Synchrophasor Data Analytics

Linear State Estimation Using Phasor Measurement Unit Data

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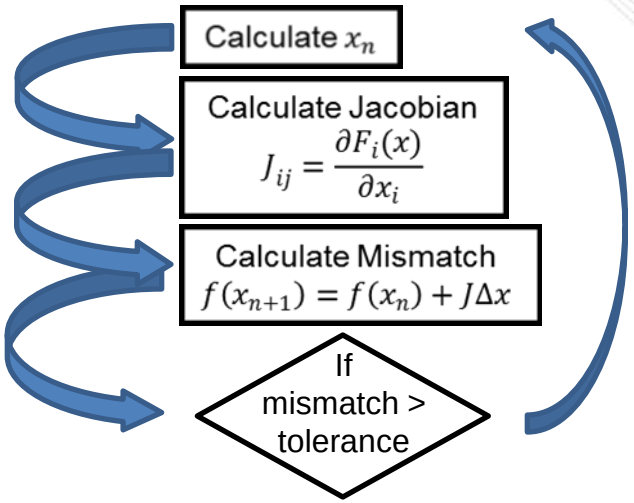
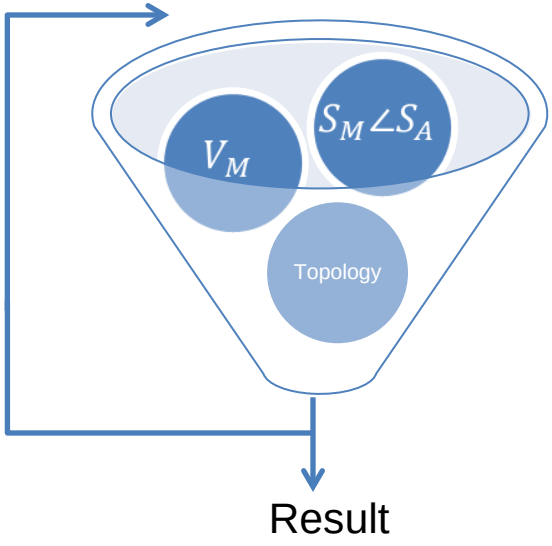
Outline

- What is a Linear State Estimator (LSE)?
- Observability
- Leveraging Redundancy: PJM's Observable and Measureable Substations
- PJM's Implementation of the Linear State Estimator Algorithm
- Lessons Learned & Engaging with our Transmission Owners
- Plans for the Future

What is a Linear State Estimator?

Non-Linear State Estimation



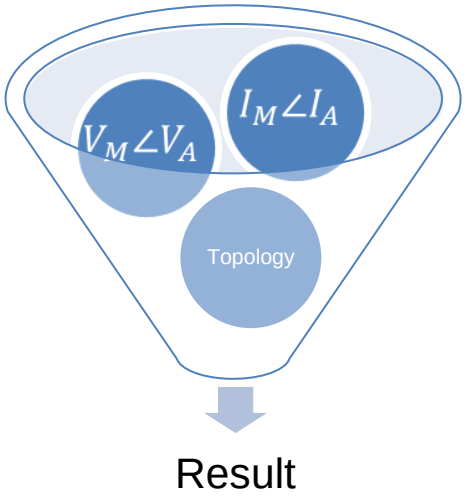


Linear State Estimation

Z=Measurement Matrix

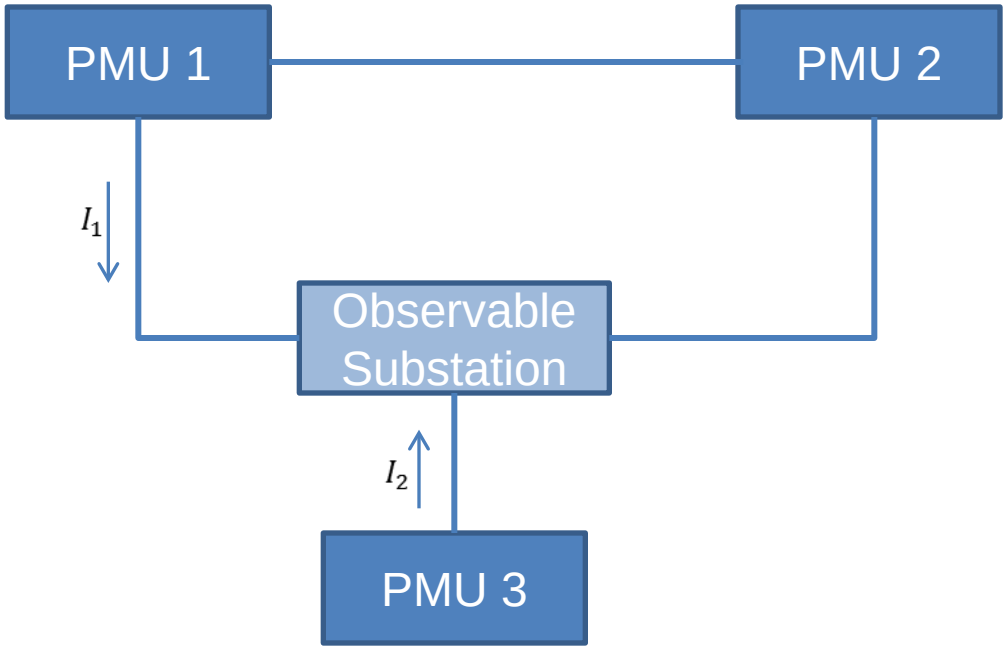
H=System transfer function

$$[x] = [(B^T B)^{-1} B^T][z] = [H][z]$$



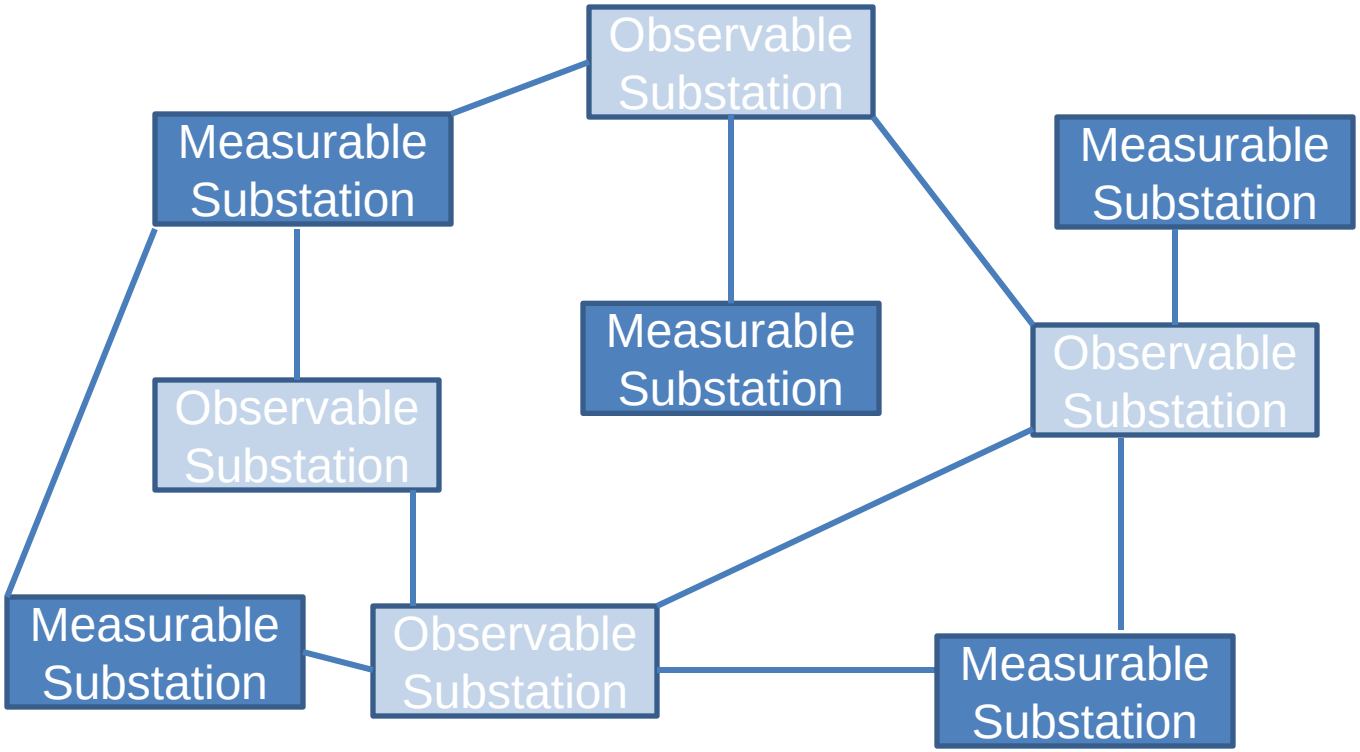
Observability

- A Linear State Estimator can be used to infer PMU equivalents, where substations without PMU measurements can still be monitored



Observability

- A Linear State Estimator fills-in the picture of our grid.
- A Linear State Estimator is the first step to improving data quality.



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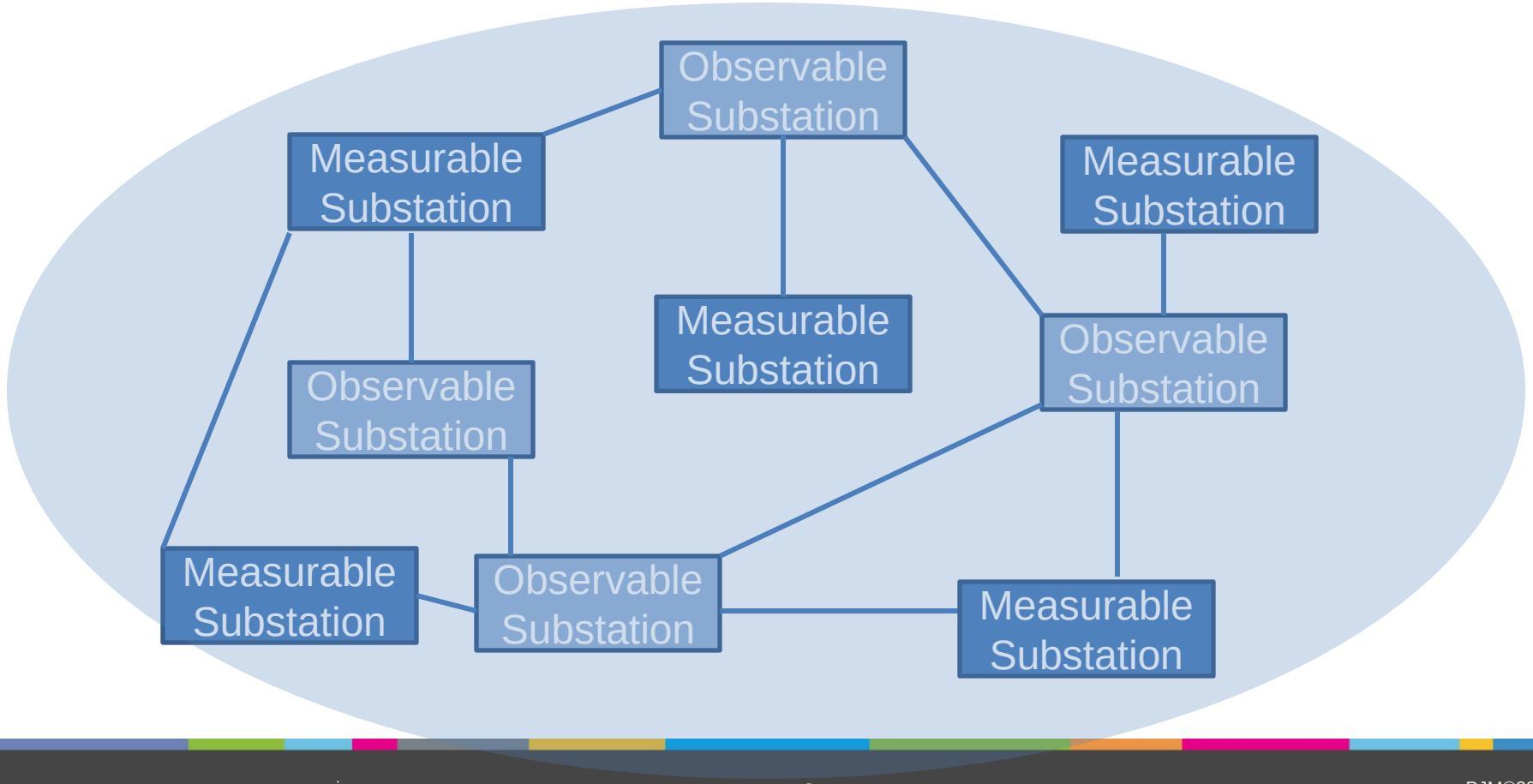
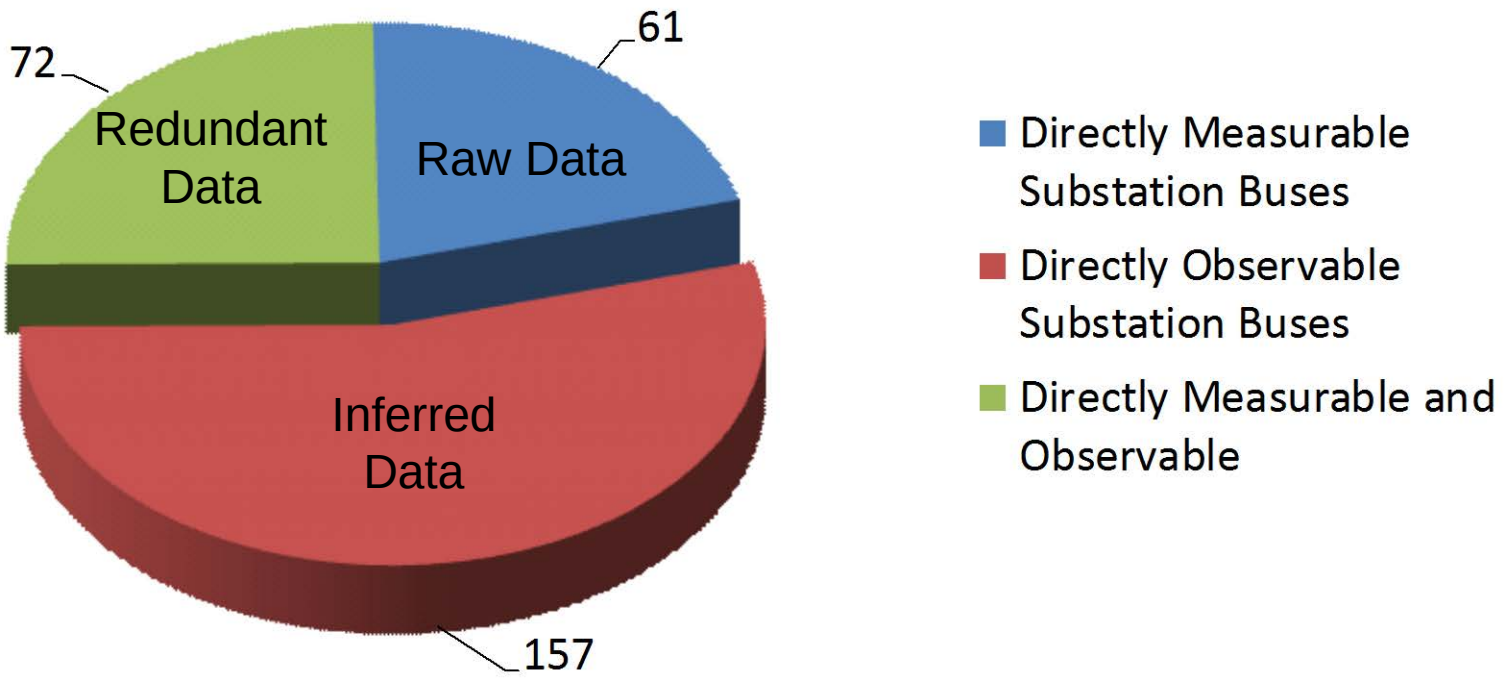


Leveraging Redundancy: PJM's Observable and Measureable Substations



PJM's Implementation of the Linear State Estimator Algorithm

- PMU data retrieved from RTDMS via SQL Query
- Source code written in Statistical Analytic Software (SAS)
- Scheduled job executed every 15 minutes for 30 consecutive data frames.
- Results outputted to PI Historian

PJM's Implementation of the Linear State Estimator Algorithm

Plausibility Checks → Run LSE Algorithm → Compare raw PMU data with LSE results

- C37 Status Word
- Voltage Magnitude between 0.7 and 1.3 Per Unit
- **Average bus voltage between 0.7 and 1.3 Per Unit**
- Current Magnitude less than 50 Per Unit
- Other Special Errors

PJM's Implementation of the Linear State Estimator Algorithm

Plausibility Check → Run LSE Algorithm → Compare raw PMU data with LSE results

Inputs:

- PMU data passing the Plausibility Checks
- Breaker Statuses
- Impedance Data

Output:

- System state of all observable substations

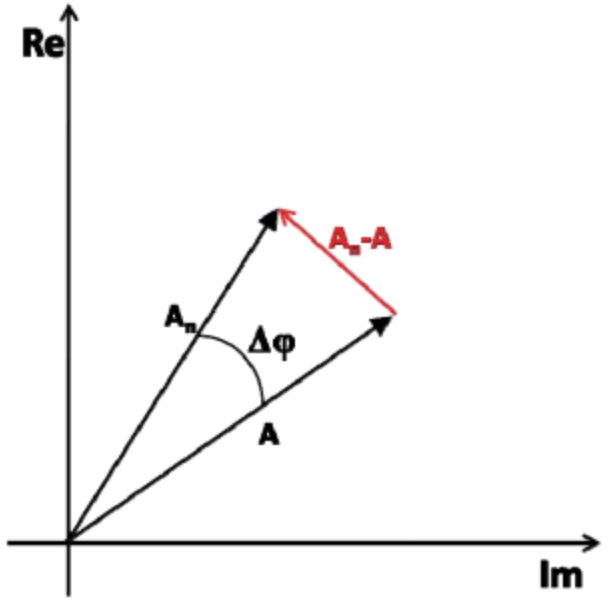
$$[x] = [(B^T B)^{-1} B^T][z] = [H][z]$$

PJM's Implementation of the Linear State Estimator Algorithm

Plausibility Check → Run LSE Algorithm → Compare raw PMU data with LSE results

1. Compute all measurement signals based on the result of the LSE algorithm.
2. Compute Total Vector Error using raw PMU data and the computed measurement value.

$$TVE = \sqrt{\frac{(A_r(n) - A_r)^2 + (A_i(n) - A_i)^2}{A_r^2 + A_i^2}}$$



Lessons Learned & Engaging with Our Transmission Owners

- Individual configuration errors identified and corrected.
- Signal dropouts identified more quickly.
- Handling of outages to PMU signals.
- Plausibility Check performance can be trended and shared with our Transmission Owners.
- Eventually, we will share TVE Calculations based on results from the Linear State Estimator.

Short-Term Issues

- Intermittent Signal Drop-outs
- Alignment of LSE results with SE phase angles

Longer-Term Issues

- Sustained Signal Drop-outs
- Permanent corrections to PMU data stream issues
- Management of calculated data

Opportunities

- Improvement to Data Quality – Additional Reporting to our Transmission Owners
- New insights to the electric grid

Questions?