EPG Products Update

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May 31, 2019
JSIS Meeting
Outline

- EPG Applications Portfolio
- Products Overview, New Features & Functions
  - RTDMS – Real-time Monitoring and Wide-area Situational Awareness
  - PGDA – Offline Analytics
  - eLSE – enhanced Linear State Estimator
  - AEM – Automated Event Mining
  - GPV - Generator Parameter Validation
- EPG Projects and Research Initiatives
- Summary
- Questions
# EPG Applications Portfolio - End to End Synchrophasor Solutions

## Phasor Data Management

<table>
<thead>
<tr>
<th>Collection &amp; Synchronization</th>
<th>Storage</th>
<th>Integration</th>
<th>Validation &amp; Conditioning</th>
</tr>
</thead>
</table>

### Substation PDC

### Control Center PDC

## Real-Time Analytics, Monitoring & Reports

- **Analytics**
- **RTDMS**
- **Monitoring**
- **Reports**

## Linear State Estimation

- **GridSmarts**

*enhanced Linear State Estimator*

## Grid Resiliency

- **PhasorNXT Platform**

## Offline Analytics Platform

- **Phasor Grid Dynamics Analyzer**
- **Automatic Event Miner**
- **Generator Parameter Validation**
- **Phasor Data Extractor**

## Training

- **Phasor Simulator For Operator Training**
- **Big Data Analytics**
- **Synchrophasor Training Courses**

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RTDMS

Real-Time Monitoring and Wide-area Situational Awareness
RTDMS Applications
Real Time Control Center Use

1. Wide Area Situational Awareness - Dashboard
2. Oscillation Detection & Monitoring
3. Phase Angle and Grid Stress Monitoring
4. Automated Event Analyzer
5. Voltage Sensitivity Monitoring
6. Frequency Stability Monitoring
7. Inter-area Power Transfer
8. Generation Trip Detection
9. Islanding Detection
10. Intelligent Alarms with Composite Logic
   > Example: Contingency Alarm such as for N-1, N-2 conditions, etc.
11. GridSmarts - Reports
   > Event List for the last 24 hours (i.e. Intelligent Alarms)
   > Comparison of Intertie flows between yesterday and today
Key Use Case Examples of RTDMS

- Phase Angle Monitoring
- Oscillation Detection & Monitoring
- Wide Area Situational Awareness
- Islanding Detection & Line Reclosing
- PMU Performance Reports
- Grid Resiliency

RTDMS

Geo-Spatial
One-Lines
Reports – Grid Performance, PMU Performance and Data Quality

Daily Summary showing Frequency, Voltage, PMU Quality, Alarms, Angle Statistics

- 24-Hour Tend
- Oscillation
- Comparison with prior day
- Voltage Profile
- Top Events
- Phase Angle Statistics

Daily Data Quality
New Features and Functions – 2020 Roadmap

- Oscillation Source Location (Dissipating Energy Flow Method)
  - RTDMS currently has Mode Meter and Oscillation Detection from Dan Trudnowski & Matt Donnelly (Montana Tech)
  - Plan to integrate Energy Flow Analytic in RTDMS - developed by Dan Trudnowski & Matt Donnelly

- User-defined Calculations and Alarms
  - Symmetrical Components
  - V2/V1 - Monitoring Voltage and Current Unbalance
  - Line Parameter Estimation
  - V/f Monitoring for generators
  - Others

- Event Analyzer Displays – Customization
  - Provide predefined templates for different event types
  - Automatically provide key information to operators following an event

- Islanding Detection & Resynchronization
  - Multiple Islands
  - Automated Resynchronization Displays

- Online Inertia Estimation using PMU Data (Prototype and Testing)
PGDA Features and Capabilities

Data Engine
- Data Merging
- Data Handling – Multiple Data Sources
- Pseudo Signal creation
- Save and Re-produce analysis
- Event Templates
- Advanced Data Conditioning Filters

Data Sources
- Databases
- Data Files

Statistical Analysis
- Baseline Daily Performance Ranges
- Identify & Locate hidden events

Sensitivity Analysis
- Quantify Variation of one metric over another (kV/100MW)
- Identify stressed locations

Plot Analysis
- Plot metrics over time
- Signal manipulation i.e. Normalize voltage by basekV
- System Model Validation, Report

Ringdown Analysis
- Oscillation Detection Tool under system dynamic conditions
- Provides Modal Frequency & Damping
- Provides Magnitude of Modes and Nature of Oscillations

Ambient Modal Analysis
- Sustained Oscillation Detection Tool
- Provides Modal Frequency
- Provides Damping
- Provides Energy

PGDA Report
- Automated Report Generator
- Word, PDF

Fault Analysis
- Fault Location
- Voltage and Frequency Ride Through
- Mho Characteristics

Significant peaks signify oscillatory modes
Identify & group location with similar oscillation patterns
Identify Nature of Oscillations

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Use Case Examples: Event Analysis To Support Planning and Operations

Oscillation Root Cause
- ERCOT, 2.7 Hz - West Texas
- ERCOT, 1.9 Hz - West Texas
- 5th Order - Control Systems
- 3rd Order, 8th Order - Control Systems
- 2nd Order, 1st Order, 2nd Order - Control Settings

Fault Analysis

Validation Models & State estimators

Model Validation – NERC MOD-033-1

NERC MOD-033-1

Fault Analysis

Identification of Renewables on Frequency Response

Fault Analysis

Phasor Grid Dynamics Analyzer (PGDA)

Grid Event Signatures

Impact of Renewables on Frequency Response

Identify Alarm Parameters

Grid Event Signatures

Generator Response

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PGDA Report for Operators, Planners & Trainers

Event Summary

Plot Analysis

Modal Analysis

Spectral Analysis

Summary

Data Source

Data Source:

Data Source:

Data Source:

Data Source:

Notes

This analysis examines the voltage magnitude and phase angle historical data over a specific period. The data includes historical measurements of voltage magnitude and phase angle at various locations. The data is used to identify trends and patterns in the electrical system.

Plot Analysis

This plot shows the historical data for voltage magnitude and phase angle at a specific location. The data is color-coded to represent different time periods. The plot allows for a visual analysis of voltage variations over time.

Modal Analysis

This analysis examines the modal characteristics of the electrical system. The data includes measurements of frequency and damping ratio for different modes. The modal analysis helps in understanding the dynamic behavior of the system.

Spectral Analysis

This analysis examines the spectral content of the electrical signals. The data includes measurements of frequency content and phase angle over a specific period. The spectral analysis helps in understanding the frequency domain characteristics of the system.
New Features and Functions

- New Features in PGDA 4.0 (2018)
  - System Model Validation – Automation, Quantify Mismatch, Reporting
  - Automated Searcher Function – Fast Analysis to find Key Event Information
    - Oscillation Analysis – Spectral and Ringdown Analysis
    - Event Analysis – Generation Trip, Line Trip, Faults etc.
  - Fault Analysis
    - Symmetrical Components
    - Fault Location
    - Mho Characteristics, Distance Relay Performance
    - Fault Ride Through – Frequency and Voltage
  - Phasor Converter (Point-on-wave to Phasors)

- Planned
  - Oscillation Source Location
  - User-defined Algorithms
  - Inertia Estimation
eLSE – enhanced Linear State Estimator

Extended Grid Visibility and Grid Resiliency
Linear State Estimation Using Synchrophasors

**eLSE: EPG’s enhanced Linear State Estimator (eLSE)**

Next generation technology made possible by synchrophasor data

- Expanded Visibility
- Pseudo PMUs
- Identify Model Errors
- Linear: Always solves
- Much faster, can track transients, not feasible with SCADA
- Accurate
- Replace Bad Data with calculated values
Addresses Practical Issues of Transmission Grid

- Provision for series capacitors
- Shunt capacitor/reactor
- Split bus
- Consistent naming convention
- Bypass breaker modeled on the line
- Multiple transmission line segments

- Bad data detection and identification module

- Can operate in individual observable islands

Automated Model Builder

- Parse CIM to LSE Model
- Mapping PMU Signal to LSE Model
- GUI, Model Maintenance & Management

- Integrated Breaker and Switch status via ICCP

- One Line Diagram Integration with RTDMS platform to show both PMU data as well as eLSE results

- Runs at fast speed – 30 or 60 frames/second

- Deployed and in use at several large ISOs and RCs since 2015
## Examples of eLSE Deployments

<table>
<thead>
<tr>
<th>Use Cases</th>
<th>BPA</th>
<th>Duke</th>
<th>SCE</th>
<th>ERCOT</th>
<th>PEAK</th>
<th>PJM</th>
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<td>Deployment</td>
<td>Months of Operation</td>
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<td>Resiliency with PhasorNXT</td>
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eLSE Extended Visibility to 52 Substations at SCE

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<tr>
<th>Elements</th>
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<td>PMU</td>
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<td>Phasor Measurements</td>
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<td>Substations with PMUs</td>
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<tr>
<td>Estimated Substations</td>
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<td>Total Substations (500kV and 230kV)</td>
<td>52</td>
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<tr>
<td>Lines</td>
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<tr>
<td>Transformers</td>
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<td>Nodes in Model</td>
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<td>Breakers</td>
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<td>Switches</td>
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<td>Series Capacitors</td>
<td>12</td>
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<tr>
<td>Shunt Capacitors</td>
<td>41</td>
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</table>
Use eLSE as Platform for Synchrophasor Applications including

- RTCA
- Cascading Analysis
- Voltage Stability Assessment
- Area Angle Monitoring
- Other DSA applications
Need for Automated Event Mining

- Large amounts of synchrophasor data is being collected (Months, Years)
- Not practical to manually go through large data sets and identify significant events of interest
- Assist planning and operation engineers to automatically mine large mounts of historical data to perform
  - Data quality analysis
  - Event detection & reporting
    - Frequency excursion – Gen trip, Line fault, Load Loss
    - Low Voltage - Faults/Metering Problem, Low Voltage, Extended Low Voltage
    - Angle Pairs - Angle pair disturbance, Grid Stress
    - Customized event (Composite event, Customized algorithm)
  - Statistics analysis for system baselining and setting alarm thresholds for real-time monitoring
- Identify repeated events/patterns
  - System Events, Equipment Issues
  - Bad PMU data quality including device calibration issues
- Build event library based on Historical Data
- Integration with Offline Analysis Application for detailed event analysis
- Event Reporting
Automated Event Mining Process

Used AEM and generated reports for
- CAISO, ERCOT, SPP, GETCO (India), OETC (Oman)

PGDA Integration for detailed event analysis
Methodology

- Read event files
- Detect the event
- Identify the event root causes
- Generate report

**Frequency Event**
- Fault/Line Trip
- Generation Loss
- Load Loss

**Low Voltage Event**
- Faults/Metering Problem
- Low Voltage
- Extended Low Voltage
- Extreme Time Low Voltage

**Oscillation Event**
- Speed Governor
- Inter-area Oscillations
- Local Plant Control Systems
- Controllers

**Angle Pair Event**
- Local Angle Pair Disturbance
- Wide Area Angle Pair Disturbance

**Mining data information**
- Date range
- Number of signals

**Detection**
- Algorithm
- Threshold

**Mining statistical result**
- Count of Events
- Lowest point
- Duration
- Signal with the most events

**Data quality statistics**
- Percentage of the good data
- Percentage of the missing data
- Root causes
Automatic Generation of Summary Report and Detailed Report
Generator Parameter Validation
PMUs provide great opportunity to validate power system models without taking equipment offline.

Current Capability – Validate and Calibrate Generator Models Offline using PMU data.

Extended Capability to Validate generator models automatically whenever there is a significant system event.

Generate Model Validation Report for MOD-26 and MOD-27 compliance using PMU data.
  > Individual Report for each event
  > Summary report for overview of generator performance

Automatically identify questionable models using several criteria – RMS Deviation, Correlation & Similarity* etc.

Email Report based on user configuration and settings.

Process

Data Concentration

Detect & Record Events

PMU Data file

PMU Data from Generators

PDC

Event Recorder

GPV

Power Flow data
Dynamic Model data

Model Validation Report
Automated Reports

Real-time Generator Parameter Validation Report

Event 1: March 23rd, 2019 3:15:22 PM

Number of Generators
- Number of generator models validated: 18
- Number of good generator models: 13
- Number of questionable generator models: 5

Summary of Validation Results

<table>
<thead>
<tr>
<th>Generator</th>
<th>Result</th>
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<tbody>
<tr>
<td>G1</td>
<td>Questionable</td>
</tr>
<tr>
<td>G2</td>
<td>Questionable</td>
</tr>
<tr>
<td>G3</td>
<td>Good</td>
</tr>
<tr>
<td>G4</td>
<td>Good</td>
</tr>
<tr>
<td>G5</td>
<td>Good</td>
</tr>
<tr>
<td>G6</td>
<td>Good</td>
</tr>
<tr>
<td>G7</td>
<td>Good</td>
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<tr>
<td>G8</td>
<td>Good</td>
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<td>G9</td>
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<td>G10</td>
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<td>G11</td>
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<td>G12</td>
<td>Good</td>
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<td>G13</td>
<td>Good</td>
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<tr>
<td>G14</td>
<td>Good</td>
</tr>
<tr>
<td>G15</td>
<td>Good</td>
</tr>
</tbody>
</table>

Validation plots for Generator G102

<table>
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<tr>
<th>Criteria for Validation for generator G102</th>
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<tbody>
<tr>
<td>Variable</td>
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<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>RMSE</td>
</tr>
<tr>
<td>Comprehensive Similarity</td>
</tr>
<tr>
<td>Correlation</td>
</tr>
<tr>
<td>Similarity of Frequency Magnitude</td>
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<tr>
<td>Similarity of Frequency Phase</td>
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</table>

RMSD := RMSD_Threshold ⇒ Good Model
Comprehensive Similarity := Comprehensive Similarity Threshold ⇒ Good Model

For more information, please refer to Appendix in Summary report
EPG Projects & Research Initiatives
EPG Current Research Initiatives – DoE Sponsored Projects

- **Real Time Applications Using Linear State Estimation Technology**
  - **DoE Grant Award #DE-OE0000849**
    - Develop Real Time Applications Using Phasor Data and Linear State Estimator Technology
    - Applications include
      - Real Time Contingency Analysis
      - Area Angle Limit Monitoring
      - Voltage Stability Monitoring
    - Industry Participants: Peak RC, PJM, Dominion, Duke Energy
    - Cost Share Partners: BPA, NYPA

- **Substation Secondary Asset Health Monitoring and Management System**
  - **DoE Grant Award #DE-OE0000850**
    - Research, design, develop and demonstrate software application in substation(s) to:
      - Collect three phase measurements from substation equipment
      - Process data from PMUs, DFRs and Instrument Transformers to derive synchrophasor equivalents and run a three phase Substation Linear State Estimator (SLSE) in real-time
      - Monitor and characterize equipment data signatures
      - Detect signature anomalies
      - Alert end-users and provide equipment signatures for detailed forensic analysis
      - Enable end-users to take needed proactive actions – calibration, repairs, replacement
    - Cost Share Partner: AEP
Eastern Interconnection Situational Awareness Monitoring System – ESAMS

- A PMU-based system that provides a common view of interconnection-wide operating conditions—focusing on conditions not currently visible with existing systems

- Key Elements of the initial high-level view will include:
  - Detect and identify forced and natural oscillations
  - Monitor phase angle pairs and identify when values are outside of normal operating ranges
  - Detect atypical behavior from an ensemble of measurements and identify which ones are contributing to the atypicality

Timing Intrusion Management Ensuring Resiliency (TIMER)

DoE Grant Award #DE-OE0000825

- Research, develop and demonstrate detection modules for timing intrusion management in the synchrophasor and other similar energy management systems to ensure resiliency of the systems:
  - The technology will be field tested and demonstrated in both laboratory and field environment with partner electric utility (IPC).

- Project Participants: Texas A&M University, Pacific Northwest National Laboratory (PNNL), Idaho Power Company (IPC), Electric Power Group (EPG)
Advanced Synchrophasor Protocol – ASP  
DoE Grant Award #DE-OE0000859  
- Objective: To develop a new phasor data publish/subscribe protocol that is performant at scale -- and a collection of tools to support it.  
- Industry Value: Less Data Loss / Lower Bandwidth  
- New protocol to be named Streaming Telemetry Transport Protocol – STTP  
- Prime: Grid Protection Alliance  
- Financial Partners include: Bonneville Power Authority, Dominion, Oklahoma Gas & Electric, San Diego Gas & Electric, Schweitzer Engineering, Southwest Power Pool, Utilicast, Tennessee Valley Authority, Washington State University, and Electric Power Group

Upcoming Projects  
- A persistence meter for nimble alarming using ambient synchrophasor data  
  - University of Wisconsin Madison (UW), WSU, EPG  
- Robust Learning of Dynamic Interactions for Enhancing Power System Resilience  
  - Iowa State University, EPG, Google Brain, IBM  
- Discovery of Signatures, Anomalies, and Precursors in Synchrophasor Data with Matric Profile and Deep Recurrent Neutral Networks  
  - University of California, Riverside (UCR), EPG, Michigan Technological University (MTU), Southern California Edison (SCE), FortisBC Inc.,
Summary

• Portfolio of Synchrophasor Applications – Over 15 applications

• Robust Comprehensive Platform for Real-time Monitoring (RTDMS) and Offline Analytics (PGDA) in use at Major ISOs and Utilities

• enhanced Linear State Estimator (eLSE) – expanded visibility, model based bad data detection, platform for applications

• Automated Event Mining – Mine through large amount of synchrophasor data and identify significant events

• Generator Parameter Validation – Automated Process for Generator Model Validation and Reporting for NERC MOD standards

• Applications developed through research projects and initiatives
  • Synchrophasor Based RTCA
  • Area Angle Monitoring
  • Voltage Stability Assessment
  • Substation Secondary Asset Health Monitoring System
Questions
Thank You

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