NASPI-2019-TR-003

Using Synchrophasor Data to Determine Disturbance Location

NASPI Control Room Solutions Task Team Paper

February 2019

NASPI North American SynchroPhasor Initiative

Acknowledgements

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

American Transmission Company (ATC)
Bonneville Power Administration (BPA)
Dominion Virginia Power
Electric Power Group (EPG)
Electric Reliability Council of Texas (ERCOT)
Entergy
ISO New England (ISO-NE)
Lower Colorado River Authority (LCRA)
Operador Nacional do Sistema Elétrico (ONS), Brazil
Peak Reliability
PJM Interconnection
Public Service Company of New Mexico
Power System Operation Corporation (POSOCO), India
Quanta Technologies
Salt River Project
Schweitzer Engineering Laboratories (SEL)
Southern California Edison (SCE)
Southwest Power Pool (SPP)
Total Reliability Solutions (TRS)
Swissgrid, Switzerland
Washington State University
Western Area Power Administration
University of Tennessee, Knoxville
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:

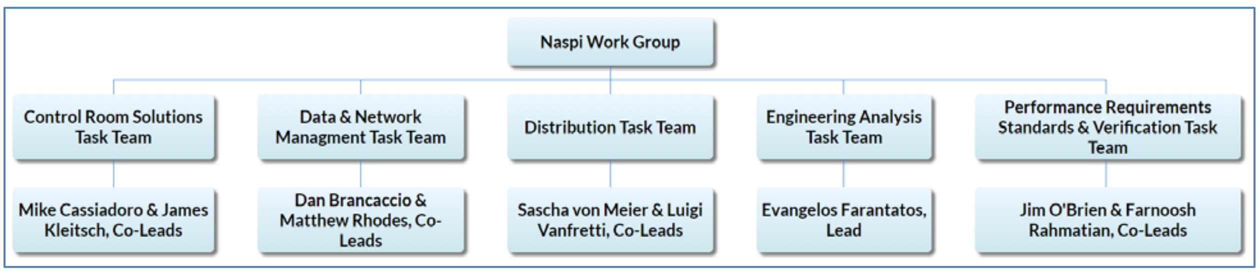

Fig1: The organization of NASPI Working Group

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. CRSTT members have already completed papers on the following topics: enhanced state estimation, phase angle monitoring, oscillation detection, system islanding detection and blackstart restoration, and voltage stability assessment. Existing versions of completed papers can be found on the CRSTT page of the NASPI website (https://www.naspi.org/crstt).

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1. Introduction

This paper describes how synchrophasor technology can be used in the Real-time Operations Horizon to determine the origin, nature and severity of disturbances on the electric power system.

Specifically, this paper considers how synchrophasor data and their application can be used by System Operations staff to analyze power system disturbances in near real-time and identify actions that can be taken to isolate faulted/failed equipment to return the electric system to an acceptable operating state.

The paper also identifies potential benefits to the utility organization in the areas of Operational Performance, Safety, Reliability, and Cost.

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 or 60 records per second and may be higher. In contrast, current SCADA[2] 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 +/- 50 microseconds, 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.[3]

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

3. NERC Functional Roles and Responsibilities for Disturbance Response

The *Glossary of Terms Used in NERC Reliability Standards* defines a Disturbance as an unplanned event that produces an abnormal system condition; any perturbation to the electric system; or an unexpected change in Area Control Error (ACE) caused by the sudden failure of generation or interruption of load.

Generally speaking, a disturbance can be viewed as any event that causes an exceedance of established operating parameters or an abnormal condition that, if left unaddressed, could adversely affect reliability or continuity of service.

The manner in which functional entities respond to Disturbances is determined by the nature and severity of the event. For example, if a loss of multiple transmission lines results in a System Operating Limit (SOL) exceedance, then the Transmission Operator(s) responsible for the affected facilities would implement the Operating Plan(s) associated with those facilities to alleviate the condition. Whereas, if a sudden failure of generation resulted in a significant ACE deviation, the responsible Balancing Authority would take action to rebalance generation-load-Interchange within the affected area and return ACE within acceptable bounds.

Since the NASPI CRSTT is primarily interested in how synchrophasor technology can be used to improve grid reliability, this considers the manner in which Reliability Coordinators (RC), Balancing Authorities (BA) and Transmission Operators (TOP) can use synchrophasor-based applications to analyze Bulk Electric System (BES) Disturbances in near real-time and identify actions that can be taken to return to an acceptable operating state.

Using Synchrophasor Technology to Determine Disturbance Location on Distribution Systems

The NASPI Distribution Task team (DisTT) white paper titled *Synchrophasor Monitoring for Distribution Systems: Technical Foundations and Applications* provides general descriptions of how synchrophasor data can be used for fault detection and analysis on distribution systems. The following excerpt from Section 3.4 of the paper is of particular interest:

"A simpler but highly relevant case of topology detection is to recognize when a conductor is severed (for example, due to a falling tree limb). Just like an open switch, a broken conductor will instantly cause a pronounced phase angle difference across the break point that is easy to detect with PMUs. This information has proven capable of actuating protection systems before an energized conductor would hit the ground and present a serious injury or fire hazard."

The NASPI CRSTT encourages those that are interested in learning more about how the synchrophasor technology can be used to analyze disturbances on the distribution system to review the latest version of the DisTT White Paper found on the NASPI website.

4. Using Synchrophasor Data to Identify and Analyze Disturbances

CRSTT surveyed grid operators, electric utilities and application vendors to determine how synchrophasor data is being used to identify and analyze disturbances, finding three primary areas of interest:

1. Diagnosing equipment health to identify potential or imminent failures.
2. Recognizing and determining the origin of excessive oscillations.
3. Analyzing the nature, severity and location of faults.

4.1. Diagnosing Equipment Health

As described in the NASPI Technical Report titled *Diagnosing Equipment Health and Mis-operations with PMU Data*, the widespread deployment of PMUs and wider availability of synchrophasor data has allowed many grid operators and transmission owners to gain unprecedented visibility into the status and health of equipment monitored by PMUs.

As detailed in the s report, grid operators and transmission owners are using PMU data to identify generator control issues, loose fuses, failing secondary transformers, relay misoperations, imbalanced phases, and a host of other undesirable operating conditions. In several instances, being able to proactively identify and address abnormal behavior allowed these entities to minimize the impact of or altogether avoid system Disturbances.

Refer to the latest version of the Diagnosing Equipment Health and Mis-operations with PMU Data Paper found on the NASPI website for more detailed information on how synchrophasor data can be used for this purpose.

Refer to NASPI CRSTT's Using Synchrophasor Data to Diagnose Equipment Health and Misoperations Event Summary Table for a general summary of the events found within the NASPI Technical Report along with a description of the safety, reliability and budgetary impacts associated with each.

4.2. Oscillation Detection

While oscillations are always present on the electric system, excessive or persistent oscillations can result in undesirable conditions or events (equipment damage, outages, instability, etc.). Oscillations are much easier to detect with PMU data than SCADA data.

Synchrophasor data (bus frequency, angles, line loading and voltage) are critical to detect potential and actual oscillations within the BES. Inter-area oscillations can be seen by examining bus voltages and frequencies, so most methods of oscillation detection are applied to transmission paths or flowgates.

Several of the events described within the NASPI Technical Report referenced in Section 4.1 of this paper were identified through the recognition of oscillatory behavior.

The basic aspects of oscillation monitoring and mitigation have been addressed NERC's Interconnection Oscillation Analysis Reliability Assessment published in November 2018.

Refer to the latest version of the NASPI CRSTT's Using Synchrophasor Data for Oscillation Detection focus area document found on the NASPI website for more information about oscillation detection applications that are in use today.

4.3. Fault Detection and Analysis

As described in NASPI Technical Report titled The Value Proposition for Synchrophasor Technology, PMU data have sufficient locational and time granularity that they can be examined immediately after a fault to determine the location of the incident.

Generally speaking, PMU data can be used to determine the nature, scope and severity of a fault to perform near Real-time analysis and inform operational decisions (e.g., whether or not to perform manual testing, where to dispatch field crews).

As indicated by the survey responses received for this paper, some grid operators and electric utilities are interested in paring synchrophasor data with smart grid fault location methods to provide a more complete picture of when/where faults have occurred on the electric system while others feel that the information provided by modern digital relays is adequate to identify fault locations, phasing, clearing time, magnitude, breaker timing, etc. and provide automated notification to office and field staff.

5. Summary of Survey Findings

In April 2018, the NASPI CRSTT distributed a disturbance location survey to over 40 parties in order to gather information to inform this paper. CRSTT received responses from 18 application users and five application vendors/developers at the time of publishing.

In summary, the responses received indicate that the synchrophasor technology is being used to determine the following:

- Large Generation Trips (from rate of frequency change)
- Source of Forced Oscillations
- Fault Location (by detecting voltage magnitude or PMU Location)[4]
- Transmission line switching (by location and detection of angle)

[4] Df/dt, dv/dt, negative sequence current can be used in combination to provide more accurate results.

- Load shedding (by frequency)
- Pumped storage tripping
- Estimated interrupted MW
- Proximity of voltage collapse
- Relay/circuit breaker mal-operation

Some of the utilities are using these applications in their operations. A few of them are in testing phase. Operations Engineering and Support personnel are the primary users for most of the applications at this time. However, a few applications are currently viewed by System Operators or expected to be in the operators' purview in the near future.

Refer to Attachments 1 and 2 of this paper for the detailed survey responses received from each party.

6. Defining the Value of Using Synchrophasor Data for Disturbance Detection

The safety, reliability and economic benefits of using synchrophasor data for disturbance detection can be summarized as follows:

6.1. Safety Benefits

There are significant safety benefits to recognizing and addressing potential equipment failures before they occur. As described in Section 4.1 of this paper, there have been several instances of transmission owners using synchrophasor data to detect abnormal conditions and isolate equipment before an imminent failure.

In addition, there are safety benefits derived from using synchrophasor data to perform near Real-time analysis of fault conditions to avoid manually testing equipment that failed to clearly properly or is likely to remain faulted.

6.2. Reliability Benefits

There are significant reliability benefits to using synchrophasor data for oscillation detection and fault analysis.

Excessive oscillations can result in unacceptable system performance and cause significant equipment damage if left unaddressed. A failure to isolate faulted equipment in a timely manner can subject the electric system to unnecessary fault conditions that could result in instability, uncontrolled separation or Cascading outages.

Providing Real-time System Operations staff with timely information about the origin, nature and severity of a disturbance will help to reduce the time required to return the system to a reliable operating state.

6.3. Economic Benefits

The economic benefits of using synchrophasor data for oscillation detection and fault analysis result from the avoidance of costs associated with equipment failures and prolonged outages. While hard to quantify, the cost savings associated with avoiding large scale outages can be significant.

Attachment 1 – Survey Responses from Application Users

A.1. American Transmission Company (ATC)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	We receive information from the UT FNET system via email. We are licensed to use the GE/Alstom PhasorPoint application which provides disturbance monitoring information, but we have not implemented that functionality yet. We have no plans at this time to pursue other applications but do see value in development of tools that identify galloping conductors, arcing switches, open phases, etc. We just don't have the coverage needed for tools like that to work reliably. Also, if we decide to pursue the use of synchrophasor data for backup EMS functionality then there would be value in being able to identify approximate locations of line trips and generator outages internal to our system as the loss of SCADA would prevent alarming which we rely on for that information.
App Objective:	Identify events outside our system that impact our system.
Type of Fault Info Provided:	The FNET information is used to help us identify when large generator trips occur or when significant oscillations occur on the system so that we can analyze the performance of interconnected units and identify anomalies. We also record data for events of interest and save those off for analysis of generator dynamics performance.
App Requirements:	We have not done enough investigation to provide details on the PhasorPoint requirements. GE/Alstom may be able to provide information on that.
App GUI Type:	
App Provider:	
App Software:	
App Users:	

Current State:	PhasorPoint is in development. Still using FNET data daily to review system events.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
FNET data is used after the fact by Ops Engineer to analyze events outside our system. Due to internal issues with available required support resources, the GE/Alstom PhasorPoint implementation is on hold until time frees up from other higher priority work items.	
Question: What's the value add from using the app in the Real-time operating environment?	
Any tool that provides enhanced situational awareness to the real time operations group is a good thing. Knowing that units are tripping offline outside your footprint is good information, especially when you can identify locations.	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Question: Is there any other relative information that you can provide?	

A.2. Bonneville Power Administration (BPA)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	Frequency Disturbance Model (FDM).
App Objective:	To show location of disturbance and impact on grid.
Type of Fault Info Provided:	The application uses rate-of-change or bus voltage angle (freq.) to determine the PMU that first detected the disturbance. It is assumed that this PMU is closest to source of the disturbance. The location is displayed on the Control Center Video wall within a minute of the disturbance, and an email is sent to a list of engineers and planners, showing the location and impact to major tie lines of the BA Area.

App Requirements:	This BPA custom app uses data retrieved from both BPA and Partner PMUs in WECC.
App GUI Type:	OSIsoft Process Book display, and event notification.
App Provider:	Custom BPA App
App Software:	In house
App Users:	Dispatchers and engineers
Current State:	In operation
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
Event notification alarm is sent from App to SCADA, where they show up on the dispatcher Alarm List.	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
Dittmer Control Room and email sent to engineers. The email includes 7 imbedded trends (2 mins long) showing freq. response and impact of major ties	
Question: What's the value add from using the app in the Real-time operating environment?	
Dispatchers like to know if the disturbance is internal or external to the BPA BA and if external then which partner was responsible (e.g. AESO, BCH…). Over time, they get an idea of what the impact will be to the BPA BA (if any), and how long it may take to recover.	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Question: Is there any other relative information that you can provide?	

A.3. Dominion Energy – Power Delivery

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
We do not have immediate goals to utilize applications like this in the control room but do have immediate plans to build and utilize applications like this for engineering analysis, transmission KPI dashboards, and automated model validation.
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.

App Name:	This will be a custom application.
App Objective:	Identify, classify, annotate and correlate grid events to provide narrative based reports to key stakeholders as well as drive metrics for transmission KPIs for reliability. This will further enable automated dynamic model validation.
Type of Fault Info Provided:	
App Requirements:	We have full network coverage. We are working with PingThings for hardware, software, and visualization. All synchrophasors are brought in through fiber.
App GUI Type:	Responsive web applications.
App Provider:	PingThings is a key collaborator.
App Software:	
App Users:	Unknown
Current State:	Development
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
We will not integrate with EMS or SCADA and have no intention to.	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
Question: What's the value add from using the app in the Real-time operating environment?	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
This is not a priority.	
Question: Is there any other relative information that you can provide?	

A.4. Electric Reliability Council of Texas (ERCOT)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
Yes
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.

App Name:	Real Time Dynamic Monitoring System (RTDMS) by Electric Power Group (EPG)
App Objective:	Quickly provide Operations Support Engineers with information related to possible system disturbances such as low voltages recorded in an area and how quickly voltage recovered after a disturbance. Also helpful in troubleshooting any related unit trips.
Type of Fault Info Provided:	Currently faults are only detected by voltage magnitude trends. Alarms are triggered when voltage magnitude get below a defined threshold or a voltage transient is greater than a defined kV/sec threshold. Faults locations can only be approximated by the PMU with the lowest recorded voltage. We only monitor positive sequence (no single phase) voltages.
App Requirements:	ERCOT currently has ~110 PMUs streaming real time data. Please refer to EPG's documentation for application requirements.
App GUI Type:	
App Provider:	EPG
App Software:	
App Users:	Engineers. Operators in the future.
Current State:	Currently exists in a test environment and being used by Operations Support Engineers. A production environment is currently being built and tested with a Go-Live date set for the summer 2018.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
Application has the ability to integrate with EMS through ICCP links. This feature will be implemented in the new production system once business develops use cases and requirements on real time data.	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
RTDMS is on the shift engineer desk and used by Operations Support engineers.	
Question: What's the value add from using the app in the Real-time operating environment?	
Quickly provide Operations Support Engineers with information related to possible system disturbances such as low voltages recorded in an area and how quickly voltage recovered after a disturbance. Also helpful in troubleshooting any related unit trips.	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Question: Is there any other relative information that you can provide?	

A.5. Entergy

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
Yes, we have an interest in fault location using PMUs.
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.
We are currently in the process of moving our PMUs into ESP, as well as, the associated OpenPDC and OSIsoft PI. Once the transition has taken place, we will begin training the operators in the use of PMU data. Eventually, we will begin working on implementing PMU applications within the operations floor however, this may take several years.

NOTE: Entergy responded to the first two questions of the survey only.

A.6. ISO New England

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
1. ISO-NE is planning to use PMU-based disturbance detection and impact estimation, i.e. a short circuit or tripping of a transmission element, to monitor mainly external disturbances. The reasons for that are the following: a. Clearing of a fault like short circuit is a function of relay protection and is supposed to be done in sub seconds time interval and has nothing to do with operator's actions. b. Identification of exact location of a fault on a transmission line and taking remedial actions is a function of Transmission Owner but not a responsibility of ISO. c. ISO operators are notified of any internal disturbances within seconds by EMS, which is based on circuit breaker statuses in SCADA data. d. ISO operators don't have direct information about external disturbances. The extra information provided by PMU may provide situational awareness benefits. 2. ISO-NE is currently using the Oscillation Source Locating (OSL) application, a PMU-based online application, to identify the location of the oscillations source. Majority of observed sustained oscillations can be classified as Forced Oscillations (FO) and they are caused by a faulty equipment or control systems. Regular relay protection is not designed to clear these

	faults. Sustained oscillations present treats to the system and the system operator is ultimately responsible to mitigate this threat. Online OSL application is an efficient tool to provide actionable information for operations for mitigating sustained oscillations.
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	1. Either PhasorPoint or a customized program. 2. Oscillation Source Locating (OSL) application.
App Objective:	1. Provide situational awareness to the operators; give them a heads-up of what's coming. 2. Localize the suspect source of sustained oscillations.
Type of Fault Info Provided:	1. Rough location, categorization (line trip, gen trip or load/pump trip) and impact (MW). 2. Location of the source of sustained oscillations as a specific area, power plant or generator depending of the available observability of the system by PMUs.
App Requirements:	1. Sample PMUs distributed in external transmission networks. 2. The OSL application uses PMU measurements from all PMUs installed at ISO-NE footprint. PMU data is taken from PhasorPoint historian, locally at ISO. The application can be run on a regular computer locally at ISO and does not require any additional hardware or telecomm. PowerWorld is used for visualization of dissipating energy flow on oneline diagram.
App GUI Type:	Online OSL version is fully automated service and does not have GUI. The results including the raw data plot and dissipating energy flow visualized on oneline diagram are in files and plots and are sent to users through email. Offline version of OSL does not have GUI and is controlled from a configuration file.
App Provider:	Entirely in-house ISO-NE development.
App Software:	
App Users:	Results in the testing mode are used by operation support engineers.
Current State:	1. R&D. Both vendor and university partners. 2. The online OSL application is in testing mode since September 2017. The application run is fully automated; no human in the loop.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
In the testing mode, the application sends results by email only. Sending results into EMS alarms capability will be developed in the future on as needed basis.	

Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?
In testing mode, the application sends result to operation support engineers but not into control room. No Time line yet to put it in operation.
Question: What's the value add from using the app in the Real-time operating environment?
1. Provide situational awareness to the operators; give them a heads-up of what's coming. 2. The application is triggered by PhasorPoint oscillatory alarm; automatically process PMU data and sends to operations personnel email with all results on the suspect source of oscillations. This information is key actionable information in prompt and successful mitigation of sustained oscillations. The application allows to identify on whether the source is located indie or outside of control area and to localize the source up to a specific generator inside of control area at sufficient system observability by PMU. The benefits are the following: a. At the presence of oscillatory alarm, ability to identify the location of the source inside or outside of control area. That identification leads to very different set of actions. For example, operator is very limited to efficient mitigation actions within control area if the source is located outside of control area. b. Ability to independently identify if the source is located outside of control area greatly reduces the need in coordination between control centers during mitigation of forced oscillations. c. Ability to initiate fast and efficient mitigation measures and thus an ability to avoid uncontrolled cascading outages, instability and even physical failure of generator equipment with catastrophic consequences. d. Ability to detect equipment issues at power plants and jointly work with power plant personnel for mitigation. Power plant may not have an ability to detect the issue.
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?
Question: Is there any other relative information that you can provide?
Publication: Slava Maslennikov, Bin Wang, Eugene Litvinov "Dissipating Energy Flow Method for Locating the Source of Sustained Oscillations", International Journal of Electrical Power and Energy Systems, Issue 88, 2017, pp.55-62 Online OSL application to integrated with ISO-NE PMU infrastructure and thus is difficult to scale for other utilities if they have an interest. ISO-NE has developed an offline version of the OSL (called OSLp) which is sufficiently generic and scalable and can be used by any utility with their PMU data sets. The OSLp can accept PMU data in several formats.

A.7. Lower Colorado River Authority Transmission Services Corp (LCRA TSC)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
No, we view relay and DFR type data more appropriate for fault indication and analysis. Modern digital relays provide a full complement of analog oscillography and digital status before, during, and after the fault event and are truly optimized in this regard. Synchrophasor data is useful in many other applications, but we already have a robust & mature vendor-supported system integrated with our protective relaying to identify fault locations, phasing, clearing time, magnitude, breaker timing, etc. and provide automated notification to office and field staff.

NOTE: LCRA TSC responded to the first question of the survey only.

A.8. Operador Nacional do Sistema Elétrico (ONS), Brazil

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
ONS’ Control Centre Phasor Measurement System (CC-PMS) is a WAMS system that will be delivered (installed and commissioned) until the end of 2018 (phase two) with a whole set of real-time and off-line applications. Among the real-time ones, there is the Disturbance Detection and Location Application which monitors the grid and provides detection, localization and characterization of system disturbances within the WAMS coverage to the user interface in real-time.	
App Name:	Disturbance Detection & Location Application (SDM)
App Objective:	After system contingencies occur, the identification of the event source and characteristics, especially during cascade outages, is one of the most important steps of the restoration process. The objective of the Disturbance Detection and Location application is to provide fast, high-fidelity information about the disturbance, suggesting their type (e.g. line trip, generation loss, load shedding) and most likely geographical location to improve the restoration process or, at least, the problem isolation.

Type of Fault Info Provided:	Location and detection of angle (i.e. a transmission line tripping) or frequency (i.e. a generation trip or a load shedding event) disturbances. The key functions of the SDM application are: • Real-time monitoring of the grid and detection of sudden disturbances in the network; • Disturbance characterization (angle or frequency disturbance); and • MW impact assessment based on the overall inertia of the system (it is based on a fixed parameter). During a disturbance, for each sequence of event, one violation marker will be shown including: • The location of the event that corresponds to the PMU location that first detects the event (i.e. is closest in proximity to the event location and therefore the most likely geographic location). • The symbol associated with the event will classify it as an angle disturbance (i.e. a transmission line tripping) or a frequency disturbance (i.e. a generation trip or a load shedding event).
App Requirements:	The algorithm identifies the location of the nearest PMU to the disturbance, so there is no lower limit on the number of available measures. The most network coverage available (system observability) the better is the identification result (precision). Considering the transient behavior of angle and frequency response during the “fault-on” period the initial response of the identification process is typically between 300 and 500ms. The SDM is part of the CC-PMS WAMS system applications which means that the hardware and software requirements were fully covered by the project scope. The alarms and results of the application are integrated in the real-time UI provided by the system supplier.
App GUI Type:	Geospatial Overview Display with data context panel (e-terravision).
App Provider:	GE Grid Solution.
App Software:	GE Grid Solution WAMS System
App Users:	Operators and engineers.
Current State:	The initial integration of the SDM is expected to be commissioned until May 2018 (the scheduled deadline of the project first phase).

Question: Does the app have the ability to integrate with other Real-time monitoring systems?
Yes. The alarms provided by the SDM application will be sent to ONS EMS system through ICCP connection.

Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?
Phase 1: May 2018 (with limited integration with the real-time UI). Phase 2: December 2018 (final version).
Question: What's the value add from using the app in the Real-time operating environment?
It is expected that the faster identification of system disturbance location and characteristics will improve the restoration process, avoiding the under-fault reconnection of equipment and streamlining the load/gen reconnection. With the conclusion of the first phase of the project (expected to be in May 2018) it will be possible to measure the impacts of the SDM integration.
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?
It will be fully integrated with the real-time WAMS GUI (e-terravision) and the alarms will be sent to the EMS System.
Question: Is there any other relative information that you can provide?

A.9. Peak Reliability

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	Peak FODSL (Forced Oscillation Detection and Source Locating Tool)
App Objective:	Detecting forced oscillation and locating the oscillation source.
Type of Fault Info Provided:	Forced Oscillation caused by generators Examples of info provided include Impacted Equipment (transmission line, station equipment, generation facility), fault type (phase-to-phase, phase-to-ground, failed equipment), fault severity (duration, percentage of voltage dip, MVA or MW interrupted), fault location (at a station, miles from station, at a tower, tower number), etc.
App Requirements:	Real-time PMU data and Real-time SCADA data, OpenPDC, PI
App GUI Type:	PI Processbook UI
App Provider:	Joint efforts between Peak Reliability and WSU

App Software:	Joint efforts between Peak Reliability and WSU
App Users:	Engineers
Current State:	In testing mode

Question: Does the app have the ability to integrate with other Real-time monitoring systems?

Currently not applicable.

Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?

Mid-2019

Question: What's the value add from using the app in the Real-time operating environment?

To detect forced oscillation and locate its source

Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?

Results are saved in PI

Question: Is there any other relative information that you can provide?

We have made two presentations at NASPI about this tool:

- April 2018 Recent Progress on Forced Oscillation Detection and Source Locating Findings at Peak Reliability
- March 2017 Peak Reliability WSU Real-time Forced Oscillation Detection and Source Location in the Western Interconnection.

Possible to share ePMU simulated event data and video in the future

Details of the work has been included in a new book about Synchrophasor published by Springer Press as follows:

Qty	ISBN#	Short Description	Status	Product Type - Binding/Format
1	9783319893778	Power System Grid Operation Using Synchrophasor Technology	Available	BOOK - Hardcover

A.10. PJM

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	GridWatch
App Objective:	Detect and triangulate large grid disturbances using PMU data and PMU location information.
Type of Fault Info Provided:	Generator trips, pumped storage / load trips, transmission line switching events.
App Requirements:	Uses all possible PMU frequency measurements.
App GUI Type:	OpenPDC running on a test server.
App Provider:	Built in-house using OpenPDC.
App Software:	Unknown at this time. It could be enhanced to use SE data or to send alerts back to EMS tools.
App Users:	Eventually, this will be used by operators and engineers.
Current State:	Proof of concept, running in the stage environment.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
Unknown at this time. It could be enhanced to use SE data or to send alerts back to EMS tools.	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
Since this is still a proof of concept, non-production email alerts are sent to a small group of engineers. This will be productionalized in the next 1-2 years.	
Question: What's the value add from using the app in the Real-time operating environment?	
Wide-area situational awareness. This can also be used to automatically trigger generator model validation.	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Question: Is there any other relative information that you can provide?	
Email alerts include a map with the estimated source location, summarized frequency deviations by PMU, and a frequency heatmap layer on top of the map.	

A.11. Public Service Company of New Mexico (PNM)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
PNM does not have plans to use PMU information for Fault Locations. PNM uses traveling wave and impedance based fault location within relay equipment to determine locations on transmission lines.

NOTE: PNM responded to the first question of the survey only.

A.12. Power System Operation Corporation (POSOCO), India

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	**A. Automated Event Analysis Tool (DA-Tool)** **B. Synchrophasor Analysis of Grid Events (SAGE)**
App Objective:	A. **Automated Event Analysis Tool:** • Proof of Concept • First Information Report of grid event • Automatic Event Reporting • Effective utilization of PMU and reduction of Expert Man hours. B. **Synchrophasor Analysis of Grid Events (SAGE):** • To identify using PMU data various events such as type of fault, generation/ load loss and the location of origin of the same through a simple user friendly GUI.

Type of Fault Info Provided:

A. **Automated Event Analysis Tool:** It first distinguishes whether the event is frequency-related or not.
   - **Frequency Related Event:** Load-Generation Loss event and Appproximate Qunatum.
   - **Non-Frequency Related Event:** Fault Type (LG, LL, LLLG, LLL) fault types and gives the fault signature event like Type of Fault, Fault Localization, Direction of Fault, Auto recloser operation, Fault initiation time, Fault Removal Time, Fault Removal Duration, Fault Clearing duration, event detection method, Top two PMUs having highest df/dt variation Ratio, Maximum dV/dT detected, Minimum Voltage dip detected, Maximum negative sequence current detected and Maximum df/dt detected.

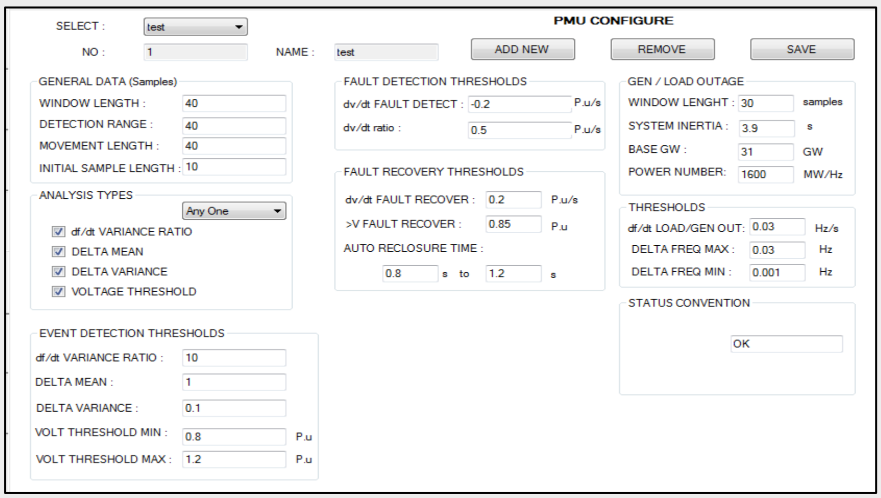


Figure 1: Layout of Analysis configuration tool

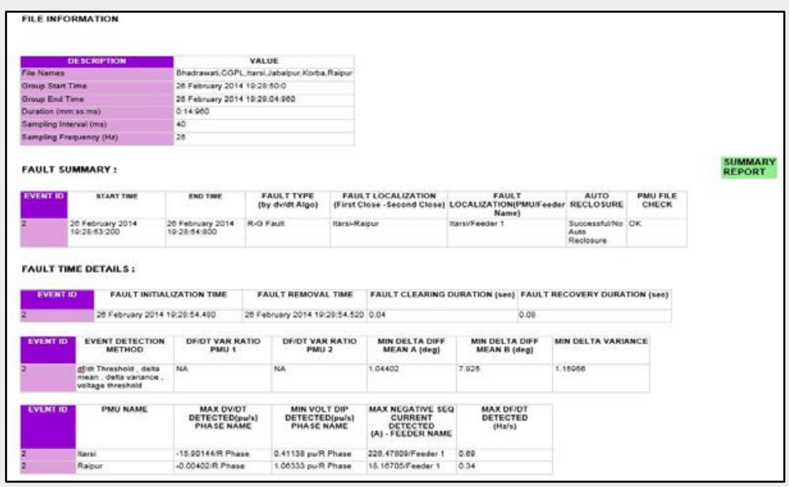


Figure 2: Sample output of Automated Event Analysis Tool

B. Synchrophasor Analysis of Grid Events (SAGE):

- Fault Event: Type of fault *(L-G, L-L, LLG)*, Location of fault (nearest PMU/location based on SoE data)
- Frequency Event: Load or Generation loss and approximate quantum

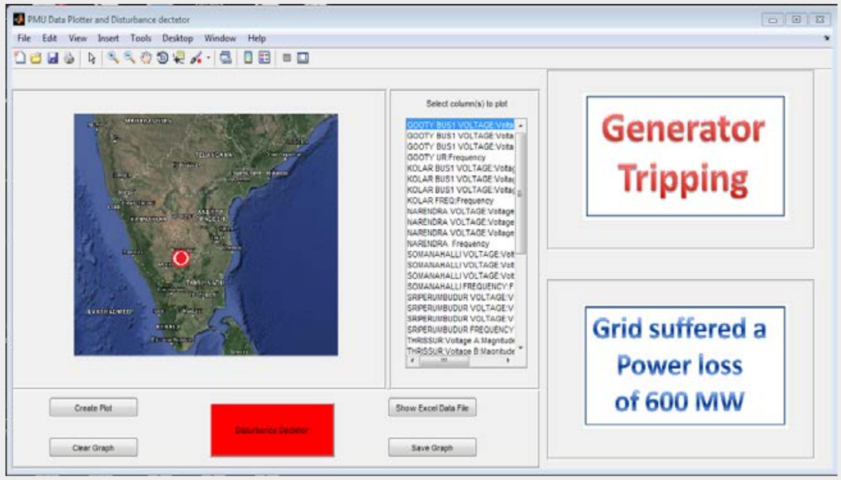


Figure 3: Signature Analysis MATLAB based GUI: Analysis for Gen. Tripping

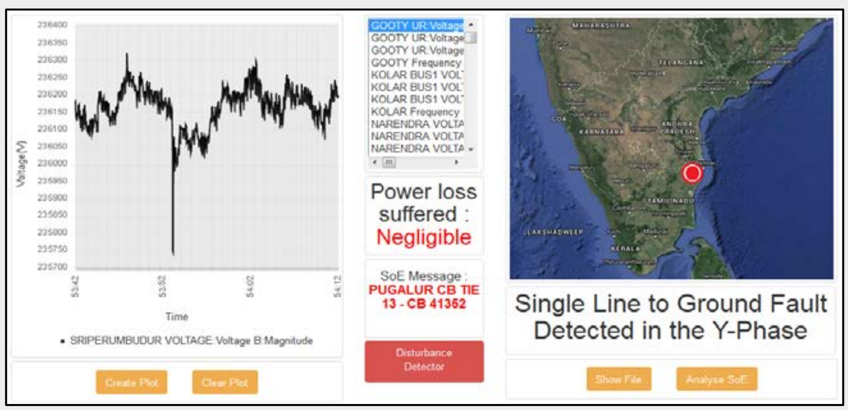


Figure 4: Signature Analysis Web based GUI: Analysis for SLG fault w/ SoE data

App Requirements:

A. **Automated Event Analysis Tool**: Require PMU data in specific .csv or COMTRADE format at a specific directory file.

Software & Hardware:

- Windows 7 Professional Edition Operating System server grade machine / workstation
- .Net Framework 4.0 Client
- Microsoft Report Viewer 2012 Runtime redistributable package Disturbance Analysis Tool software
- DATABASE: Microsoft SQL Server Express Edition 2008 or above

	B. Synchrophasor Analysis of Grid Events (SAGE): • PMU data in IEEE C37.118 format • Hardware: Server/PC with min 4 GB RAM • • Software: MATLAB R2013b, MS Office 2007 or higher
App GUI Type:	A. **Automated Event Analysis Tool:** Standalone GUI based on .NET framework. B. **Synchrophasor Analysis of Grid Events (SAGE):** MATLAB based GUI and Web based GUI (on python) available for offline analysis. MATLAB GUI to be used in future for online display.
App Provider:	**A. Automated Event Analysis Tool:** Power Research Development Consultant Pvt Ltd. India. **B. Synchrophasor Analysis of Grid Events (SAGE):** Developed In-house with the help of students from NIT Calicut and SASTRA University.
App Software:	**A. Automated Event Analysis Tool:** Proprietary **B. Synchrophasor Analysis of Grid Events (SAGE):** In House Development
App Users:	A. **Automated Event Analysis Tool:** POSOCO (All RLDC/NLDC). B. **Synchrophasor Analysis of Grid Events (SAGE):** At Southern Regional Load Despatch Centre (SRLDC) in India.
Current State:	**A. Automated Event Analysis Tool:** Proof of Concept completed, planning for online version for large PMU deployments. **B. Synchrophasor Analysis of Grid Events (SAGE):** Developed, tested and deployed. Presently being used offline i.e. for post fault analysis. Online integration of the application being developed.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
A. Automated Event Analysis Tool: Current version is offline application **B. Synchrophasor Analysis of Grid Events (SAGE)**: Current version is offline Application. SoE data from SCADA can be downloaded and used for analysis readily for better resolution of location.	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
A. Automated Event Analysis Tool: At Western Regional Load Despatch Centre (WRLDC), POSOCO, Mumbai as proof of concept project. Used by Control Room as well as Offline Team. **B. Synchrophasor Analysis of Grid Events (SAGE):** At Southern Regional Load Despatch Centre (SRLDC), POSOCO, Bangalore. It is currently being used by the Protection and Synchrophasor department Engineers. Time line for being ready: **A. Automated Event Analysis Tool:** Will be developed for online fault analysis after URTDSM. **B. Synchrophasor Analysis of Grid Events (SAGE):** Online monitoring under development and will be completed by 2018.	

Question: What's the value add from using the app in the Real-time operating environment?
A. **Automated Event Analysis Tool:** This is a proof of concept R & D Project developed for Offline analysis. As per the current rate of PMU deployment in India, this tool shall help in Quick identification of Affected area, First Information Report, Type of fault for attempting test charging and Graphical view of parameters of the most affected location. B. **Synchrophasor Analysis of Grid Events (SAGE):** At present post event fault analysis is done by downloading the PMU data and plotting the various parameters such as Voltages & sequence component which is time consuming and cumbersome. The SAGE tool developed gives more accurate information about the type of fault and had reduced the fault analysis time. The application developed is cost effective as it is done in-house with involvement from Academia as expense is only on the hardware.
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?
A. **Automated Event Analysis Tool**: By integrating the application with Historian through API. B. **Synchrophasor Analysis of Grid Events (SAGE):** Socket programming for integrating PMU data with C/MATLAB has been completed. Work being carried out to integrate the applications for control room real time purpose.
Question: Is there any other relative information that you can provide?
Related Publications: 1. P. Mukhopadhyay, R. Anumasula, C. Kumar, R. Nagaraja, F. Khan and D. Nitesh Kumar, "Disturbance analysis tool based on Synchrophasor data," 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Mumbai, 2014, pp. 1-6. 2. Automated Event Analysis in Indian Grid, NASPI Work Group Meeting March 2015 https://www.naspi.org/sites/default/files/2016-09/psoc_india_anumasula_automated_event_analysis_tool_20150323.pdf

A.13. Southern California Edison (SCE)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
SCE is currently in a pilot with EPG's RTDMS system.
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.

App Name:	EPG's RTDMS (Real-time Dynamics Monitoring System)
App Objective:	Improve situational awareness for SCE's Grid Control Center
Type of Fault Info Provided:	
App Requirements:	RTDMS receives PMU data from our ePDCs that are also EPG's product. RTDMS uses a linear state estimator to add visibility to our Phasor system since SCE only has 29 PMUs in the field. SCE opted for the thick client option, so RTDMS has to be installed locally on each PC that uses it. We currently have 8 PCs with RTDMS installed. Each PC needed an upgrade to their video card in order to support RTDMS visualization. This system is not redundant, so we are only sending data from our Alhambra PDC. If that site goes down, we will have to set up Irvine to send to RTDMS. Since this project is currently in pilot, we do not offer off hour support.
App GUI Type:	
App Provider:	EPG
App Software:	
App Users:	The Goal is to have this application used by the operators for real-time analysis and the by engineering operators for post analysis study.
Current State:	RTDMS is currently in the pilot phase. The Grid Control Center has to determine if they would like to move forward with a project, continue the pilot, or to not continue further with this product.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
RTDMS has a connection to the EMS system through an ICCP link to collect breaker status points. This is needed for the Linear State Estimator to increase SCE's visibility of the phasor system.	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
Only the computers in the control room have RTDMS installed.	
Question: What's the value add from using the app in the Real-time operating environment?	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Question: Is there any other relative information that you can provide?	

A.14. Southwest Power Pool (SPP)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes, although this information is currently only utilized by back-office staff.	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	EPG RTDMS
App Objective:	Input into post-event analysis
Type of Fault Info Provided:	Alarming when PMU voltage magnitude drops below a threshold value for a specified period of time. The alarm specifies the PMU name, phasor name, duration, and lowest P.U. voltage value.
App Requirements:	The more PMU coverage we have, the better/more accurate results we will get across the footprint. Right now, we really just have a limited PMU footprint which limits the application's use.
App GUI Type:	
App Provider:	EPG
App Software:	Proprietary
App Users:	Back office Engineers
Current State:	Testing
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
N/A	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
TBD	
Question: What's the value add from using the app in the Real-time operating environment?	
Not used in real-time	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Yes. More tuning is required to eliminate false triggers due to bad data or dropouts.	
Question: Is there any other relative information that you can provide?	

A.15. Salt River Project (SRP)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
Yes, but indirectly for fault detection. SRP System Protection uses SynchroWAVe as an additional tool to determine fault location in its report to Operations for dispatching field personnel.
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.
SRP is seeking to introduce Oscillation Monitoring in Operations but experiencing slow build-up of interest. This also applies to fault detection and failed equipment monitoring for the same reason. We have been using our R&D to introduce new synchrophasor software.

NOTE: SPP responded to the first two questions of the survey only.

A.16. SWISSGRID, Switzerland

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	
App Objective:	In Switzerland we have due geographical reasons – crossing the Alps – with difficult geography – avalanches etc. a high-sophisticated system of rapid and delayed auto-reclosing systems for our overhead lines of the transmission system, single-phase, three-phase with synchro check etc. The WAM systems can assist in a quite good way the subsequent analysis after successful or unsuccessful auto-reclosing's as well as monitoring of a special

<table>
<tr><td></td><td>protection scheme we operate together with Terna (Italy TSO) in order to avoid cascading events as it happened in 2003 during the Italian blackout.</td></tr>
<tr><td>Type of Fault Info Provided:</td><td>We use synchrophasor technology as a complementary tool beside – digital relay recordings or/and transient recorders so far available. Of course, the PMU-based recordings do cover only the electromechanically part of the more system-wide fault analysis including power plant behavior etc. and the transient stability of the highly-meshed Continental Europe power system.</td></tr>
<tr><td>App Requirements:</td><td>Additionally, we have a permanent monitoring system in used which is fine-tuned for detecting critical inter-area oscillations either of the main East-West or North-South mode of the CE (Continental Europe) power system.

The related system is composed by the data acquisition of a few CE PMUs and a subsequent on-line modal analysis with subsequent intelligent alarm generation (low damping & high oscillatory amplitude & wait for a few oscillations) – summarizing PMUs, PDC, tailored software -> link to SCADA system.</td></tr>
<tr><td>App GUI Type:</td><td>Embedded web browser technology seems to be the most promising solution.</td></tr>
<tr><td>App Provider:</td><td>Development could take place on different levels, e.g. manufacturer/vendor, university, TSO etc. – important is a good communication and link between all those entities and related resources in terms of money and time!</td></tr>
<tr><td>App Software:</td><td>As already mentioned above – the most successful mix will have to be found out from country and company to company. The most important issue is to identify in time the correct key persons who will give a drive to the related activities. Therefore, technical expertise and comprehensive understanding are a pre-requisite.</td></tr>
<tr><td>App Users:</td><td>Control room staff and back-office engineers.</td></tr>
<tr><td>Current State:</td><td>A few elements are already in operation since a couple of years, a few others are under testing and will be implemented soon. One main issue is to deliver to the control room the information in the right way as clear messages together with related actions. Permanent and intensive training of control room staff is crucial for the success of this approach!</td></tr>
<tr><td colspan="2">Question: Does the app have the ability to integrate with other Real-time monitoring systems?</td></tr>
<tr><td colspan="2">Definitively if this goal will not be possible to be achieved most of the synchrophasor-based application will probably disappear after some years by being too expensive in terms of maintenance and correct date archiving. Consequently, the only way to survive is to succeed by linking the timely accurate stamped measurements with the state-of-the-art SCADA in a clever way!</td></tr>
<tr><td colspan="2">Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?</td></tr>
<tr><td colspan="2">First step was to implement the correct visualization and alarming on the back-office level by engineers, second step is to train the control room staff (which are usually not yet engineers) into the right way.</td></tr>
</table>

One crucial issue is the permanent cooperation between research, universities, manufacturer and the user = TSO itself by involving in the TSO organization different departments (Asset management = protection dept.; Operation Dept. with control room staff and Planning Dept. (dynamic model calibration) together with Analysis team = back office for event analysis and reporting teams. See progress of CIGRE C2.17 technical brochure which will be probably ready end of year 2018.
Question: What's the value add from using the app in the Real-time operating environment?
The control room operators get a comprehensive additional information to be correlated with the SCADA measurements and information. The most sensitive and tricky part is to be able to generate the exact mitigation actions by pre-preparing a corresponding catalogue of measures.
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?
Question: Is there any other relative information that you can provide?
Wait until CIGRE TB of WG C2.17 will be published end of this year.

A.17. Western Area Power Administration (WAPA)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
No
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.
More PMUs are needed in the field. Implementing applications in real-time needs to be easier, cheaper and faster. 2 PDCs need to be installed in each control room with redundant comm. Redundant historians need to be purchased and installed. A connection from the PDC to SCADA needs to be set-up. PMU applications need to be purchased, configured, installed and maintained.

NOTE: WAPA responded to the first two questions of the survey only.

A.18. XM, Columbia

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?
No
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.
Given that XM is the system operator and we are not owner for power system equipment, our focus is more concentrated in the security of the operation in a more systemic way. According with this, we are more interested in the development of applications based on synchrophasors that help us to identify sources of instabilities (frequency or voltage), oscillations, voltage profiles, WAMPACs, Situational awareness, WAMS development, and early warnings for operation staff.

NOTE: XM, Columbia responded to the first two questions of the survey only.

Attachment 2 – Survey Responses from Application Vendors/Developers

B.1. Electric Power Group (EPG)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes, EPG has a suite of 15 Wide-Area Real-Time Monitoring and Visualization Systems products/solutions covering all end-to-end process of data collection, processing, visualization and analysis of phasor data. EPG's Real-time Dynamics Monitoring System (RTDMS) is a comprehensive platform for real-time wide-area analysis and monitoring using synchrophasor data for use in control centers. RTDMS provides capability to detect system events and disturbances including faults and indicate the location of the events/disturbances based on PMU data.	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	Real-Time Dynamics Monitoring System (RTDMS)
App Objective:	The objective of RTDMS® is to enable operators to monitor and identify stressed grid conditions, severe oscillations, limit violations etc. and take timely corrective actions to address vulnerabilities like oscillations, low damping, large phase angle, diverging phase angle trend, high voltage sensitivity etc. It helps make better use of the transmission system by knowing how far we are from the edge and improve models by comparing actual system behavior with model results. • RTDMS provides operators with: • Wide Area Situational Awareness • Phase Angle Monitoring • Event Detection and • Oscillation Detection and Monitoring • Islanding Detection and Line Reclosing • Automated Reports • Grid Resiliency
Type of Fault Info Provided:	RTDMS detects system events such as faults, line trips, generation trip, oscillations, islanding etc. For each event detected, RTDMS indicates the PMU

	location and severity of the event. For example, for a generation trip event, RTDMS indicates the location of PMU closest to the generation trip. For an islanding event, RTDMS identifies the PMU locations in the island. RTDMS allows users to configure up to 8 levels of alarms. When events are detected, alarm colors and alarm level are shown based on the severity of the event. For oscillations, RTDMS displays oscillations into four frequency bands. When an oscillation is detected, RTDMS classifies the oscillation into one of the bands based on the frequency of oscillation. For example, an oscillation of frequency 3 Hz will fall in band 3 corresponding to control systems related oscillations. Frequency of an oscillation is an important indicator of the cause and the spread of the oscillation. Using geospatial map view, operators can identify if there are any oscillations detected, where is the location, what is the probable cause and how severe is the oscillation
App Requirements:	RTDMS Platform uses a Visualization client to view the results, displays, alarms etc. and a Server which performs the processing, runs algorithms and calculations. Hardware Requirements for the RTDMS Visualization client are given below:

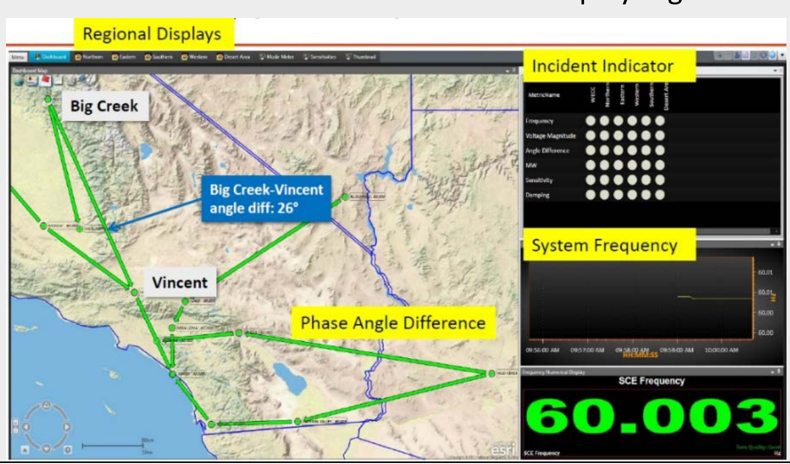
Individual PC Hardware Requirements Will run EPG's RTDMS Client	
Operating System	Microsoft Windows 7 or later, 64-bit
Processor Speed	2.5 GHz or faster
Processor Type	Intel Core2 Quad or i7 processor
Memory	8 GB or more
I/O ports	1 Network Interface Card (NIC) 1 GBPS
Video Card	• Any of the following with 1 GB RAM or more: o AMD Radeon 7500 series or higher o HD 6500 or higher o FirePro V7900 or higher

Hardware requirements for RTDMS Server application is provided below:

Hardware Requirements for RTDMS Server	
Operating System	Microsoft Windows 2008 R2, 2012 – Standard Ed.
Processor Speed	2.5GHz
Processors-Cores/CPU	2 Physical Processors
Memory	8 Gigabytes or more
I/O ports	1 Network Interface Card (NIC) supporting 1GbPS
Hard Disk Storage	100 Gigabytes

<table>
<tr>
<td>App GUI Type:</td>
<td>RTDMS uses standard technologies such as Windows Platform Foundation (WPF) that provides advantages given below. RTDMS also provides a web-based user interface through GridSmarts module that can be used to create near real-time dashboards as well as generate automated reports on system events, grid performance and PMU data quality. RTDMS can also be deployed through a mobile interface that allows the visualization without the need for any thick desktop deployment, specialized client hardware etc. The mobile solution is an elegant and scalable deployment mechanism for remote and local access to applications concurrently. It offers all the advantages of a browser-based client without the limitations. In addition, it is available securely on all standard platforms including iOS® and Android® devices.

Highspeed rendering of high-resolution real-time data
High Performance
High Availability
Low latency
Supports load balancing using routing services and server clustering
Uses decoupled components to provide modular, incremental & independent implementation
Variety of base maps and layers for geospatial rendering of data
Resolution Independent Vector based graphics
Scalable and robust
Flexible & extendable
Easy Navigation
Free form drawing tools
Smart Decluttering
Integrated Point Configuration
Flexible display builder and display configuration
Role based profile and display management
Library of Built-in Visualization Templates

An example of RTDMS visualization of a Dashboard display is given below:


</td>
</tr>
</table>

App Provider:	Electric Power Group (EPG)
App Software:	Proprietary
App Users:	RTDMS is in use in control centers as well as by operation engineers for supporting control system operations.
Current State:	RTDMS is currently operational and in use at 15 + Customer locations including major ISOs, utilities and reliability coordinators such as PJM, NYISO, ERCOT, Duke Energy, TVA, SPP etc.

Question: Does the app have the ability to integrate with other Real-time monitoring systems?

RTDMS has capability to integrate with different vendor offerings: with phasor measurement units, phasor data concentrators, historians (OSI Soft PI, eDNA), EMS/SCADA (GE, ABB, Alstom, Siemens and Monarch).

Examples of some 3rd party product integrations include:

- PMUs – ABB, GE, Alstom, ERL - Tesla, SEL
- PDCs – enhanced Phasor Data Concentrator (ePDC®), OpenPDC, SEL PDC
- Historians – PI, Phasor Archiver, openHistorian, eDNA
- Simulators – RTDS, PowerWorld, ePhasorSim, PSLF, PSS\E, TSAT
- GIS Integration – ArcGIS, SmallWorld
- One Line Diagram Integration - Macomber Maps and Alstom (GE) DDLs
- Hybrid State Estimator
- Montana Tech Oscillation Monitoring and Detection Algorithms

EPG products and modules for EMS/SCADA integration with RTDMS are listed below:

a. ICCP – EPG's ICCP adapter is developed to integrate Synchrophasor data with EMS using Field-Proven SISCO ICCP Stack. This enables data exchange with ISO's and Utilities including raw PMU Measurements (voltages, currents, frequency, etc.), calculated values (angle difference, real/reactive power, mode, sensitivity, oscillation, etc.), and alarms/events (threshold violation, rate of change violation).
b. DNP-3 – EPG's DNP3 module sends Synchrophasor data and alarms to EMS/SCADA through DNP3 standard.
c. PI Gateway – EPG's PI Gateway has two components PI Gateway Service and PI Web App. PI Gateway Service, a Windows Service, implements archiving functions to send data to PI Server for data storage. PI Web App implements functions to configure and monitor PI Gateway Service.

Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?

Question: What's the value add from using the app in the Real-time operating environment?	
RTDMS is in use in control centers as well as by operation engineers for supporting control system operations. Examples of RTDMS Deployments include: • PJM • Duke Energy • New York ISO (NYISO) • ERCOT • Southern California Edison • Southwest Power Pool (SPP) • Tennessee Valley Authority • Commonwealth Edison (ComEd) • California ISO • Oman Electricity Transmission Company (OETC) • Empresa de Transmisión Eléctrica Dominicana (ETED) • Consolidated Edison (ConEd) • Dominion Virginia Power • Los Angeles Dept. of Water & Power • Lower Colorado River Authority • New York Power Authority • Sharyland Utilities • Hydro One	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Question: Is there any other relative information that you can provide?	
EPG has conducted a series of webinars for the industry on maximizing the use of synchrophasor technology. Presentation material and webinar recording are available at: http://electricpowergroup.com/webinars.html Additional Information can be obtained by contacting EPG at contact@electricpowergroup.com Phone: 626-685-2015.	

B.2. Quanta Technologies

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	Real-time Voltage Instability Indicator (RVII)
App Objective:	Provide real-time, on-lime voltage stability indices and voltage stability trends for operators. Possibility to use it as part of the automated protection and control scheme to detect and initiate actions to prevent voltage instability both locally and system-wide.
Type of Fault Info Provided:	RVII provides indices that tells the proximity to voltage collapse for a bus, transmission corridor, or transmission interface. When implemented all over a system, RVII results can be used to determine the paths of power flow that is closest to voltage collapse. Disturbances will cause sudden changes to the voltage stability indices.
App Requirements:	Requires streaming PMU data (voltages and currents) at the locations of interest. RVII is suited for integration with existing PDC/synchrophasor application platform.
App GUI Type:	Dependent on synchrophasor application platform with which RVII is integrated.
App Provider:	Quanta Technology LLC
App Software:	In house, proprietary
App Users:	In use by engineers
Current State:	RVII is actively being tested and developed. It has been implemented in the test facilities of several utilities.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
• Pacific Gas & Electric • ISO New England • Tenaga Nasional Berhad, Malaysia	

Question: What's the value add from using the app in the Real-time operating environment?
RVII, being a purely measurement-based voltage stability tool, is a complement to existing mode-based voltage stability tools in EMS systems. RVII provides real-time, synchrophasor-rate information, while the model-based tools provide more accurate power transfer margins every few minutes. RVII is useful for catching fast-acting voltage stability issues that may be missed by the model-based tools.
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?
Question: Is there any other relative information that you can provide?

B.3. Schweitzer Engineering Laboratories (SEL)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	• SynchroWAVe Central • AcSELerator TEAM • SynchroWAVe Event
App Objective:	Wide-area situational awareness of power systems using synchrophasor and relay information.
Type of Fault Info Provided:	The software provides notification of detected power system disturbances (fault, oscillation, generation trip, etc.) via synchrophasor data. Disturbance notifications provide guidance to possible disturbance locations, in addition to frequency and voltage trends of the detected disturbance for quick assessment of wide-area impact. Disturbances are synchronized visually with protective relay event report indicators that provide fault summary information including fault location and faulted phase(s). Capability also exists for further investigation, into the direct

	point on wave data captured for the fault condition. By combining wide-area disturbance data with local protective relay fault data engineers and operators can quickly identify a disturbances wide-area impact and know the exact location of the fault condition in one dashboard.
App Requirements:	Windows server and web-client.
App GUI Type:	Web-based clients.
App Provider:	Schweitzer Engineering Laboratories, Inc.
App Software:	
App Users:	
Current State:	Standard software product offering in production worldwide.
Question: Does the app have the ability to integrate with other Real-time monitoring systems?	
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?	
SynchroWAVe Central and AcSELerator TEAM are in use worldwide by a large number of utilities and industrial operations.	
Question: What's the value add from using the app in the Real-time operating environment?	
Disturbance location information improves operator response to disturbances. Integration of relay event information, including high sample-rate event report file analysis, with synchrophasor data, improves the ability for operations and operations support engineering to understand the root-cause of present conditions	
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?	
Question: Is there any other relative information that you can provide?	
"Integrating Synchrophasors and Oscillography for Wide-Area Power System Analysis" Technical Paper by Hawaii Electric Light Company and SEL https://cdn.selinc.com/assets/Literature/Publications/Technical%20Papers/6750_IntegratingSynchrophasors_JB_20170130_Web2.pdf?v=20171110-151608 "System for Event Summary Notifications: Preliminary Operational Results at SDG&E" https://cdn.selinc.com/assets/Literature/Publications/Technical%20Papers/6792_SystemEvent_EB_20170127_Web2.pdf?v=20170502-105012	

B.4. Washington State University (WSU)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	1. Failure diagnosis and Asset Monitoring in protection system at transmission level (FDProSys) 2. Synchrophasor Based Event Detection (SyncED)
App Objective:	1. FDProSys: The existing methods for power system fault diagnosis do not systematically address the possible malfunctions or failures of protective devices. When a fault occurs in the system along with failures in protection devices, conflicting information and alarms makes the problem identification by system engineers/operators very difficult. An automated algorithm is required for power system transmission network protection system failure diagnosis to precisely identify the malfunctions and failures of protective devices. There is no automated tool available to identifying the malfunctions of protective devices during a fault, hence, creates an ambiguous reason for the observed state of the system. In the proposed FDProSys tool, automatic detection of malfunction or failures of distance relays and circuit breakers in transmission system is developed. Additionally, data science based approach is use for continuous health monitoring of instrument transformers. 2. SyncED: The objective of the Event Detection algorithm is to detect events in real time and help the operator zoom into the exact region of event in a wide area power system. This would help the operator to know the exact cause of changes in the system at a higher speed than the existing SCADA system. This can be essential in improving operator's decision-making ability and avoid wide area blackouts.
Type of Fault Info Provided:	1. FDProSys: The proposed application identifies the relay or circuit breaker mal-operation following multiple tripping of relays on event of a fault. The application also identifies the zone of protection of the transmission line

	on which the fault occurred and asset monitoring for instrument transformers. 2. SyncED: SyncED uses the synchrophasor measurements and detects signature of transients between two steady state conditions. It further classifies the events into three categories: Active Power Events, Reactive Power Events and Faults. Signatures of events on different PMUs will be detected differently depending upon the type and location of the events from the PMUs.
App Requirements:	1. FDProSys: Compared with the existing methods, the proposed algorithms use synchrophasor measurement, topology information and breaker status to find the root cause of the observed state of the system evolved through set of events. The FDProSys tool proposed in this work uses voltage and current as well as the other parameters related to relay/CB status to estimate malfunctions in protective devices, which was not possible using only relay/CB status based on local measurements or EMS alarms. 2. SyncED: The algorithm uses only the PMU measurements and uses the instances where there is a change in the steady state. These instances are detected by clustering-based algorithm. This only requires optimal placement of PMUs to make the area observable. It can be further extended to exactly detecting events in real time if the topology information is provided. One of the requirements of this application is that the PMU data should be checked of any anomalies such as, outliers, missing data etc.
App GUI Type:	1. FDProSys: The system operator can assist the selection of the portion of the network on which the postmortem analysis is required to be performed. For continuous monitoring of instrument transformers, specific devices can be identified to be monitored. 2. SyncED: The system operator can easily zoom into the exact event and its location. The area to be monitors would depend on the operator.
App Provider:	Washington State University
App Software:	In-house development
App Users:	
Current State:	1. FDProSys: The current state of the application is under testing. 2. SyncED: The first version of application is ready and tested. Second version is in the process of adding topology information to exactly find out the event such as the exact location of fault, operation of cap bank etc.

Question: Does the app have the ability to integrate with other Real-time monitoring systems?
1. FDProSys: The developed centralized FDProSys tool is designed to run in the control center for automated diagnostic of protective device failures and malfunction inspired by multiple hypotheses. Confused with conflicting information and alarms, the operator can launch the proposed algorithm to identify the malfunctioned devices. 2. SyncED: The application can be run in the control center and could use the information available in the EMS system to enhance the accuracy and fulfill the real time event detection objective.
Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?
1. FDProSys: The application can be made operational in 6 months for industry adoption. The FDProSys is a postmortem analysis tool which can be used after part of the power system is blackout following cascaded relay tripping and fault. The application collects synchrophasor measurement and relay/CB status from the faulted part of the system to perform matrix operation and hypothesis generation, which is relatively fast for typical networks. Hence, the real time operation horizon is relaxed for this application. 2. SyncED: The application can be made operational in a year. The SyncED is designed for near real time monitoring purposes and with the help of utility which can provide the topology and system information it can be made compatible for control centers. Initial development of algorithm assumes topology and is under development for a prototype.
Question: What's the value add from using the app in the Real-time operating environment?
1. FDProSys: In the existing industry practice, the system operator or engineer may be required to send personnel to substation for identifying the device malfunctions and requiring more effort and a long time to restore the system. The most common causes of malfunction are incorrect setting/logic/design errors and relay failures/malfunctions. The traditional fault location involves demand based downloading the fault information sent to the control centers by the relay/CB installed in the field generally triggered by the alarms. The relay typically uses local measurements to generate alarms and fault information or Energy Management System (EMS) can generate alarms based on SCADA data. Hence, any relay operation resulted due to malfunctions of protective devices in the neighboring buses presents an apparent reason of fault instead of true cause, resulting in ambiguity for the system operator. In the existing practice, the system operator also does not have any means to identify such malfunctions of protective devices in the neighboring buses using the relay/CB status, which are based on local measurements but analyze multiple events files from relays. The proposed method provides the most possible reason for multiple protective device malfunctions resulting in multiple lines outage scenario, which is time consuming following existing manual process by the system operator/ protection engineers. 2. SyncED: When a system is stressed, and the operator is fatigued there might be a small event that can cause various operating violation in the system leading to several alarms appearing in

the control room. The operators do not have much time to react to these alarms and they have to address these alarms. The traditional system can be slow to provide the information is exact event and its location to operators. The Synchrophasor based Event Detection (SyncED) provides the type and location of the event in near real time. This gives the operator extra time to respond to a stressed system and avoid any blackouts.
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?
Question: Is there any other relative information that you can provide?
1. FDProSys: The following paper provides the background of the FDProSys algorithm and presented several case studies and scenarios on which this tool can be applied. B. Cui, A. Srivastava and P. Banerjee, "Automated Failure Diagnosis in Transmission Network Protection System Using Synchrophasors," in IEEE Transactions on Power Delivery. doi: 10.1109/TPWRD.2018.2823343 2. SyncED: The following Presentation provides the background of the SyncED algorithm. Data Mining Based Anomaly Detection In PMU Measurements and Event Detection, by P. Banerjee, S. Pandey, M. Zhou, A. Srivastava, Y.Wu, in JSIS Meeting, Salt Lake, Utah, May 2017.

B.5. University of Tennessee, Knoxville (UTK)

Question. Is your company using, planning to use, or have interest in synchrophasor-based apps to provide System Ops staff with data, info, or guidance about an electrical system disturbance (e.g. fault or failed equipment)?	
Yes	
Question. If your company is not using or planning to use such apps at this time but is interested in doing so in the future, please provide any feedback or insights you can offer as to what needs to happen before you can move forward. In other words, please let us know if are there specific issues that need to be resolved or actions that must be taken before you can introduce such applications to the control room environment.	
App Name:	1. FNET/GridEye Event Triangulation 2. Grid Monitoring-FNET/GridEye
App Objective:	1. FNET/GridEye Triangulation: FNET/GridEye Event Triangulation was designed to detect significant disturbance events in power grids, including generation trip, load shedding, low-frequency oscillation, islanding, etc.

	2. Grid Monitoring – FNET/GridEye: FNET/GridEye Event Triangulation was designed to detect significant disturbance events in power grids, including generation trip, load shedding, low-frequency oscillation, islanding, etc.
Type of Fault Info Provided:	1. FNET/GridEye Triangulation: The information provided by FNET/GridEye Event Triangulation includes: a. Event time b. Event location (latitude and longitude) c. Event type (generation trip, load shedding and etc.) d. Estimated interrupted MW. 2. Grid Monitoring – FNET/GridEye: This application provides the following fault information: a. As for the generation trip, we provide the power plant information or the estimated location information (if we cannot confirm which power plant is on fault), the MW estimation, and the system frequency behavior. b. As for the load shedding event, we provide the pump storage plant information or the estimated location information (if we cannot confirm which pump storage plant stops), the MW estimation, and the system frequency behavior. c. As for the line trip, we provide an alert information. Up to now, we cannot provide more information, such as where it is, or which type this fault is.
App Reqs:	1. FNET/GridEye Triangulation: a. PMUs installed in the monitored power grid i. Number of installed PMUs > 3 ii. In theory, FNET/GridEye Event Triangulation can detect power system events with data from only three PMUs in a power grid. To meet a satisfied accuracy, it requires more PMUs installed in a power grid. The reasonable number of PMUs deployed in a power grids is depended on the power grid territory size and locations of PMUs. b. Phasor Data Concentrator and communication network i. For a real time application, a Phasor Data Concentrator is required to collect PMU data as data input source for the FNET/GridEye Event Triangulation. A reliable communication network is also required to guarantee stable data transfer between PMUs and Phasor Data Concentrator. For an offline analysis, FNET/GridEye Event Triangulation compatible with different data sources, such as database, data files. c. C++ and Matlab running environments 2. Grid Monitoring – FNET/GridEye: We developed the highly accurate Frequency Disturbance Recorder (FDR) to measure the frequency, phase angle, and voltage of the power signal found at ordinary 120-V electrical outlets. Up to now, we have deployed more than 200 FDRs in main interconnection systems of North America. Their measurement data are continuously

	transmitted over the Internet to the FNET/GridEye server housed at the University of Tennessee.
App GUI Type:	1. FNET/GridEye Triangulation: Event Triangulation provides several ways to present information for user, including a detail event report, event location marked in a map, and frequency measurement diagram from different PMUs during events. As Event Triangulation has been integrated into FNET/GridEye system, users can also access Event Triangulation results via web-based GUI provided by FNET/GridEye system. 2. Grid Monitoring – FNET/GridEye: Here is an example of our web-based GUI system. http://powerit2.eecs.utk.edu/eventreport.php?eventid=16940&type=2&AuthCode=Ox2038A1AE
App Provider:	1. FNET/GridEye Triangulation: Power IT Lab in the Department of Electrical Engineering and Computer Science at the University of Tennessee. 2. Grid Monitoring – FNET/GridEye: We developed this application by ourselves.
App Software:	1. FNET/GridEye Triangulation: Event Triangulation is in-house development and patented in U.S. 2. Grid Monitoring – FNET/GridEye: Our application is in-house development. We also use some open source to manage our streaming data.
App Users:	1. FNET/GridEye Triangulation: Researchers in University of Tennessee at Knoxville 2. Grid Monitoring – FNET/GridEye: Unknown
Current State:	1. FNET/GridEye Triangulation: Event Triangulation application has been operating on FNET/GridEye system for more 10 years. 2. Grid Monitoring – FNET/GridEye: This application has been running for many years.

Question: Does the app have the ability to integrate with other Real-time monitoring systems?

1. FNET/GridEye Triangulation: Event Triangulation is able to integrate with any system as long as accurate synchronous dynamic frequency data is available.
2. Grid Monitoring – FNET/GridEye: Unknown. Up to now, no further testing to integrate with other Real-time monitoring systems has been done.

Question: If the app is operational, where is it being used and by whom? If it is not operational, what is the timeline for becoming operational?

1. FNET/GridEye Triangulation: Event Triangulation results are used for analysis and research. Besides, it also provides an event report to utilities or ISOs upon their requests.
2. Grid Monitoring – FNET/GridEye: FNET/GridEye server is now housed at the University of Tennessee and the Oak Ridge National Laboratory (ORNL).

We are not familiar with how to put our application into Real-time Operation Horizon. Up to now, we sent the alert by email. Maybe in the further, the alert and all information can be integrated with EMS.
Question: What's the value add from using the app in the Real-time operating environment?
1. FNET/GridEye Triangulation: FNET/GridEye Event Triangulation application provides an effective approach for power grid situation awareness monitoring in real-time operation. One of successful example of Event Triangulation application is deploying on FNET/GridEye system at University of Tennessee at Knoxville. FNET/GridEye, a wide area monitoring system, is consisted of more than 200 PMUs over the world. Based on FNET/GridEye system, Event Triangulation is able to detect major power grid disturbance events in U.S. in real-time. 2. Grid Monitoring – FNET/GridEye: All event alerts are sent out through emails in real time to our subscribers, with information including event type, estimated trip amount and location. They may use this valuable information to guide their operations.
Question: If the app is not in operational use yet, can it be operationalized and how can that be achieved?
Question: Is there any other relative information that you can provide?
1. FNET/GridEye Triangulation: Following are some references related to FNET/GridEye Event Triangulation and FNET/GridEye system: [1]. T. Xia et al., "Wide-area Frequency Based Event Location Estimation," 2007 IEEE Power Engineering Society General Meeting, Tampa, FL, 2007, pp. 1-7. [2]. Wei Wang, L. He, P. Markham, H. Qi and Y. Liu, "Detection, recognition, and localization of multiple attacks through event unmixing," 2013 IEEE International Conference on Smart Grid Communications (SmartGridComm), Vancouver, BC, 2013, pp. 73-78. [3]. S. You et al., "Disturbance location determination based on electromechanical wave propagation in FNET/GridEye: a distribution-level wide-area measurement system," in IET Generation, Transmission & Distribution, vol. 11, no. 18, pp. 4436-4443, 12 21 2017. [4]. Y. Liu et al., "A Distribution Level Wide Area Monitoring System for the Electric Power Grid–FNET/GridEye," in IEEE Access, vol. 5, pp. 2329-2338, 2017. More info about FNET/GridEye system can be found at following link: http://fnetpublic.utk.edu/ 2. Grid Monitoring – FNET/GridEye: Some video demonstrating our detected events can be found in https://www.youtube.com/channel/UC40n2KTjwRhC9_CvtIasaWA Some papers published by your organization are listed below. [1] R.M. Gardner, J.N. Bank, J.K. Wang, A.J. Arana, and Y. Liu, " Non-Parametric Power System Event Location Using Wide-Area Measurements," in 2006 IEEE Power and Energy Society General Meeting, 2006, pp. 1-8. [2] T. Xia, H. Zhang, R. Gardner, J. Bank, J. Dong, J. Zuo, Y. Liu, L. Beard, P. Hirsch, G. Zhang, and R. Dong, "Wide-area Frequency Based Event Location Estimation," in 2007 IEEE Power and Energy Society General Meeting, 2007, pp. 1-7.

[3] R. Gardner, J.K. Wang, and Y. Liu, "Power System Event Location Analysis Using Wide-Area Measurements," in 2006 IEEE Power and Energy Society General Meeting, 2006, pp. 1-7.

[4]Y. Ye and Y. Liu, "Monitoring power system disturbances based on distribution-level phasor measurements," in Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES, 2012, pp. 1-8.

[5] Jingyuan Dong, "Power system disturbance analysis and detection based on wide-area measurements". Virginia Polytechnic Institute and State University, Dec. 10, 2008.

[6] D. Zhou, Y. Liu, and J. Dong, "Frequency-based real-time line trip detection and alarm trigger development," 2014, pp. 1-5.

[7] Z. Lin, T. Xia, Y. Ye, Y. Zhang, L. Chen, Y. Liu, K. Tomsovic, T. Bilke, and F. Wen, "Application of wide area measurement systems to islanding detection of bulk power systems," IEEE Trans. Power Systems, vol. 28, no. 2, pp. 2006-2015, May. 2013.

[8] Y. Zhang "Frequency Monitoring Network (FNET/GridEye) Data Center Development and Data Analysis" PhD dissertation, Dept. Elect. Eng., University of Tennessee, Knoxville, TN, 2014.