Using Synchrophasor Data during System Islanding Events and Blackstart Restoration

NASPI Control Room Solutions Task Team Paper

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Acknowledgments

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Background

The North American Synchrophasor Initiative (NASPI) is a collaborative effort between the U.S. Department of Energy, North American Electric Reliability Corporation (NERC), 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.

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 the following areas of interest and determine if value can be added in the near future by using synchrophasor data and applications: enhanced state estimation, phase angle monitoring, oscillation detection, system islanding detection and blackstart restoration, determining disturbance locations and voltage stability assessment. Existing versions of these 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 explores the value that can be added in the near future by using synchrophasor data and applications in the areas of system islanding detection and blackstart restoration. It includes descriptions of:

- Related functional entity roles and responsibilities
- Ways that synchrophasor technology may be used to detect islanding events and aid entities in meeting certain restoration objectives
- Related commercial applications that are currently on the market for which the NASPI CRSTT received information from application users or vendors

This paper may be updated in the future to include additional applications, functionality and methodologies as new information is provided.

2 Functional Entity Roles and Responsibilities

When an event results in an emergency condition that requires automatic or immediate manual action to prevent or limit the failure of transmission Facilities or generation supply, certain functional entities must coordinate with adjacent parties to ensure the appropriate actions are taken to alleviate the unacceptable condition and return to normal operation in a timely manner.

In accordance with applicable NERC Reliability Standards, these entities must prepare for unlikely but critical conditions to reduce the risk of non-performance. Specifically, the NERC Emergency Operations and Preparedness (EOP) Standards require entities to:

- Develop, maintain and implement a set of plans to mitigate operating emergencies
- Prepare to address capacity and energy emergencies
- Shed load rather than risk an uncontrolled failure of the Interconnection as a result of insufficient generation or transmission capacity
- Report certain types of events to the Electric Reliability Organization and other appropriate parties
- Prepare to enable system restoration from Blackstart Resources to assure reliability is maintained during restoration and priority is placed on restoring the Interconnection
- Mitigate the effects of geomagnetic disturbances events by implementing Operating Plans, Processes and Procedures

The majority of NERC Reliability Standard requirements related to electrical system islanding and system restoration can be found in NERC Standards *EOP-005-2 – System Restoration from Blackstart Resources* and *EOP-006-2 – System Restoration Coordination.*[1]

2.1 NERC Standard EOP-005-2 – System Restoration from Blackstart Resources

The purpose of this standard is to:

- Ensure plans, Facilities, and personnel are prepared to enable System restoration from Blackstart Resources
- Assure reliability is maintained during restoration
- Assure priority is placed on restoring the Interconnection

The majority of requirements found in this standard are applicable to the Transmission Operator (TOP) and Generator Operator (GOP) functions although some requirements are applicable to Distribution Providers (DP) and Transmission Owners (TO) that are identified in the TOP restoration plan.

In summary, this standard requires each TOP to have a restoration plan that allows for restoration of the TOP's System following a Disturbance in which one or more areas of the Bulk Electric System (BES) shuts down and the use of Blackstart Resources is required to restore the shut down area to service.

These restoration plans must:

- Be approved by the Reliability Coordinator (RC) of each TOP
- Include strategies for system restoration that are coordinated with the RC's high level strategy for restoring the Interconnection
- Identify acceptable operating voltage and frequency limits to be applied during restoration
- Include Operating Processes for restoring Loads required to restore the System and reestablishing connections

[1] This paper focuses on the NERC Standard EOP-005-2 and EOP-006-2 requirements since they are the most relevant to control room operations. This paper does not address NERC standard requirements for the reporting of system islanding or operational failure or shut down of the electrical system (EOP-004-2), identification and assessment of islands that serve as a basis for Underfrequency Load Shedding Schemes (PRC-006-1), or notification to Generator Owners and Transmission Owners of Elements that form the boundary of an island (PRC-026-1).

The restoration plan must include:

- Minimum criteria for meeting the objectives of the plan
- Operating processes for restoring the Interconnection
- Descriptions of elements of coordination between individual TOP restoration plans
- Criteria and conditions for reestablishing interconnections between TOPs

2.2 NERC Standard EOP-006-2 – System Restoration Coordination

This standard is applicable to the RC function only.

The purpose of this standard is to ensure:

- RC Area restoration plans are established
- Personnel are prepared to enable effective coordination of the System restoration process to ensure reliability is maintained during restoration and priority is placed on restoring the Interconnection

In summary, this standard requires each RC to have an RC Area restoration plan that starts when one or more of the following situations occurs:

- Blackstart Resources must be utilized to re-energize a shut down area of the BES
- Separation has occurred between neighboring RCs
- An energized island has been formed on the BES within the RC Area.

The scope of the RC's restoration plan ends when all of its TOPs are interconnected and its RC Area is connected to all of its neighboring RC Areas.

3 Overview of Synchrophasor Technology

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

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

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

4 Using Synchrophasor Data during Islanding Events and System Restoration

As described in the previous section, the RC and TOP functions are responsible for identifying events that result in electrical system islanding or an area of the BES shutting down and initiating restoration activities as appropriate. In order to meet applicable requirements, these entities must identify when such events occur; analyze the potential cause and resulting system conditions; determine actions that must be taken to return the system within acceptable operating parameters; and execute and coordinate these actions with other entities as necessary to restore the system to normal operation.

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[2] Refer to the *Synchrophasor Fact Sheet* dated October 2014 for additional information about synchrophasor technology and its uses: https://www.naspi.org/documents

There are several ways in which synchrophasor data can provide value during islanding events and blackstart restoration:

Detecting System Islanding Events – real-time synchrophasor data may be used to identify conditions where frequency and voltage angle changes are not in synchronism across the system indicating that an islanding event may have occurred.

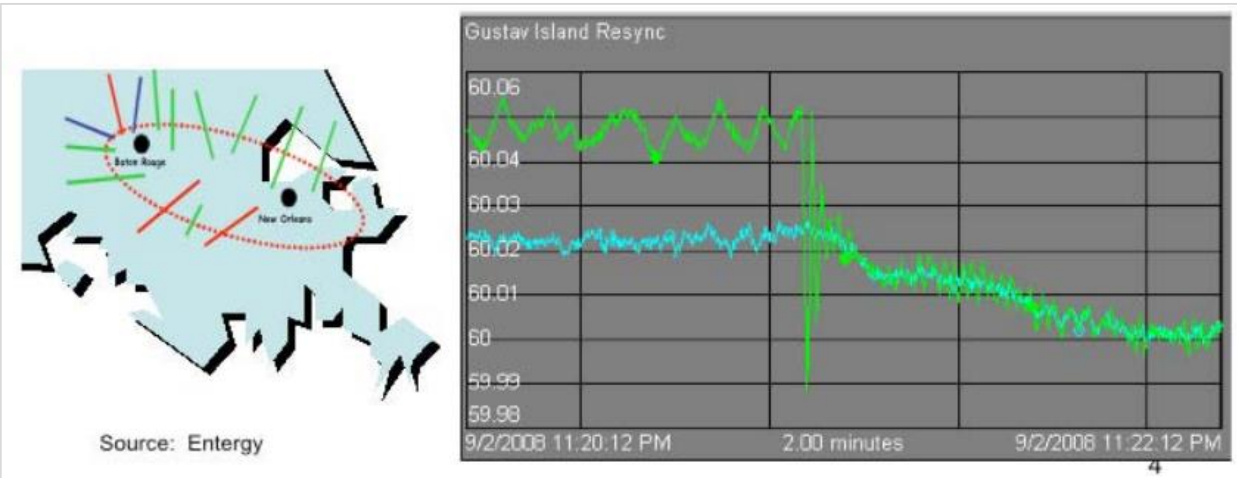
Analyzing Cause and Resulting System Conditions – since synchrophasor data is time-stamped, synchronized and sampled at a much higher rate than SCADA data, it can be used quickly to determine the sequence of events and identify possible causes. This highly granular, time-specific information can prove extremely useful during restoration events and, depending on the nature and severity of the event, may allow the operator to isolate failed Facilities and return the system to a reliable state more quickly than might be possible using SCADA data alone.

Returning the System within Acceptable Parameters – following a major Disturbance, operations personnel must assess the status of generation and transmission Facilities that remain energized to determine if unacceptable operating conditions exist. Failing to stabilize portions of the system that remain operational may result in significant equipment damage and widespread outages. Synchrophasor data can be used to quickly assess post-event conditions and determine risk. Specifically, this data may be used to detect and address power system oscillations and voltage instability.

Determining Restoration Activities – when an RC and its impacted TOPs implement their respective restoration plans, they must ensure their activities to restore shut down areas to service and parallel electrical islands to the main grid are coordinated and do not jeopardize the overall objective of returning the system to a reliable state. Synchrophasor data can be used to more accurately assess the impact such actions may have to system voltage and frequency. The use of this data to detect power system oscillations and potential voltage stability issues resulting from restoration activities may also prove useful.

Entergy's use of PMU data and analytical tools after Hurricane Gustav struck the Gulf Coast in 2008 provides an excellent example of how synchrophasor technology can be used during islanding events and system restoration. After the hurricane struck the area, so many of Entergy's transmission lines were damaged that an electrical island was formed within the heart of the service territory. Entergy's SCADA system did not detect this island, but its phasor data system revealed its existence by showing two distinct frequency plots.

Once they recognized that their planned service restoration activities would compromise the operational integrity of the island, Entergy reevaluated and redesigned its restoration plan. The utility then used its phasor system to observe both the island and the rest of its service territory, watching the two frequency lines (as shown in the figure below), as it executed a new restoration and synchronization plan that successfully resynchronized the island 33 hours later.[3]



[4]

The remaining section of this paper describes some of the synchrophasor-related commercial applications that are currently on the market. As previously stated, this paper describes applications for which the NASPI CRSTT received information from application users or vendors and may be updated to include additional applications if new information is provided. Screen captures from the applications are included as reference at the end of the document.

[3] See NERC Report titled *Real-Time Application of Synchrophasors for Improving Reliability* dated 10/18/2010: http://www.nerc.com/docs/oc/rapirtf/RAPIR%20final%20101710.pdf

5 Commercial Synchrophasor Applications for Islanding Detection and Blackstart Management

The detection of electrical islands is not trivial especially for operations personnel who are new to the desk and not familiar with the history and detailed workings of the grid they are operating. Using real-time synchrophasor data, the advanced applications can identify situations where frequency and voltage angle changes are not in synchronism with the surrounding electrical system and send alarms to the operators to provide them with better situational awareness than SCADA alone can provide. Due to the synchronized nature of the synchrophasor data being presented, using these applications gives the operator the ability to better manage reconnection activities when restoring the island and tying it back into the main grid.

No application stands alone. Every application has some hardware, software, visualization and telecommunications requirements. Each of the islanding detection and blackstart management applications discussed below requires the following elements to function effectively:

- At a minimum, real-time PMU data that allows for monitoring of key generation and load centers on either side of those natural break points in the region or Interconnection. The application can be expanded as additional PMUs are deployed and the TO gains experience with the application
- Frequency and voltage data (magnitudes and angles) are needed for the application to properly monitor the system.
- Phasor Data Concentrator (PDC)
- Robust and reliable communications infrastructure from the PMU to the control center PDC. If restoration management tools are envisioned, low latencies in data exchange between the PMU and control center are also required.
- Visualization application
- Islanding detection algorithms
- Restoration tools (monitoring frequency and voltage angle differences)
- Eventually, direct restoration controls are a possibility where the application decides when to reconnect the islands and issues the necessary controls. This could require additional security measures be applied at the PMU level, PDC level, network level, etc.

These applications have specific data requirements as well:

- Real-time synchrophasor data (30 samples per second or greater) from all significant generating stations and load centers that could potentially operate as part of an islanded system. Data from geographically close stations may be adequate but depending on the islanding mode it may not be sufficient to properly identify an islanded system.

- At minimum frequency, delta frequency, voltage magnitude, and voltage angle are required. Positive sequence data at minimum. Phase voltage data can also be used if available.
- SCADA data (2-4 second scan rates) may also be used to enhance visibility for stations where PMU data is not available.

Each of these applications enables tools for islanding management for operations that are not available using SCADA-only information. Because islanding and blackstart events occur infrequently, operators and support staff must receive training to ensure a common understanding of the data presented and how to use the tool. These tools and their operator interfaces should be automated and integrated into existing systems for display and alarm purposes, to enable operators and support staff to identify and manage the event challenge immediately rather than having to wrestle with managing the data and analytical processes as well as the event.

Using these applications offers specific benefits in the real-time operating environment:

- Synchrophasor-based applications can provide real-time operations staff with dynamic system operating information pertaining to an event that is not available using traditional SCADA scan rates, such as:
  - Notification that an islanding event has occurred in the region or Interconnection
  - The location in the region or Interconnection the islanding has occurred
  - Whether an island has excessive generation or is deficient (high or low frequency)
- Synchrophasor-based applications allow the Transmission Owner to be proactive in monitoring the grid and also enable the ability to identify actual islanding events that may not be obvious to less experienced operations personnel.
- Synchrophasor-based applications provide an interface to monitor island performance and assist with resynchronization of the island to the system.

There are four commercial islanding detection and blackstart management tools discussed below.

5.1 Alstom (Psymetrix) – PhasorPoint

1. Current status of the application

- Globally implemented product with users in Australia, Iceland, UK, Canada (Manitoba Hydro, AESO), Columbia, and USA (WECC, MISO, ATC, MP). Will be implemented as part of a recently announced India smart grid project involving 1300 PMUs. (http://www.alstom.com/press-centre/2014/2/alstom-achieves-a-new-milestone-for-indias-secure-electrical-grid/)
- Uses range from after-the-fact analysis to real-time oscillation monitoring to islanding detection and disturbance monitoring.
- Mature product with broad user base should encourage further tool development

2. Application software (open source, proprietary)

PhasorPoint was developed by Psymetrix and in 2012 purchased by Alstom to reinforce its smart grid capabilities. The code is proprietary.

3. Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI)

PhasorPoint can be integrated with the Alstom EMS/SCADA system to allow the exchange of alarms and limited synchrophasor data. Additional connectivity is available between PhasorPoint and Alstom's eterraVision application. PhasorPoint has its own local PDC which can store full fidelity PMU scan data for a configured time period. After that period is over the data is down-sampled and stored in long term archives to reduce storage requirements. The system also has a snapshot feature that stores full fidelity PMU data "permanently" until manually removed from the system.

4. Type of application GUI

- Stand-alone application with dynamic visualization presentation capabilities. Historical and real-time trending capabilities also exist and alarming for violations and user defined events is available.

5.2 OSIsoft PI Systems

1. Current status of the application

   - Standard display capabilities in ProcessBook can be used to develop wide area overviews and situational awareness displays.
   - In house tools need to be developed to identify islands, alarm, etc.
   - Already used by many utilities so base tools may already be available and just need to be further developed.

2. Application software (open source, proprietary)

   OSIsoft PI Systems base functionality is proprietary but displays and algorithms developed by end users could be open sourced if desired.

3. Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI)

   OSIsoft PI Systems can integrate with many EMS vendors through defined interfaces developed by OSIsoft. These interfaces allow data to flow to and from most EMS vendor applications.

4. Type of application GUI

   - User configurable displays available for situational awareness overviews and trending.

5.3 EPG – Real-Time Dynamics Monitoring System

1. Current status of the application(s)

   - The application is being used at ERCOT, NYISO, PJM, Duke Energy, Dominion Virginia Power, CAISO, SRP, ConEd, AEP, LCRA, LADWP.
   - User configurable displays available with multiple charting options (line, bar, scatter, gauge, etc..) and alarming capabilities

2. Application software (open source, proprietary)

   EPG RTDMS code is proprietary.

3. Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI)

   RTDMS can integrate with historical data systems and SCADA systems using DNP3. It can also integrate with OSIsoft PI systems.

4. Type of application GUI

   - Canned tile layout display consists of line chart, bar chart, multi Y axis trend chart, scatter chart, gauge chart, etc.
   - User configurable displays
   - Sample screen capture shown in the last two page table:
     - Islanding detection from automated event analyzer on geospatial map
     - Drill down in automated event analyzer to show detail info
     - Island re-synchronization display

5.4 SEL – SynchroWAVe Central

1. Current status of the application(s)

   - Real-time and historic synchrophasor visualization application with an installed base world-wide.
   - Applications range in size from local generation monitoring with a signal PMU to wide-area monitoring with more than 100 PMUs.

2. Application software (open source, proprietary)

   SEL SynchroWAVe Central code is proprietary.

3. Applications ability to integrate with EMS/SCADA systems or data historians (e.g. PI)

   SEL SynchroWAVe Central supports multiple C37.118 data stream inputs.

4. Type of application GUI

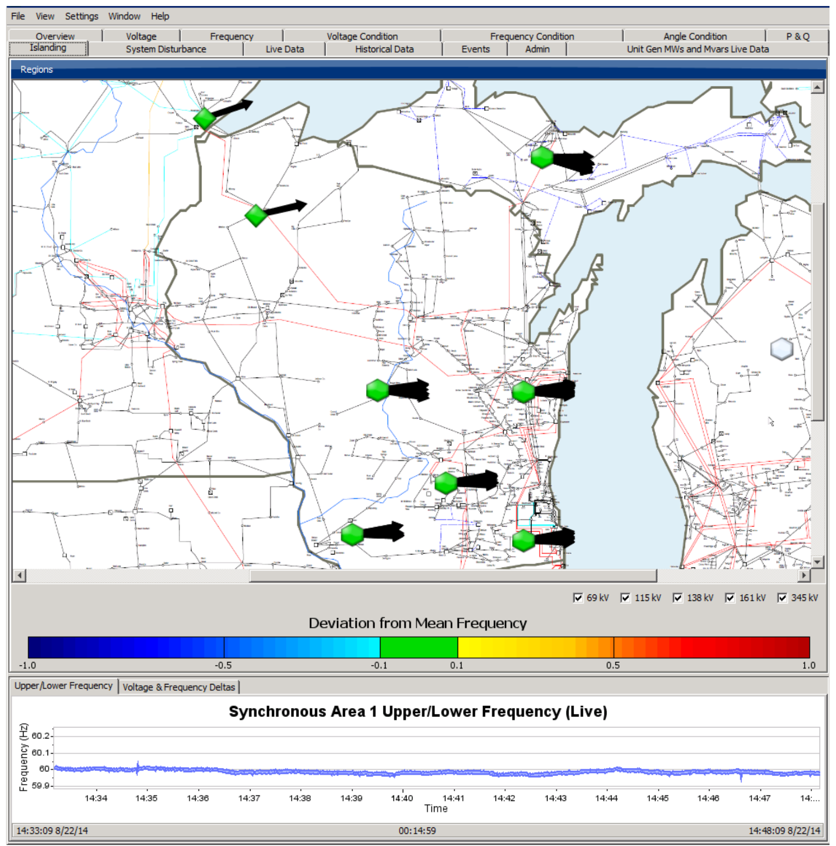
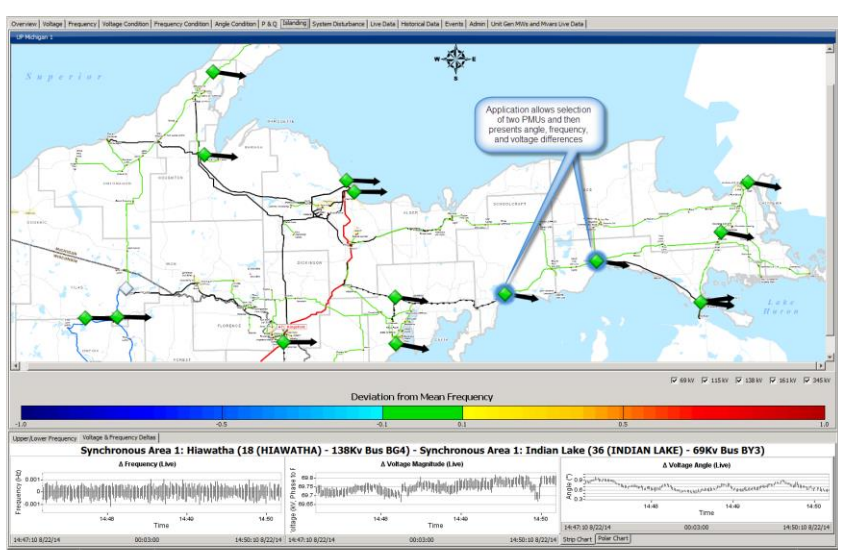
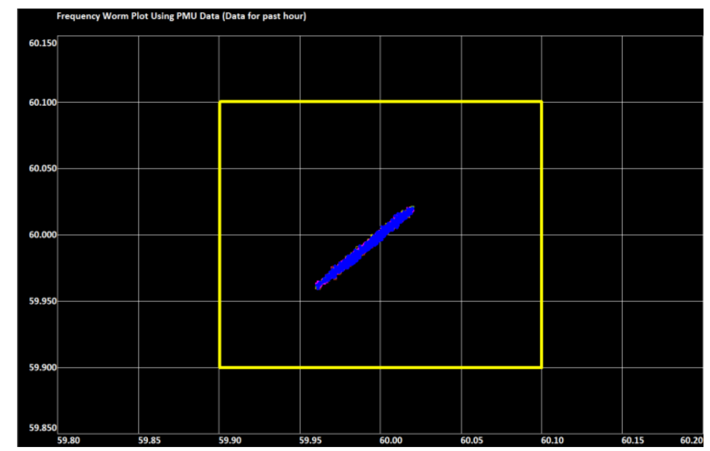
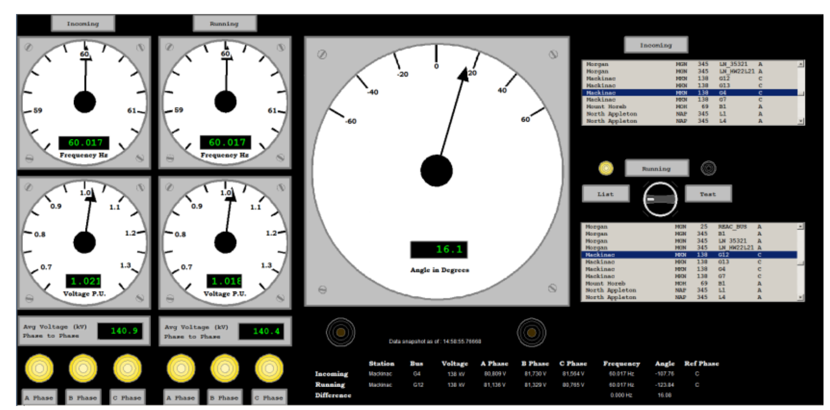
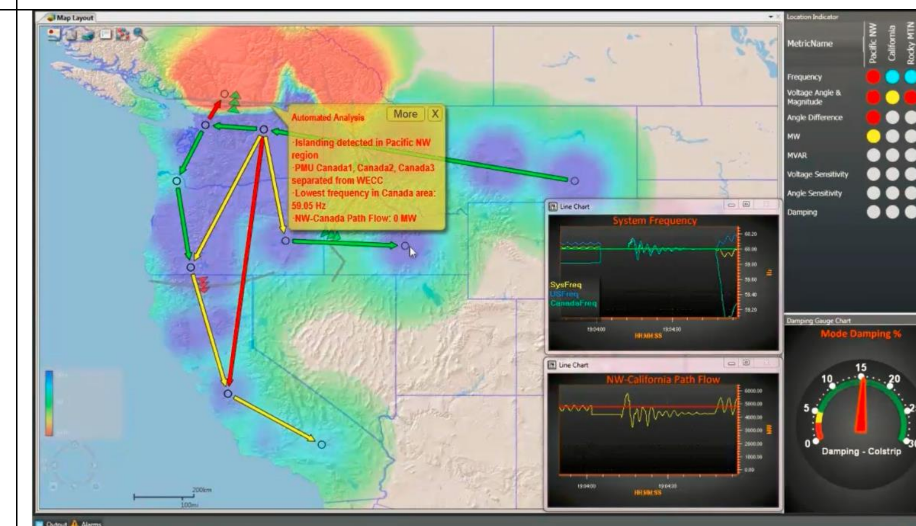
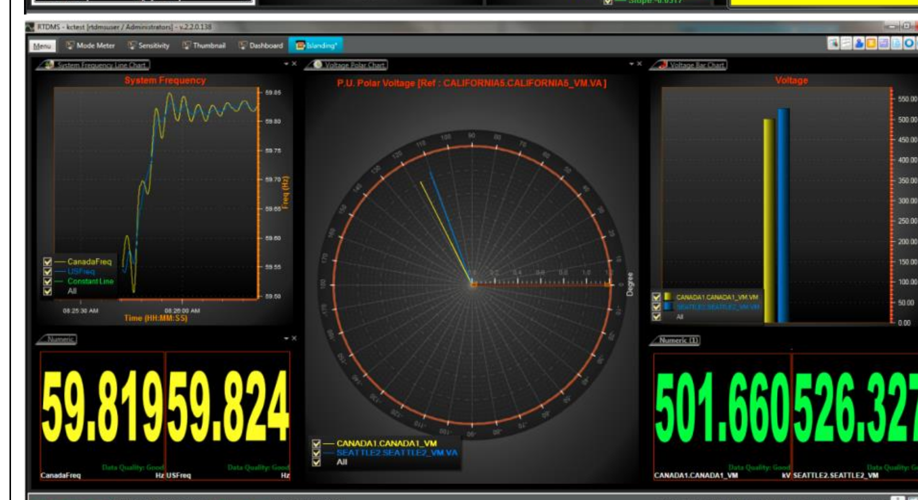
   - Server\Web-client application for easy access and sharing of customizable displays.

NASPI North American SynchroPhasor Initiative

Glossary of Acronyms

Acronym	Definition
AESO	Alberta Electric System Operator
ATC	American Transmission Company
BA	Balancing Authority
BES	Bulk Electric System
CAISO	California Independent System Operator
CRSTT	Control Room Solutions Task Team
DNP	Distributed Network Protocol
DP	Distribution Provider
EEA	Energy Emergency Alert
EOP	Emergency Operations and Preparedness
EPG	Electric Power Group
EMS	Energy Management System
ERCOT	Electric Reliability Council of Texas
FRCC	Florida Reliability Coordinating Council
GO	Generator Owner
GOP	Generator Operator
GPS	Global Positioning System
LADWP	Los Angeles Department of Water and Power
LCRA	Lower Colorado River Authority
MISO	Midcontinent Independent System Operator

Acronym	Definition
MP	Minnesota Power
NASPI	North American Synchrophasor Initiative
NERC	North American Electric Reliability Corporation
NYISO	New York Independent System Operator
PDC	Phasor Data Concentrator
PJM	PJM Interconnection, LLC
PMU	Phasor Measurement Unit
RC	Reliability Coordinator
RTDMS	Real-Time Dynamics Monitoring System
SCADA	Supervisory Control and Data Acquisition
SEL	Schweitzer Engineering Laboratories
SRP	Salt River Project
TO	Transmission Owner
TOP	Transmission Operator
WECC	Western Electricity Coordinating Council

Alstom PhasorPoint	OSIsoft PI Systems	EPG RTDMS
 	 	  

SEL SynchroWAVe Central