Using Synchrophasor Data for Oscillation Detection



NASPI Control Room Solutions Task Team Paper

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Acknowledgements

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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:

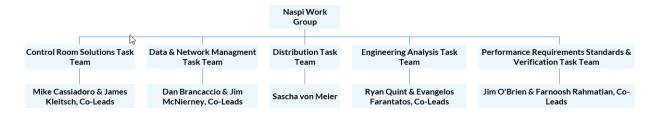


Fig1: The organization of NASPI Working Group

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 (<u>https://www.naspi.org/crstt</u>).

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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

¹NASPI, "Synchrophasor Technology Fact Sheet", 2014. Available at <u>https://www.naspi.org/node/384</u>. ²Phadke, 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 world⁴. 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. (<u>http://www.nerc.com/docs/oc/rapirtf/RAPIR%20final%20101710.pdf</u>)

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 BookIdentify operating entities that are using the applicationDispatch, engineersDisplays, augmented with VB processing.Displays, augmented output of the second sec		
Any other relevant	See paper and presenta	ation.	
information:	 [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

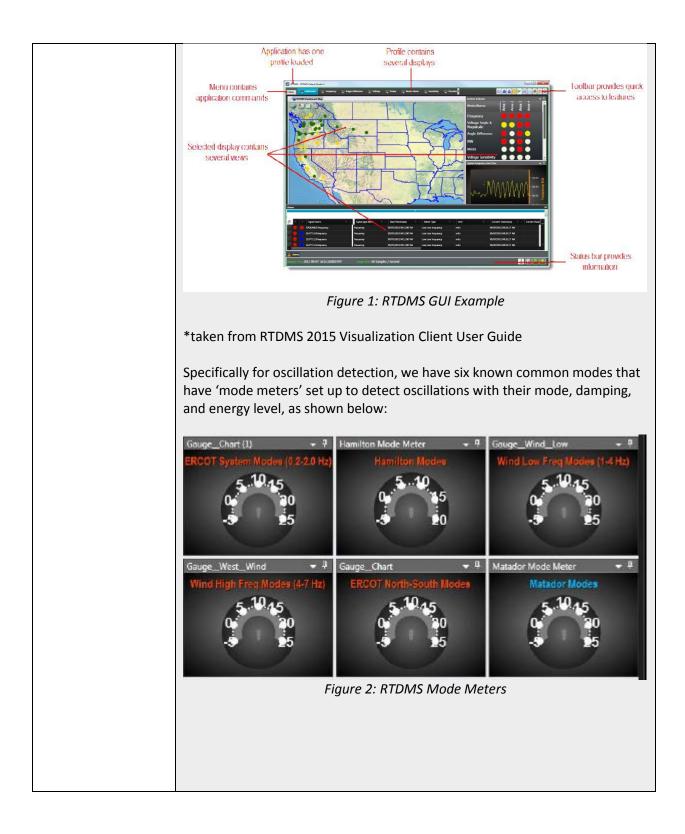
Application name:	RTDMS		
Objective of the application:	Visualization		
Application requirements (hardware, software, visualization telecommunications, etc.):	Database Server, Gateway Server, Client Servers, Software License	Definition of data requirements (e.g. phasor, SCADA, resolution, etc.):	Phasor Data
Application software (open source, proprietary):	Proprietary	Current status of the application (in development, testing, in operation):	Visualization - In Operation, Oscillation – in development
		Γ	
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 l	imits to detect oscillatio	ns
Type of application GUI	RTDMS	Identify operating entities that are using the application	Duke Energy Carolinas

Any other relevant	None
information:	

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 			

	 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 		
Describe how the application could be operationalized (i.e. used in real-time):	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.		
Type of application GUI	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.Identify operating entities that are using the applicationPlease refer to EPG's response (Section 		
Any other relevant information:	Sample videos have been previously provided to NASPI. Application GUI Examples:		



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 applicationOperations 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 versionDefinition 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 operationalize d (i.e. used in real-time):	the overall Oscillation Mar PhasorPoint alarm and will location. Both types of info and (ii) locating the source operation support engineer For proper system observa fidelity information on the is located outside of the co	production version of the OSL hagement process. The OSL too l automatically provide inform ormation (i) characterization of of oscillations will be provide ers. ability by PMU, the OSL tool is source location (i) identify wh ontrol area and (ii) identify the source is located inside of the	ol will be triggered by ation on the source f oscillation by PhasorPoint d to Control Room and to capable of providing high en the source of oscillation source to a specific	
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 applicationResearch engineers and Operations support engineers at ISO-NEIdentify operating entities that are using the applicationResearch 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: <u>http://curent.utk.edu/research/test-cases/</u> 2016 IEEE PES General Meeting Tutorial: Use of Synchrophasors in Grid Operations: <u>http://web.eecs.utk.edu/~kaisun/TF/Tutorial_2016IEEEPESGM/Synchrophasor_7_SI ava.pdf</u> 			

4.8 LCRA Transmission Services Corporation

Application name:	RTDMS			
Objective of the	Wide-area visualization and recording of triggered events such as oscillations.			
application:				
Application	Server based PDC and	Definition of data	Phasor data	
requirements	visualization package	requirements (e.g.	transmitted via relay-	
(hardware,	(single vendor	phasor, SCADA,	based PMUs at 30	
software, visualization	provided)	resolution, etc.):	msgs/second	
telecommunications,				
etc.):				
Application software (open source, proprietary):	Proprietary	Current status of the application (in development, testing, in operation):	In use by Operations Engineer	
	Γ			
If in operation, where?	By Operations Engineer placed in Control Room during normal business hours.	Application provider or developer:	EPG	
Applications ability to EMS/SCADA systems of PI):	-	Able to integrate with GE E accomplished but planned 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 EMS/SCADA systems of PI):	-	EMS and PI	
Identify the increment benefit to be derived l in the real-time opera	by using this application	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	
(open source,	Proprietary	application (in development, testing, in	Under testing at Peak	
(open source,	Proprietary PhasorPoint application is in Peak's real-time environment, but not used for real- time operation now.	application (in development, testing, in	Under testing at Peak MAS – Montana Tech PhasorPoint and GSA – GE-Alstom	
(open source, proprietary): If in operation, where?	PhasorPoint application is in Peak's real-time environment, but not used for real- time operation now.	application (in development, testing, in operation): Application provider or developer:	MAS – Montana Tech PhasorPoint and GSA – GE-Alstom	
(open source, proprietary): If in operation,	PhasorPoint application is in Peak's real-time environment, but not used for real- time operation now. integrate with	application (in development, testing, in operation): Application provider or	MAS – Montana Tech PhasorPoint and GSA – GE-Alstom	
(open source, proprietary): If in operation, where? Applications ability to EMS/SCADA systems of	PhasorPoint application is in Peak's real-time environment, but not used for real- time operation now. integrate with	application (in development, testing, in operation): Application provider or developer: The ODM results can be pa Grid Stability Assessment (MAS – Montana Tech PhasorPoint and GSA – GE-Alstom	

Describe how the application could be operationalized (i.e. used in real-time):Once the software testing is done a baselining work is done (to set up the and alarm levels), the ODM tool car time operation.		set up the proper alert	
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		
benefit to be derived by using this application		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		

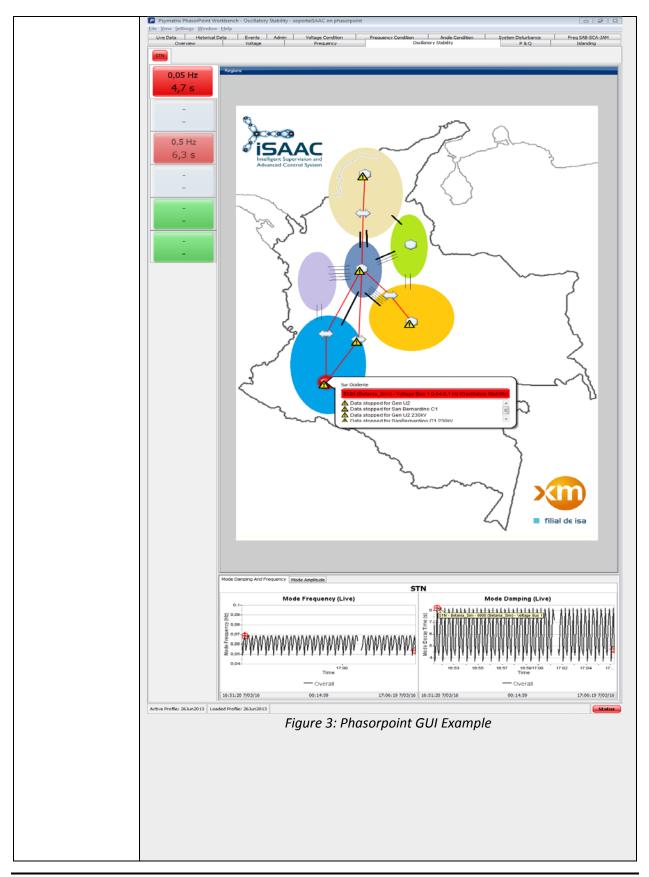
4.12 PJM Interconnection

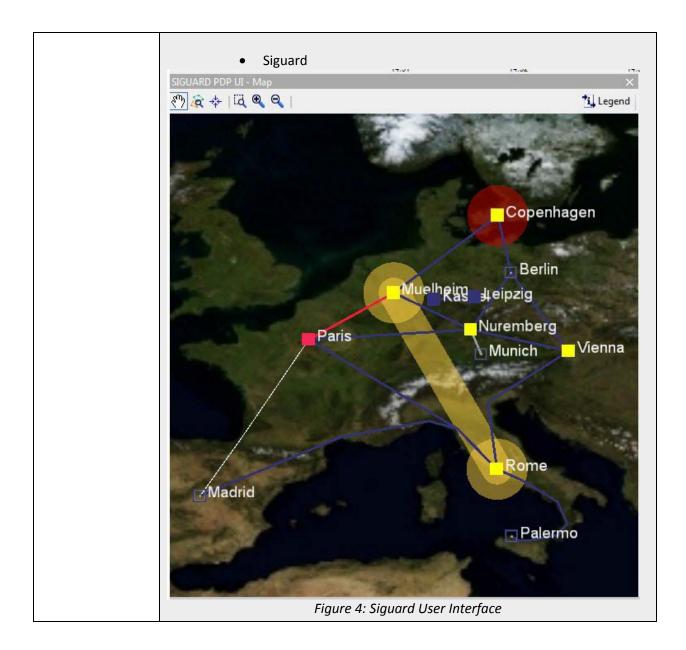
Application name: Objective of the application:	RTDMS [®] (Real Time Dynamics Monitoring System) RTDMS [®] (Real Time Dynamics Monitoring System) is a synchrophasor software application for providing real time, wide area situational awareness to Operators, and Engineers, as well as the capability to 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
		of developer.	(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
(open source,	Oscillation detector alg	Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI): corithm and engine are s vill be running all the tim	Can be integrated with PI till in testing phase. If it
(open source, proprietary): Describe how the application could be operationalized (i.e.	Oscillation detector alg works as expected, it w	Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI): corithm and engine are s vill be running all the tim	Can be integrated with PI till in testing phase. If it

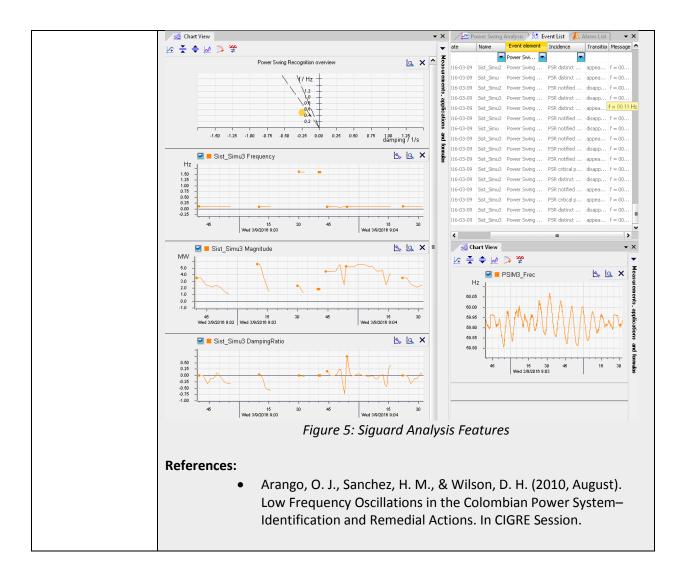
4.13 XM S.A E.S.P, Columbia

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 displayPhasorpoint:		







5 Survey Responses Received from Application Vendors/Developers

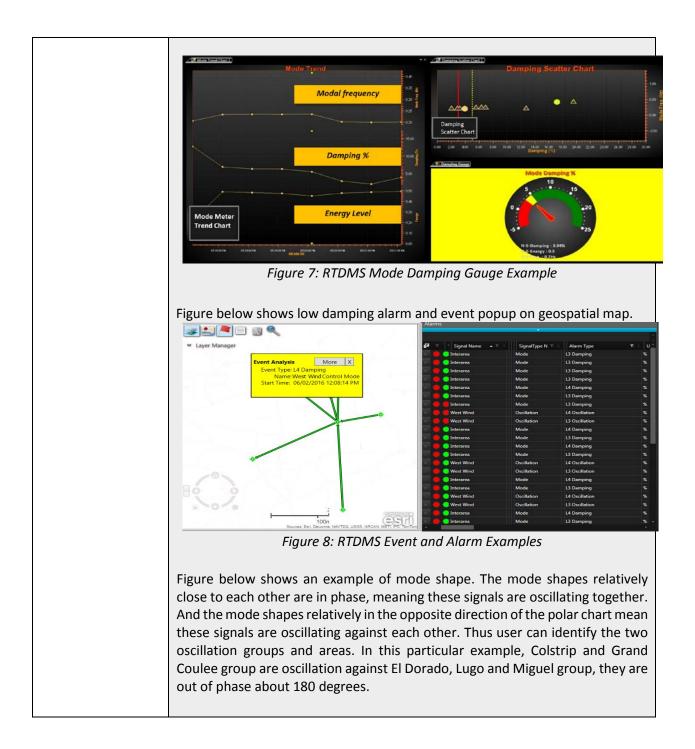
5.1 Electric Power Group (EPG)

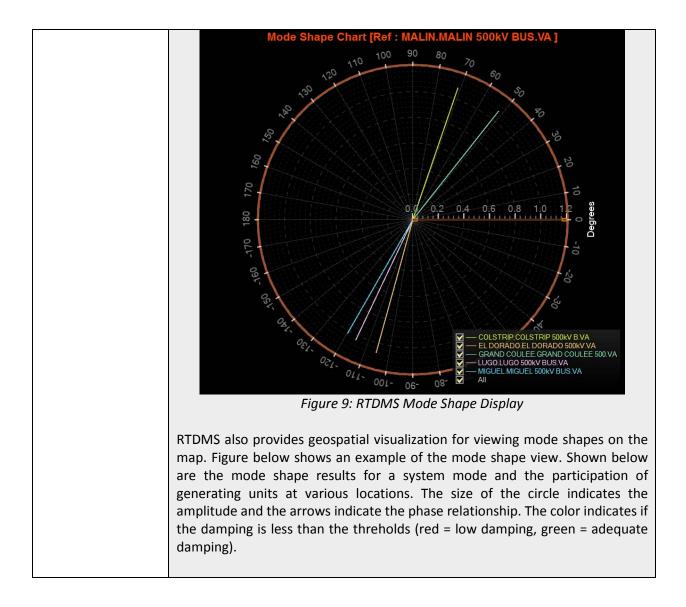
Application name:	Real-Time Dynamics Monitoring System (RTDMS) – Mode Meter & Oscillation			
	Detection			
Objective of the	Analysis and monitoring of natural system modes			
application:	Calculate modal frequency, damping, energy & mode shape			
	 Real-time alarming on low damping / high energy over 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	This application will b	e part of the RTDMS Server Typical hardware and		
requirements	• •	This application will be part of the RTDMS Server. Typical hardware and software configuration for production servers are:		
(hardware,	Software configuratio	interproduction servers are.		
software,				
visualization		Hardware Requirements for EPG Products		
telecommunication		In Requirements		
s, etc.):	Operating	TDMS Server software		
	System	Microsoft Windows 2008 R2		
	Processor Speed			
	Processors-			
	Cores/CPU	2 Physical Processors		
	Memory	8 Gigabytes Minimum		
		1 Network Interface Card (NIC) supporting		
	I/O ports	1GbPS		
	Hard Disk			
	Storage	100 Gigiabytes		
	Server 2 Hardwa	Server 2 Hardware Requirements - Real Time Data Storage		
	Will run EPG's R	TDMS Database hosted in Microsoft SQL Server		
	Operating			
	System	Microsoft Windows 2008 R2		
	Database Systen			
	Processor Speed 2.5GHz			

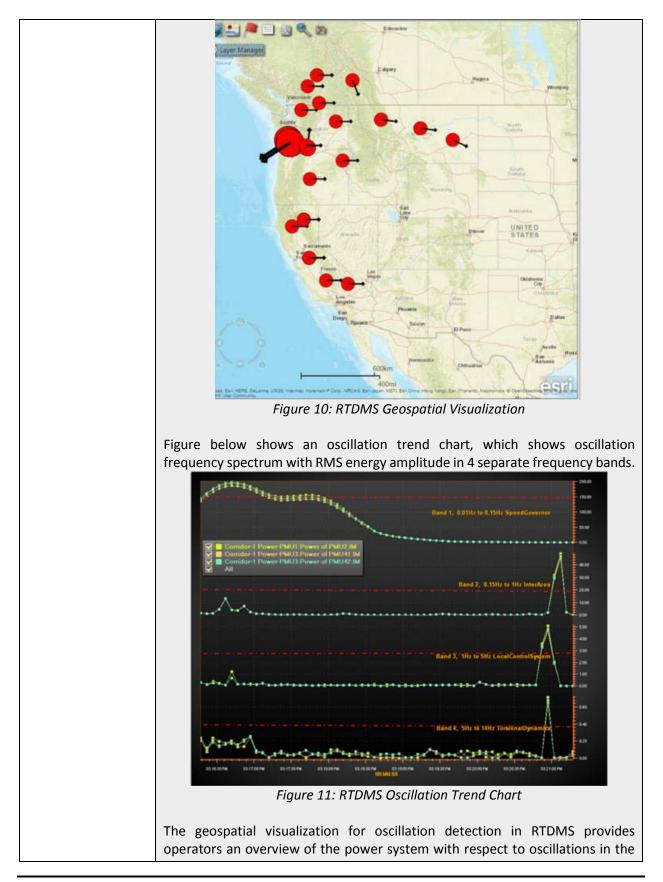
	Dus			
	Processors- Cores/CPU	2 Dhysical Drocoss	ors (each with quad-core)	
	Memory	· ·		
	wemory	24 Gigabytes Minir	e Card (NIC) supporting	
	I/O ports	1GbPS		
	Hard Disk		e (200 PMUs for 30 Days	
	Storage		calculated data, alarms,	
		and events)		
	Individual PC Ha	rdware Requirements		
		FDMS Client Applicatio	n	
	Operating			
	System	Microsoft Window	s 7, 32 or 64-bit.	
	Processor Speed			
	Processor Type	Intel Core2 Quad o	r i7 processor	
	Memory	8 Gigabytes Minim	•	
	I/O ports	e ,	e Card (NIC) 1 GBPS	
			series or better, or HD	
	Video Card		FirePro V7900 or better,	
	Video cara	with 2GB RAM or n		
Definition of data	• Dhacor data at the r	ato available at the e	ntity using the application	
requirements (e.g.			ntity using the application,	
phasor, SCADA,	usually 30 samples/se		'second.	
	 voitage priasor and 	e phasor and current phasor measurements		
resolution. etc.):			urements	
resolution, etc.):			urements	
	Proprietary	·		
Application	Proprietary	Current status of	urements In Operation	
	Proprietary	Current status of the application (in		
Application software (open	Proprietary	Current status of		
Application software (open source,	Proprietary	Current status of the application (in development,		
Application software (open source,	Proprietary	Current status of the application (in development, testing, in		
Application software (open source,	Proprietary RTDMS is deployed at	Current status of the application (in development, testing, in		
Application software (open source, proprietary):		Current status of the application (in development, testing, in operation):	In Operation Application vendor is Electric Power Group,	
Application software (open source, proprietary):	RTDMS is deployed at NYISO, PJM, SPP, Dominion, Duke	Current status of the application (in development, testing, in operation): Application	In Operation Application vendor is Electric	
Application software (open source, proprietary):	RTDMS is deployed at NYISO, PJM, SPP, Dominion, Duke Energy, ERCOT, LCRA,	Current status of the application (in development, testing, in operation): Application provider or	In Operation Application vendor is Electric Power Group,	
Application software (open source, proprietary):	RTDMS is deployed at NYISO, PJM, SPP, Dominion, Duke Energy, ERCOT, LCRA, Southern Co., CAISO,	Current status of the application (in development, testing, in operation): Application provider or	In Operation Application vendor is Electric Power Group,	
Application software (open source, proprietary):	RTDMS is deployed at NYISO, PJM, SPP, Dominion, Duke Energy, ERCOT, LCRA, Southern Co., CAISO, SRP, LADWP, TVA,	Current status of the application (in development, testing, in operation): Application provider or	In Operation Application vendor is Electric Power Group,	
Application software (open source, proprietary): If in operation,	RTDMS is deployed at NYISO, PJM, SPP, Dominion, Duke Energy, ERCOT, LCRA, Southern Co., CAISO,	Current status of the application (in development, testing, in operation): Application provider or	In Operation Application vendor is Electric Power Group,	

Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI): Identify the incremental improvement or benefit to be derived by using this application in the real-time	 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 One-line Diagram Editor ISG API Synchrophasor Distribution Service (SDS) 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% 		al of ts	
operating environment:	based freque	on operating ency bands, as s	ly for oscillations that may be unexpected or unknow experience. The application considers oscillations in fou shown in the table below.	
	Тс #	able 2: Oscillation Frequency	on Detection Frequency Bands and Type of Oscillations Type of Oscillations	
	П	Band (Hz)		
	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.
	Marco Darkowi Vew Dwit North Marco Nort North Marco </th
	Figure 6: RTDMS GUI Example One







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 Admini	istration Archive Walker Sof	tware (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 no	ow – the tool is PMU data fo	cused 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-basedIdentify operating entities that are using the applicationBonneville PowerAdministration will be the using the applicationAdministration 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.		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
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)

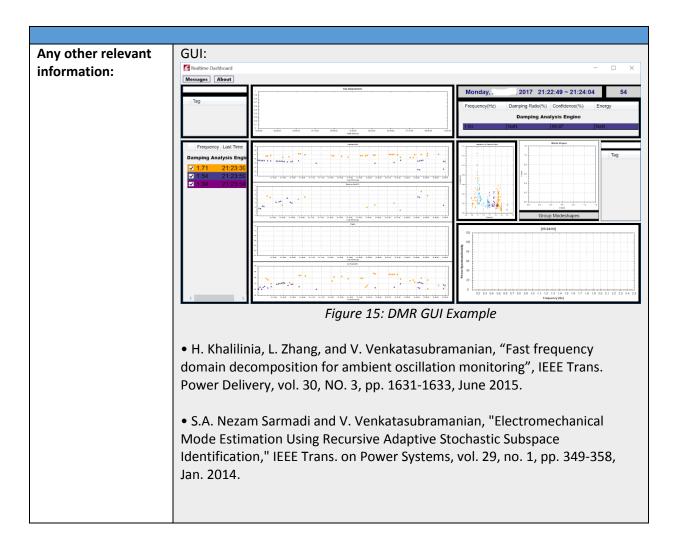
Application name:	SynchroWAVe Central			
Objective of the	Provide utilities and transmission system operators with a synchrophasor			
application:	based Wide-Area Situational Awareness (WASA).			
Application	Hardware: Microsoft	Definition of data	IEEE C37.118	
requirements	Windows	requirements (e.g.	synchrophasor data	
(hardware, software,	computer/server with hard drive for archiving	phasor, SCADA, resolution, etc.):	stream	
visualization	of synchrophasor data.	resolution, etc.j.		
telecommunications,	or synem ophasor data.			
etc.):				
Application software (open source,	Proprietary	Current status of the application (in	In operation	
proprietary):		development, testing, in operation):		
If in operation, where?	Utilities and Transmission System Operators (TSOs)Application provider or developer:Schweitzer Eng Laboratories			
	throughout the world, details can be provided upon request.			
	apon request.			
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.			

	60.04 Hz	Frequency	3/6/2016 2 (3.08 m	
		A Mar March	Top Locations	Percent Dist. of Max Level
	60.02 Hz		PMU 1	100% 502.95
		· · · · · · · · · · · · · · · · · · ·	PMU 2	99% 498.37
	60.00 Hz		PMU 3	99% 497.21 48% 243.83
	59.98 Hz		🗸 💻 РМU 5	48% 242.00
	3:00:00 P	M 3:00:50 PM 3:01:40 PM 3:02:30 PI	PMU 6	47% 237.28
			PMU 7	46% 233.33 45% 226.29
	135.4 kV	Voltage Magnitude	PMU 9	45% 224.89
	135.4 KV		PMU 10	44% 222.72
	125.0 147	(El 18) (A El 19) (A	PMU 12	44% 222.25 44% 222.25
	135.0 kV	in the second	PMU 13	44% 222.25
	134.6 kV		PMU 14	43% 218.73
	134.0 KV MMM	A CONTRACT OF	a	43% 216.95
	134.2 kV		Total Station Count: 4	31 07 83
			Frequency Bins	
		Disturbance Level	5.00-14.00 Hz	
	600	Bistarbance Lever	Peak Frequency: 5.08	3 Hz
	/	~		
	004 400 200 Z-Katio			
	N 200			
	0			
	0			
	·			
	Figure 14.	: SvnchroWAVe Automatic C	scillation Detec	tion
	Figure 14.	: SynchroWAVe Automatic C	oscillation Detec	tion
Describe how the				
Describe how the	Upon detection of a	n oscillation or disturbance	an alarm/notific	ation will be
application could be	Upon detection of a available to the oper	n oscillation or disturbance rator in a dashboard providi	an alarm/notific ng them with de	ation will be etails of the
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope	an alarm/notific ng them with de erator/engineer	ation will be etails of the
application could be	Upon detection of a available to the oper oscillation/disturbar	n oscillation or disturbance rator in a dashboard providi	an alarm/notific ng them with de erator/engineer	ation will be etails of the
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ	an alarm/notific ng them with de erator/engineer	ation will be etails of the
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ	an alarm/notific ng them with de erator/engineer	ation will be etails of the
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce.	an alarm/notific ng them with de erator/engineer ired for the	ation will be etails of the can
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line a	an alarm/notific ng them with de erator/engineer ired for the nd substation ca	ation will be etails of the can n be quickly
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarm	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss	ation will be etails of the can n be quickly sue at a
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarn These dashboard displays wi	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s	ation will be etails of the can n be quickly sue at a such as
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarm These dashboard displays wi phase angle, current, power	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro	ation will be etails of the can n be quickly sue at a such as
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarn These dashboard displays wi	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro	ation will be etails of the can n be quickly sue at a such as
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarm These dashboard displays wi phase angle, current, power	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro	ation will be etails of the can n be quickly sue at a such as
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarn These dashboard displays wi phase angle, current, power llation or disturbance at tha	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro t location.	ation will be etails of the can n be quickly sue at a such as eater insight
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarm These dashboard displays wi phase angle, current, power llation or disturbance at tha rds with voltage contours, p	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro t location.	ation will be etails of the can n be quickly sue at a such as eater insight
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar power flows can pro	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarn These dashboard displays wi phase angle, current, power llation or disturbance at tha	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro t location.	ation will be etails of the can n be quickly sue at a such as eater insight
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarm These dashboard displays wi phase angle, current, power llation or disturbance at tha rds with voltage contours, p	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro t location.	ation will be etails of the can n be quickly sue at a such as eater insight
application could be operationalized (i.e. used in real-time):	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar power flows can pro system at a glance.	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarn These dashboard displays wi phase angle, current, power llation or disturbance at tha rds with voltage contours, p povide operators the ability to	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss flow, etc for gro t location. hase angle diffe o see the overall	ation will be etails of the can n be quickly sue at a such as eater insight rences, and state of the
application could be operationalized (i.e.	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar power flows can pro	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requ nce. for each transmission line an erator when an SCADA alarn These dashboard displays wi phase angle, current, power llation or disturbance at tha rds with voltage contours, p povide operators the ability to	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss Il provide data s flow, etc for gro t location.	ation will be etails of the can n be quickly sue at a such as eater insight rences, and state of the
application could be operationalized (i.e. used in real-time):	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar power flows can pro system at a glance.	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requince. for each transmission line an erator when an SCADA alarn These dashboard displays wi phase angle, current, power llation or disturbance at tha rds with voltage contours, p ovide operators the ability to ral Identify operating	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss flow, etc for gro t location. hase angle diffe o see the overall	ation will be etails of the can n be quickly sue at a such as eater insight rences, and state of the
application could be operationalized (i.e. used in real-time):	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar power flows can pro system at a glance.	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requince. for each transmission line an erator when an SCADA alarm These dashboard displays wi phase angle, current, power llation or disturbance at tha rds with voltage contours, p ovide operators the ability to ral Identify operating entities that are	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss flow, etc for gro t location. hase angle diffe o see the overall Utilities and T System Opera	ation will be etails of the can n be quickly sue at a such as eater insight rences, and state of the Transmission ators (TSOs)
application could be operationalized (i.e. used in real-time):	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar power flows can pro system at a glance. SynchroWAVe Centr is a server/web-clier application. Charting	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requince. for each transmission line an erator when an SCADA alarm These dashboard displays wi phase angle, current, power llation or disturbance at tha rds with voltage contours, p ovide operators the ability to ral Identify operating entities that are	an alarm/notific ng them with de erator/engineer ired for the nd substation can indicates an iss flow, etc for gro t location. hase angle diffe see the overall Utilities and T System Opera throughout th	ation will be etails of the can n be quickly sue at a such as eater insight rences, and state of the Transmission ators (TSOs) ne world,
application could be operationalized (i.e. used in real-time):	Upon detection of a available to the oper oscillation/disturbar determine whether oscillation/disturbar Dashboard displays pulled up by the oper particular location. T frequency, voltage, p into a potential oscil Geospatial dashboar power flows can pro system at a glance.	n oscillation or disturbance rator in a dashboard providi nce. From the details, an ope further investigation is requince. for each transmission line an erator when an SCADA alarm These dashboard displays with phase angle, current, power llation or disturbance at that rds with voltage contours, p povide operators the ability to ral ldentify operating entities that are using the application	an alarm/notific ng them with de erator/engineer ired for the nd substation ca n indicates an iss flow, etc for gro t location. hase angle diffe o see the overall Utilities and T System Opera	ation will be etails of the can n be quickly sue at a such as eater insight rences, and state of the Transmission ators (TSOs) ne world, e provided

	provide dashboard for specific applications.		
Any other relevant	An online demonstration	on of SynchroWAVe Cent	ral software is available at
information:	 <u>https://selinc.com/solution</u> A technical paper descributed detection capability depleted detection capability depleted detection fault Disturbative 	ons/wasa/ ibing automatic disturba oyed at SDG&E will be pr bance Analysis 2017 cor	ance and oscillation resented at PEAC 2017 and

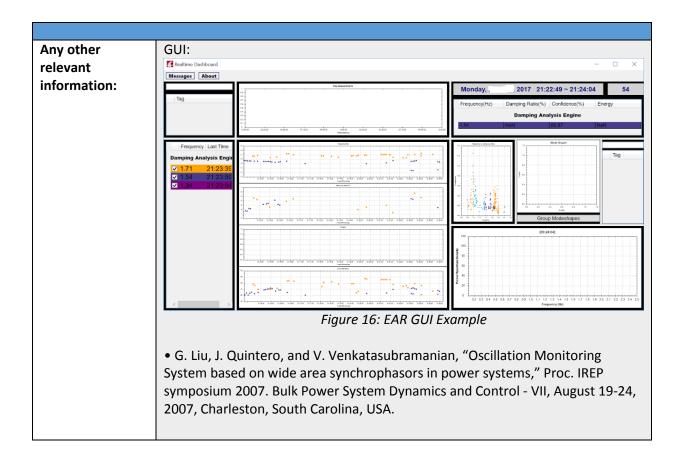
5.4 Washington State University (Damping Monitor Real-time- DMR)

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 of developer:	r Prof. Mani Venkatasubramanian, WSU, Pullman, WA.		
	Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		any PDC using IEEE C37.118 and a export results to PI and nd McDonnell has also r interfaces for EMS		
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):				
Type of application GUI	See example below	Identify operating entities that are using the application	WRLDC, India, Peak RC, Entergy and Southern CO		



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

Application name:	Event Analysis Real-tin	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		
Amuliantia	Drewsieten				
Application software (open source, proprietary):	Proprietary	Current status of the application (in development, testing, in operation):	Under testing.		
		I			
If in operation, where?	Being tested at Entergy, Peak RC, and Southern CO.	Application provider of developer:	or Prof. Mani Venkatasubramanian, WSU, Pullman, WA		
Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI):		SIEGate protocols. C ar	any PDC using IEEE C37.118 and n export results to PI and and McDonnell has also r interfaces for EMS		
Identify the incremental improvement or benefit to be derived by using this application in the real-time operating environment:			of major system events, and system modes and oscillations		
Describe how the appl operationalized (i.e. u		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		



Washington State University (Forced Oscillation Detection and Source 5.6 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, i 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 EMS/SCADA systems of 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 appl operationalized (i.e. us		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.			



	Response	Application(s)	Status	Objectives	App Software	General Requirements	Data Requirements	Integration Info	GUIInfo	Incremental Improvements	How to Operationalize	Additional info
101	Туре	Oscillation Detection	In Operation in BPA Primary and	Oscillation Detection application scans	Status	1. On Finite Detection Medicin (2014) and and and and in To. Day Technology Manhaes T.	Application inputs raw,	All raw PMU data and COM	All Synchrophasor Displays are OSIsoft Process Book Displays, sugmented with VB processing	The benefit is to detect oscillations in real-time and have operators take	It has been coerationalized.	Relevant Papers [1]. D. Kosterev, LBurns, N.Leitschub,
BPA	User	Module (ODM) engine	In Operation in BPA Primary and Alternate Control Centers	multiple signals (power, frequency,	Proprietary	 Oscillation Detection Module (ODM) engine developed by Dr. Dan Trudnowski, Montana Tech University Real-time processing uses uncompressed C87.118 data from 66 PMUs, 140 total measurement points 	uncompressed PMU Voltag	ge processed data is written to PL A	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.		J.Anasis, A.Donahoo, D.Trudnowski, M.Donnelly, J.Pierre,
		developed by Dr. Dan Trudnowski, Montana		voltages) across the grid for indication of erowing or sustained high energy			and Current Phasor measurements input into	custom link was written by BPA to notify SCADA when an oscillation			Should an oscillation alarm occur, a corresponding frequency band at a corresponding PMU will turn "red". The display provides very effective	Implementation and Operating Experience with Oscillation Detection Apolication at Bonneville Power Administration'.
		Tech University		oscillations			the OSIsoft PI system via the OSIsoft CI7.118	has been detected. An Alarm is emerated on the SCADA Alarm list			strend indication on solution the mellation is level much in some free	CICRE 2016 Cold of the Datase Formersham, Ontoher 20
							Interface. The data is puller	generated on the SCADA Alarm list when an oscillation is detected.			second off an internet down state. For solds over an finite an endiate	November 1, 2016, Philadelphia, USA. [2]. Matt Donnelley, Timplementation and Operating
							from the OSIsoft PI snapshot using the AF-SDK Interface	c			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	Experience with Oscillation Detection at Bonneville Power Administration' NASPI Meeting.
							Interface				PALLs will go into an alarm state. For water we detained in, interpre- PALLs will go into an alarm state over a large georgaphic 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 lasve an alarm.	
											determined time pends for the appecation to asse an aarm.	
Dominion Virginia Power	liver	Dantala Danuar Canada	is control execution (each control to	Datast and failer marks at smaller	Provide terms	A Windows server (physical server, not virtual server) with good processing capability.	Synchrophasor data at 30	or bissessie of DECODE	Wheelerse confection federates beindare	Provide to detect and one or endlation must exceed a to be made	Provide SWAR door leader dealers in the secondary in double of	The second data and the of their section is deterior
occurrent vagina rower	Contract of the second se	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 menories server (projects or res, interview server) were provided by consisting capacity.	phasors/second data rate	can integrate with EMS/SCADA systems via DNP3 (maybe other connections too), and also with PI		Be able to detect and see an oscillation event occurring in the control room. Is a part sciellation event at Dominion, operators were not able to see the oscillation is their SCAA Adaptic SCAA Adamming/SCAA displays, and dd not how it was execuring until the power plant projected to the systematic that controllate survailies ago ago on SUA they appear to a some that the set of the set of the set of the powerstors also only had SCADA Adaptic.	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.	tool and the RTDMS application.
		Detection" tool	operators), continuing to test/validate prior to giving to	that occur in Dominion's grid				connections tool, and also with Pi		to see the oscillation in their SCADA data/SCADA alarms/SCADA displays, and did not know it was occurring until the power plant	to the operators in their DAG screens.	
			operators.							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).		
Duke Energy	User	EPG's RTDMS	Vaualization - In Operation, Oscillation - in development, In	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	Need to better define limits to detect oscillations	
			Oscillation – in development. In Use Back Hall Engineering, Control							improvement for short term oscillations – the system will react before operators can).		
Electric Power Group (EPG)	Vendor/Dev	Mode Meter and	Room RTDMS was deployed at NYISD.	Analysis and monitoring of natural	Proprietary	This application will be part of the RTDMS Server. Typical hardware and software configuration for production servers are:	Phasor data at the rate	Integration with EMS installations	RTDMES has its own visualization : \ See Word document for details.	The mode meter application performs modal analysis on both ambient	As indicated above, geospatial map view provides an overview of the system in terms of oscillations such that any severe oscillation could be	
	elopmer	Oscillation Detection in Real-Time Dynamics	PJM, Dominion, Duke Energy, SPP, ERCOT, LCRA, Southern Co., CAISD,	system modes		1) Server 1 Hardware Requirements: Will run EPG's RTDMS Server anthrane	available at the entity using the application, usually 30	g - Alstorn, GE, Siemens, ABB, Monarch	And	system conditions and under transient disturbance conditions. It	system in terms of oscillations such that any severe oscillation could be	
		Monitoring System	SRP, LADWP, TVA, SCE.	energy & mode shape		Operating System: Microsoft Windows 2008 R2	constant for an and	and an and a second s		estimates the modal frequency, damping ratio, energy amplitude level and mode shapes of oscillations of interest. A condition that damping	system in terms of oscillations such that any severe accillation could be detected in read-term. The map were with opprovide the tability to identify the location of the oscillation and the severity of the oscillation. Operators also have the ability to citil down to the oscillation analysis results and boat the oscillation energy, signal trends and mode shape or oscillation shape for forced oscillations.	
		(RTDMS)		 Real-time alarming on low damping / high energy over time 		Processor Speed: 2.5GHz Processors- Cores/CPU: 2 Physical Processors	Voltage phasor and current phasor measurements	 Integrates with PI Historian. Phasor data and intelligence with the LNS system using ICCP and 	5412	ratio is below 5% triggers alerts to catch operators' attention, and a condition that damping ratio is less than 3% triggers alarms.	Operators also have the ability to drill down to the oscillation analysis results and look at the oscillation energy, signal trends and mode shape	
				Provide geospatial visualization Indication participation of severators in		Memory: Il Gigabytes Minimum 1/D ports - 1 Network Interface Card (NIC) supporting 1GNOS	measurements	the EMS system using ICCP and DMP3	and the state of the state	The oscillation detection application is designed for rapid identification of formed nucliations, annacially for oscillations that may be unavaranted	or oscillation shape for forced oscillations.	
				the system modes		Mard Disk Storage: 100 Giglabytes		DNP3. • Generate .cxv and COMTRADE	Contraction of the second	or unknown based on operating experience. The application considers		
				Colcute mode Requery, demong- energy. It node the part of the part Red here during on low damping / byth more; our to the Prode groupstative status Prode groupstative status Colcuter, part objection of generations The system modes Colcuter fored oscillations in the system Colcuter IMMS energy, spectral and hopps for fored colcitations in definition Prodeg groupstative status Prodeg groupstative status Prodeg groupstative status Prodeg accelerations Prodeg cologitations and deminity root-cause of collitions haved deminity root-cause of collitions haved deminity root-cause of collitions haved parts of parts of collitions and deminity root-cause of collitions haved parts of collitions in the distribution of collitions in the dis		with our UPC SITUADE Survey marknews Constrainty Survey Monochim Waters 2008 02 American Stream Monochim Waters 2008 02 American Stream Monochim Waters 2008 02 American Stream Waters 2008 02 American Stream Waters 2008 02 American Waters 2008 02		file formats for data analysis. • APIs for third party tools to subscribe data through	Contraction of the International Contractional	and node should of condition of a thermal. A Location that a sample time of the last black of Sciegoria devia to that should only a similar and a last black of Sciegoria devia to that should be should be should be the northern deviation, and a should be should be should be should be the should be should be should be should be should be should be should be should be should be should be should be should be should be should be should be should be should be should be the should be should be should be should be should be deviated by the should be should be should be should be deviated by the should be should be should be should be a should be should be should be should be should be should be deviated by the should be should be should be should be should be a should be should be should be should be should be should be a should be should be should be should be should be should be a should be should be should be should be should be should be a should be should be should be should be should be should be a should be should be should be should be should be should be should be a should be s		
				shape for forced oscillations Provide recognital visualization to detect		Operating System: Microsoft Windows 2008 R2 Database System: Microsoft SQL Server 2008 R2		subscribe data through Synchrophasor Distribution	Committee Destantioners and the second se	# Frequency Band (Hz) Type of Oscillations 1 0.01 – 0.15 Speed Governor Oscillation Band		
				location of severe oscillations in real time,		Processor Speed: 2.5GHz		Service (SDS). • Ability to integrate new		2 0.15 - 1.0 Inter-area Oscillations (Electromechanical Band)		
				identify root-cause of oscillation based on		Memory: 24 Gigabytes Minimum		algorithms using Service Oriented		4 5.0 - 14 Torsional Dynamics Band		
	1	1	1	the frequency band and spread of the oscillation	1	I/D 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)	1	Architecture. • Web Map Service (WMS) for		The Root Mean Square (RMS) of energy is a quick indicator of type of	1	
	1	1	1		1	3) Individual PC Hardware Requirements: Will run EPG's RTDMS Client Application	1	displaying Geo displays rendered by RTDMS.		oscillations and could be an event indicator as well. The oscillation detection calculates the RMS energy for each input signal, and it triggers		
	1	1	1		1	Operating System: Microsoft Windows 7, 32 or 64-bit.	1	Integration Tools: ICCP Adapter		an alarm when a RMS Energy value exceeds threshold in a particular	1	
	1	1	1		1	Processor Speed : 2.5GHz Processor Type: Intel Care2. Quad or i7 processor	1	- Pi Adapter		frequency band and for a user-defined time duration.	1	
						Memory: Il Gigabytes Minimum 1/D ports: 1 Network Interface Card (NIC) 1 GBPS Video Card: AND		- DNP3 Adapter - One-line Diagram Editor		RTDMS provides geospatial visualization for both the mode meter and oscillation detection applications. The map view of oscillations provide		
						Radeon 7500 series or better, or HD 6500 or better, or FirePro V7900 or better, with 268 RAM or more		- ISG API - Synchrophanor Distribution		ability to quickly detect severe oscillations in real-time and identify the location of the oscillation (recention units - wind farms, nuclear unit.		
						5 mm		- synchroprator Distribution Service (SDG) Currently, RTDMS is a completely		iocation of the occustion generating units – wind tarms, nuclear une, etc.1 assertion of the ourillation and the frequency hand in which the Current State:		Sample videos have been posted on NASPI's website
Electric Reliability Council of Texa (ERCOT)	at User	D'GT KIDMS	Current State: • Used in control room by shift	To provide real-time, wide-area situational awareness and real-time dynamics monitoring of the power grid for use by	Proprietary	See D/G 1 requirement	Accepts phasor data input from a Phasor Data	separate system from	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'	 Used in control room by shift engineer as well as by support engineers 	Currently, the RTDMS is being used in the control room at the shift engineer's desk and by control room support engineers. The primary	sample videos nave been posted on NKSPT's websize
			engineer as well as by support engineers to monitor voltage angles				Concentrator (PDC) using either C37.118 or	EMS/SCADA. We are currently investigating our options with	set up to detect oscillations with their mode, damping, and energy level, as shown below:	to monitor voltage angles and oscillations across the system • Developed a PMU-based operator training simulator, and will beein	purposes of the system are to monitor voltage angles and system oscillations, as well as replaying system events for post mortem	
			and oscillations across the system	Planners, and Operating Engineers, as well as the capability to analyze system			PDCStream data format	implementing alarms from the PMU system into our EMS. We are		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 reaccurrence	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	
				performance and events. The major use				also working on using triggers from the OTS to simulate PMU	The second states and s		place. Although we currently have requirements on PMU locations, data	
				cases of the application within ERCOT are the ability to observe and alert operators				data to stream directly to the	3"E 3"E 3"E	dominant oscillation mode, damping, and energy level of the oscillation	recording, and data retention, there are no requirements for data quality, which will need to be addressed before operator actions can be	
				to voltage angle differences across the interconnection, detect and mitigate local				Phasor Simulator for operator training.	3 5 3 5 3 5	Future Gash: • Build out redundant PMU monitorine system	based solely on PMU data.	
				and system-wide oscillations, and the ability to save and replay system events.					Name and all and that the State and the	Develop procedures for operators and train operators on the PMU operator training simulator		
				recorded by PMUs across the system.					3"E 3"E 3"E	 Add in PMU Estimation on interfaces as a backup for IROLs 		
									3**E 3**E 3**E	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 ki 	P	
										 A Control Boom event reporting including dynamic system performance Incorporate into Blackstart training, using blanding detection features and abilities to monitor angle difference across breakers for reclosing 		
										and abilities to monitor angle difference across breakers for reclosing		
										normhum		
										procedures		
										procedures		
Falsan		Workington Fiste	Connect State: Do references		Providence	Terreshand all managing in 10 with 10 August 10	Minimuter (1949) data faces	Internet State of the State of the State		procedures	Willing and Records	
Entergy	User	Washington State University(WSU) Dampin Monitor Offline	Current State: Development &	Oscillation postmortem analysis	Proprietary	Server based with connection to Obtach PL OperPTC	Historical PMU data from OSIsoft PI	Interoperable with OSI soft PI	Sau, nade for pottworks mayor	procedures Identification of the location of Inter-Area location of forced oscillations	WSU has a neef-time version	
Entergy ISO New England	User User	Washington State University(WSU) Dampin Monitor Offline PhasorPoint	Current State: Development g	Discillation postmortem analysis Detect oscillations (umbient and	Proprietary Proprietary	Sever band with convectors to Dischift, OperPDC	Hatorkal PMU data from QStooft PI Synchrophasor data at 30	Interoperable with OSI soft PI Phasor Point has its own storage	Saul, nako for postnovino varkjen Sauli na postpolici družu, ali o dvat	procedures Identification of the location of Inter-Area location of forced oscillations		
Entergy ISO New England	User User	Washington State University(WSU) Dampin Monitor Offline PhasorPoint	Current State: Development g PhasorPoint is in production use. It is used Outside of the control room for use by operation support	Oscillation postmortem analysis Detect oscillations (ambient and ringdown), characterice oscillations and generate alarmachist. Characterization of	Proprietary Proprietary	Server based with schedules to Diffuel PL QuerPDC Medicater standard strater: Mandater standard strater:		Interoperable with DSI off PI PhasorPoint has its own storage and can be connected to GE EMS	Saul, mali la potradin anten Saul ma populat Anten Saul	procedures Identification of the location of Inter-Area location of forced oscillations		
Entergy ISD New England	User User	Washington State University(WSU) Dampin Monitor Offline PhasorPoint	Current State: Development # Presor/Point Is in production uses. It is used Outside of the control room for use by operation support engineers.	Dicflation postnortem analysis Defect excillations (prelimit and registrow), characterize excillations and generate alterna(wint: Daracterization et exciliations constraints)	Proprietary Proprietary	Sever hand with convectors to OSudi PL OperFOC Reductive should ensure Andware size on our over and loss on direct		Interoperable with OSI soft PI PhaserPoint has its own storage and can be connected to GE EMS	tani, nadio fer pantono sen andição. Const Tag, pregmento: degiña, dina chant	protokine Liestifuction of the location of later Anal location of forced excellutors Socialized advantages of the programmed the field before socialized advantages of the programmed the field before visitations to be registrated reducing the field and reducing and regaring on an images.		
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	1.		Under testing at Peak. PhasorPoint	la a su	I	PhasoPoint has its own server in Peak's real-time environment.	Terror -	The ODM results can be passed to	Peak Customize the MAS V1.0 into GE-Alstom's PhasorPoint application	Provide the operators more information about system oscillation. And	I	
PEAC felability	User	Model Analysis Software (MAS) – Ostillation Detection (DDM), Application Provider/developer: MA – Montrar Teleper: MA Mason Point and GSA–G Alston	Under tracking al Paul. Paulur Paul application in Provident and Energy tracking and the provident and the read- time sponsition new.	The Outliarion Detection Models provides to obtain of data in to outputs. In the tampets case, the Could provides MOS and the Could provide MOS and the Could provide Moster and the tampet and the transmission of pro- trangements from regions of prover system from the model coupling common to governer activity, Barod to another the stand to tappet common to governer activity and another the stand to tappet common to governer activity and another the stand to tappet activity, An Inverse time distanciation in the stand to provide proper alert and alarm.	n n	Dhaadhad ta fa baan sinaid in Park Y na bhe annsannan.	PMU Data	The COM results can be parated to dist strong (2004) and and the strong (2004) parates and then historice in PL	Anat Casternove hu MAY YI, B vie GLA Mazer A Masar Anit a spakadion	People for generative their self-self-self-self-self-self-self-self-	One has alterna listing a dire and dire progress insuling outs a time of the out of the progress of an all direct local, buy COM and on the and the direct and all direct local, buy COM and on the and the direct and all direct local and all direct local and and the direct direct and all direct local and all direct local and all direct local and all direct local and all direct local and all direct local and all direct local and all direct local and all direct local and all direct local and all direct local and all direct local and all di	
PIM Interconnection	User	RTOMS by EPG	Testing. The application is available to 12 PMH transmission owners and 8 of them are using it.	RTDMS* (Real Time Dynamics Monitoring System) is a synchrophaser software application for providing real time, wide area situational awareness to Operation, and Engineera, used as the capability to monitor and analyze the dynamics of the power system.	Proprietary	Der genar twert im 1936 forgerin er best 1938 inder oord nemary Ferlagen Mitstank Werken anstaden heren eite her 6 daer he acheer af unschnaduur dae		a Can be integrated with PI	Radon gibato Gi	Mode Meter is configured to monitor the known system outflations, it will generate the align of an outflation event is detected.	Deciding devices approximation require we will be testing phase. If a model as requested, as the memory all the time, scan and optime the without synthem condition results.	I ac online demonstration of SectorsWAVE Central Units areas
Lideordizer Egyberrig Lideordizer (SIL)	Vendor/De	 Synchroeide/WAR Central by Schweitzer Engineering Laboratories 	in Operations of Utilities and annual Control of the Annual Section of Control Control of Control of Control of Control Control of Control of Control of Control Section Control of Control of Control of Control Section Control of Control of Control of Control Section Control of Control of Control of Control of Control Section Control of Con	Produ Allies and trastinians system operations with system based on the system of the	Proprietary	fondaaren biorealt Wenkens europeier jarret esti had dine har etning di gedroppaare das	idtt C17-118	Software support consection to SUECC7118 spectrophase data dream.	Spectraffer Coller & Lendral Andra Spectralia. Opening angunesis and the grouped together to provide durbated for specific durbations		The determinant of the standard or the details of the standard or the details of the standard of the details of the standard o	A schedule company mission of perchedition (schedule and schedule a
Swingrid	User	Power Oscillation Monitoring (POM): Power Damping Monitoring (PDM): Application developer are ABB & Switsgrid: PSGaard, standard interfacing via IEC 104 and TASE.2	In operation in a dedicated environment close to SZADA ans already lincked to the SCADA System Tridies 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 (site) (PMA)), Phase Sala Conventrator (PGM), relation tealson looks, PGM, PGM	PMU measurements with a time resolution with 100 m	It has ability to integrate with EME/SCADA systems or data historian line PL	SIGA, RCCarrier	dynamic events	entelligent altern (tion derroging & Nigh outlietten meditatele & waiting fo Refer cyclen), propared to be distributed to neighboring or data sending partners	
Washigton State University	Vendor/De eloper	 Damping Movilor Real- time (DMR) developed b Prof. Mari Verbataschramanian, WSU, Pullman, WA 	In Operation and under testing at owner estillas. Anging tested at Entropy, Preik RC, and Southern CD. In operation at WRLDC, Mumbal, India.	Red time a cilitation manhoring using ambient data	Proprietary	gentic Ulicar	Phasor data	Eai import data from any PCC using IEEE CT-118 and BEGate protocols. Can export results to PI and questifatorian. Buren and McConnel has also developed custom user interfaces for EMS integration.		Continuous mentarizerg of the damping face of of dominant rytem and one of actification. The dominant of the second second second second administration of the other of excludions.	in, diesely read line	 H. Oubellan, L. Smag, and V. Menkasanknewstein, "Fatti Impeants (summa description for a molecular califiation mentating", IEET Insu. Faveur Galaway, yosi 20, NO. 3, pp. 1313–1451, June 2014. T. S. N. Basen Sormad and V. Wohlshambertmeine, "Encourse-shared radio Elimination Unit generative Electronic Science (Science Science), Science & Acgino Electronic Science (Science), pp. 346–336, June 2014
Washigton State University	Vendor/De eloper	 Event Analysis Real-time (DAR) developed by Pref. Manil Weskatasubramanian, WSSU, Pullman, WA 	In Operation and under texting at some entities. Any operating texted at Entergy, Peak RC, and Southern CD.	Red time and lation monitoring using event data	Proprietary	gentic Uličer	Phasor data	Eav import data from any PCC using IEEC 27.11 and SEGate protocols. Can seport results to PJ and operhitotocan. Burns and McConnol has also developed custom user interfaces for EMS integration.		Autorate descise of region groups metric, and autorate analysis of waters modes and outliketion from regions disc.	in, diesely read line	E. Liu, J., Opterter, and V. Verstandur environ. "Orchitetto Nachtrefe System and an olida ear any optendiature: In power system," Proc. IEEP symposium. 2007. Sub Power System Dynamics. Earls Carolina, USA. 20 Claritetton, South Carolina, USA. 2
Washigton State University	Vendor/De eloper	V Forced Oscillation Detection and Source Location (FOSL), developed by Prof. Most Venkatasub-smannian, WSL, Pullman, WA.	Reng tested at Peak RC	Real time outliktion monitoring using PAR and SCADA data	J Proprietary	genitič Liličer, n	Phonor data and SCADA Data	Can import duto from any POC any REE 072.13 and SEColar protocols. Can import SCAOA data from FI hatarian. Can export results to PI.	Sold Soldgowe	Selection of multilations using Mild data. Source loaders workput using SASIA data.		Dollin, Tillin, Vilkelandschandlin, N.Dueg, "Socie Landsnin of Franz Molifikani, Vulig, Springhaw and SCAID, Ada,", Proceedings of the 30th Issuel International Conference on System Science, 2017. 8
Mi Cântă	User	- Plasorpalet Aktan	The line of events of the second seco	 Montine of primer unless sing werkengings of the methods of the primer services and fenguesing of the primer serges. 	Frogrietary	- Saharan Spanef Amanganis. - Makanomula dalam, Albada gabarar ada ut 35 tana per uscand.	The network success The network success the second s	- Manupurt II. - Signard H. Schlack system Danad Spectrum (PP)		• Increasing the spectrum of a service. Any paper sheeps that the set of a direct set states are been as a set of a set of a set of a direct set states are been as a set of a set of a set of a transpace of a set of a	The significance are available for wattime, perform generation as a proving the fielding of sequencing sequences. In these situational assertees importing to prove units:	Ample D. Jondon, H. M. Almon, R. H. 2020. Appel- ter for program Collector and the Collector Paper Paper-control and the order Advance in COEI Second