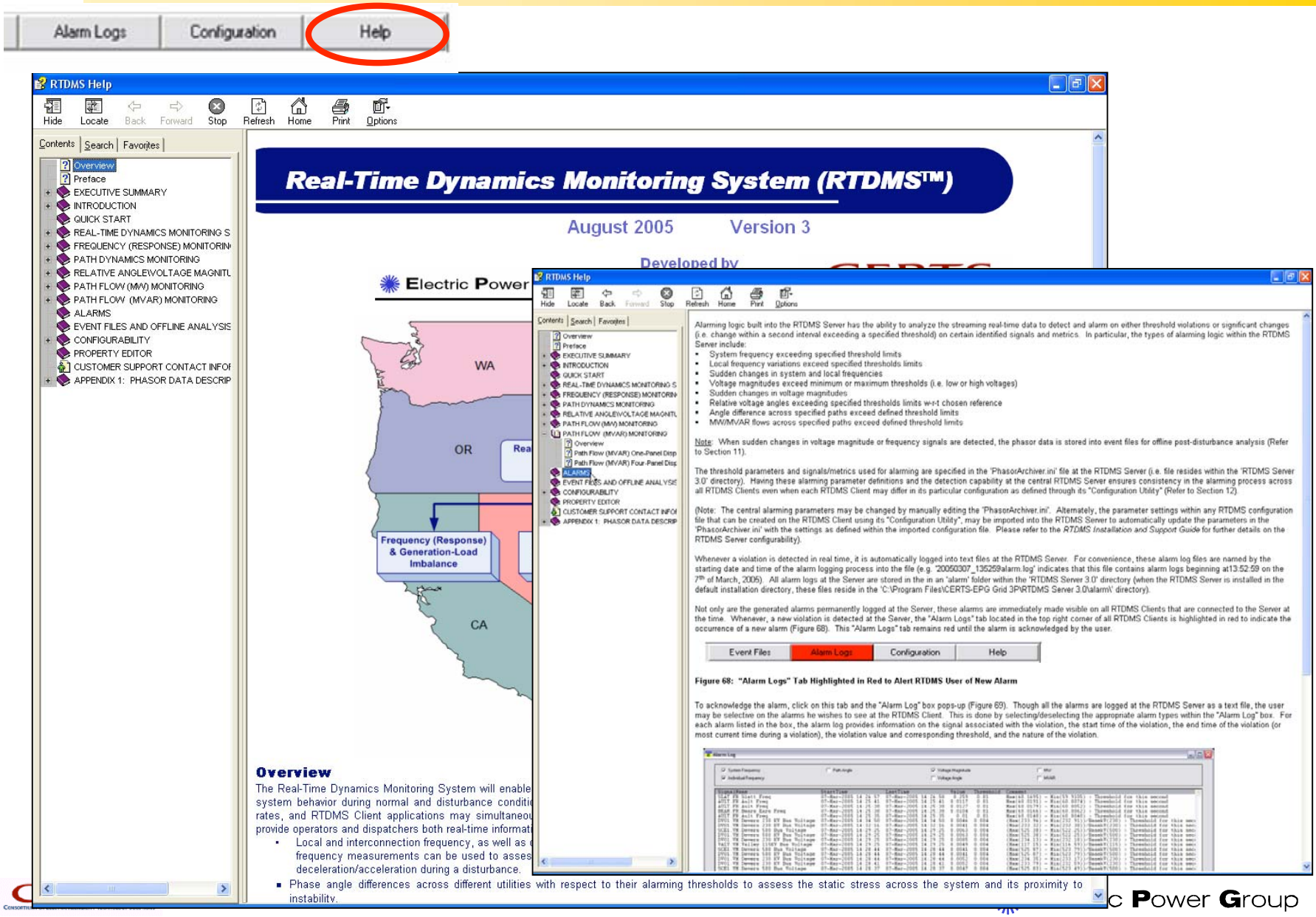
- **Includes BPA, SCE, WAPA, and PGE phasor data shown in real-time**
- **Server-Client architecture (Multi-user capability)**
- **Geographic visualization on Voltages, Angle Differences, Frequency, MW & MVAR**
- **End user configurability**
- **Replay capability**
- **Real-time alarming and event detection**
- **Event archiving and playback**

System Support and Help Tab

Help Tab


Real-Time Dynamics Monitoring System v3.0 - GridSP
Frequency (Response)
Path Dynamics
Rel. Angle/Volt. Magnitude
Path Flow - MW
Path Flow - MVAR
Event Files
Alarm Logs
Configuration
Help
Real-Time Frequency (Response) Monitoring - 1 Second Refresh Rate
60.020
60.016
60.012
60.008
60.004
60.000
59.996
59.992
59.988
59.984
59.980
Interconnection Frequency (Hz)
14:22:42
14:24:42
14:26:42
14:28:42
14:30:42
14:32:42
HH:MM:SS
Date/Time
07-Mar-2005 14:32:42
Auto Refresh
Scroll Monitoring
Panel 1 Data
Panel 2 Data
Panel 3 Data
Scroll Monitoring Data
Replay
Frame:
Freq. (Hz)
60.02
60
59.98

Help Overview



Contact Information

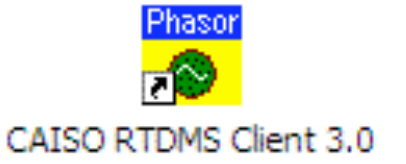
Manu Parashar

Office: (626) 685-2015 ext 130

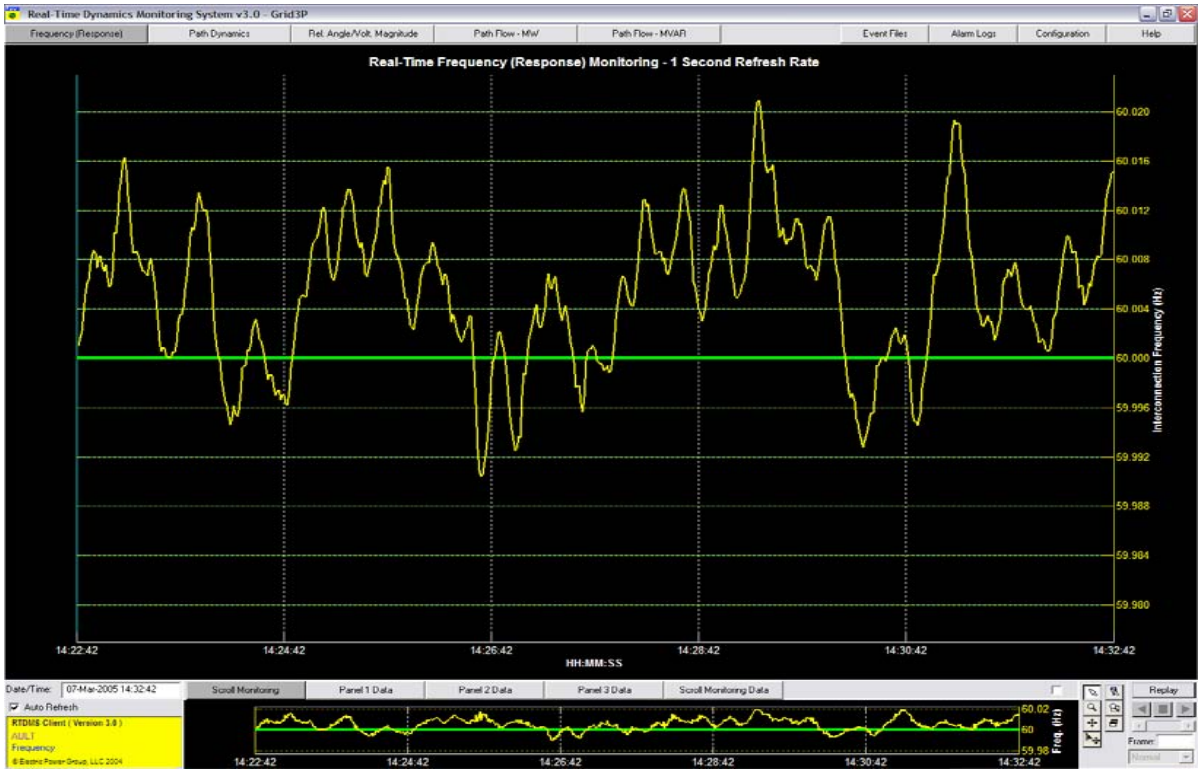
parashar@electricpowergroup.com

Any Questions Before We Move On To The Demo?

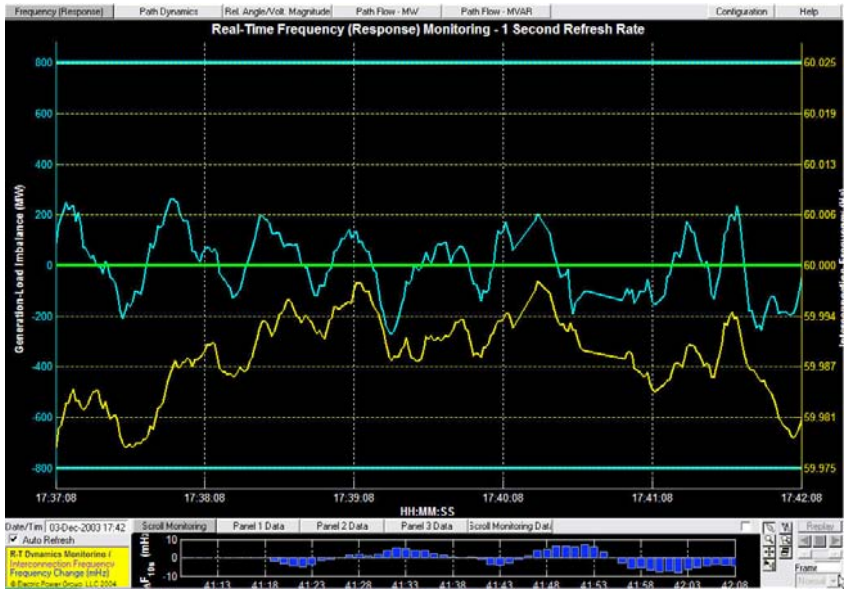
Start RTDMS Client Application



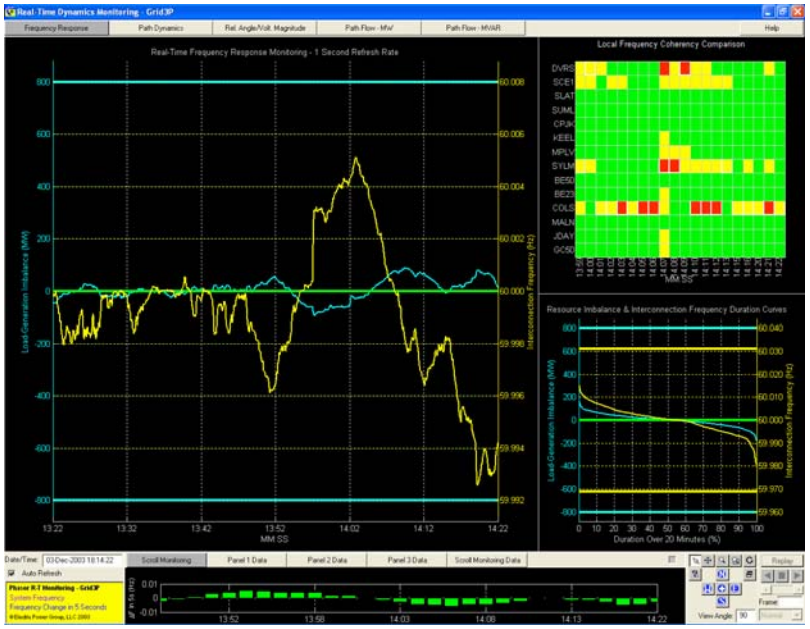
Frequency (Response) Monitoring Display (default)



Frequency Monitoring Display



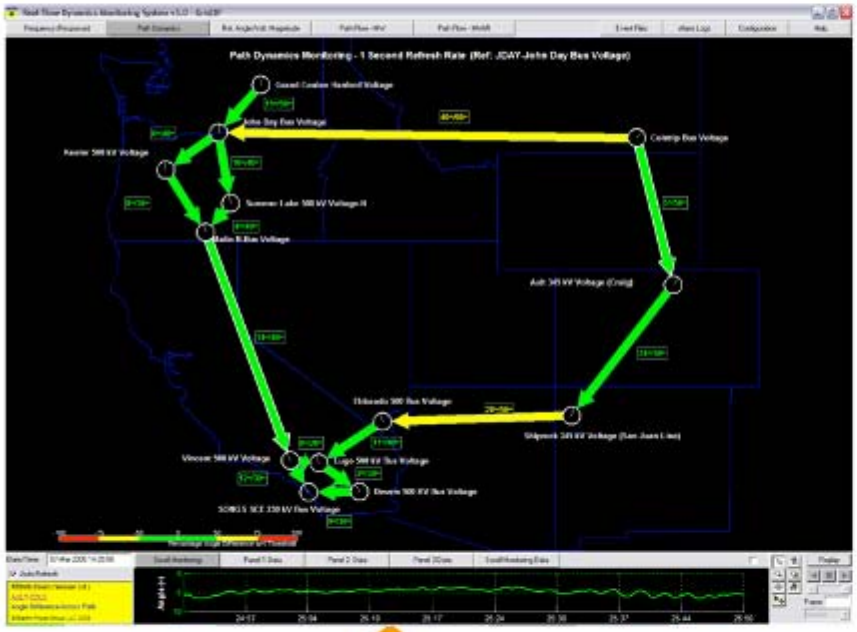
1-Panel Visual



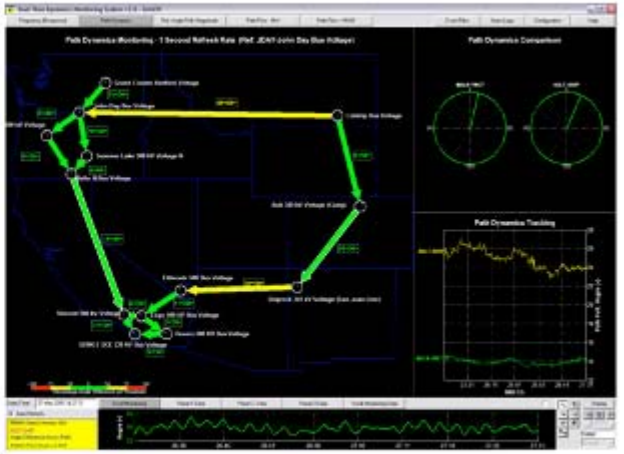
4-Panel Visual

Path Dynamics Monitoring Display – Local and Wide-Area Views

Wide-Area View



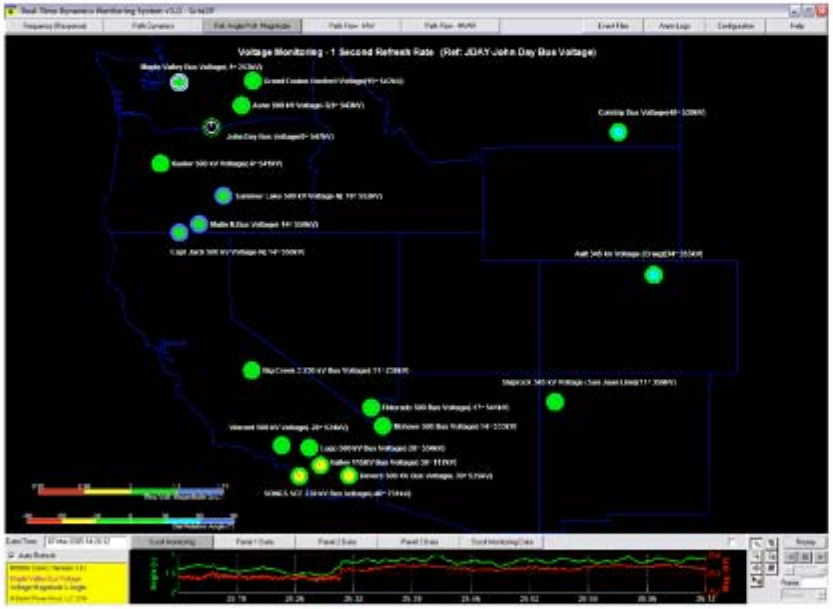
One Panel View



Local View

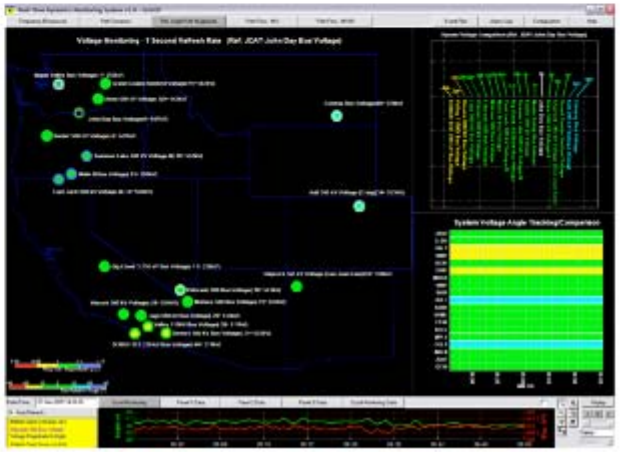
Relative Angle/Voltage Magnitude Monitoring Display – Local and Wide-Area Views

Wide-Area View



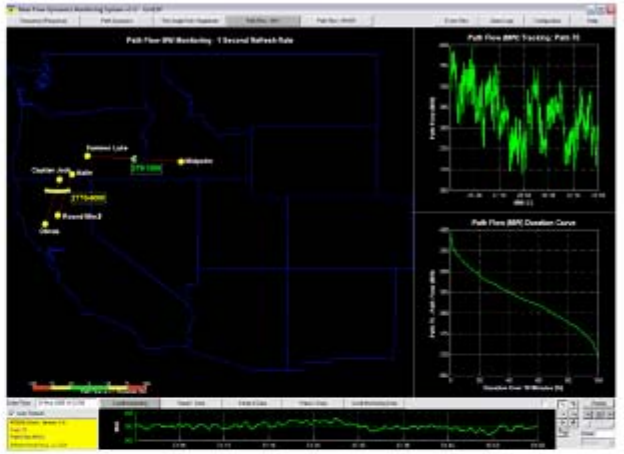
One Panel View

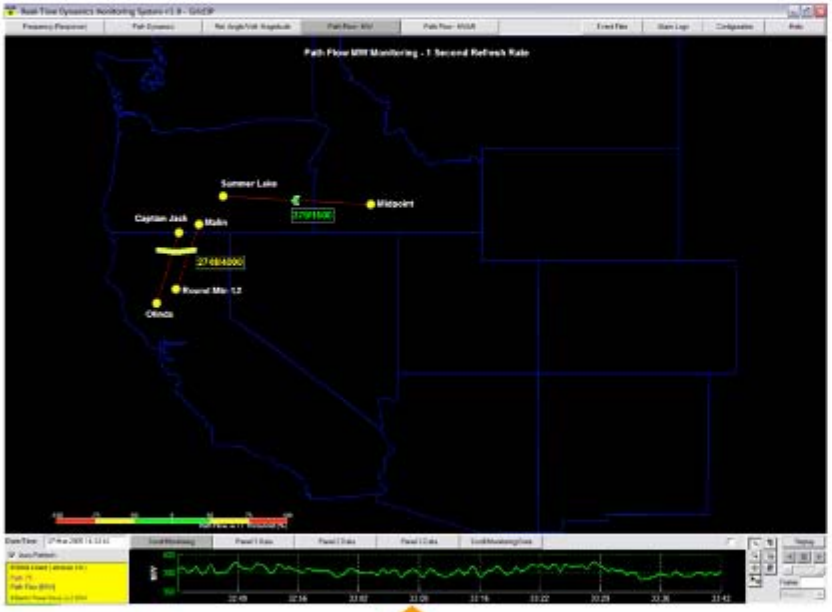
Local View



MW and MVAR Monitoring Displays

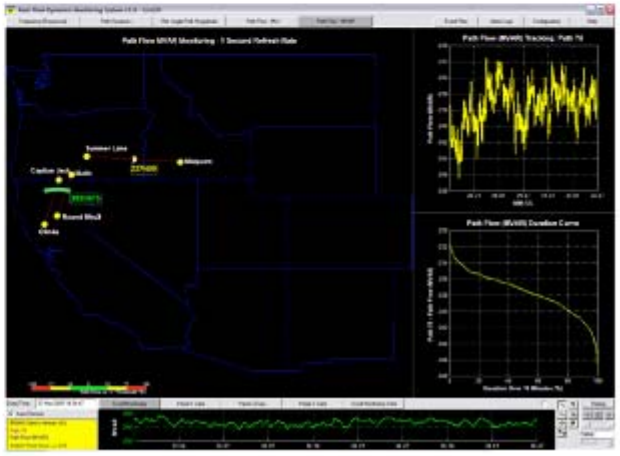
4-Panel View MW





One Panel MW/MVAR

4-Panel View MVAR



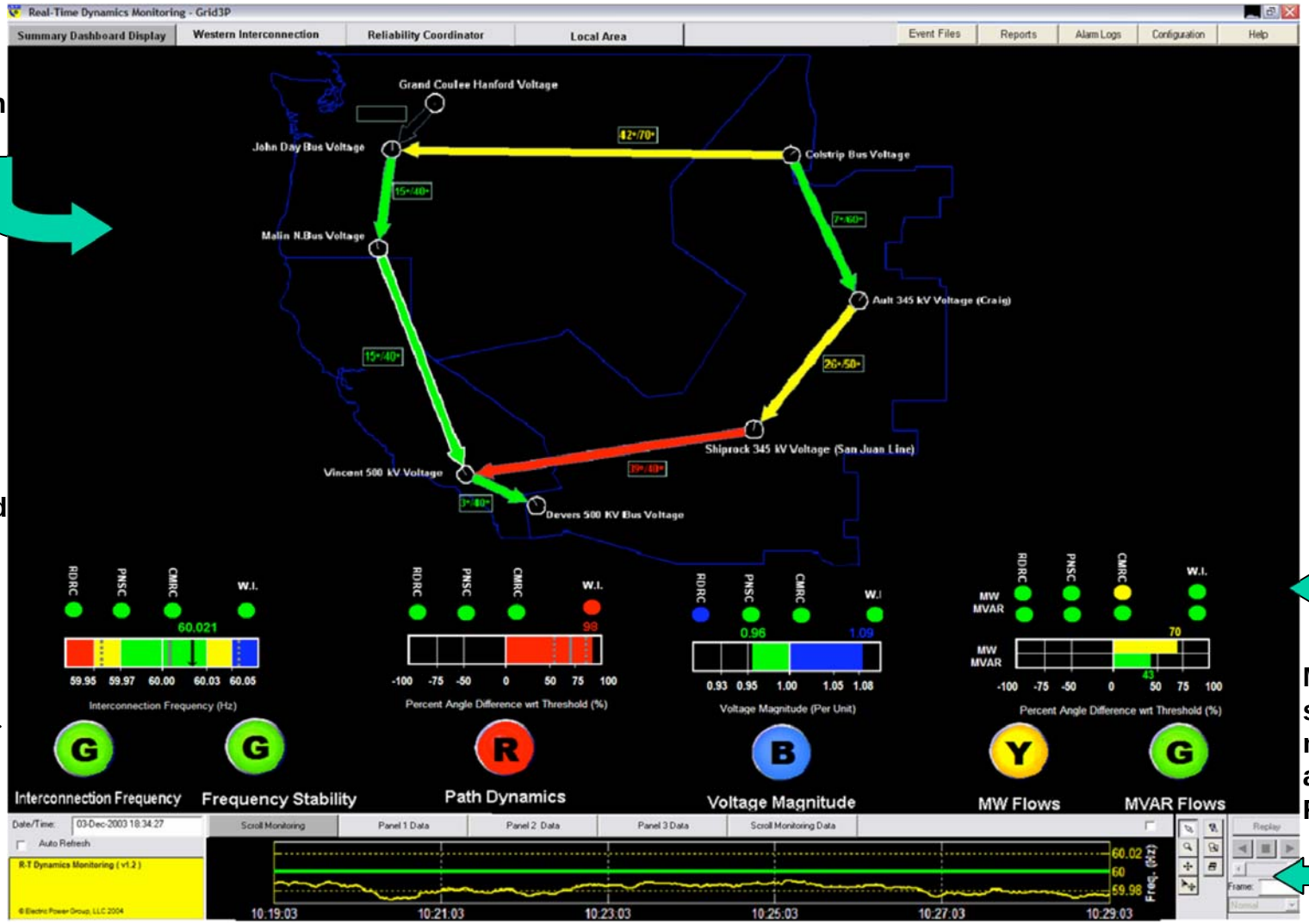
RTDMS Version 4.0 - End of 1 Quarter 2006

RTDMS DASHBOARD SUMMARY

WI Partitioned into 3 Regions Inter-Area Path Dynamics Shown in Geographic Display

Gauges to quantify worst performing metric (i.e., current value, mean, standard deviation, etc)

Monitor status of key WI metrics



Monitor status of metrics at each RC

Track worst performing point/path for selected metric

CERTS

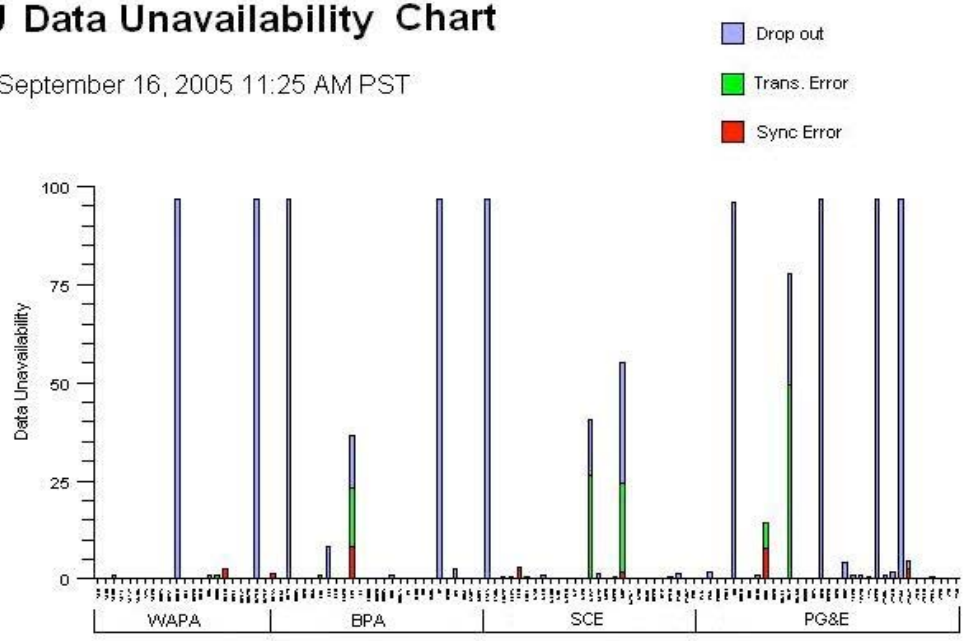
Electric Power Group

RTDMS PMU PERFORMANCE MONITORING

- Real-time PMU status information provided within RTDMS displays
- Historical PMU performance shown as charts/tables:

PMU Data Unavailability Chart

Friday, September 16, 2005 11:25 AM PST



PMU Data Unavailability Report

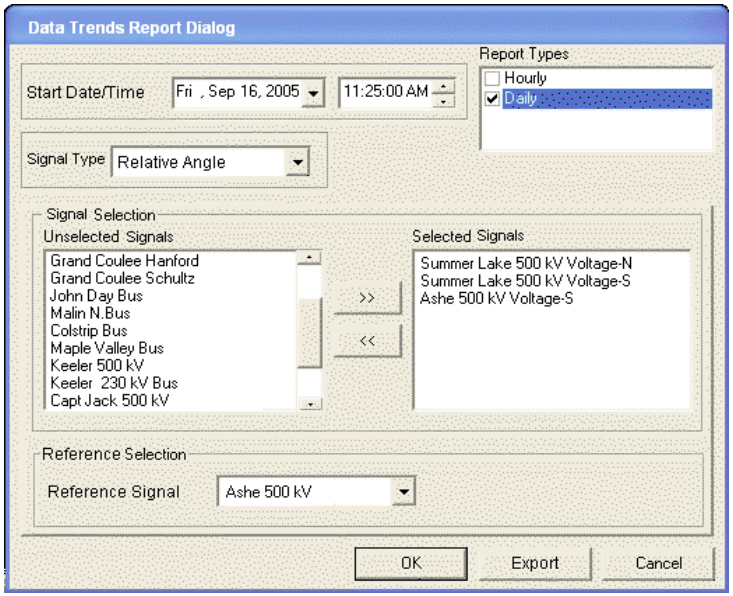
Friday, September 16, 2005 11:25 AM PST

	PMU Name	Available (%)	Unavailable (%)			Contact Information
			Drop out	Trans. Error	Sync. Error	
WAPA	WAPA PMU1	99.10	0.90			(123) 456-7890
			0.70	0.20	0	
	WAPA PMU2	0	100.00			(123) 456-7890
			100.00	0	0	
	WAPA PMU3	98.00	2.00			(123) 456-7890
			1.00	0	1.00	
BPA	BPA PMU1	100	0			(123) 456-7890
			0	0	0	
	BPA PMU2	100	0			(123) 456-7890
			0	0	0	
	BPA PMU3	0	100.00			(123) 456-7890
			100.00	0	0	
	BPA PMU4	65.00	35.00			(123) 456-7890
			34.00	0	1.00	

Daily

Plots and Tables indicate data unavailability by:
'Dropouts', 'Transmission Errors', 'Synchronization Errors'

RTDMS TRENDING AND REPORTING



Select 'Signals', 'Signal Type' and 'Date/Time'

- **Create trend plots**
- **Export data into excel or text files**