



Dominion[®]

Three Phase Linear State Estimation

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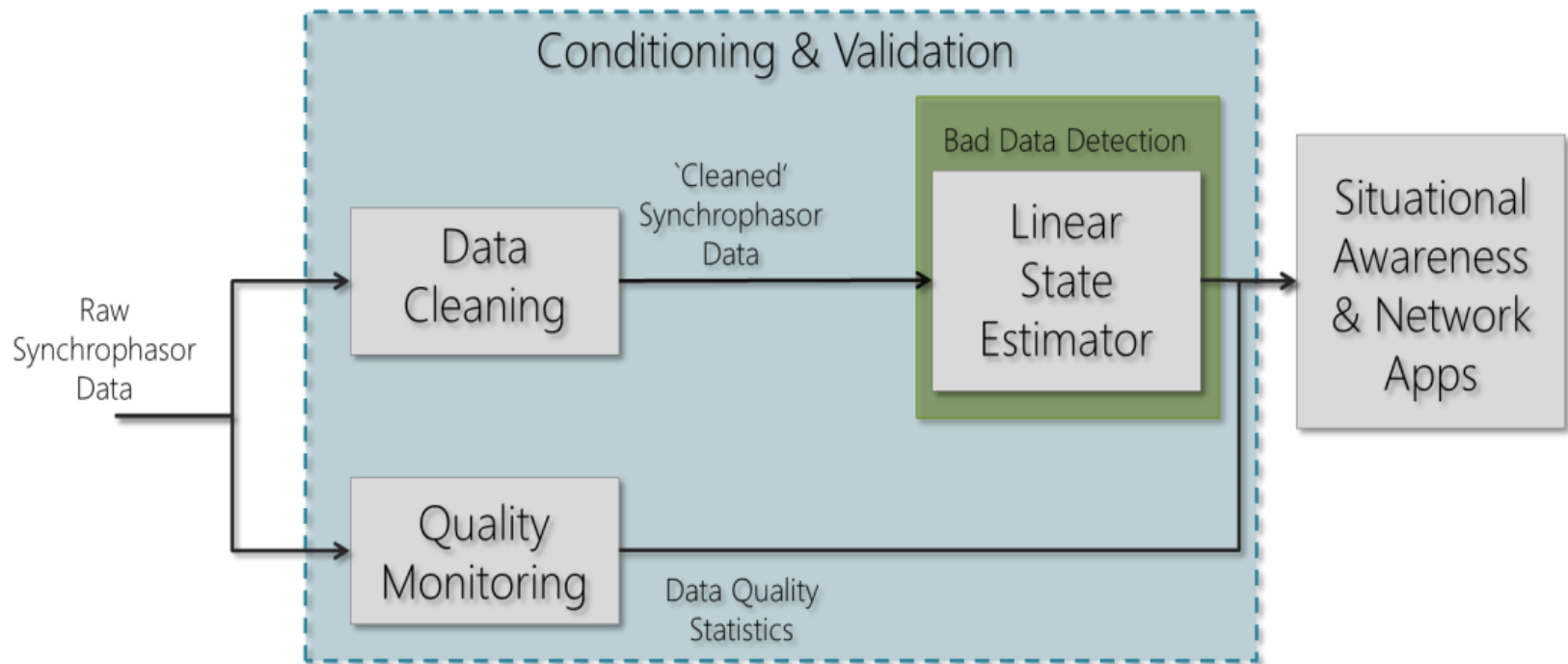
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Motivation & Objective

- Obtain wide-area monitoring of Dominion's EHV system with large scale deployment of PMUs
- Develop and implement novel synchrophasor applications including a **Synchrophasor-Only Three Phase Linear State Estimator**
- Why state estimation?
 - Improve data quality
 - Extend observability

Synchrophasor-Only State Estimation

The linear state estimator should serve as the data conditioning front end for any network application or consumer of synchrophasor data

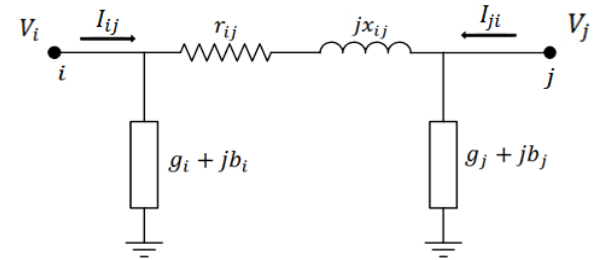


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Synchrophasor-Only State Estimation

LSE appeared early in PMU literature (1980)

- Directly measuring the system state
- No scan times!
- No divergence!
 - **State estimator availability is critical during stressed conditions**
- Three Phase LSE is the **only way to get true sequence (+, -, 0) components**
- Value proposition for three phase is growing



Synchrophasor-Only State Estimation

- PMUs measure complex voltages and currents
- Optimal state derived from redundant measurements
- Observability expanded through transmission lines with current phasor measurements

$$z = \begin{bmatrix} I \\ YA + Y_s \end{bmatrix} E + \varepsilon = HE + \varepsilon$$

- An over-determined system; a linear transformation from measurements to state estimate

Handling Bad or Missing Data

Need for commissioning process

- Scripts for finding data quality problems before connected to SOC

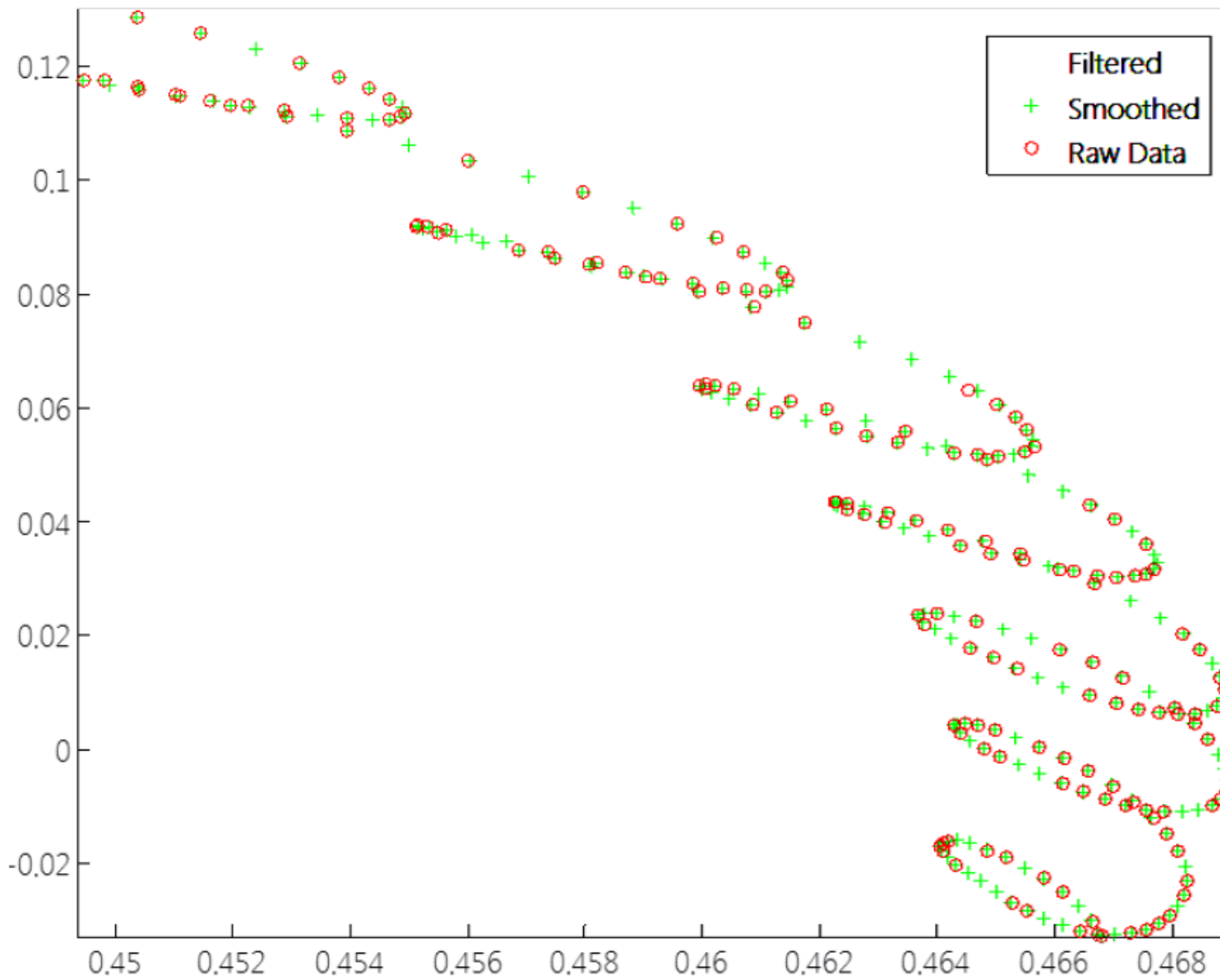
Filtering & Smoothing

- Predictive capability to mitigate bad or missing data
- Useful for LSE pre-processing

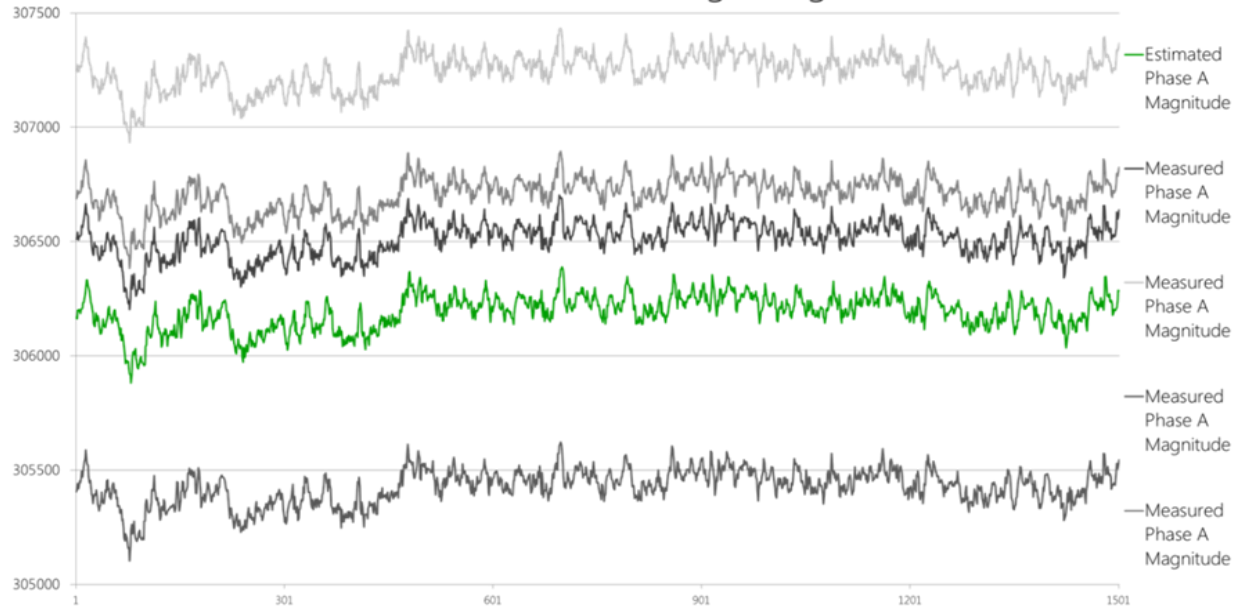
$$\hat{y}_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-1} + \cdots + \alpha_m y_{t-m} + \omega_t \quad t = m+1, \cdots, n$$

$$\hat{x}(n) = 3x(n-1) - 3x(n-2) + x(n-3)$$

Oscillation, Complex Voltage, 30% Dropouts



Substation 1 Phase A Voltage Magnitude



Substation 1 Phase A Voltage Angle



Utility Perspective

State estimation is inherently a real-time network application

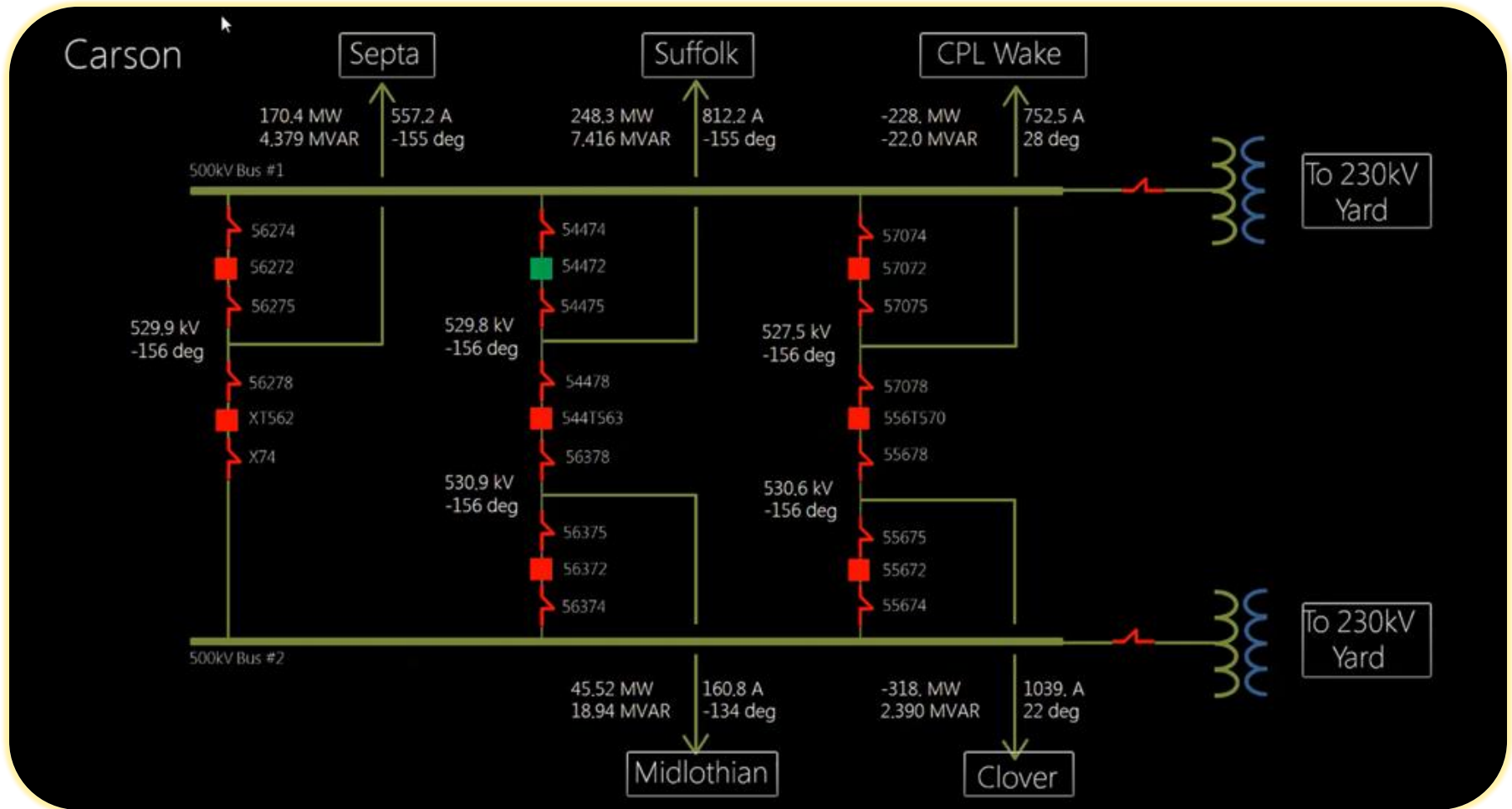
- How does this fit into today's strategy?
- How does this fit into the long term strategy?
- Maintaining parallel systems?

LSE as EHV Backup Observability

Fully paralleled infrastructure from substation

- If EHV observability lost through EMS, operations must dispatch resources to all EHV substations and monitor by phone
- EHV network fully/redundantly observed using the linear state estimator
- **Solves in real-time**, omnipresent, high availability
- **Comfortable, familiar visualization** reminiscent of EMS

LSE as EHV Backup Observability

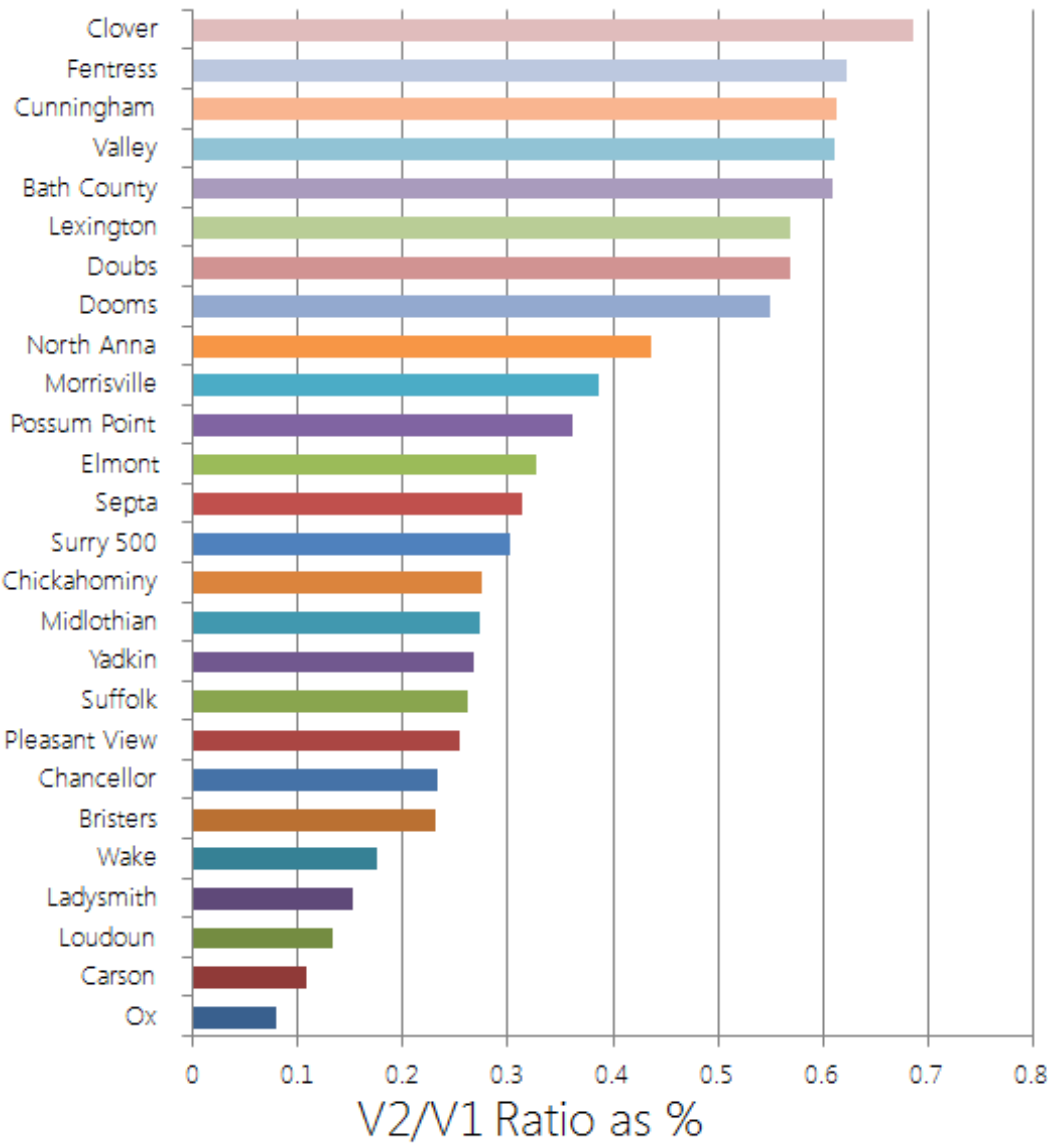


Augmenting the Production EMS

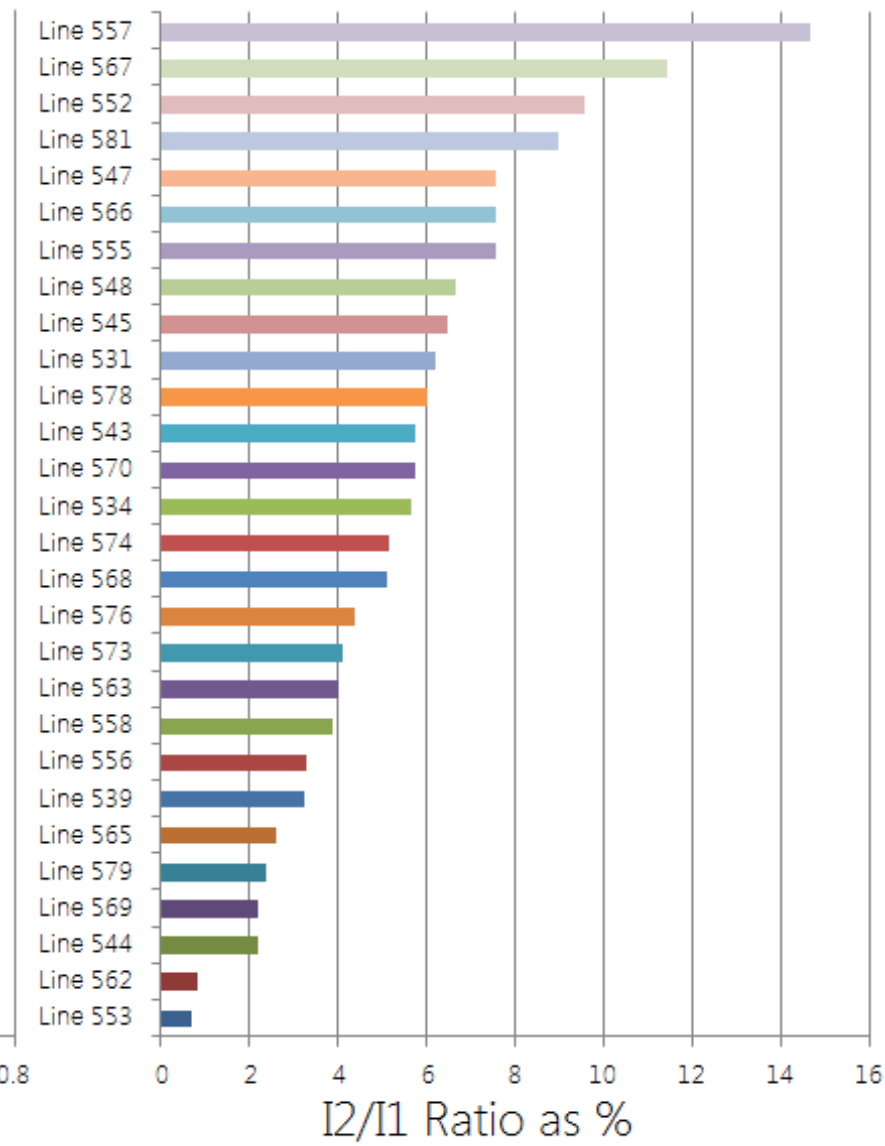
Improved state estimator performance through:

- ISD Adapter in PDC Architecture for PMU Data to EMS
 - **Use output of LSE as high accuracy pseudo-measurements**
 - Voltage magnitude, P-Q flow
- CT/PT calibrations to improve raw SCADA measurements
- Empirically determined/tracked impedance values
- Real-time observation of sequence components

Negative Sequence Voltage



Negative Sequence Current



Summary

- Production realization of PMU-only LSE
 - Industry first LSE; Industry first 3 Φ LSE
- LSE as front end for PMU data consumers
- LSE can serve as EHV backup observability
- LSE & applications augment production EMS
- Real-time sequence component monitoring