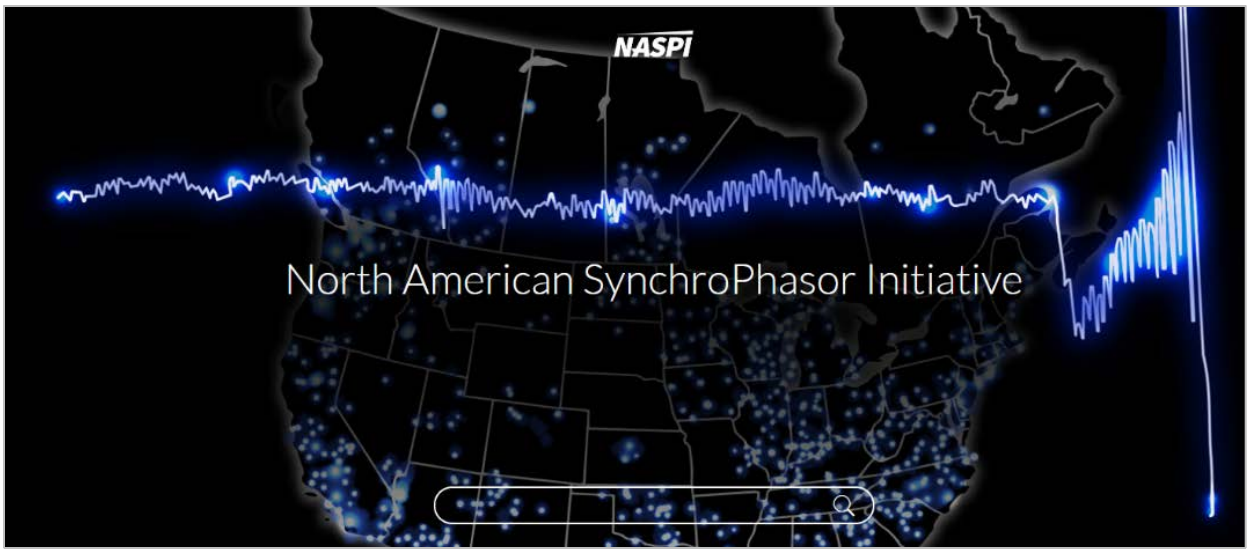
NASPI-2017-TR-007

Using Synchrophasor Data for Oscillation Detection



NASPI Control Room Solutions Task Team Paper

October 2017

NASPI North American SynchroPhasor Initiative

Acknowledgements

The North American Synchrophasor Initiative (NASPI) would like to extend special thanks to the following organizations, who each provided information critical to the development of this report.

Bonneville Power Administration (BPA)
Dominion Virginia Power
Duke Energy – Tim Bradberry
Electric Power Group (EPG)
Electric Reliability Council of Texas (ERCOT)
Entergy
ISO New England (ISO-NE)
Lower Colorado River Authority (LCRA)
New York ISO
Pacific Northwest National Laboratory (PNNL)
Peak Reliability
PJM Interconnection
Schweitzer Engineering Laboratories (SEL)
Swissgrid
Washington State University
XM Columbia

Background

The North American Synchrophasor Initiative (NASPI) is a collaborative effort between the U.S. Department of Energy, North American Electric Reliability Corporation, and electric utilities, vendors, consultants, federal and private researchers, and academics. The NASPI mission is to improve power system reliability and visibility through wide area measurement and control. The NASPI community is working to advance the deployment and use of networked phasor measurement devices, phasor data-sharing, applications development and use, and research and analysis. Important applications today include wide-area monitoring, real-time operations, power system planning, and forensic analysis of grid disturbances.

An overview of the NASPI Work Group structure is provided below:

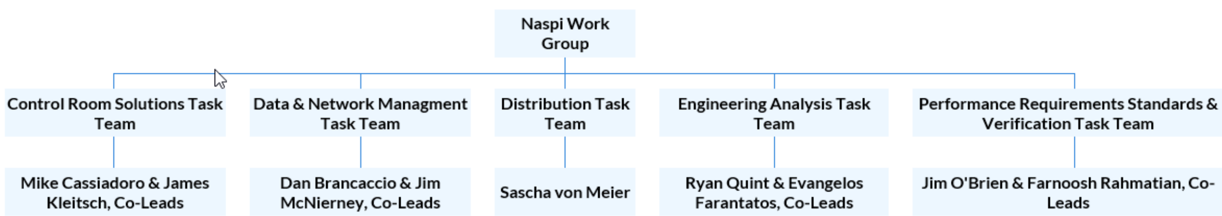


Fig1: The organization of NASPI Working Group

The NASPI Control Room Solutions Task Team (CRSTT) mission is to work collectively with other NASPI task teams to advance the use of real-time synchrophasor applications for the purpose of improving control room operations and grid reliability. This team utilizes its experience and regional diversity to provide advice, direction, support and guidance to NASPI stakeholders and other organizations involved in the development and implementation of real-time synchrophasor applications.

This is one of a series of papers being developed by CRSTT members to explore areas of interest and determine if value can be added in the near future by using synchrophasor data and applications: enhanced state estimation, phase angle monitoring, oscillation detection, system islanding detection and blackstart restoration, determining disturbance locations, and voltage stability assessment. Existing versions of completed papers can be found on the CRSTT page of the NASPI website (https://www.naspi.org/crstt).

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1. Introduction

This paper describes certain functional entity roles and responsibilities related to oscillation detection monitoring, considers how synchrophasor technology may be used to identify actual oscillation events or issues, and describes some of the related commercial applications that are currently available to the industry to perform these tasks.

This paper describes applications for which the NASPI CRSTT received information from application users or vendors and may be updated to include additional applications as new information is provided.

Synchrophasor technology provides high resolution and time-synchronized measurements of voltage and/or current magnitude and angle, frequency and rate of change of frequency along with other power system measurements over the wide-area of the utility system and its interconnection. These measurements are input to applications for determining if oscillatory behavior exists on the grid and whether the identified oscillations can negatively impact the reliability of the grid.

2. Overview of Synchrophasor Technology

A synchrophasor is a time-synchronized measurement of a quantity described by a phasor.[1] Like a vector, a phasor has magnitude and phase information. Devices called Phasor Measurement Units (PMU) measure voltage and current and with these measurements calculate parameters such as frequency and phase angle. Data reporting rates are typically 30 to 60 records per second, and may be higher. In contrast, current Supervisory Control and Data Acquisition (SCADA) systems often report data every four to six seconds – over a hundred times slower than PMUs.

PMU measurements are time-stamped to an accuracy of a microsecond, synchronized using the universal clock timing signal available from Global Positioning System (GPS) satellites or other equivalent time sources. Measurements taken by PMUs in different locations are therefore accurately synchronized with each other and can be time-aligned, allowing the relative phase angles between different points in the system to be determined as directly-measured quantities. Synchrophasor measurements can thus be combined to provide a precise and comprehensive "view" of an entire interconnection.

The accurate time resolution of synchrophasor measurements allows unprecedented visibility into system conditions, including rapid identification of details such as oscillations and voltage instability that cannot be seen from SCADA measurements. Complex data networks and sophisticated data analytics and applications convert PMU field data into high-value operational and planning information.[2]

[1] NASPI, "Synchrophasor Technology Fact Sheet", 2014. Available at https://www.naspi.org/node/384.
[2] Phadke, A.G.; Thorp, J.S. *Synchronized Phasor Measurements and Their Applications*, New York, Springer, 2008.

3. Oscillation Detection Using Synchrophasor Data

One of the very important use cases of synchrophasor technology is 'oscillation detection'.[3,5] There are already successful demonstrations of this in different parts of the world[4]. The basic aspects on Oscillation Monitoring and mitigation are covered in the 'Reliability Guideline for Forced Oscillation Monitoring and Mitigation' published by the NERC Synchronized Measurement Subcommittee [SMS] and published September 2017 [5].

The purpose of this CRSTT document is to provide detailed information on the various tools already being used to monitor oscillations using synchrophasor data at different organizations. A template requesting information was routed to different organizations and a summary of their responses is included on the following pages.

3 NERC Reliability Guideline on Forced Oscillations Monitoring and Mitigation (Draft), June 2017 (http://www.nerc.com/pa/RAPA/rg/ReliabilityGuidelines/Reliability_Guideline_-_Forced_Oscillations_-_2017.pdf)

4 NERC Report on 'Real-time Application of Synchrophasors for Improving Reliability', October 2010. (http://www.nerc.com/docs/oc/rapirtf/RAPIR%20final%20101710.pdf)

5 IEEE Power and Energy Society Magazine, Sept/Oct 2015.

6 http://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_-_Forced_Oscillations_-_2017-07-31_-_FINAL.pdf

4 Survey Responses Received from Application Users

4.1 Bonneville Power Administration (BPA)

Application name:	Oscillation Detection		
Objective of the application:	Oscillation Detection application scans multiple signals (power, frequency, voltages) across the grid for indication of growing or sustained high energy oscillations.		
Application requirements (hardware, software, visualization telecommunications, etc.):	• Oscillation Detection Module (ODM) engine developed by Dr. Dan Trudnowski, Montana Tech University • Real-time processing uses uncompressed C37.118 data from 66 PMUs, 140 total measurement points	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Application inputs raw, uncompressed PMU Voltage and Current Phasor measurements input into the OSIsoft PI system via the OSIsoft C37.118 Interface. The data is pulled from the OSIsoft PI snapshot using the AF-SDK interface.
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	In operation
If in operation, where?	BPA Primary and Alternate Control Centers	**Application provider or developer:**	Oscillation Detection Module (ODM) engine developed by Dr. Dan Trudnowski, Montana Tech University

Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	The benefit is to detect oscillations in real-time and have operators take action to help mitigate those oscillations.	**Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):**	All raw PMU data and ODM processed data is written to PI. A custom link was written by BPA to notify SCADA when an oscillation has been detected. An Alarm is generated on the SCADA Alarm list when an oscillation is detected.
Describe how the application could be operationalized (i.e. used in real-time):	It has been operationalized. Should an oscillation alarm occur, a corresponding frequency band at a corresponding PMU will turn "red". The display provides very effective visual indication on whether the oscillation is local or wide-area. For local oscillation, only one or a few PMUs in the vicinity of oscillation source will go into an alarm state. For wide-area oscillations, multiple PMUs will go into an alarm state over a large geographic area. The display also provides initial indication of the type of oscillation based on the frequency band alarmed. The oscillation must persist for pre-determined time period for the application to issue an alarm.		
Type of application GUI	All Synchrophasor Displays are OSIsoft Process Book Displays, augmented with VB processing.	**Identify operating entities that are using the application**	Dispatch, engineers
Any other relevant information:	See paper and presentation. [1]. D.Kosterev,J.Burns, N.Leitschuh, J.Anasis, A.Donahoo, D.Trudnowski, M.Donnelly, J.Pierre, 'Implementation and Operating Experience with Oscillation Detection Application at Bonneville Power Administration', CIGRE 2016 Grid of the Future Symposium, October 30 - November 1, 2016, Philadelphia, USA. [2]. Matt Donnelley, 'Implementation and Operating Experience with Oscillation Detection at Bonneville Power Administration' NASPI Meeting.		

4.2 Dominion Virginia Power

Application name:	Electric Power Group's RTDMS "Oscillation Detection" tool		
Objective of the application:	Detect oscillation events at specific frequencies (known from previous events) that occur in Dominion's grid.		
Application requirements (hardware, software, visualization telecommunications, etc.):	A Windows server (physical server, not virtual server) with good processing capability.	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Synchrophasor data at 30 phasors/second data rate
Application software (open source, proprietary):	RTDMS (proprietary)	**Current status of the application (in development, testing, in operation):**	In partial operation (only available to engineering teams, not operators), continuing to test/validate prior to giving to operators.
If in operation, where?	See "Current Status"	**Application provider or developer:**	Electric Power Group
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		Yes, can integrate with EMS/SCADA systems via DNP3 (maybe other connections too), and also with PI.	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Be able to detect and see an oscillation event occurring in the control room. In a past oscillation event at Dominion, operators were not able to see the oscillation in their SCADA data/SCADA alarms/SCADA displays, and did not know it was occurring until the power plant reported to the operators that something unusual was going on (but they also did not know the extent of what was going on, as the plant operators also only had SCADA data).	
Describe how the application could be operationalized (i.e. used in real-time):		Give the RTDMS visualization displays to the operators to visualize when and where oscillations are occurring. Also give RTDMS oscillation alarms to the operators in their EMS screens.	

Type of application GUI	Windows application/windows interface	Identify operating entities that are using the application	Many entities are using RTDMS today. Not sure how many are using the oscillation detection tool. This is a question for EPG.
Any other relevant information:	EPG has many videos available of their oscillation detection tool and the RTDMS application.		

4.3 Duke Energy

Application name:	RTDMS		
Objective of the application:	Visualization		
Application requirements (hardware, software, visualization telecommunications, etc.):	Database Server, Gateway Server, Client Servers, Software License	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Phasor Data
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	Visualization - In Operation, Oscillation – in development
If in operation, where?	Back Hall Engineering, Control Room	**Application provider or developer:**	Electric Power Group
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	Quicker detection of long term oscillations (no incremental improvement for short term oscillations – the system will react before operators can).	**Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):**	Yes – PI.
Describe how the application could be operationalized (i.e. used in real-time):	Need to better define limits to detect oscillations		
Type of application GUI	RTDMS	**Identify operating entities that are using the application**	Duke Energy Carolinas

Any other relevant information:	None

4.4 ERCOT

Application name:	Real Time Dynamic Monitoring System (RTDMS) developed by EPG.		
Objective of the application:	To provide real-time, wide-area situational awareness and real-time dynamics monitoring of the power grid for use by Operators, Reliability Coordinators, Planners, and Operating Engineers, as well as the capability to analyze system performance and events. The major use cases of the application within ERCOT are the ability to observe and alert operators to voltage angle differences across the interconnection, detect and mitigate local and system-wide oscillations, and the ability to save and replay system events recorded by PMUs across the system.		
Application requirements (hardware, software, visualization telecommunications, etc.):	Please see EPG's vendor response (Section 5.1).	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Accepts phasor data input from a Phasor Data Concentrator (PDC) using either C37.118 or PDCStream data format.
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	In use by shift engineers and operations support
If in operation, where?	Control room and Operations Support Dept.	**Application provider or developer:**	Electric Power Group (EPG)
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	Currently, RTDMS is a completely separate system from EMS/SCADA. We are currently investigating our options with implementing alarms from the PMU system into our EMS. We are also working on using triggers from the OTS to simulate PMU data to stream directly to the Phasor Simulator for operator training.		
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	Current State: • Used in control room by shift engineer as well as by support engineers to monitor voltage angles and oscillations across the system • Developed a PMU-based operator training simulator, and will begin training operators on PMU software in the coming months • Six 'Mode meters' have been implemented to detect the reoccurrence of common known oscillation modes, with the ability to calculate the dominant oscillation mode, damping, and energy level of the oscillation		

<table>
<tr><td></td><td colspan="3">Future Goals:
• Build out redundant PMU monitoring system
• Develop procedures for operators and train operators on the PMU operator training simulator
• Add in PMU Estimation on interfaces as a backup for IROLs
• Monitor grid disturbances and notify Generators to collect data for model validation on these events
• Add PMU data into EMS for improved state estimation, and/or develop a linear state estimator for monitoring a significant portion of the 345 kV system
• Control Room event reporting including dynamic system performance
• Incorporate into Blackstart training, using islanding detection features and abilities to monitor angle difference across breakers for reclosing procedures</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Describe how the application could be operationalized (i.e. used in real-time):</td><td colspan="3">Currently, the RTDMS is being used in the control room at the shift engineer’s desk and by control room support engineers. The primary purposes of the system are to monitor voltage angles and system oscillations, as well as replaying system events for post mortem analysis. There are no official procedures for operators at this time, but will be developed in the near future, once there is a redundant system in place. Although we currently have requirements on PMU locations, data recording, and data retention, there are no requirements for data quality, which will need to be addressed before operator actions can be based solely on PMU data.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Type of application GUI</td><td>The RTDMS user interface is made up of many tools for visualizing data and monitoring alarms. It consists of a hierarchy of layers that together provide a rich user experience for viewing data.</td><td>Identify operating entities that are using the application</td><td>Please refer to EPG’s response (Section 5.1).</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Any other relevant information:</td><td colspan="3">Sample videos have been previously provided to NASPI.

Application GUI Examples:</td></tr>
</table>

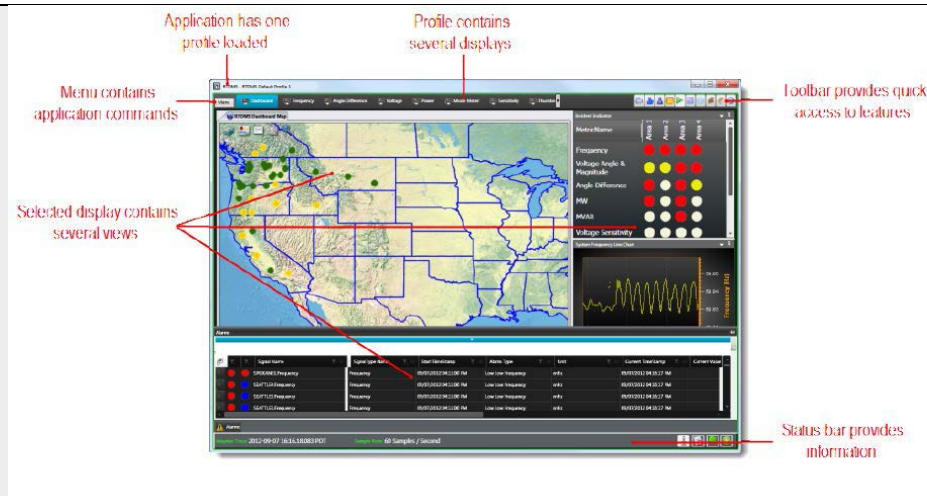


Figure 1: RTDMS GUI Example

*taken from RTDMS 2015 Visualization Client User Guide

Specifically for oscillation detection, we have six known common modes that have ‘mode meters’ set up to detect oscillations with their mode, damping, and energy level, as shown below:

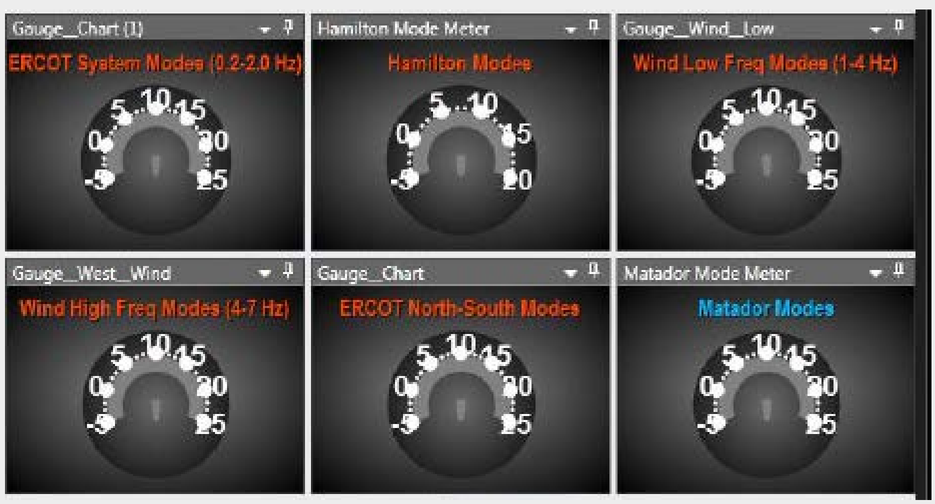


Figure 2: RTDMS Mode Meters

4.5 Entergy

Application name:	Washington State University(WSU) Damping Monitor Offline		
Objective of the application:	Oscillation postmortem analysis		
Application requirements (hardware, software, visualization telecommunications, etc.):	Server based with connection to OSIsoft PI, OpenPDC	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Historical PMU data from OSIsoft PI
Application software (open source, proprietary):	PROPRIETARY must be licensed through WSU	**Current status of the application (in development, testing, in operation):**	Development
If in operation, where?	NOT in OPERATIONS	**Application provider or developer:**	Washington State University (WSU)
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		Interoperable with OSIsoft PI	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Identification of the location of Inter-Area location of forced oscillations	
Describe how the application could be operationalized (i.e. used in real-time):		WSU has a real-time version	
Type of application GUI	Basic, made for postmortem analysis	**Identify operating entities that are using the application**	
Any other relevant information:	N/A		

4.6 ISO New England (Phasor Point)

Application name:	PhasorPoint		
Objective of the application:	Detect oscillations (ambient and ringdown), characterize oscillations and generate alarms/alerts. Characterization of oscillations consists of determination of frequency, amplitude, damping and mode shape. PhasorPoint provides characterization of a single mode with the highest energy for every frequency band defined for monitoring in the frequency range of electromechanical modes.		
Application requirements (hardware, software, visualization telecommunications, etc.):	Hardware: standard server. Software: Linux on server and Java on client.	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Synchrophasor data at 30 samples / second.
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	PhasorPoint is in production use.
If in operation, where?	Outside of the control room for use by operation support engineers.	**Application provider or developer:**	Psymetrix/GE
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	PhasorPoint has its own storage and can be connected to GE EMS.		
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	Sustained oscillations with high magnitude represent the risk for the system stability, uncontrolled outages and increased mechanical vibrations to the equipment reducing the life span of the equipment and requiring more frequent maintenance. Detection and characterization of oscillations is the first step in identifying the threat for the system and to initiate a mitigation process. Detection of oscillations only is not sufficient for Control Room. Clear Operational instructions on mitigation measures should exist and be available for Operator to utilize the benefit of oscillations detection in real-time operations.		

Describe how the application could be operationalized (i.e. used in real-time):	Use of PhasorPoint information on detected oscillations only without operating procedures on how to mitigate oscillations has a limited value for Control Room and could be used for information/education purposes. Real benefit will be coming when the detection of oscillation is accompanied with actionable operational information.		
Type of application GUI	Event log, geographic display, strip chart.	**Identify operating entities that are using the application**	Operations support engineers
Any other relevant information:			

4.7 ISO New England (Oscillation Source Location: OSL)

Application name:	Oscillation Source Location (OSL) Tool based on Dissipating Energy Flow (DEF) method.		
Objective of the application:	Determine the source of sustained oscillations in power systems for both poorly damped natural and forced oscillations. The OSL tool is capable of detecting single or multiple sources of one or several simultaneously observed modes of sustained oscillations.		
Application requirements (hardware, software, visualization telecommunications, etc.):	Hardware: standard server or PC, Matlab for the prototype version	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Synchrophasor data at 30 samples / second. Other sample rates also can be used. Network map to trace the dissipating energy flow for visualization purposes.
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	Current version of the OSL tool is a Matlab prototype version. The efficiency of the tool was demonstrated on a representative set of simulated cases and 30+ actual events in ISO-NE and two events in WECC systems.
If in operation, where?	The OSL tool is used offline, outside of Control Room by engineers.	**Application provider or developer:**	ISO-NE
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	The OSL tool extracts PMU data from PhasorPoint storage via JDBC. The OSL tool can potentially use PMU data from any storage.		

Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	Locating the source of sustained oscillations is key actionable information for mitigation of oscillations. Majority of practically observed sustained oscillations has a forced nature and the only efficient mitigation measure is to locate the source and disconnect it from network. Providing the information on the source of sustained oscillations together with characterization of oscillations is the basis for quick and efficient mitigation of dangerous oscillations in real-time environment.		
Describe how the application could be operationalized (i.e. used in real-time):	ISO-NE plans to develop a production version of the OSL tool which will be a part of the overall Oscillation Management process. The OSL tool will be triggered by PhasorPoint alarm and will automatically provide information on the source location. Both types of information (i) characterization of oscillation by PhasorPoint and (ii) locating the source of oscillations will be provided to Control Room and to operation support engineers. For proper system observability by PMU, the OSL tool is capable of providing high fidelity information on the source location (i) identify when the source of oscillation is located outside of the control area and (ii) identify the source to a specific generator resolution if the source is located inside of the control area.		
Type of application GUI	Matlab version provides tabular and chart data output. Production version will be capable of visualizing the DEF flow in a network diagram similar to regular MW flow.	**Identify operating entities that are using the application**	Research engineers and Operations support engineers at ISO-NE
Any other relevant information:	• Test case library for simulated cases for the methods locating the source of oscillations: http://curent.utk.edu/research/test-cases/ • 2016 IEEE PES General Meeting Tutorial: Use of Synchrophasors in Grid Operations: http://web.eecs.utk.edu/~kaisun/TF/Tutorial_2016IEEEPESGM/Synchrophasor_7_Slava.pdf		

4.8 LCRA Transmission Services Corporation

Application name:	RTDMS		
Objective of the application:	Wide-area visualization and recording of triggered events such as oscillations.		
Application requirements (hardware, software, visualization telecommunications, etc.):	Server based PDC and visualization package (single vendor provided)	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Phasor data transmitted via relay-based PMUs at 30 msgs/second
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	In use by Operations Engineer
If in operation, where?	By Operations Engineer placed in Control Room during normal business hours.	**Application provider or developer:**	EPG
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		Able to integrate with GE EMS (integration not yet accomplished but planned for next EMS upgrade cycle)	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Situational awareness, post-disturbance analysis, real-time voltage condition feedback to Operators (via Operations Engineer). Application also chosen to match system operator (ERCOT) tools.	
Describe how the application could be operationalized (i.e. used in real-time):		Operators would need adequate training to be able to act upon oscillation detection alerts. Oscillation detection triggers must be refined to minimize false positives. Operator response rules need to be developed so alerts are actionable, not just informative.	

Type of application GUI	Similar to standard EMS interface design (alert on abnormal situation, present concise summary/alarm data, Operators are able to acknowledge situation)	**Identify operating entities that are using the application**	Refer to vendor for full set of users.
Any other relevant information:	N/A		

4.9 New York ISO

Application name:	Smart Grid Applications		
Objective of the application:	abnormal system detection		
Application requirements (hardware, software, visualization telecommunications, etc.):	PMU installation, RTDMS	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	phasor data, 30 samples per second
Application software (open source, proprietary):	RTDMS	**Current status of the application (in development, testing, in operation):**	in operation
If in operation, where?	Within the control room	**Application provider or developer:**	internal engineering resources utilizing EPG platform
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		EMS and PI	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Identify fault location and the nature of the issues (system-wide vs. local)	
Describe how the application could be operationalized (i.e. used in real-time):		• Investigation would start once oscillations are identified by operators. • The first priority is to determine the frequency and the location of the oscillation. • If the frequency is low (0.5 hz to 2 hz), the oscillation is more likely interregional and the solution could be more complicated. If the frequency is high and the issue is local, it could be due to power electronics in the vicinity such as HVDC, type 4 WTG, SVC, etc. • Coordinate with TO and facility owners to identify the solutions.	

Type of application GUI	N/A	**Identify operating entities that are using the application**	NYISO
Any other relevant information:	N/A		

4.10 PEAK Reliability (Model Analysis Software: MAS – Oscillation Detection: ODM)

Application name:	Model Analysis Software (MAS) by Montana Tech Oscillation Detection (ODM) by GE-Alstom		
Objective of the application:	The Oscillation Detection Module provides two levels of detail in its outputs. In the simplest case, the ODM provides RMS energy in each of four frequency ranges each time the module iterates. The four frequency ranges, labeled "Band1" through "Band4", are intended to approximate four regions of power system dynamic activity visible from PMU measurements. Band1 roughly corresponds to governor activity; Band2 to interarea oscillations; Band3 to local oscillations; and Band4 to higher frequency phenomena, possibly including some SubSynchronous Resonance (SSR) activity. An inverse-time characteristic can be used to provide proper alert and alarm.		
Application requirements (hardware, software, visualization telecommunications, etc.):	PhasorPoint has its own server in Peak's real-time environment.	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	PMU data
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	Under testing at Peak
If in operation, where?	PhasorPoint application is in Peak's real-time environment, but not used for real-time operation now.	**Application provider or developer:**	MAS – Montana Tech PhasorPoint and GSA – GE-Alstom
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		The ODM results can be passed to EMS through Grid Stability Assessment (GSA) application and then historize in PI.	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Provide the operators more information about system oscillation. And potentially how to mitigate in a timely manner.	

Describe how the application could be operationalized (i.e. used in real-time):		Once the software testing is done and the proper baselining work is done (to set up the proper alert and alarm levels), the ODM tool can be used in real-time operation.	
Type of application GUI	Peak Customize the MAS V1.0 into GE-Alstom's PhasorPoint application	**Identify operating entities that are using the application**	BPA, Peak Reliability
Any other relevant information:	N/A		

4.11 PEAK Reliability (WSU Damping Monitor)

Application name:	WSU Damping Monitor		
Objective of the application:	To detect and monitor oscillation modes in the system with oscillation frequency ranges from 0.1 to 2.0 Hz. The engine would give estimates about oscillation mode frequency, damping ratio, mode shape and oscillation energy for multiple oscillation modes every 10 seconds.		
Application requirements (hardware, software, visualization telecommunications, etc.):	• Operating system: window server 2012 • Database: Sql server 2008 • Cores: >= 8 • Memory >= 64G • Hard disk >= 128G • OpenPDC installed with live PMU data stream feed	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	30 Hz sampling rate PMU data
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	Development
If in operation, where?	Control room	**Application provider or developer:**	Washington State University, Dr. Mani Venkatasubramanian's research team
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		The offline version of damping monitor and event analysis engine can run using historian data in comtrade format	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Monitor system oscillation mode, monitor inter-area mode damping ratio, monitor mode shape change for system oscillation mode	
Describe how the application could be operationalized (i.e. used in real-time):		Enhance system stability awareness by providing system operators real-time oscillation monitoring results.	

Type of application GUI	C# based WPF, will be embedded into advanced control room visualization platform later	Identify operating entities that are using the application	Entergy, Idaho Power, better ask WSU
Any other relevant information:	N/A		

4.12 PJM Interconnection

Application name:	RTDMS® (Real Time Dynamics Monitoring System)		
Objective of the application:	RTDMS® (Real Time Dynamics Monitoring System) is a synchrophasor software application for providing real time, wide area situational awareness to Operators, and Engineers, as well as the capability to monitor and analyze the dynamics of the power system.		
Application requirements (hardware, software, visualization telecommunications, etc.):	One special need is RTDMS requires at least 1GB video card memory.	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	30 samples/sec phasor data
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	Mode Meter is configured to monitor the known system oscillations, It will generate the alarm if an oscillation event is detected.	**Current status of the application (in development, testing, in operation):**	Testing
If in operation, where?	N/A	**Application provider or developer:**	Electric Power Group (EPG)
Application software (open source, proprietary):	Proprietary	**Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):**	Can be integrated with PI
Describe how the application could be operationalized (i.e. used in real-time):	Oscillation detector algorithm and engine are still in testing phase. If it works as expected, it will be running all the time; scan and capture the unknown system oscillation events.		
Type of application GUI	Windows application GUI	**Identify operating entities that are using the application**	The application is available to 12 PJM transmission owners and 8 of them are using it.
Any other relevant information:	N/A		

4.13 XM S.A E.S.P, Columbia

Application name:	Phasorpoint - Alstom Siguard - Siemens		
Objective of the application:	Monitoring of power swings using synchrophasor data. Evaluation of the damping, amplitude and frequency of the power swings.		
Application requirements (hardware, software, visualization telecommunications, etc.):	• Software: Siguard, Phasorpoint. • Telecommunications: At least a phasor rate of 10 frame per second.	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	• The minimum source phasor rate is 10 frame per second. • For Siguard is required Sinaut Spectrum SP7 in order to have communication with the SCADA system.
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	Testing in operation.
If in operation, where?	• Phasor point: Control center, post-mortem analysis, and I+D. • Siguard: Control Center, post-mortem analysis, and I+D (Since October 2016).	**Application provider or developer:**	• Phasorpoint - Alstom • Siguard - Siemens
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	• Phasorpoint: PI. • Siguard: PI, SCADA system (Sinaut Spectrum SP7)		

Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	• Increasing the operational awareness: Any power swings that occur are detected quickly and reliably. • The graphical interface can display the current situation in terms of time, geography, and content. • Online power swing recognition: For Siguard, there are two ways of detecting a power swing, based on angle differences between two voltages (two PMUs necessary) or based on power swing recognition of the active power (one PMU for current and voltage measured values is adequate). For Phasor Point, the power swing is detecting using modal analysis, based on the system frequency or the active power.		
Describe how the application could be operationalized (i.e. used in real-time):	The applications are available for real time, and they are used as a prototype for helping the operators to have situational awareness regarding to power swings.		
Type of application GUI	• The monitored zone can be flexibly adjusted to the present situation in terms of time, geography, and content. • The applications allow to see graphically the damping, frequency and amplitude of the power swing.	Identify operating entities that are using the application	• Phasorpoint: Souter California Edison, Esckon (South Africa), Landsnet (Iceland), and Powerlink (Australia). • Siguard: Transpower Stromübertragungs Gmbh (Germany), and EWZ (Switzerland).
Any other relevant information:	**Real time display** • Phasorpoint:		

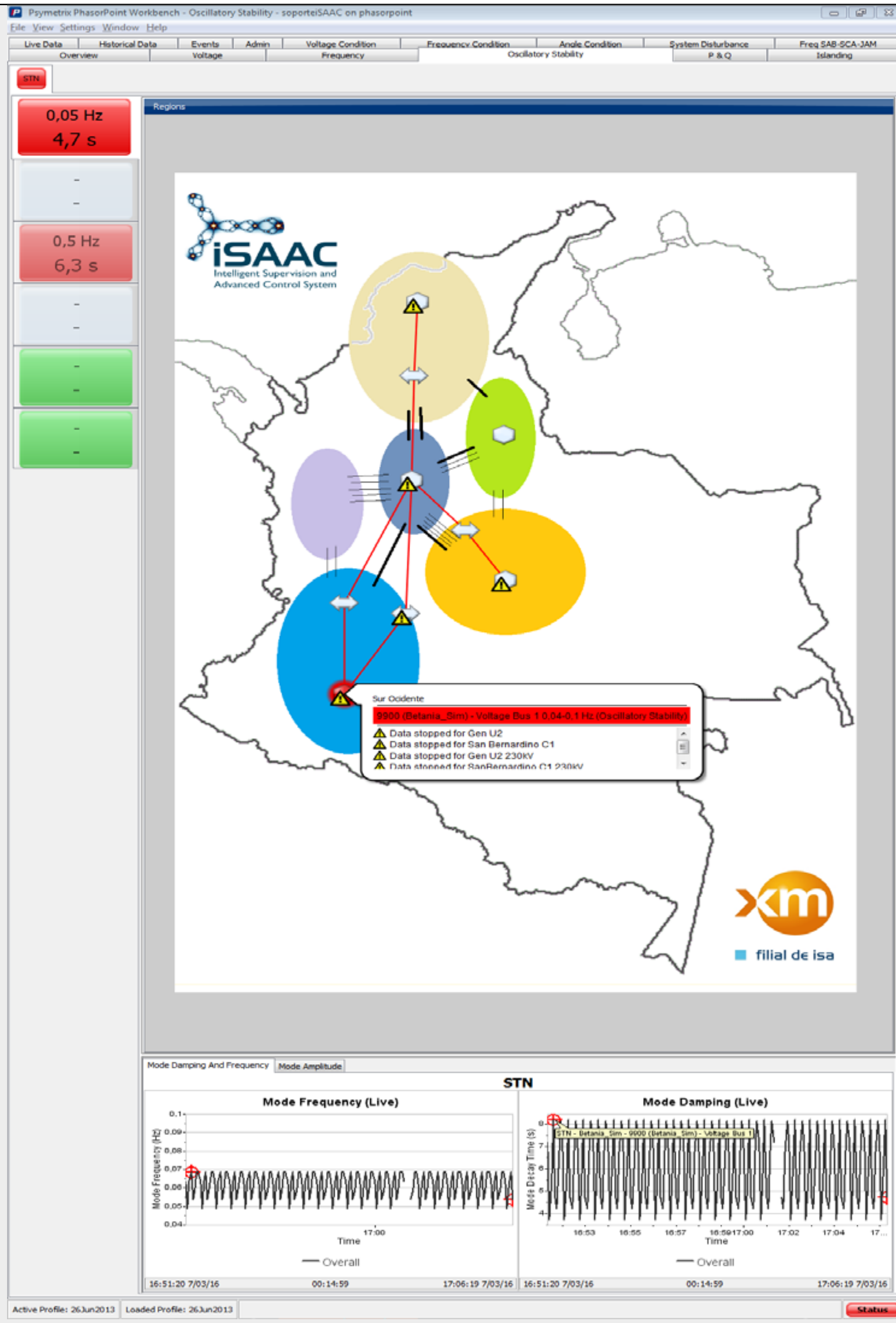
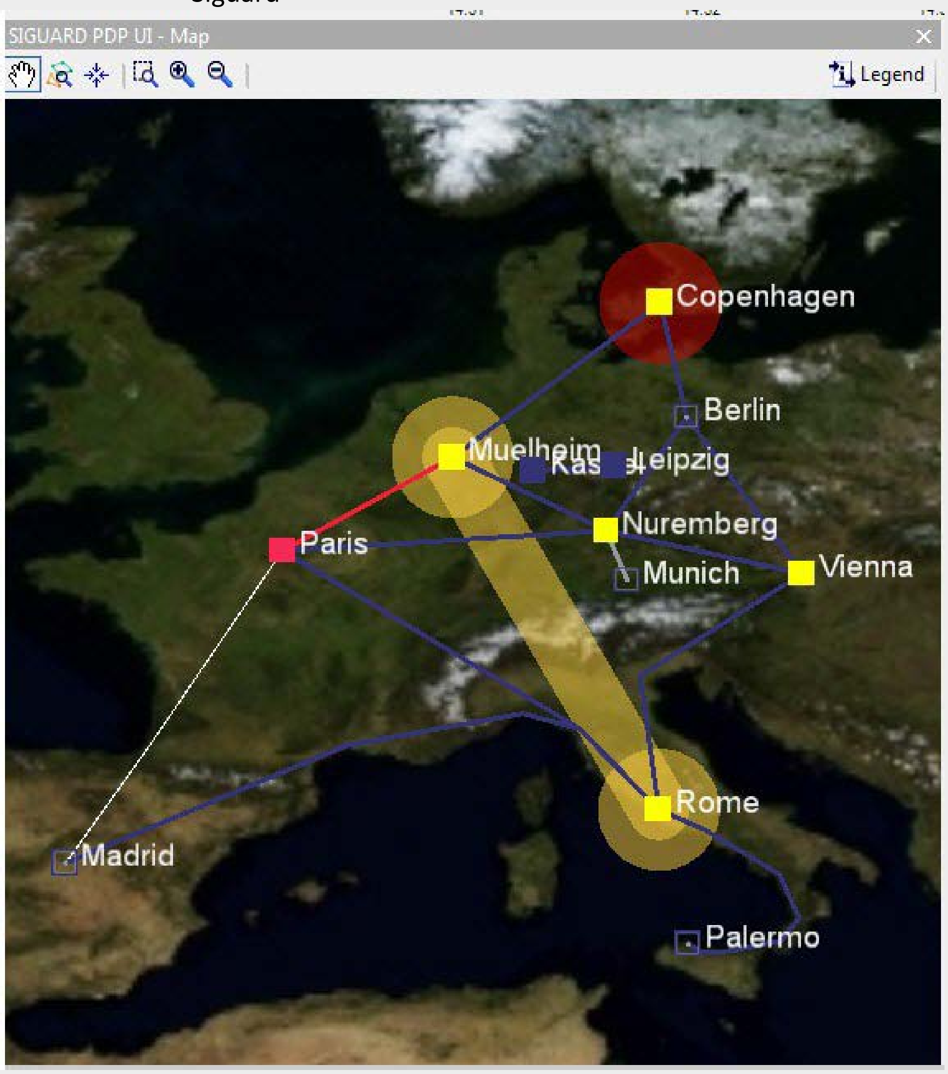


Figure 3: Phasorpoint GUI Example

	• Siguard  *Figure 4: Siguard User Interface*

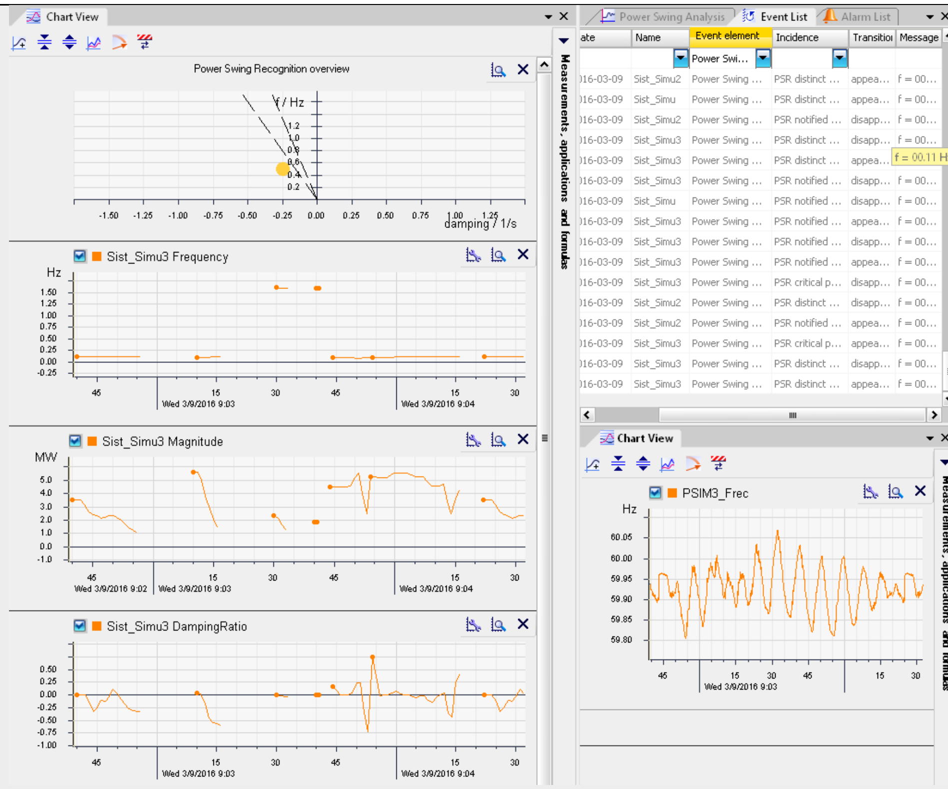


Figure 5: Siguard Analysis Features

References:

- Arango, O. J., Sanchez, H. M., & Wilson, D. H. (2010, August). Low Frequency Oscillations in the Colombian Power System–Identification and Remedial Actions. In CIGRE Session.

5 Survey Responses Received from Application Vendors/Developers

5.1 Electric Power Group (EPG)

Application name:	Real-Time Dynamics Monitoring System (RTDMS) – Mode Meter & Oscillation Detection
Objective of the application:	• Analysis and monitoring of natural system modes • Calculate modal frequency, damping, energy & mode shape • Real-time alarming on low damping / high energy over time • Provide geospatial visualization indicating participation of generators in the system modes • Detect forced oscillations in the system • Calculate RMS energy, spectral and shape for forced oscillations • Provide geospatial visualization to detect location of severe oscillations in real time, assess severity of the oscillation and identify root-cause of oscillation based on the frequency band and spread of the oscillation
Application requirements (hardware, software, visualization telecommunications, etc.):	This application will be part of the RTDMS Server. Typical hardware and software configuration for production servers are:

Table 1: Hardware Requirements for EPG Products

Server 1 Hardware Requirements Will run EPG's RTDMS Server software	
Operating System	Microsoft Windows 2008 R2
Processor Speed	2.5GHz
Processors-Cores/CPU	2 Physical Processors
Memory	8 Gigabytes Minimum
I/O ports	1 Network Interface Card (NIC) supporting 1GbPS
Hard Disk Storage	100 Gigiabytes

Server 2 Hardware Requirements - Real Time Data Storage Will run EPG's RTDMS Database hosted in Microsoft SQL Server	
Operating System	Microsoft Windows 2008 R2
Database System	Microsoft SQL Server 2008 R2
Processor Speed	2.5GHz

	Processors-Cores/CPU	2 Physical Processors (each with quad-core)	
	Memory	24 Gigabytes Minimum	
	I/O ports	1 Network Interface Card (NIC) supporting 1GbPS	
	Hard Disk Storage	2.5 TB Disk Storage (200 PMUs for 30 Days RAW phasor data, calculated data, alarms, and events)	

Individual PC Hardware Requirements Will run EPG's RTDMS Client Application	
Operating System	Microsoft Windows 7, 32 or 64-bit.
Processor Speed	2.5GHz
Processor Type	Intel Core2 Quad or i7 processor
Memory	8 Gigabytes Minimum
I/O ports	1 Network Interface Card (NIC) 1 GBPS
Video Card	AMD Radeon 7500 series or better, or HD 6500 or better, or FirePro V7900 or better, with 2GB RAM or more

Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):	• Phasor data at the rate available at the entity using the application, usually 30 samples/second. • Voltage phasor and current phasor measurements		
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	In Operation
If in operation, where?	RTDMS is deployed at NYISO, PJM, SPP, Dominion, Duke Energy, ERCOT, LCRA, Southern Co., CAISO, SRP, LADWP, TVA, SCE.	**Application provider or developer:**	Application vendor is Electric Power Group, www.electricpowergroup.com

Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	▪ Integration with EMS installations – Alstom, GE, Siemens, ABB, Monarch etc. ▪ Integrates with PI Historian. ▪ Phasor data and intelligence with the EMS system using ICCP and DNP3. ▪ Generate .csv and COMTRADE file formats for data analysis. ▪ APIs for third party tools to subscribe data through Synchrophasor Distribution Service (SDS). ▪ Ability to integrate new algorithms using Service Oriented Architecture. ▪ Web Map Service (WMS) for displaying Geo displays rendered by RTDMS. ▪ Integration Tools: - ICCP Adapter - PI Adapter - DNP3 Adapter - One-line Diagram Editor - ISG API - Synchrophasor Distribution Service (SDS)
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	The mode meter application performs modal analysis on both ambient system conditions and under transient disturbance conditions. It estimates the modal frequency, damping ratio, energy amplitude level and mode shapes of oscillations of interest. A condition that damping ratio is below 5% triggers alerts to catch operators' attention, and a condition that damping ratio is less than 3% triggers alarms. The oscillation detection application is designed for rapid identification of forced oscillations, especially for oscillations that may be unexpected or unknown based on operating experience. The application considers oscillations in four frequency bands, as shown in the table below.

Table 2: Oscillation Detection Frequency Bands and Type of Oscillations

#	Frequency Band (Hz)	Type of Oscillations
1	0.01 – 0.15	Speed Governor Oscillation Band
2	0.15 – 1.0	Inter-area Oscillations (Electromechanical Band)
3	1.0 – 5.0	Local and Control System Oscillations
4	5.0 - 14	Torsional Dynamics Band

	The Root Mean Square (RMS) of energy is a quick indicator of type of oscillations and could be an event indicator as well. The oscillation detection calculates the RMS energy for each input signal, and it triggers an alarm when a RMS Energy value exceeds threshold in a particular frequency band and for a user-defined time duration. RTDMS provides geospatial visualization for both the mode meter and oscillation detection applications. The map view of oscillations provide ability to quickly detect severe oscillations in real-time and identify the location of the oscillation (generating units – wind farms, nuclear unit, etc.), severity of the oscillation and the frequency band in which the oscillation lies. The frequency band is closely related to the likely cause and the spread of the oscillations.
Describe how the application could be operationalized (i.e. used in real-time):	As indicated above, geospatial map view provides an overview of the system in terms of oscillations such that any severe oscillation could be detected in real-time. The map view also provides the ability to identify the location of the oscillation and the severity of the oscillation. Operators also have the ability to drill down to the oscillation analysis results and look at the oscillation energy, signal trends and mode shape or oscillation shape for forced oscillations.
Type of application GUI	Figure below shows the information for Modes A (yellow) and B (blue): mode frequency, damping and energy amplitude in a single chart so that the three can be co-related to determine mode, damping level and energy level at a glance. The figure also shows the mode scatter chart on the upper right and two mode damping gauge views on the lower right of the display.  *Figure 6: RTDMS GUI Example One*

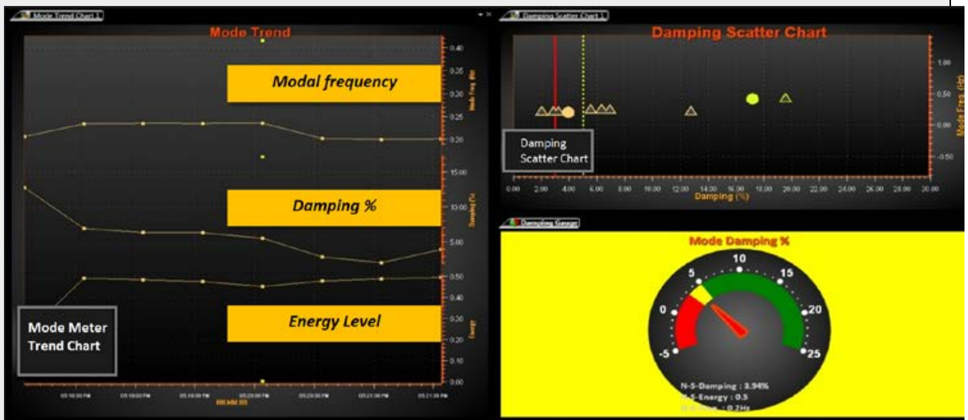


Figure 7: RTDMS Mode Damping Gauge Example

Figure below shows low damping alarm and event popup on geospatial map.

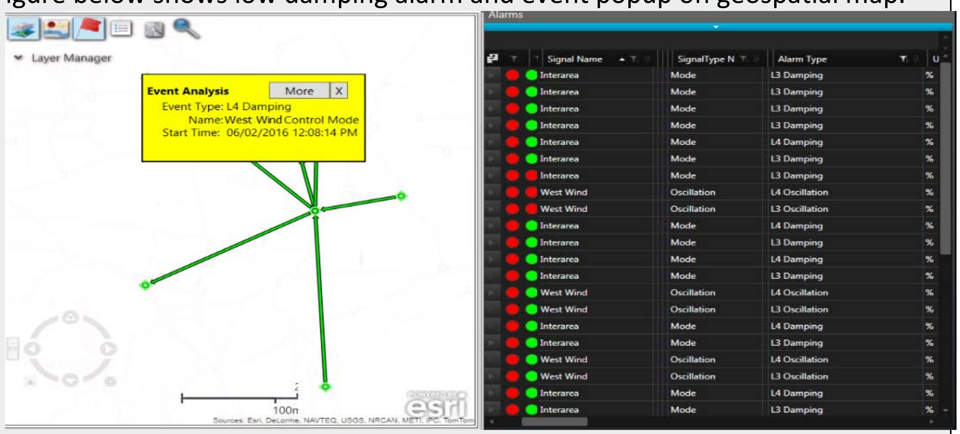


Figure 8: RTDMS Event and Alarm Examples

Figure below shows an example of mode shape. The mode shapes relatively close to each other are in phase, meaning these signals are oscillating together. And the mode shapes relatively in the opposite direction of the polar chart mean these signals are oscillating against each other. Thus user can identify the two oscillation groups and areas. In this particular example, Colstrip and Grand Coulee group are oscillation against El Dorado, Lugo and Miguel group, they are out of phase about 180 degrees.

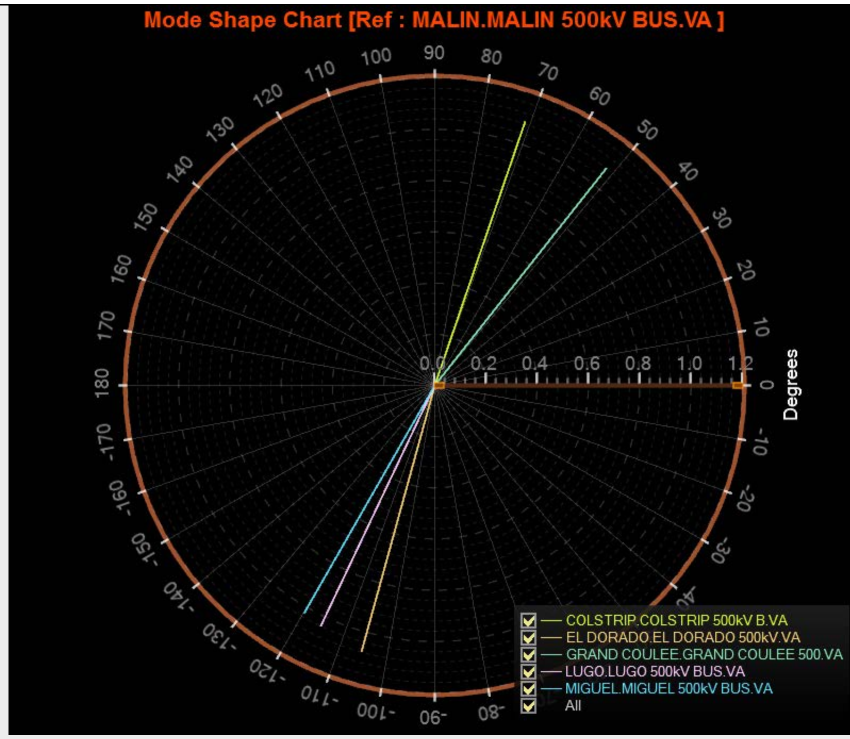


Figure 9: RTDMS Mode Shape Display

RTDMS also provides geospatial visualization for viewing mode shapes on the map. Figure below shows an example of the mode shape view. Shown below are the mode shape results for a system mode and the participation of generating units at various locations. The size of the circle indicates the amplitude and the arrows indicate the phase relationship. The color indicates if the damping is less than the threholds (red = low damping, green = adequate damping).

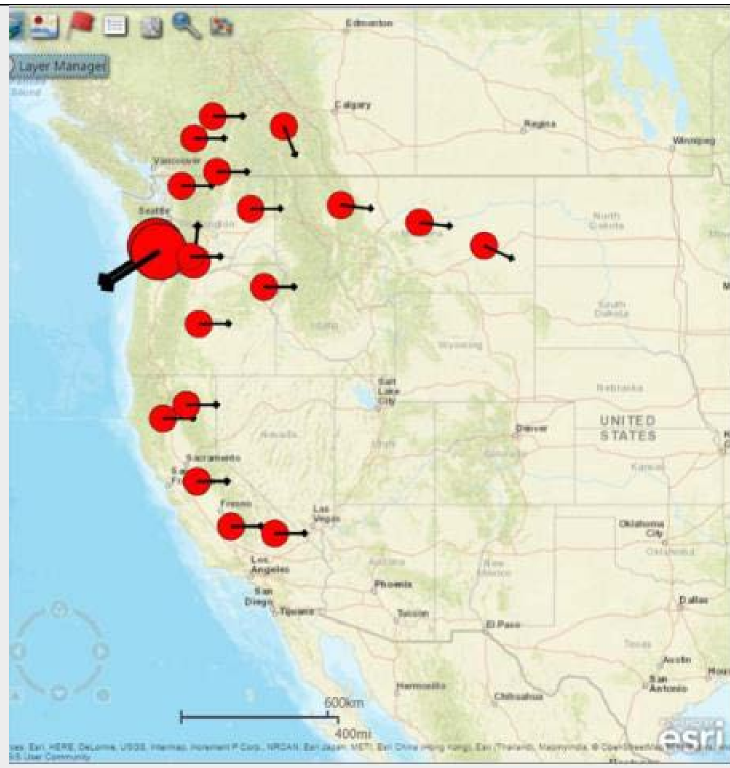


Figure 10: RTDMS Geospatial Visualization

Figure below shows an oscillation trend chart, which shows oscillation frequency spectrum with RMS energy amplitude in 4 separate frequency bands.

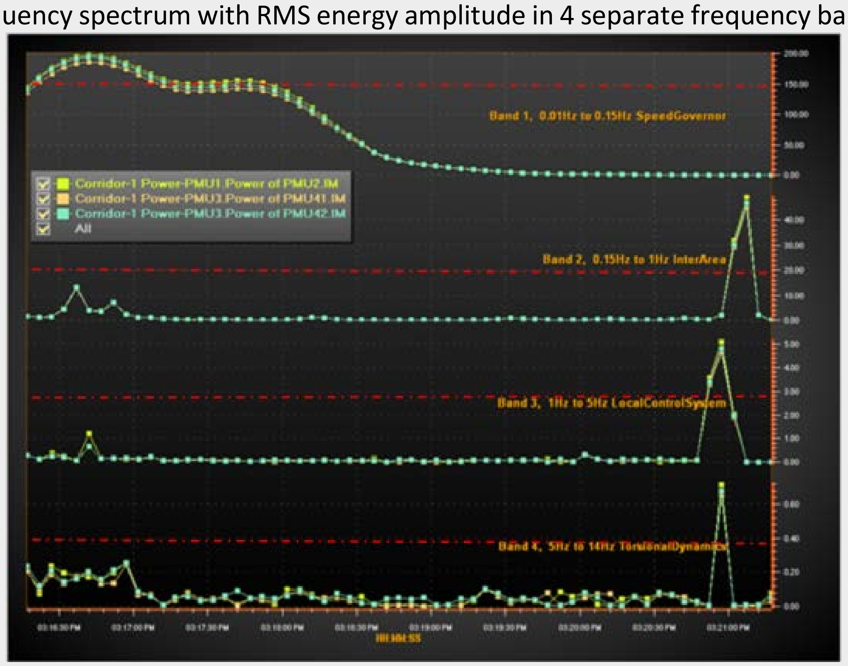
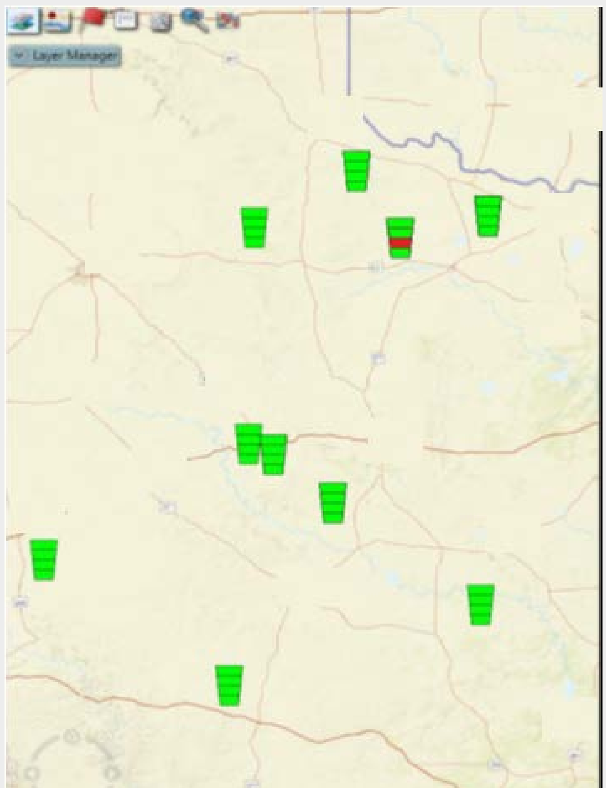
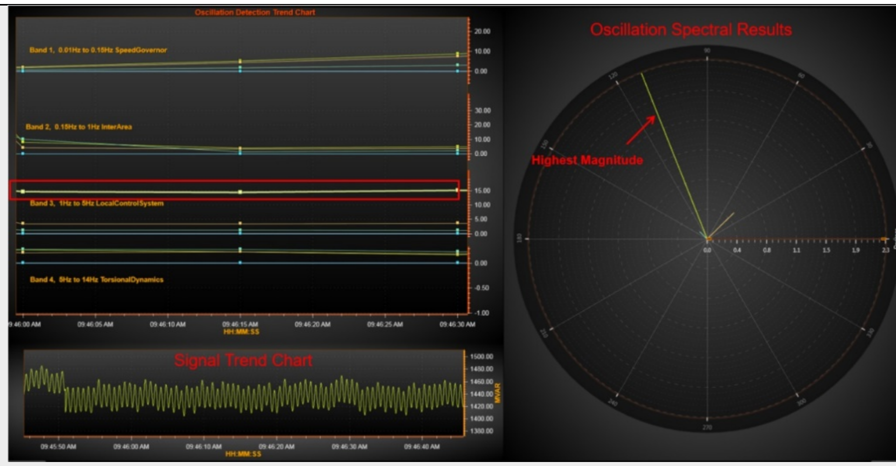


Figure 11: RTDMS Oscillation Trend Chart

The geospatial visualization for oscillation detection in RTDMS provides operators an overview of the power system with respect to oscillations in the

	system and allows operators to quickly identify the source of an event and severity of the event. This enables quick event identification, diagnosis and remedial action when there are forced oscillations in the system. For example, the oscillation layer on RTDMS map shown below gives a direct indication of source of oscillation, severity of oscillation using alarm colors and the frequency band of the oscillations that indicates the like cause. As shown, below we can see that there is an oscillation alarms (red) at one location in the frequency band 3 (1 – 5 Hz) indicating a local oscillation related to control systems. Each icon represents a PMU location and shows oscillation alarms in different signals form that PMU.  *Figure 12: The Oscillation Layer on RTDMS Map* The icon can be double clicked to obtain a drill down view for further analysis. The drill down view shown below shows oscillation energy for top 10 signals sorted on the basis of oscillation amplitude (Top left). It also shows the trend chart for the signal that alarmed (bottom left) and spectral analysis results indicating oscillation shape for the forced oscillations (right chart).

	 *Figure 13: RTDMS Oscillation Drill Down View* The mode meter and oscillation detection display can be configured in any way that fits the user's need, using various view templates in RTDMS.
Identify operating entities that are using the application	This application is used at NYISO, PJM, SPP, ERCOT, Dominion, Duke Energy, LCRA, CAISO.
Any other relevant information:	N/A

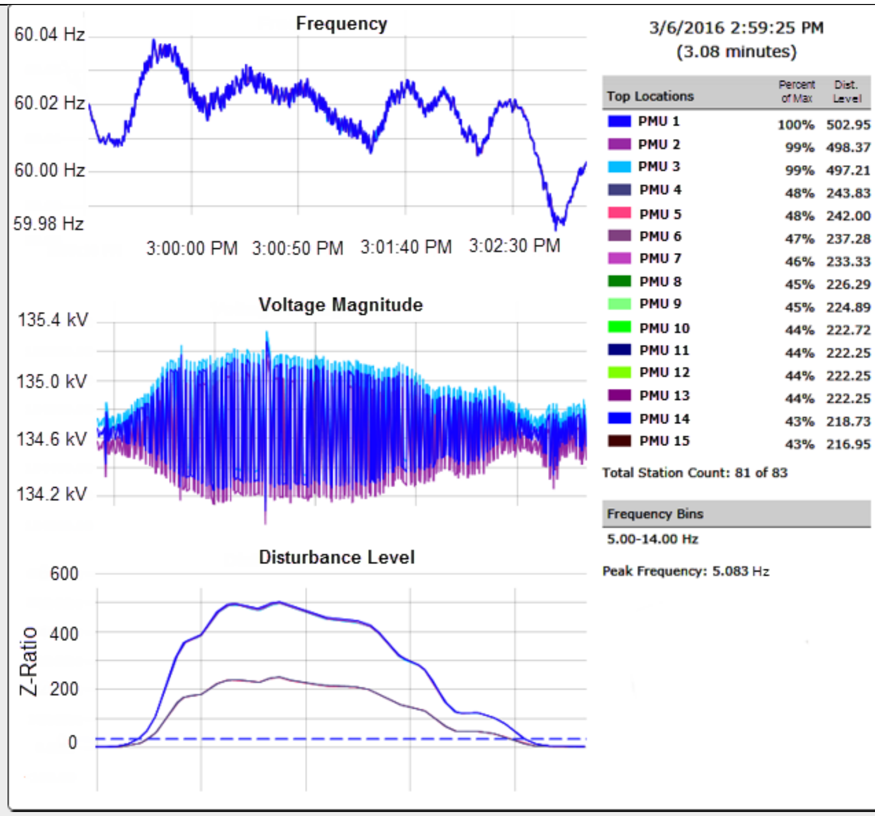
5.2 Pacific Northwest National Laboratory (PNNL)

Application name:	Bonneville Power Administration Archive Walker Software (BAWS)		
Objective of the application:	BAWS reads in and processes archived and near-real time data to detect events in the data, which are provided to the user via summary reports and alerts. Events of interest can include forced oscillations and oscillatory events (e.g., ringdown), as well as conditions such as frequency and voltage excursions.		
Application requirements (hardware, software, visualization telecommunications, etc.):	The MATLAB software environment is currently required to run the software, but the final product is expected to be utilize the MATLAB run-time libraries and not require an active MATLAB license.	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	BAWS currently requires phasor data in PDAT or JSIS CSV format.
Application software (open source, proprietary):	Eventually open-source, when the development is further along.	**Current status of the application (in development, testing, in operation):**	In development
If in operation, where?	N/A	**Application provider or developer:**	Application being developed by the Pacific Northwest National Laboratory, under contract from the Bonneville Power Administration
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	No explicit ability right now – the tool is PMU data focused for the time being.		

Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	BAWS is meant to be used as a near-real time software and not in the direct operational environment. It is more of a planning engineer tool and a method to evaluate large swaths of PMU data and find the intervals of interest for further examination/study.		
Describe how the application could be operationalized (i.e. used in real-time):	The application could be running on a near real-time PMU data stream (within minutes of real time) and provide detection of events in the PMU data. These include events such as oscillations (forced and ringdown), voltage excursions, and frequency excursions.		
Type of application GUI	MATLAB GUIDE-based	**Identify operating entities that are using the application**	Bonneville Power Administration will be the first entity to use the application, but it is not expected to be in an operational environment. This is more of a tool for the planning or operational engineer to evaluate archived data or near-real time data.
Any other relevant information:	Development is on-going. The large contribution of this particular application is the deployment of algorithms developed at PNNL to detect events on the system, especially forced oscillations. There are reports and transactions papers detailing the algorithms and approaches, which can be provided, if necessary.		

5.3 Schweitzer Engineering Laboratories (SEL)

Application name:	SynchroWAVe Central		
Objective of the application:	Provide utilities and transmission system operators with a synchrophasor based Wide-Area Situational Awareness (WASA).		
Application requirements (hardware, software, visualization telecommunications, etc.):	Hardware: Microsoft Windows computer/server with hard drive for archiving of synchrophasor data.	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	IEEE C37.118 synchrophasor data stream
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	In operation
If in operation, where?	Utilities and Transmission System Operators (TSOs) throughout the world, details can be provided upon request.	**Application provider or developer:**	Schweitzer Engineering Laboratories
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	Software supports connection to IEEE C37.118 synchrophasor data stream.		
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	Automatically detects oscillations and disturbances in real-time, and provides operators and engineer an overview of the oscillation/disturbance's impact. The screen capture below shows an oscillation automatically detected from a solar farm connected to the substation that PMU 1, 2 and 3 are monitoring.		

	 *Figure 14: SynchroWAVe Automatic Oscillation Detection*		
Describe how the application could be operationalized (i.e. used in real-time):	Upon detection of an oscillation or disturbance an alarm/notification will be available to the operator in a dashboard providing them with details of the oscillation/disturbance. From the details, an operator/engineer can determine whether further investigation is required for the oscillation/disturbance. Dashboard displays for each transmission line and substation can be quickly pulled up by the operator when an SCADA alarm indicates an issue at a particular location. These dashboard displays will provide data such as frequency, voltage, phase angle, current, power flow, etc for greater insight into a potential oscillation or disturbance at that location. Geospatial dashboards with voltage contours, phase angle differences, and power flows can provide operators the ability to see the overall state of the system at a glance.		
Type of application GUI	SynchroWAVe Central is a server/web-client application. Charting components can be grouped together to	**Identify operating entities that are using the application**	Utilities and Transmission System Operators (TSOs) throughout the world, details can be provided upon request.

	provide dashboard for specific applications.		
Any other relevant information:	• An online demonstration of SynchroWAVe Central software is available at https://selinc.com/solutions/wasa/ • A technical paper describing automatic disturbance and oscillation detection capability deployed at SDG&E will be presented at PEAC 2017 and Georgia Tech Fault Disturbance Analysis 2017 conference. The technical paper is available online at https://selinc.com/literature/technical-papers/		

5.4 Washington State University (Damping Monitor Real-time- DMR)

Application name:	Damping Monitor Real-time (DMR)		
Objective of the application:	Real-time oscillation monitoring using ambient data		
Application requirements (hardware, software, visualization telecommunications, etc.):	openPDC, SIEGate	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Phasor data
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	In operation and under testing.
If in operation, where?	Being tested at Entergy, Peak RC, and Southern CO. In operation at WRLDC, Mumbai, India.	**Application provider or developer:**	Prof. Mani Venkatasubramanian, WSU, Pullman, WA.
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		Can import data from any PDC using IEEE C37.118 and SIEGate protocols. C an export results to PI and openHistorian. Burns and McDonnell has also developed custom user interfaces for EMS integration.	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Continuous monitoring of the damping levels of dominant system modes and oscillations. Detection of problematic oscillations along with automatic analysis of the nature of oscillations.	
Describe how the application could be operationalized (i.e. used in real-time):		It’s already real-time	
Type of application GUI	See example below	**Identify operating entities that are using the application**	WRLDC, India, Peak RC, Entergy and Southern CO

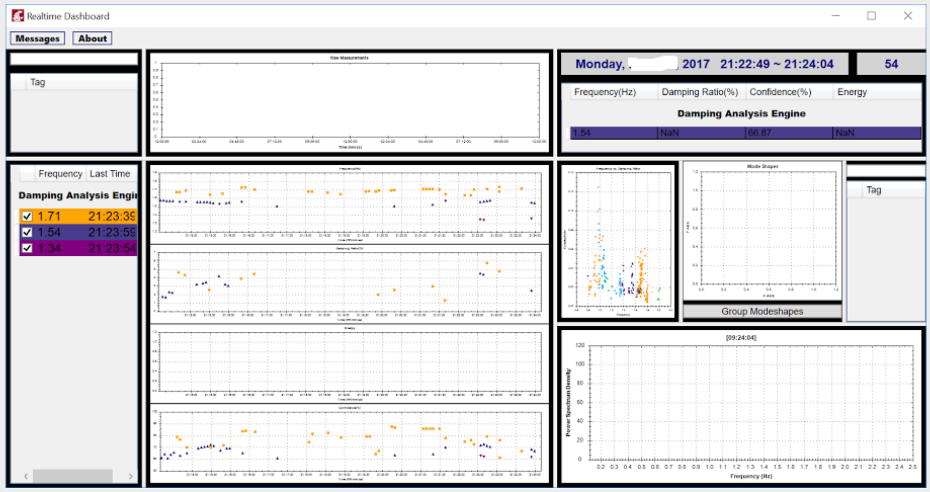
<table>
<tr><th></th><th></th></tr>
<tr><td>Any other relevant information:</td><td>GUI:


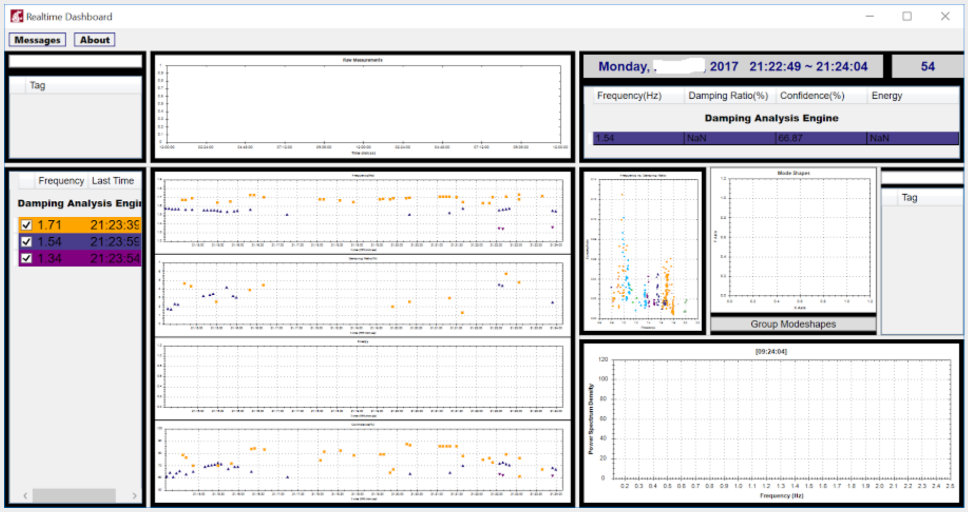
Figure 15: DMR GUI Example

• H. Khalilinia, L. Zhang, and V. Venkatasubramanian, “Fast frequency domain decomposition for ambient oscillation monitoring”, IEEE Trans. Power Delivery, vol. 30, NO. 3, pp. 1631-1633, June 2015.

• S.A. Nezam Sarmadi and V. Venkatasubramanian, "Electromechanical Mode Estimation Using Recursive Adaptive Stochastic Subspace Identification," IEEE Trans. on Power Systems, vol. 29, no. 1, pp. 349-358, Jan. 2014.</td></tr>
</table>

5.5 Washington State University (Event Analysis Real-time- EAR)

Application name:	Event Analysis Real-time (EAR)		
Objective of the application:	Real-time oscillation monitoring using event data		
Application requirements (hardware, software, visualization telecommunications, etc.):	openPDC, SIEGate	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Phasor data
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	Under testing.
If in operation, where?	Being tested at Entergy, Peak RC, and Southern CO.	**Application provider or developer:**	Prof. Mani Venkatasubramanian, WSU, Pullman, WA
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):	Can import data from any PDC using IEEE C37.118 and SIEGate protocols. C an export results to PI and openHistorian. Burns and McDonnell has also developed custom user interfaces for EMS integration.		
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:	Automatic detection of major system events, and automatic analysis of system modes and oscillations from ringdown data.		
Describe how the application could be operationalized (i.e. used in real-time):	It's already real-time		
Type of application GUI	See example below	**Identify operating entities that are using the application**	Peak RC, Entergy and Southern CO

Any other relevant information:	GUI:  *Figure 16: EAR GUI Example* • G. Liu, J. Quintero, and V. Venkatasubramanian, “Oscillation Monitoring System based on wide area synchrophasors in power systems,” Proc. IREP symposium 2007. Bulk Power System Dynamics and Control - VII, August 19-24, 2007, Charleston, South Carolina, USA.

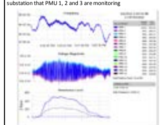
5.6 Washington State University (Forced Oscillation Detection and Source Location - FODSL)

Application name:	Forced Oscillation Detection and Source Location (FODSL)		
Objective of the application:	Real-time oscillation monitoring using PMU and SCADA data		
Application requirements (hardware, software, visualization telecommunications, etc.):	openPDC, SIEGate, PI	**Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):**	Phasor data and SCADA data
Application software (open source, proprietary):	Proprietary	**Current status of the application (in development, testing, in operation):**	Under testing.
If in operation, where?	Being tested at Peak RC	**Application provider or developer:**	Prof. Mani Venkatasubramanian, WSU, Pullman, WA
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		Can import data from any PDC using IEEE C37.118 and SIEGate protocols. Can import SCADA data from PI historian. Can export results to PI.	
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:		Detection of oscillations using PMU data. Source location analysis using SCADA data.	
Describe how the application could be operationalized (i.e. used in real-time):		It's already real-time	
Type of application GUI	Under development.	**Identify operating entities that are using the application**	Peak RC
Any other relevant information:	• J OBrien, T Wu, V Venkatasubramanian, H Zhang, "Source Location of Forced Oscillations Using Synchrophasor and SCADA Data", Proceedings of the 50th Hawaii International Conference on System Sciences, 2017.		

NASPI North American SynchroPhasor Initiative

Party	Response Type	Application(s)	Status	Objectives	App Software Status	General Requirements	Data Requirements	Integration Info	GUI Info	Incremental Improvements	How to Operationalize	Additional Info
BPA	User	Oscillation Detection Module (ODM) engine developed by Dr. Dan Trudnowski, Montana Tech University	In Operation in BPA Primary and Alternate Control Centers	Oscillation Detection application scans multiple signals (power, frequency, voltages) across the grid for indication of growing or sustained high energy oscillations	Proprietary	1. Oscillation Detection Module (ODM) engine developed by Dr. Dan Trudnowski, Montana Tech University 2. Real-time processing uses uncompressed C37.118 data from 66 PMUs, 140 total measurement points	Application inputs raw, uncompressed PMU Voltage and Current Phasor measurements input into the OSIsoft PI system via the OSIsoft C37.118 Interface. The data is pulled from the OSIsoft PI snapshot using the AF-SDK interface	All raw PMU data and ODM processed data is written to PI. A custom link was written by BPA to notify SCADA when an oscillation has been detected. An Alarm is generated on the SCADA Alarm list when an oscillation is detected.	All Synchrophasor Displays are OSIsoft Process Book Displays, augmented with VB processing	The benefit is to detect oscillations in real-time and have operators take action to help mitigate those oscillations.	It has been operationalized. Should an oscillation alarm occur, a corresponding frequency band at a corresponding PMU will turn "red". The display provides very effective visual indication on whether the oscillation is local or wide-area. For local oscillation, only one or a few PMUs in the vicinity of oscillation source will go into an alarm state. For wide-area oscillations, multiple PMUs will go into an alarm state over a large geographic area. The display also provides initial indication of the type of oscillation based on the frequency band alarmed. The oscillation must persist for pre-determined time period for the application to issue an alarm.	Relevant Papers:[1]. D.Kosterev,J.Burns, N.Leitschuh, J.Anasis, A.Donahoo, D.Trudnowski, M.Donnelly, J.Pierre, 'Implementation and Operating Experience with Oscillation Detection Application at Bonneville Power Administration', CIGRE 2016 Grid of the Future Symposium, October 30 - November 1, 2016, Philadelphia, USA. [2]. Matt Donnelley, 'Implementation and Operating Experience with Oscillation Detection at Bonneville Power Administration' NASPI Meeting.
Dominion Virginia Power	User	Electric Power Group's RTDMS "Oscillation Detection" tool	In partial operation (only available to engineering teams, not operators), continuing to test/validate prior to giving to operators.	Detect oscillation events at specific frequencies (known from previous events) that occur in Dominion's grid	Proprietary	A Windows server (physical server, not virtual server) with good processing capability.	Synchrophasor data at 30 phasors/second data rate	can integrate with EMS/SCADA systems via DNP3 (maybe other connections too), and also with PI.	Windows application/windows interface	Be able to detect and see an oscillation event occurring in the control room. In a past oscillation event at Dominion, operators were not able to see the oscillation in their SCADA data/SCADA alarms/SCADA displays, and did not know it was occurring until the power plant reported to the operators that something unusual was going on (but they also did not know the extent of what was going on, as the plant operators also only had SCADA data).	Give the RTDMS visualization displays to the operators to visualize when and where oscillations are occurring. Also give RTDMS oscillation alarms to the operators in their EMS screens.	EPG has many videos available of their oscillation detection tool and the RTDMS application.
Duke Energy	User	EPG's RTDMS	Visualization - In Operation, Oscillation – in development. In Use Back Hall Engineering, Control Room	Visualization	Proprietary	Database Server, Gateway Server, Client Servers, Software License	Phasor Data	Integrate with PI	RTDMS	Quicker detection of long term oscillations (no incremental improvement for short term oscillations – the system will react before operators can).	Need to better define limits to detect oscillations	
Electric Power Group (EPG)	Vendor/Developmer	Mode Meter and Oscillation Detection in Real-Time Dynamics Monitoring System (RTDMS)	RTDMS was deployed at NYISO, PJM, Dominion, Duke Energy, SPP, ERCOT, LCRA, Southern Co., CAISO, SRP, LADWP, TVA, SCE.	• Analysis and monitoring of natural system modes • Calculate modal frequency, damping, energy & mode shape • Real-time alarming on low damping / high energy over time • Provide geospatial visualization indicating participation of generators in the system modes • Detect forced oscillations in the system • Calculate RMS energy, spectral and shape for forced oscillations • Provide geospatial visualization to detect location of severe oscillations in real-time, assess severity of the oscillation and identify root-cause of oscillation based on the frequency band and spread of the oscillation	Proprietary	This application will be part of the RTDMS Server. Typical hardware and software configuration for production servers are: 1) Server 1 Hardware Requirements: Will run EPG's RTDMS Server software Operating System: Microsoft Windows 2008 R2 Processor Speed: 2.5GHz Processors- Cores/CPU: 2 Physical Processors Memory: 8 Gigabytes Minimum I/O ports: 1 Network Interface Card (NIC) supporting 1GbPS Hard Disk Storage: 100 Gigiabytes 2) Server 2 Hardware Requirements: - Real Time Data Storage Will run EPG's RTDMS Database hosted in Microsoft SQL Server Operating System:Microsoft Windows 2008 R2 Processor Speed: 2.5GHz Processors- Cores/CPU 2 Physical Processors (each with quad-core) Memory: 24 Gigabytes Minimum I/O ports: 1 Network Interface Card (NIC) supporting 1GbPS Hard Disk Storage: 2.5 TB Disk Storage (200 PMUs for 30 Days RAW phasor data, calculated data, alarms, and events) 3) Individual PC Hardware Requirements: Will run EPG's RTDMS Client Application Operating System: Microsoft Windows 7, 32 or 64-bit. Processor Speed: 2.5GHz Processor Type: Intel Core2 Quad or i7 processor Memory: 8 Gigabytes Minimum I/O ports: 1 Network Interface Card (NIC) 1 GBPS Video Card: AMD Radeon 7500 series or better, or HD 6500 or better, or FirePro V7900 or better, with 2GB RAM or more	• Phasor data at the rate available at the entity using the application, usually 30 samples/second. • Voltage phasor and current phasor measurements	Integration with EMS installations – Alstom, GE, Siemens, ABB, Monarch etc. • Integrates with PI Historian. • Phasor data and intelligence with the EMS system using ICCP and DNP3. • Generate .csv and COMTRADE file formats for data analysis. • APIs for third party tools to subscribe data through Synchrophasor Distribution Service (SDS). • Ability to integrate new algorithms using Service Oriented Architecture. • Web Map Service (WMS) for displaying Geo displays rendered by RTDMS. • Integration Tools: - ICCP Adapter - PI Adapter - DNP3 Adapter - One-line Diagram Editor - ISG API - Synchrophasor Distribution …	RTDMES has its own visualization : \ See Word document for details. 	The mode meter application performs modal analysis on both ambient system conditions and under transient disturbance conditions. It estimates the modal frequency, damping ratio, energy amplitude level and mode shapes of oscillations of interest. A condition that damping ratio is below 5% triggers alerts to catch operators' attention, and a condition that damping ratio is less than 3% triggers alarms. The oscillation detection application is designed for rapid identification of forced oscillations, especially for oscillations that may be unexpected or unknown based on operating experience. The application considers oscillations in four frequency bands, as shown in the table below. Oscillation Detection Frequency Bands and Type of Oscillations # Frequency Band (Hz) Type of Oscillations 1 0.01 – 0.15 Speed Governor Oscillation Band 2 0.15 – 1.0 Inter-area Oscillations (Electromechanical Band) 3 1.0 – 5.0 Local and Control System Oscillations 4 5.0 - 14 Torsional Dynamics Band The Root Mean Square (RMS) of energy is a quick indicator of type of oscillations and could be an event indicator as well. The oscillation detection calculates the RMS energy for each input signal, and it triggers an alarm when a RMS Energy value exceeds threshold in a particular frequency band and for a user-defined time duration. RTDMS provides geospatial visualization for both the mode meter and oscillation detection applications. The map view of oscillations provide ability to quickly detect severe oscillations in real-time and identify the location of the oscillation (generating units – wind farms, nuclear unit, …	As indicated above, geospatial map view provides an overview of the system in terms of oscillations such that any severe oscillation could be detected in real-time. The map view also provides the ability to identify the location of the oscillation and the severity of the oscillation. Operators also have the ability to drill down to the oscillation analysis results and look at the oscillation energy, signal trends and mode shape or oscillation shape for forced oscillations.	
Electric Reliability Council of Texas (ERCOT)	User	EPG's RTDMS	Current State: • Used in control room by shift engineer as well as by support engineers to monitor voltage angles and oscillations across the system	To provide real-time, wide-area situational awareness and real-time dynamics monitoring of the power grid for use by Operators, Reliability Coordinators, Planners, and Operating Engineers, as well as the capability to analyze system performance and events. The major use cases of the application within ERCOT are the ability to observe and alert operators to voltage angle differences across the interconnection, detect and mitigate local and system-wide oscillations, and the ability to save and replay system events recorded by PMUs across the system.	Proprietary	See EPG's requirements	Accepts phasor data input from a Phasor Data Concentrator (PDC) using either C37.118 or PDCStream data format	Currently, RTDMS is a completely separate system from EMS/SCADA. We are currently investigating our options with implementing alarms from the PMU system into our EMS. We are also working on using triggers from the OTS to simulate PMU data to stream directly to the Phasor Simulator for operator training.	The RTDMS user interface is made up of many tools for visualizing data and monitoring alarms. It consists of a hierarchy of layers that together provide a rich user experience for viewing data.Specifically for oscillation detection, we have six known common modes that have 'mode meters' set up to detect oscillations with their mode, damping, and energy level, as shown below: 	Current State: • Used in control room by shift engineer as well as by support engineers to monitor voltage angles and oscillations across the system • Developed a PMU-based operator training simulator, and will begin training operators on PMU software in the coming months • Six 'Mode meters' have been implemented to detect the reoccurrence of common known oscillation modes, with the ability to calculate the dominant oscillation mode, damping, and energy level of the oscillation Future Goals: • Build out redundant PMU monitoring system • Develop procedures for operators and train operators on the PMU operator training simulator • Add in PMU Estimation on Interfaces as a backup for IROLs • Monitor grid disturbances and notify Generators to collect data for model validation on these events • Add PMU data into EMS for improved state estimation, and/or develop a linear state estimator for monitoring a significant portion of the 345 kV system • Control Room event reporting including dynamic system performance • Incorporate into Blackstart training, using islanding detection features and abilities to monitor angle difference across breakers for reclosing procedures	Currently, the RTDMS is being used in the control room at the shift engineer's desk and by control room support engineers. The primary purposes of the system are to monitor voltage angles and system oscillations, as well as replaying system events for post mortem analysis. There are no official procedures for operators at this time, but will be developed in the near future, once there is a redundant system in place. Although we currently have requirements on PMU locations, data recording, and data retention, there are no requirements for data quality, which will need to be addressed before operator actions can be based solely on PMU data.	Sample videos have been posted on NASPI's website
Entergy	User	Washington State University(WSU) Damping Monitor Offline	Current State: Development	Oscillation postmortem analysis	Proprietary	Server based with connection to OSIsoft PI, OpenPDC	Historical PMU data from OSIsoft PI	Interoperable with OSIsoft PI	Basic, made for postmortem analysis	Identification of the location of Inter-Area location of forced oscillations	WSU has a real-time version	
ISO New England	User	PhasorPoint	PhasorPoint is in production use. It is used Outside of the control room for use by operation support engineers.	Detect oscillations (ambient and ringdown), characterize oscillations and generate alarms/alerts. Characterization of oscillations consists of determination of frequency, amplitude, damping and mode shape. PhasorPoint provides characterization of a single mode with the highest energy for every frequency band defined for monitoring in the frequency range of electromechanical modes.	Proprietary	Hardware: standard server. Software: Linux on server and Java on client	Synchrophasor data at 30 samples / second	PhasorPoint has its own storage and can be connected to GE EMS	Event log, geographic display, strip chart	Sustained oscillations with high magnitude represent the risk for the system stability, uncontrolled outages and increased mechanical vibrations to the equipment reducing the life span of the equipment and requiring more frequent maintenance. Detection and characterization of oscillations is the first step in identifying the threat for the system and to initiate a mitigation process. Detection of oscillations only is not sufficient for Control Room. Clear Operational instructions on mitigation measures should exist and be available for Operator to utilize the benefit of oscillations detection in real-time operations.	Use of PhasorPoint information on detected oscillations only without operating procedures on how to mitigate oscillations has a limited value for Control Room and could be used for information/education purposes. Real benefit will be coming when the detection of oscillation is accompanied with actionable operational information	
ISO New England	Developer and User	Oscillation Source Location (OSL) Tool based on Dissipating Energy Flow (DEF) method. Application developer is ISO-NE	Current version of the OSL tool is a Matlab prototype version. The efficiency of the tool was demonstrated on a representative set of simulated cases and 30+ actual events in ISO-NE and two events in WECC systems. The OSL tool is used offline, outside of Control Room by engineers. Operating entities that are using the application are: Research engineers and Operations support engineers at ISO-NE	Determine the source of sustained oscillations in power systems for both poorly damped natural and forced oscillations. The OSL tool is capable of detecting single or multiple sources of one or several simultaneously observed modes of sustained oscillations	Proprietary	Hardware: standard server or PC, Matlab for the prototype version	Synchrophasor data at 30 samples / second. Other sample rates also can be used. Network map to trace the dissipating energy flow for visualization purposes	The OSL tool extracts PMU data from PhasorPoint storage via JDBC. The OSL tool can potentially use PMU data from any storage.	Matlab version provides tabular and chart data output. Production version will be capable to visualize the DEF flow in a network diagram similar to regular MW flow.	Locating the source of sustained oscillations is key actionable information for mitigation of oscillations. Majority of practically observed sustained oscillations has a forced nature and the only efficient mitigation measure is to locate the source and disconnect it from network. Providing the information on the source of sustained oscillations together with characterization of oscillations is the basis for quick and efficient mitigation of dangerous oscillations in real-time environment	ISO-NE plans to develop a production version of the OSL tool which will be a part of the overall Oscillation Management process. The OSL tool will be triggered by PhasorPoint alarm and will automatically provide information on the source location. Both types of information (i) characterization of oscillation by PhasorPoint and (ii) locating the source of oscillations will be provided to Control Room and to operation support engineers. For proper system observability by PMU, the OSL tool is capable of providing high fidelity information on the source location (i) identify when the source of oscillation is located outside of the control area and (ii) identify the source to a specific generator resolution if the source is located inside of the control area.	Test case library for simulated cases for the methods locating the source of oscillations: http://curent.utk.edu/research/test-cases/ 2016 IEEE PES General Meeting Tutorial: Use of Synchrophasors in Grid Operations: http://web.eecs.utk.edu/~kaisun/TF/Tutorial_2016IEEEPESGM/Synchrophasor_7_Slava.pdf
LCRA Transmission Services Corporation	User	RTDMS by EPG	In use by Operations Engineer, placed in Control Room during normal business hours.	Wide-area visualization and recording of triggered events such as oscillations.	Proprietary	Server based PDC and visualization package (single vendor provided)	Phasor data transmitted via relay-based PMUs at 30 msgs/second	Able to integrate with GE EMS (integration not yet accomplished but planned for next EMS upgrade cycle)	Similar to standard EMS interface design (alert on abnormal situation, present concise summary/alarm data, Operators are able to acknowledge situation)	Situational awareness, post-disturbance analysis, real-time voltage condition feedback to Operators (via Operations Engineer). Application also chosen to match system operator (ERCOT) tools.	Operators would need adequate training to be able to act upon oscillation detection alerts. Oscillation detection triggers must be refined to minimize false positives. Operator response rules need to be developed so alerts are actionable, not just informative.	
NY ISO	User	Smart Grid Applications. This was developed by internal engineering resources utilizing EPG platform. Used RTDMS by EPG.	in operation within the control room	abnormal system detection	Proprietary	PMU installation, RTDMS	phasor data, 30 samples per second	EMS and PI		identify fault location and the nature of the issues (system-wide vs. local)	• Investigation would start once oscillations are identified by operators. • The first priority is to determine the frequency and the location of the oscillation. • If the frequency is low (0.5 hz to 2 hz), the oscillation is more likely interregional and the solution could be more complicated. If the frequency is high and the issue is local, it could be due to power electronics in the vicinity such as HVDC, type 4 WTG, SVC, etc. • Coordinate with TO and facility owners to identify the solutions.	
Pacific Northwest National Laboratory (PNNL)	Vendor/Developmer	Bonneville Power Administration Archive Walker Software (BAWS). Application being developed by the Pacific Northwest National Laboratory, under contract from the Bonneville Power Administration	In Development. Bonneville Power Administration will be the first entity to use the application, but it is not expected to be in an operational environment. This is more of a tool for the planning or operational engineer to evaluate archived data or near-real time data.	BAWS reads in and processes archived and near-real time data to detect events in the data, which are provided to the user via summary reports and alerts. Events of interest can include forced oscillations and oscillatory events (e.g., ringdown), as well as conditions such as frequency and voltage excursions.	Eventually open-source, when the development is further along.	The MATLAB software environment is currently required to run the software, but the final product is expected to be utilize the MATLAB run-time libraries and not require an active MATLAB license.	BAWS currently requires phasor data in PDAT or JSIS CSV format	No explicit ability right now – the tool is PMU data focused for the time being	MATLAB GUIDE-based	BAWS is meant to be used as a near-real time software and not in the direct operational environment. It is more of a planning engineer tool and a method to evaluate large swaths of PMU data and find the intervals of interest for further examination/study.	The application could be running on a near real-time PMU data stream (within minutes of real time) and provide detection of events in the PMU data. These include events such as oscillations (forced and ringdown), voltage excursions, and frequency excursions.	Development is on-going. The large contribution of this particular application is the deployment of algorithms developed at PNNL to detect events on the system, especially forced oscillations. There are reports and transactions papers detailing the algorithms and approaches, which can be provided, if necessary.

NASPI North American SynchroPhasor Initiative

PEAK Reliability	User	Model Analysis Software (MAS) – Oscillation Detection (ODM). Application Provider/developer: MAS – Montana Tech PhasorPoint and GSA – GE-Alstom	Under testing at Peak. PhasorPoint application is in Peak's real-time environment, but not used for real-time operation now.	The Oscillation Detection Module provides two levels of detail in its outputs. In the simplest case, the ODM provides RMS energy in each of four frequency ranges each time the module iterates. The four frequency ranges, labeled "Band1" through "Band4", are intended to approximate four regions of power system dynamic activity visible from PMU measurements. Band1 roughly corresponds to governor activity; Band2 to interarea oscillations; Band3 to local oscillations; and Band4 to higher frequency phenomena, possibly including some SubSynchronous Resonance (SSR) activity. An inverse-time characteristic can be used to provide proper alert and alarm.	Proprietary	PhasorPoint has its own server in Peak's real-time environment.	PMU Data	The ODM results can be passed to EMS through Grid Stability Assessment (GSA) application and then historize in PI.	Peak Customize the MAS V1.0 into GE-Alstom's PhasorPoint application	Provide the operators more information about system oscillation. And potentially how to mitigate in a timely manner.	Once the software testing is done and the proper baselining work is done (to set up the proper alert and alarm levels), the ODM tool can be used in real-time operation.	
PJM Interconnection	User	RTDMS by EPG	Testing. The application is available to 12 PJM transmission owners and 8 of them are using it.	RTDMS® (Real Time Dynamics Monitoring System) is a synchrophasor software application for providing real time, wide area situational awareness to Operators, and Engineers, as well as the capability to monitor and analyze the dynamics of the power system.	Proprietary	One special need is RTDMS requires at least 1GB video card memory.	30 samples/sec phasor data	Can be integrated with PI	Windows application GUI	Mode Meter is configured to monitor the known system oscillations, it will generate the alarm if an oscillation event is detected.	Oscillation detector algorithm and engine are still in testing phase. If it works as expected, it will be running all the time; scan and capture the unknown system oscillation events.	
Schweitzer Engineering Laboratories (SEL)	Vendor/Developmer	SynchroWAVe Central by Schweitzer Engineering Laboratories	In Operation at Utilities and Transmission System Operators (TSOs) throughout the world, details can be provided upon request by SEL.	Provide utilities and transmission system operators with a synchrophasor based Wide-Area Situational Awareness (WASA)	Proprietary	Hardware: Microsoft Windows computer/server with hard drive for archiving of synchrophasor data	IEEE C37.118 synchrophasor data stream	Software supports connection to IEEE C37.118 synchrophasor data stream.	SynchroWAVe Central is a server/web-client application. Charting components can be grouped together to provide dashboard for specific applications	Automatically detects oscillations and disturbances in real-time, and provides operators and engineer an overview of the oscillation/disturbance's impact. The screen capture below shows an oscillation automatically detected from a solar farm connected to the substation that PMU 1, 2 and 3 are monitoring 	Upon detection of an oscillation or disturbance an alarm/notification will be available to the operator in a dashboard providing them with details of the oscillation/disturbance. From the details an operator/engineer can determine whether further investigation is required for the oscillation/disturbance. Dashboard displays for each transmission line and substation can be quickly pulled up by the operator when an SCADA alarm indicates an issue at a particular location. These dashboard displays will provide data such as frequency, voltage, phase angle, current, power flow, etc for greater insight into a potential oscillation or disturbance at that location. Geospatial dashboards with voltage contours, phase angle differences, and power flows can provide operators the ability to see the overall state of the system at a glance.	An online demonstration of SynchroWAVe Central software is available at https://selinc.com/solutions/wasa/ A technical paper describing automatic disturbance and oscillation detection capability deployed at SDG&E will be presented at PEAC 2017 and Georgia Tech Fault Disturbance Analysis 2017 conference. The technical paper is available online at https://selinc.com/literature/technical-papers/
Swissgrid	User	Power Oscillation Monitoring (POM); Power Damping Monitoring (PDM). Application developer are ABB & Swissgrid. PSGuard, standard interfacing via IEC 104 and TASE.2	In operation in a dedicated environment close to SCADA ans already linked to the SCADA System.. Entities that are currently using the application are Swissgrid and other ENTSO-E CE TSOs	awareness about dynamic stability with respect to interarea oscillation damping behavior	Proprietary	Phase Measurent Units (PMUs), Phase Data Concentrator (PDM), reliable telecom links, POM, PDM	PMU measurements with a time resolution with 100 ms	It has ability to integrate with EMS/SCADA systems or data historian line PI.	SCADA, PDC interface	Correlation with other SCADA information as topology, corridor active power flows – investigation / information about non-SCADA detectable dynamic events	intelligent alarm (low damping & high oscillation amplitude & waiting for a few cycles), prepared to be distributed to neighboring or data sending partners	
Washington State University	Vendor/Developer	Damping Monitor Real-time (DMR) developed by Prof. Mani Venkatasubramanian, WSU, Pullman, WA	In operation and under testing at some entities. Being tested at Entergy, Peak RC, and Southern CO. In operation at WRLDC, Mumbai, India.	Real-time oscillation monitoring using ambient data	Proprietary	openPDC, SIEGate	Phasor data	Can import data from any PDC using IEEE C37.118 and SIEGate protocols. C an export results to PI and openHistorian. Burns and McDonnell has also developed custom user interfaces for EMS integration.		Continuous monitoring of the damping levels of dominant system modes and oscillations. Detection of problematic oscillations along with automatic analysis of the nature of oscillations.	It's already real-time	1. H. Khalilinia, L. Zhang, and V. Venkatasubramanian, "Fast frequency domain decomposition for ambient oscillation monitoring", IEEE Trans. Power Delivery, vol. 30, NO. 3, pp. 1631-1633, June 2015. 2. S.A. Nezam Sarmadi and V. Venkatasubramanian, "Electromechanical Mode Estimation Using Recursive Adaptive Stochastic Subspace Identification," IEEE Trans. on Power Systems, vol. 29, no. 1, pp. 349-358, Jan. 2014
Washington State University	Vendor/Developer	Event Analysis Real-time (EAR) developed by Prof. Mani Venkatasubramanian, WSU, Pullman, WA	In operation and under testing at some entities. Being tested at Entergy, Peak RC, and Southern CO.	Real-time oscillation monitoring using event data	Proprietary	openPDC, SIEGate	Phasor data	Can import data from any PDC using IEEE C37.118 and SIEGate protocols. C an export results to PI and openHistorian. Burns and McDonnell has also developed custom user interfaces for EMS integration.		Automatic detection of major system events, and automatic analysis of system modes and oscillations from ringdown data	It's already real-time	G. Liu, J. Quintero, and V. Venkatasubramanian, "Oscillation Monitoring System based on wide area synchrophasors in power systems," Proc. IREP symposium 2007. Bulk Power System Dynamics and Control - VII, August 19-24, 2007, Charleston, South Carolina, USA.
Washington State University	Vendor/Developer	Forced Oscillation Detection and Source Location (FODSL), developed by Prof. Mani Venkatasubramanian, WSU, Pullman, WA.	Being tested at Peak RC	Real-time oscillation monitoring using PMU and SCADA data	Proprietary	openPDC, SIEGate, PI	Phasor data and SCADA Data	Can import data from any PDC using IEEE C37.118 and SIEGate protocols. Can import SCADA data from PI historian. C an export results to PI.	Under Development	Detection of oscillations using PMU data. Source location analysis using SCADA data.	Being tested at Peak RC.	J O'Brien, T Wu, V Venkatasubramanian, H Zhang, "Source Location of Forced Oscillations Using Synchrophasor and SCADA Data", Proceedings of the 50th Hawaii International Conference on System Sciences, 2017.
XM Columbia	User	• Phasorpoint - Alstom • Siguard - Siemens	Testing in operation. • Phasor point: Control center, post-mortem analysis, and I+D. • Siguard: Control Center, post-mortem analysis, and I+D (Since October 2016). Operating entities using the application are as follows: • Phasorpoint: Souter California Edison, Esckon (South Africa), Landsnet (Iceland), and Powerlink (Australia). • Siguard: Transpower Stromübertragungs Gmbh (Germany), and EWZ (Switzerland).	• Monitoring of power swings using synchrophasor data. • Evaluation of the damping, amplitude and frequency of the power swings.	Proprietary	• Software: Siguard, Phasorpoint. • Telecommunications: At least a phasor rate of 10 frame per second.	• The minimum source phasor rate is 10 frame per second. • For Siguard is required Sinaut Spectrum SP7 in order to have communication with the SCADA system.	• Phasorpoint: PI. • Siguard: PI, SCADA system (Sinaut Spectrum SP7).	• The monitored zone can be flexibly adjusted to the current situation in terms of time, geography, and content. • The applications allow to see graphically the damping, frequency and amplitude of the power swing. 	• Increasing the operational awareness: Any power swings that occur are detected quickly and reliably. • The graphical interface can display the current situation in terms of time, geography, and content. • Online power swing recognition: For Siguard, there are two ways of detecting a power swing, based on angle differences between two voltages (two PMUs necessary) or based on power swing recognition of the active power (one PMU for current and voltage measured values is adequate). For Phasor Point, the power swing is detecting using modal analysis, based on the system frequency or the active power.	The application are available for real time, and they are used as a prototype for helping the operators to have situational awareness regarding to power swings.	Arango, O. J., Sanchez, H. M., & Wilson, D. H. (2010, August). Low Frequency Oscillations in the Colombian Power System–Identification and Remedial Actions. In CIGRE Session.