PMU-based Linear State Estimator for bad data detection and correction

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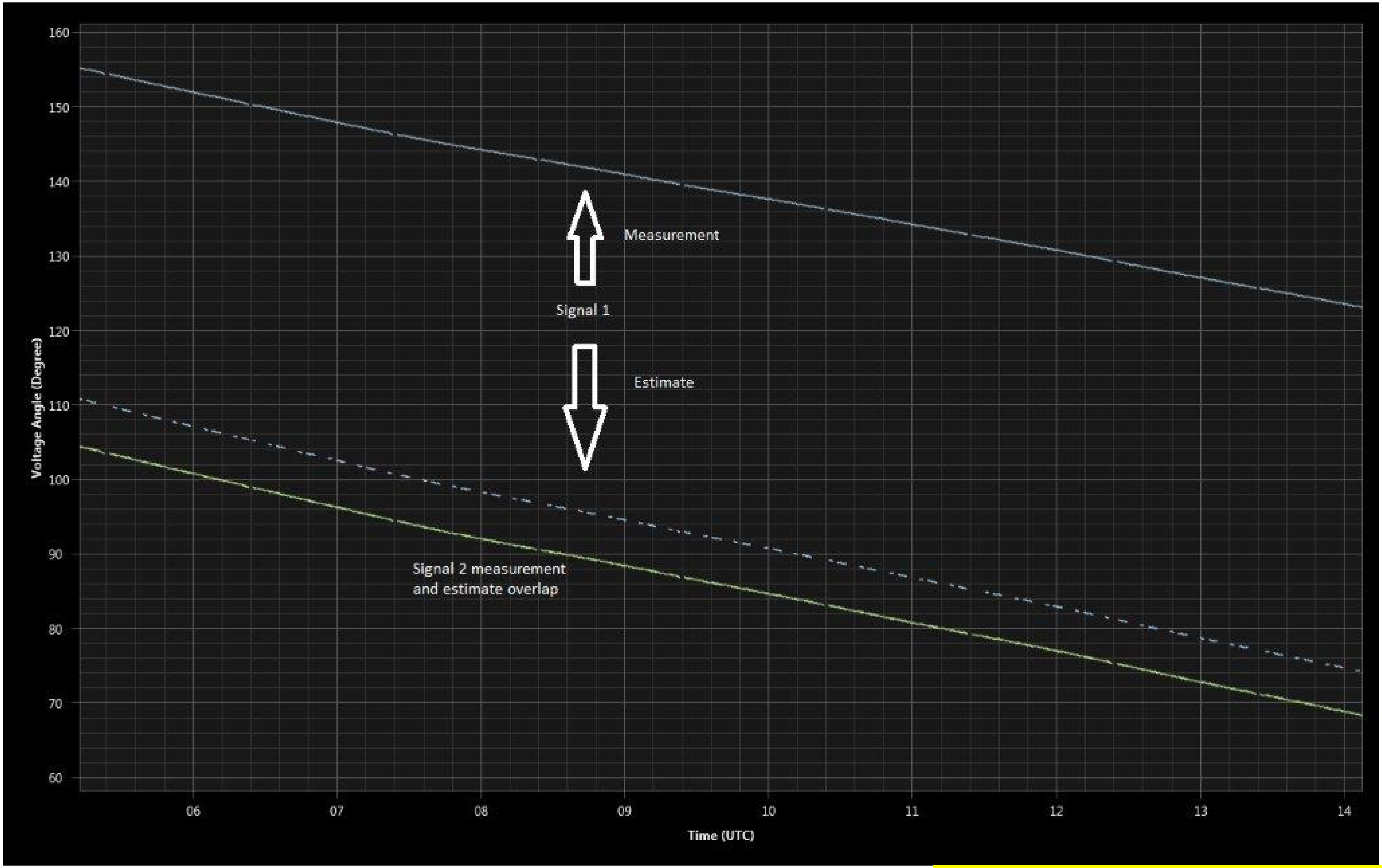
March 2016

Imagination at work.

Example Business Use Case



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)

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

ISO-NE has WAMS infrastructure in place

Study LSE using historical WAMS data from various events in ISO-NE on a large system

Gain operational insights

Previous PMU Data Validation at ISO-NE

Comprehensive data validation process is a must

- Initial data validation: 6 minutes of data captured using the PMU Connection Tester
- Detailed analysis of several snapshots of data taken at different times under different system conditions
- Online Data Quality Monitoring System – PMU vs. SCADA and SE solution,

Non-model based

GE WAMS Product Portfolio

e-terra*phasorpoint* - Synchrophasor Applications for Real-Time Operations

GSA - Hybrid WAMS/EMS Solution for the Control Room

e-terra*vision* – Unified UI for WAMS/EMS

e-terra*phasoranalytics* - Synchrophasors for Offline Engineering Analysis

e-terra*phasorcontroller* - Synchrophasors for Wide Area Control

e-terra*phasorpoint applications*

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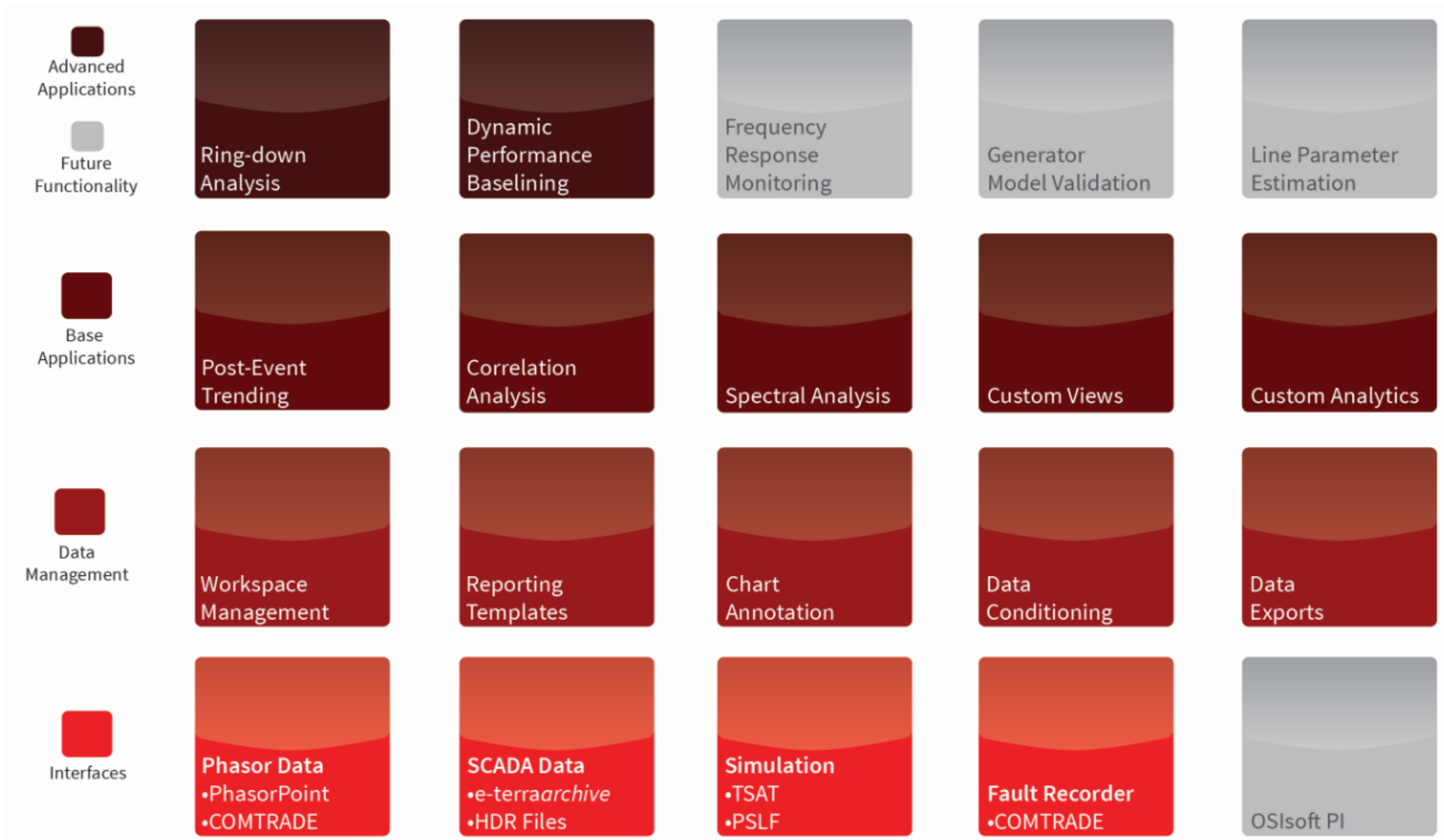
Roadmap

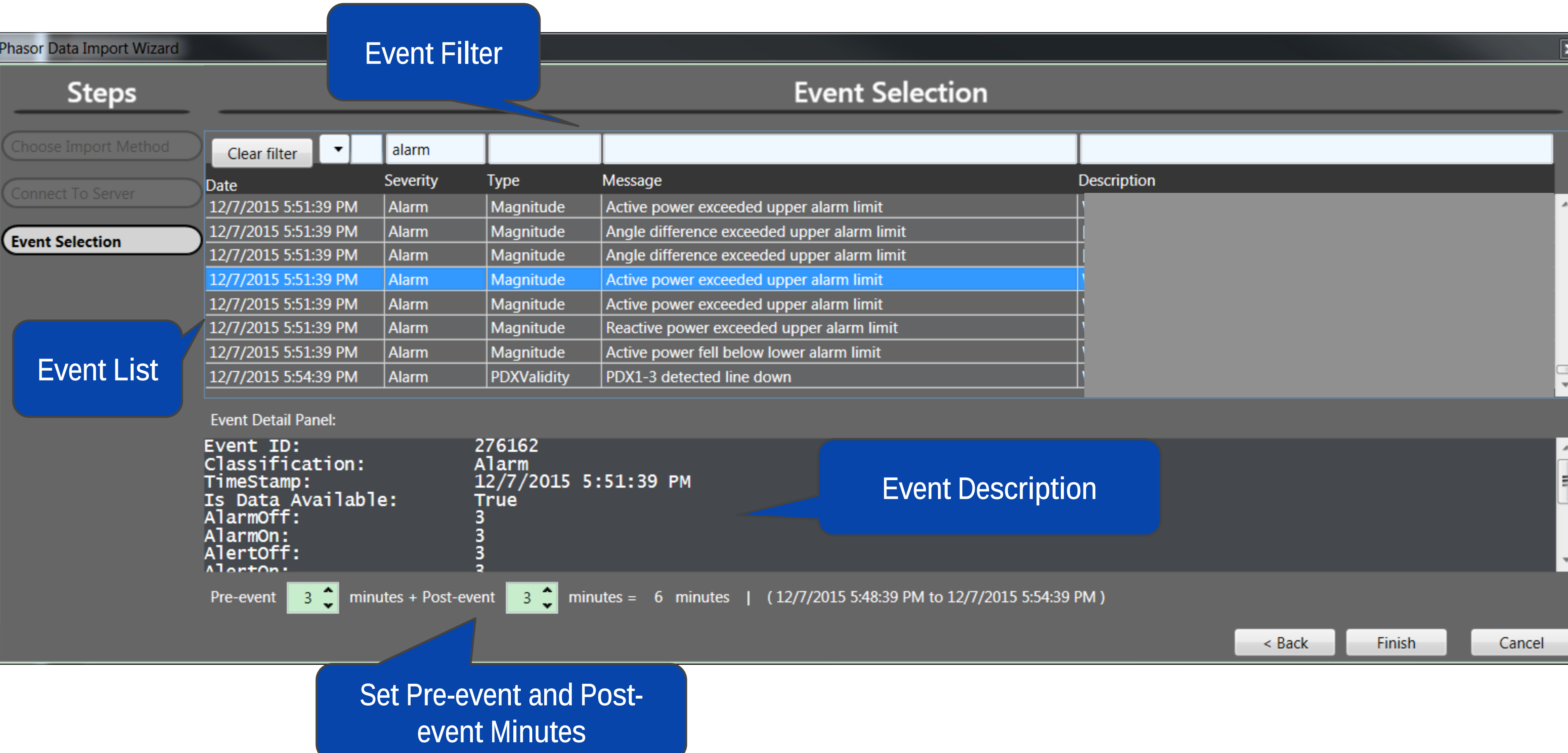
TSOs Implementations Worldwide

e-terra*phasoranalytics*



Event Selection - Example

Find the event using event filter and date/type.



ISO-NE System

7 TOs continuously stream PMU data

EMS network model data:

Substations	**1219**
Transmission Line Segments	2262
Transformers	1603
Buses	2909

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

SCADA data: Historical SCADA breaker status data from the archive were extracted and were made available to LSE.

ISO-NE 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.)

ISO-NE System - Scenarios of interest (Contd)

ISO-NE provided recent historical data for three events:

1. External event: an event in the neighbor's EHV system caused ISO-NE to export energy to its neighbor (instead of usual import).
2. Internal event: On one of the parallel lines at 345-kV, which have PMUs at both ends, had a breaker open from one side only.
3. Leap second change: On 30th June 2015, the time was adjusted to account for the leap second.

LSE – Observability Analysis

- Based on available PMU signals and network topology, LSE automatically identifies observability and builds LSE model for observable islands for every PMU data frame.
- A total of 115 buses were observable.
- At the 345-kV level
  - There is one large observable island consisting of 74 buses.
  - An additional 9 buses are in two observable islands which are not connected to the big island with current phasor measurements.
- Below the 345-kV level there are five observable islands, consisting of 32 buses.

LSE – Observability Analysis (Contd)

- The LSE solves all the observable islands.
- This analysis helped identify the gaps in PMU locations to make the 345-kV network fully observable.
- This analysis also helped in identifying areas where more PMU measurements would increase the redundancy helping to improve LSE robustness.

External Event

In this event, 1400 MW import loss had eventually resulted in a 830 MW power export over a short period of time.

The figures show only a part of event but the decreasing current trend can be observed clearly from Figure 2.

Both voltage and current angle estimates match the corresponding measurements and is very difficult to distinguish between the measurements and their estimates.

Internal Event

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

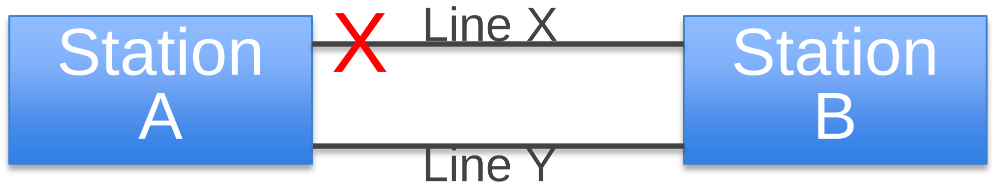
Many synchrophasor installations only provide phasor values (sequence and phase quantities) and the absence of breaker status information may result in erroneous results of Linear State Estimator, much like the conventional state estimator.

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.

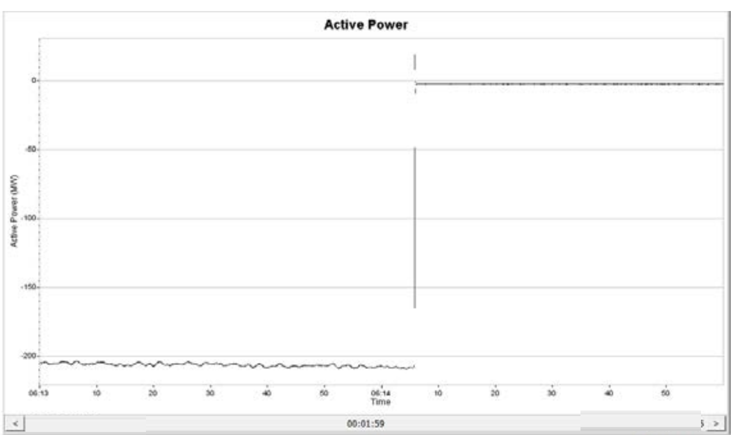
Data collected from an event that occurred in the NE grid was used to study the impact.

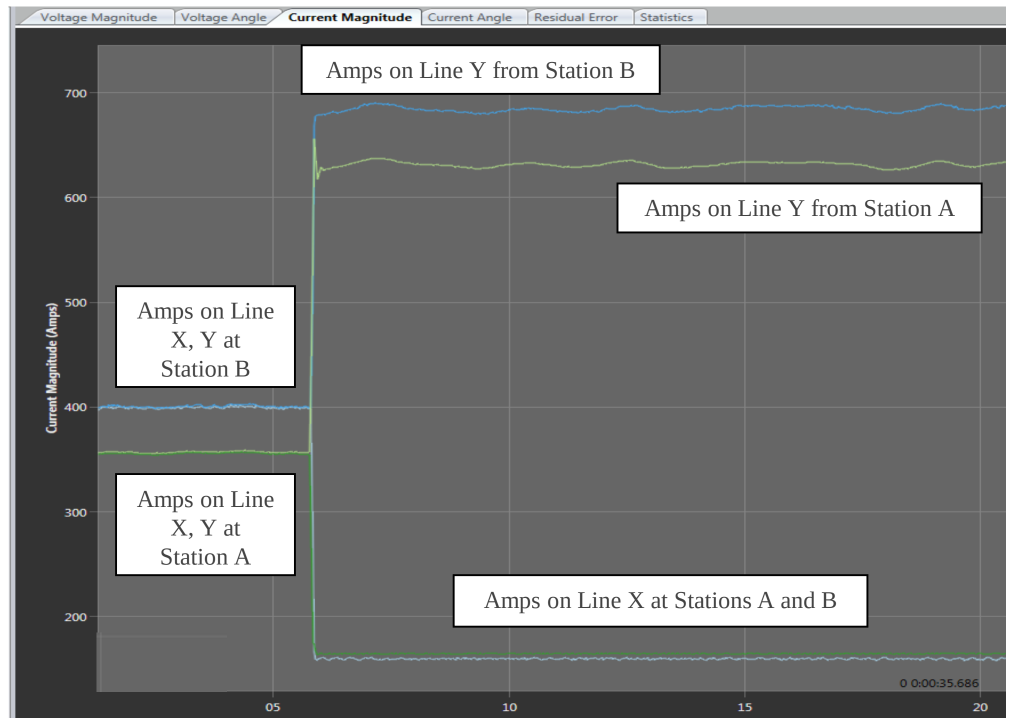
Internal Event (Contd)

PMUs are installed on both sides of both the lines X and Y.



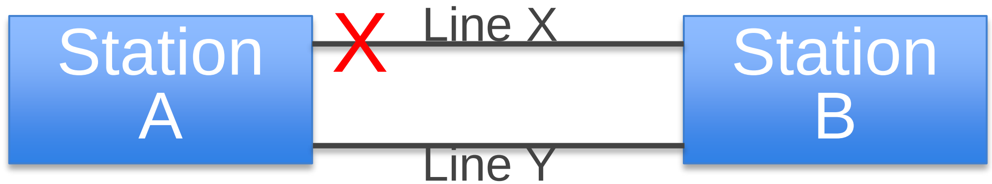
Line X at Station A is open-ended by a breaker operation at 06:14:05. The change in line flow on X is shown below:



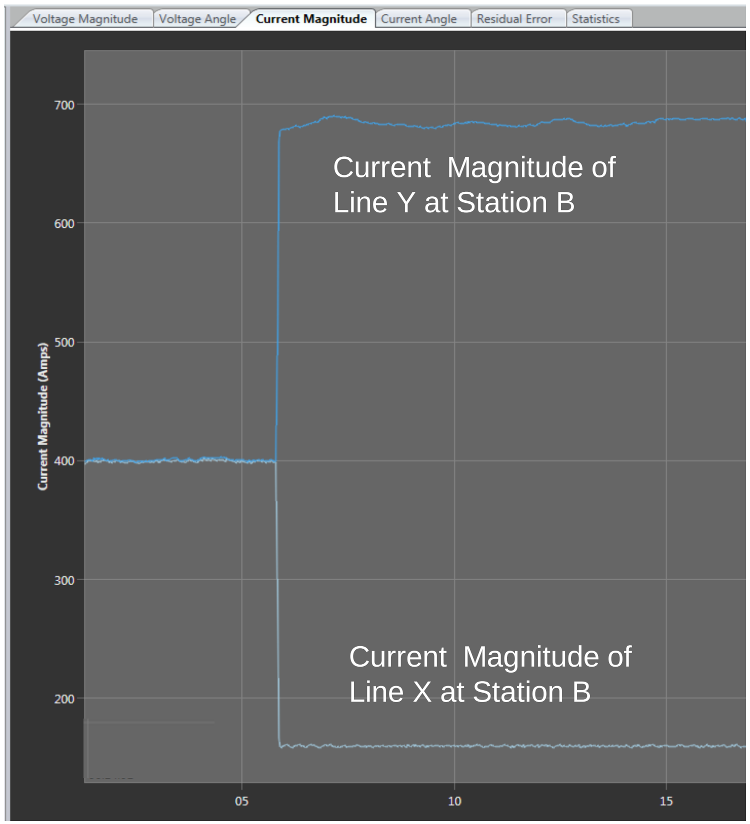


Pre and post-event current flows magnitudes on Lines X and Y from both ends are as shown above.

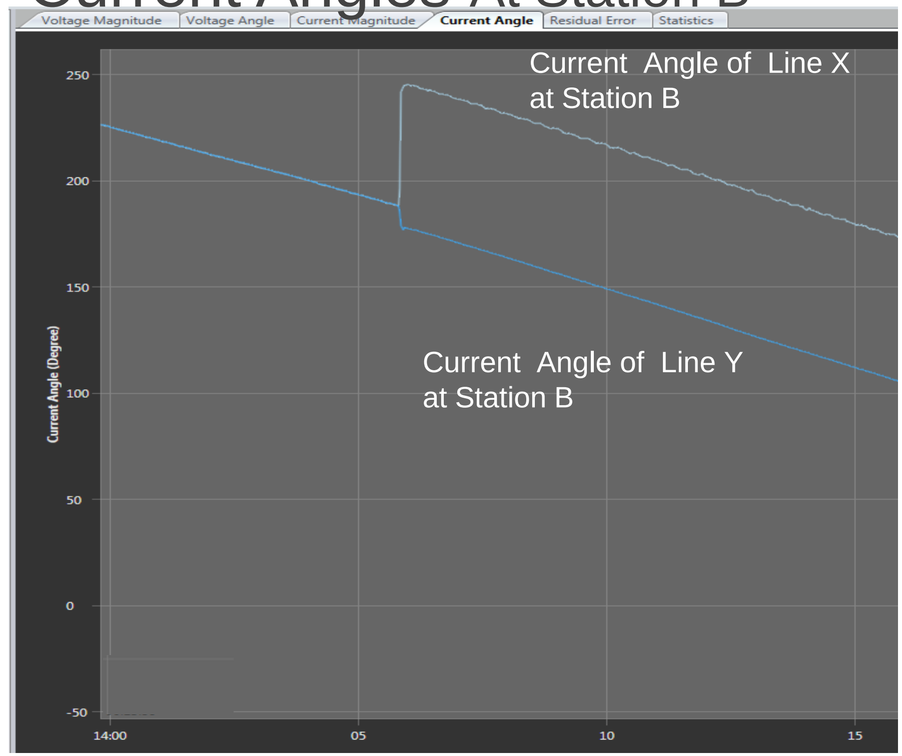
Internal Event (Contd)



Current Magnitudes At Station B

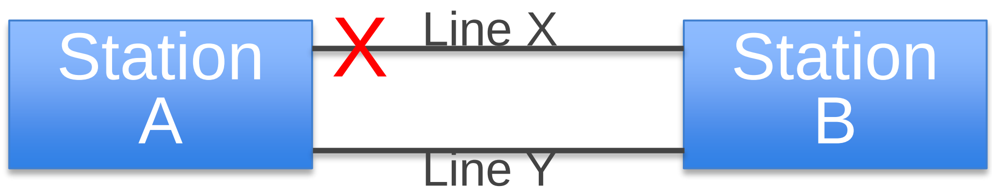


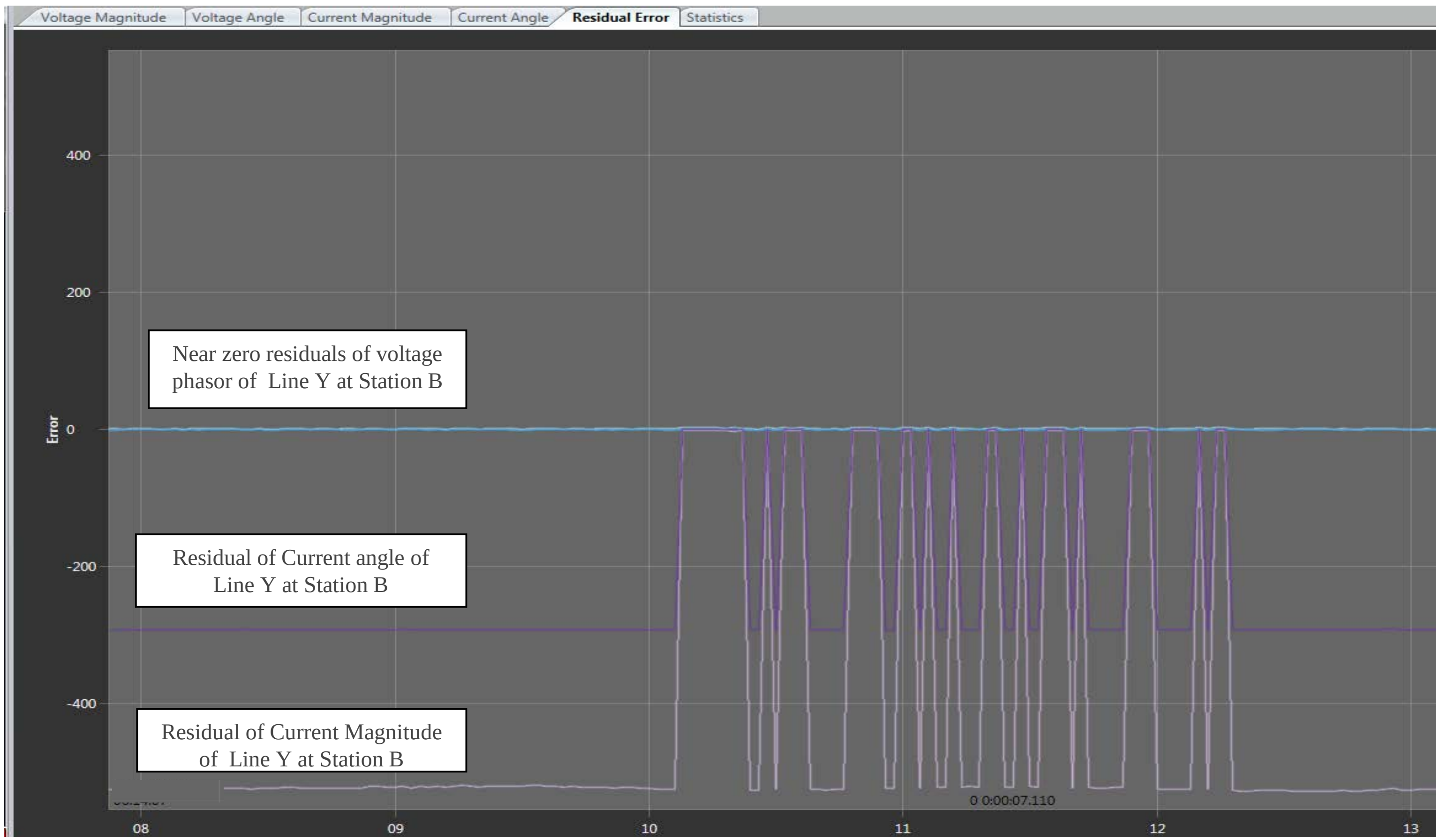
Current Angles At Station B



Internal Event (Contd)

Residuals of Current and Voltage Phasors At Station B





Internal Event - Conclusion

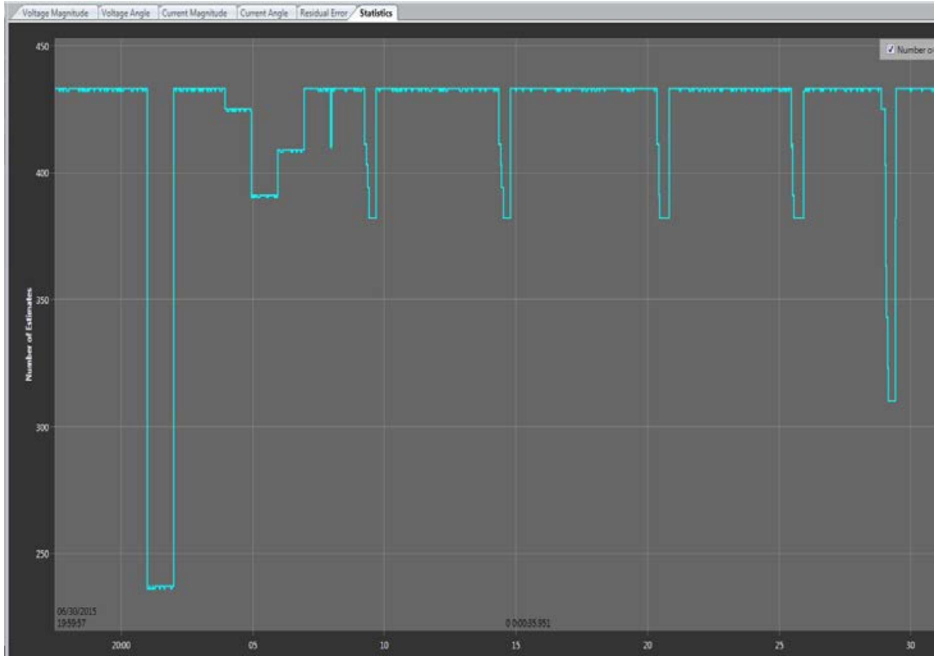
When the line X was tripped from one side, change in the status of corresponding breaker was not updated immediately in the LSE model. As expected, LSE estimates are erroneous (due to topology errors) and mainly current phasor estimates are substantially different from the measurements.

The same study was reran with changes reflecting the correct moment of breaker change status. Estimates matched the measurements very closely in this study.

Leap Second Transition

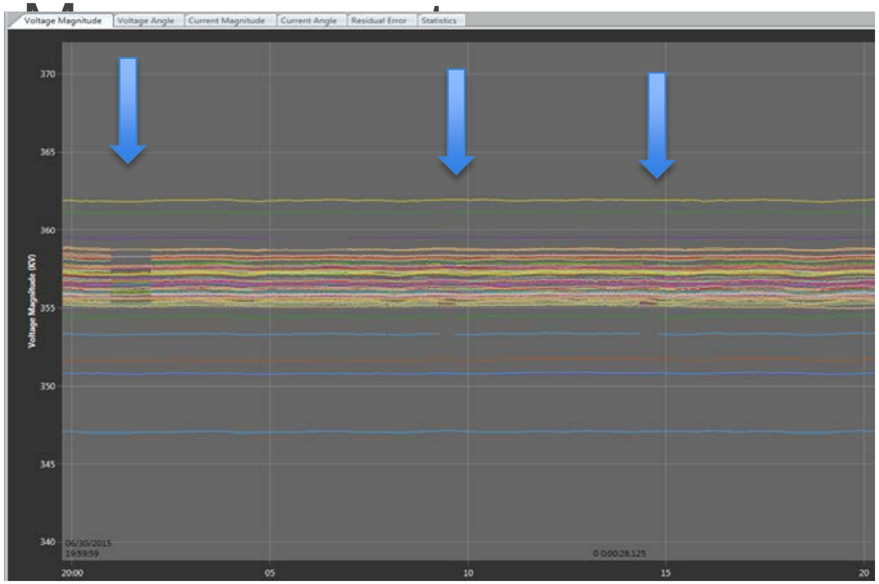
On June 30, 2015, at 20:00:00 EDT (24:00:00 UTC), leap second adjustment to UTC occurred and UTC time was incremented by 1 second.

Measurement availability changed significantly in the first 30 seconds as shown.

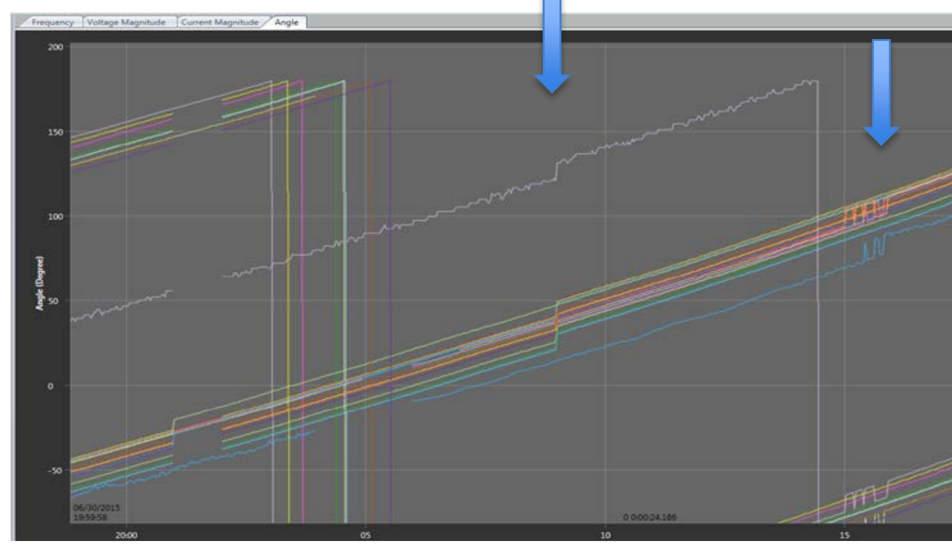


Leap Second Transition (Contd)

Voltage Magnitude

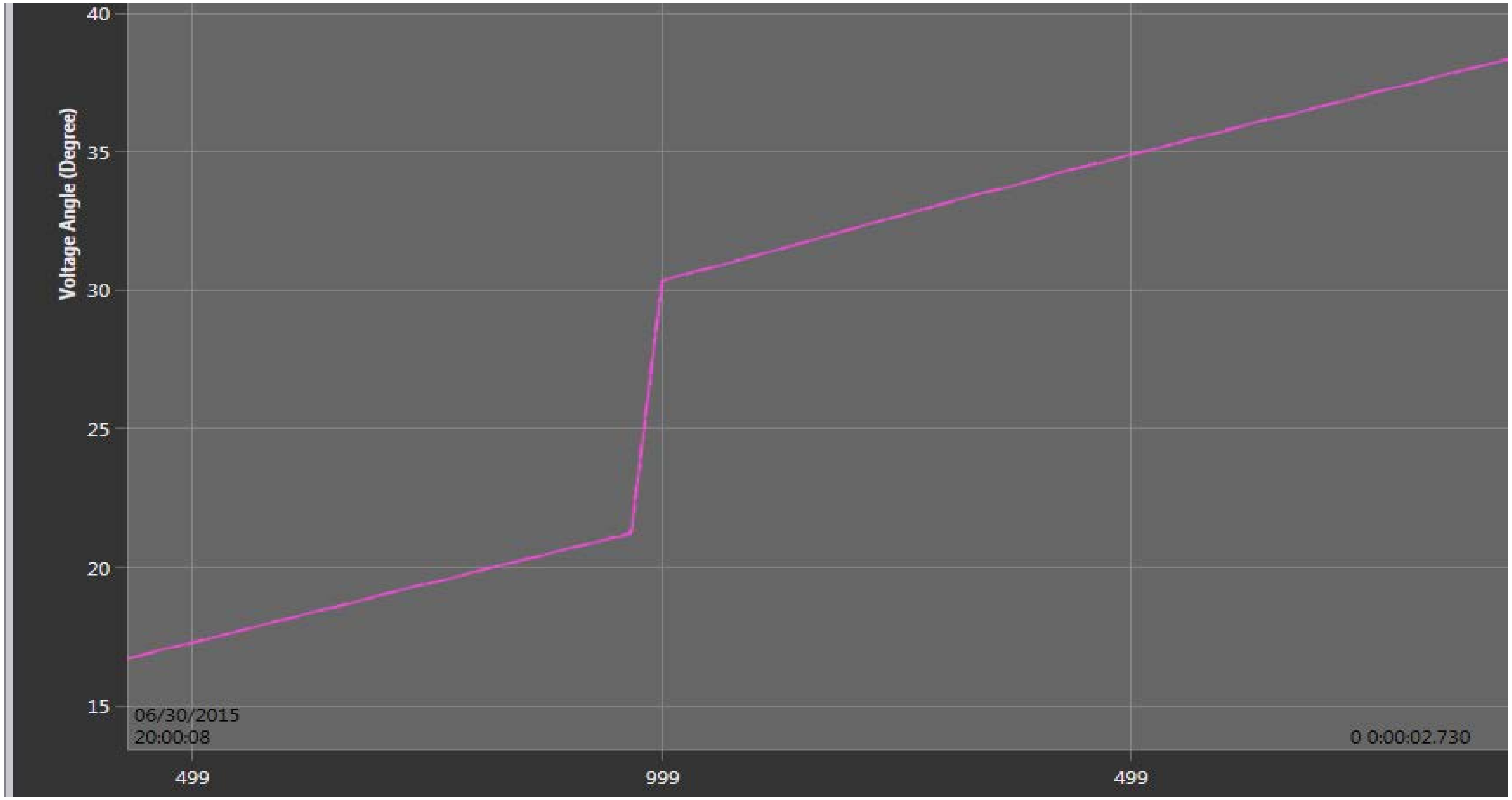


Voltage Angle Measurements.



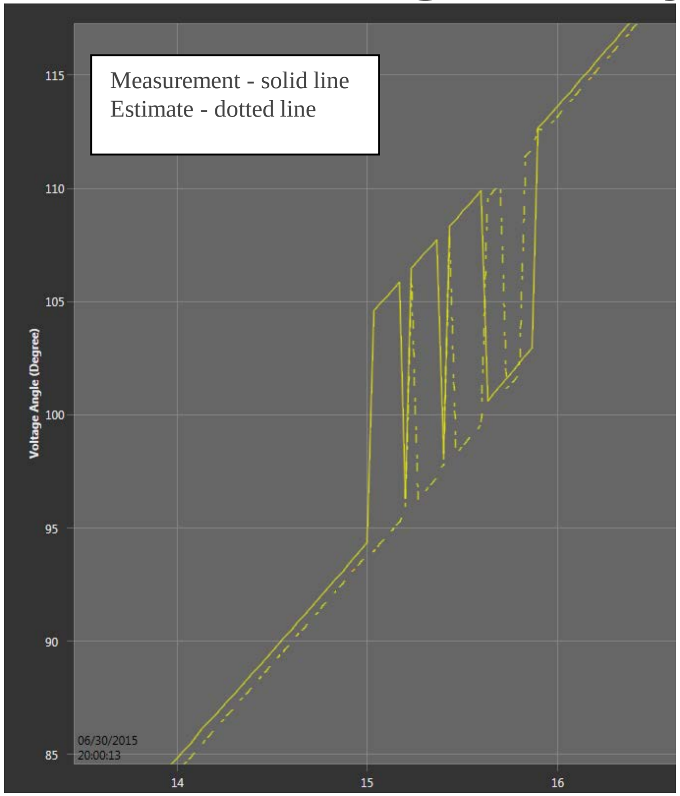
Leap Second Transition (Contd)

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.



LSE Extensions

- Capability to change measurement weights
- Exporting LSE results into CSV format
- Using Common Information Model (CIM) of EMS database.

Summary

Validated LSE for a variety of conditions using historical data on a relatively large model.

This study has been valuable in understanding the applicability and limitations of the LSE on a large scale model.

It underscored the 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 further investigation and particularly in small size PMU observable islands.

There is also a need for installing additional PMUs that would improve the observability and redundancy.


Any
Questions?