Lessons in Model Validation Using Phasor Measurements with Linear State Estimator (LSE)

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Imagination at work.

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PG&E Context

- **Model Based Applications** (Energy Management System)
- **PMU Measurement Based Applications** (e-terraphasorpoint)
- **E-terraStability**
  - Non-EMS based applications
    - Use network model (e.g. netmom.csv) and PMU measurements
    - Linear State Estimator (Study and real-time)
    - Model Validation (Future)
  - EMS based applications –
    - Use network model and PMU measurements
      » Angle-based Grid Monitoring (AGM)
      » Enhanced Island Management (EIM)
Highly Redundant (Situational Awareness)

PG&E SynchroPhasor Data Flow Overview

SFGO Control Center

EMS A

EMS B

PP A

PP B

PDC A

PDC B

(EMS)

(PhasorPoint)

VGCC Control Center

EMS C

EMS D

PP C

PP D

PDC C

PDC D

(EMS)

(PDC)

Highly Redundant

ETV Client

PMU Data
Business Case for LSE - Recent Example

Catch errors in PMU measurements

- LSE corrected the Signal 1 Angle Measurement
- Angle Difference between Signals 1 and 2 is 8 degrees (matches SE angle)
Business Drivers

- LSE is to PMU data what SE is to SCADA RTU data
- Cleanses any bad data in the PMU observable network
- High resolution of incoming data (30 to 120 samples/second)
- LSE Study – uses historical PMU data
Linear State Estimator (LSE)

- Uses PMU measurements only

Network Model
- Static portion (topology and parameters)
- Dynamic (breaker status)

Mapping
- Location of PMU measurements in the network model

Non-Iterative WLS Estimation
- Solve $Ax=b$
- Find out if there are any measurement errors

PG&E and ISO-NE projects
LSE Study

Part of Data Validation in **e-terraphasoranalytics**

- Model comes from EMS (QKNET’s netmom)
- Breaker Status information is needed
- Mapping file

Useful for model validation after an event.
Another Example: Missing Signal?
Earlier Example from PG&E POC

Mapped to the wrong signal
Good PMU data is important

- WAMS increases the stability limits of existing assets, while keeping the security of the grid
- WAMS provides actions to damp oscillations
- WAMS improves state estimator robustness and accuracy
- WAMS combined with EMS provides look-ahead capability for corrective action
Our story points

1. PG&E has WAMS infrastructure in place
2. Study LSE using historical WAMS data from various events in PG&E on a large system
3. Gain operational insights
Event Selection in e-terra phasor analytics - Example
Find the event using event filter and date/type.

Event Filter

Event List

Set Pre-event and Post-event Minutes

Event Description
PG&E System

**EMS** network model data:

<p>| | |</p>
<table>
<thead>
<tr>
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<tr>
<td><strong>Substations</strong></td>
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<td><strong>Buses</strong></td>
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</tbody>
</table>

**Phasor** data: Historical PMU data were exported from the archive in COMTRADE 2014 format.

**SCADA** data: Historical SCADA breaker status data from the archive (HDR) were extracted and were made available to LSE.
PG&E System - Scenarios of interest

**Power System** Related:
- Internal events – an event occurring in the part of the network observable by LSE.
- External events

**Phasor Measurement Unit (PMU) Data** Related:
- Change in redundancy and change in observability
- PMU data is not valid or PMU has sync errors. This does affect redundancy; it may or may not affect observability.

PMU data with noise: Scenario where the noise is abnormal (beyond normal white noise)
Wrong mapping (between PMU signal and the network model.)
Sample events:

1. **External event**: an event in the neighbor’s EHV system caused frequency excursion

2. **Internal event**: One of the 500-kV line relayed due to a fault.

From an ISO:

**Leap second change**: On 30th June 2015, the time was adjusted to account for the leap second.
**External Event**

In this event, 700-800 MW generation was lost in the north.

The figures show only a part of event. Both voltage and current estimates match the corresponding measurements.
Internal Event

In this event, a 500kV line (WAPA) relayed.
The figures show only a part of event.
Both voltage and current estimates match the corresponding measurements.
Lesson Learned – Time-aligned Breaker Status

When state estimators do not have correct topology, the estimates would not match measurements.

Many synchrophasor installations only provide phasor values (sequence and phase quantities) and the absence of breaker status information may result in erroneous results of Linear State Estimator, much like the conventional state estimator.

In such cases, one option is to use the breaker statuses from SCADA which will not be time-aligned and will have certain time-delays.
Lesson Learned – Face New Challenges

- Clock problem on 1/26/2016, timing signal off by 13 microseconds
- Leap Second Transition (of an ISO)

On June 30, 2015, at 20:00:00 EDT (24:00:00 UTC), leap second adjustment to UTC occurred and UTC time was incremented by 1 second.

Measurement availability changed significantly in the first 30 seconds as shown.
Leap Second Transition (Contd)

Voltage Magnitude Measurements.

Voltage Angle Measurements.
Leap Second Transition (Contd)

Some PMUs transitioned quickly and for these, the angle measurements and estimates matched as shown in Fig (relative angles are used):
Leap Second Transition (Contd)

For some PMUs, the voltage angle measurements and estimates varied in the transition as shown in Fig. (relative angle are used); outside of transition time range, they matched closely.
Lesson Learned – New requirements from Customers

LSE Extensions
• Capability to change measurement weights
• Exporting LSE results into CSV format
• Using Common Information Model (CIM) of EMS database
• Alarm when measurement errors are found
Lessons Learned –

- **Integrate, Integrate, Integrate:** After an event, information needs to be gathered from different silos
- Make it easy for end user
- **On-going verification and validation is a must:**
  - Many devices, PDCs, Applications, EMS
  - Tsunamis are rare BUT PMU Data tsunami happens every day!
- Make use of it for model validation
The Most Important Lesson Learned –

• Don’t work with Vahid

Unless You are ready for
• a 7:30 AM Friday call
• Partner, Collaborate
• Innovate
Summary

**Validated** LSE for a variety of conditions using historical data.

Need for **time-aligned breaker status** information or in its absence, handling of topological errors more elegantly.

Potential capability of using estimated results as more accurate comparing to original PMU measurements needs
Any Questions?