Enhanced State Estimation

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CRSTT & PRSVTT Joint Panel
NASPI Work Group Meeting
Philadelphia, PA • October 23, 2018

NASPI North American SynchroPhasor Initiative

Agenda

I. Define how functional entities use state estimation to perform reliability-related tasks.

II. Explain how synchrophasor technology can be used to enhance state estimation.

III. Discuss the status of enhanced state estimation in today's control room environment and lessons learned.

IV. Describe impediments that must be addressed to fully integrate enhanced state estimation into the operational toolset.

V. Consider how CRSTT & PRSVTT can coordinate on related work efforts to their mutual benefit.

Recent NERC & IRO Standard Changes

Recent NERC Standard changes emphasize the:

- Performance of Operational Planning Analyses (OPA) to assess pre- and post-Contingency performance for day-ahead timeframe,
- Development of Operating Plans for issues identified in OPA,
- Performance of RTAs to identify actual or expected SOL and IROL exceedances,
- Implementation of Operating Plans to prevent or mitigate SOL and IROL exceedances, and
- Robust outage coordination processes to ensure reliability under outage conditions.

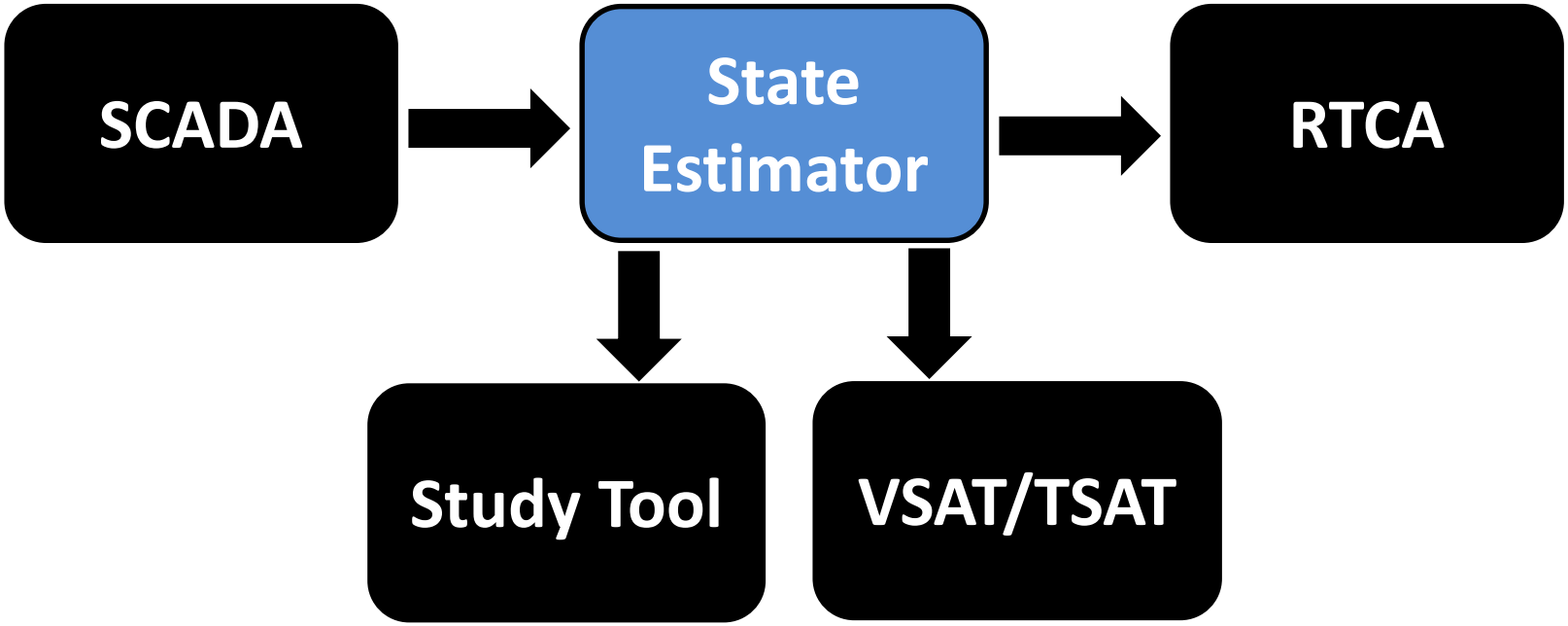
Functional Entity Roles & Responsibilities

The ultimate task of Reliability Coordinators (RC) and Transmission Operators (TOP) is to continually assess and evaluate projected system conditions as Real-time approaches with the objective of ensuring acceptable system performance.

These assessments are typically performed in an iterative fashion within the Operations Horizon:

- Seasonal planning studies and other special studies
- Outage coordination studies
- Operational Planning Analyses (OPA)
- Real-time Assessments (RTA)

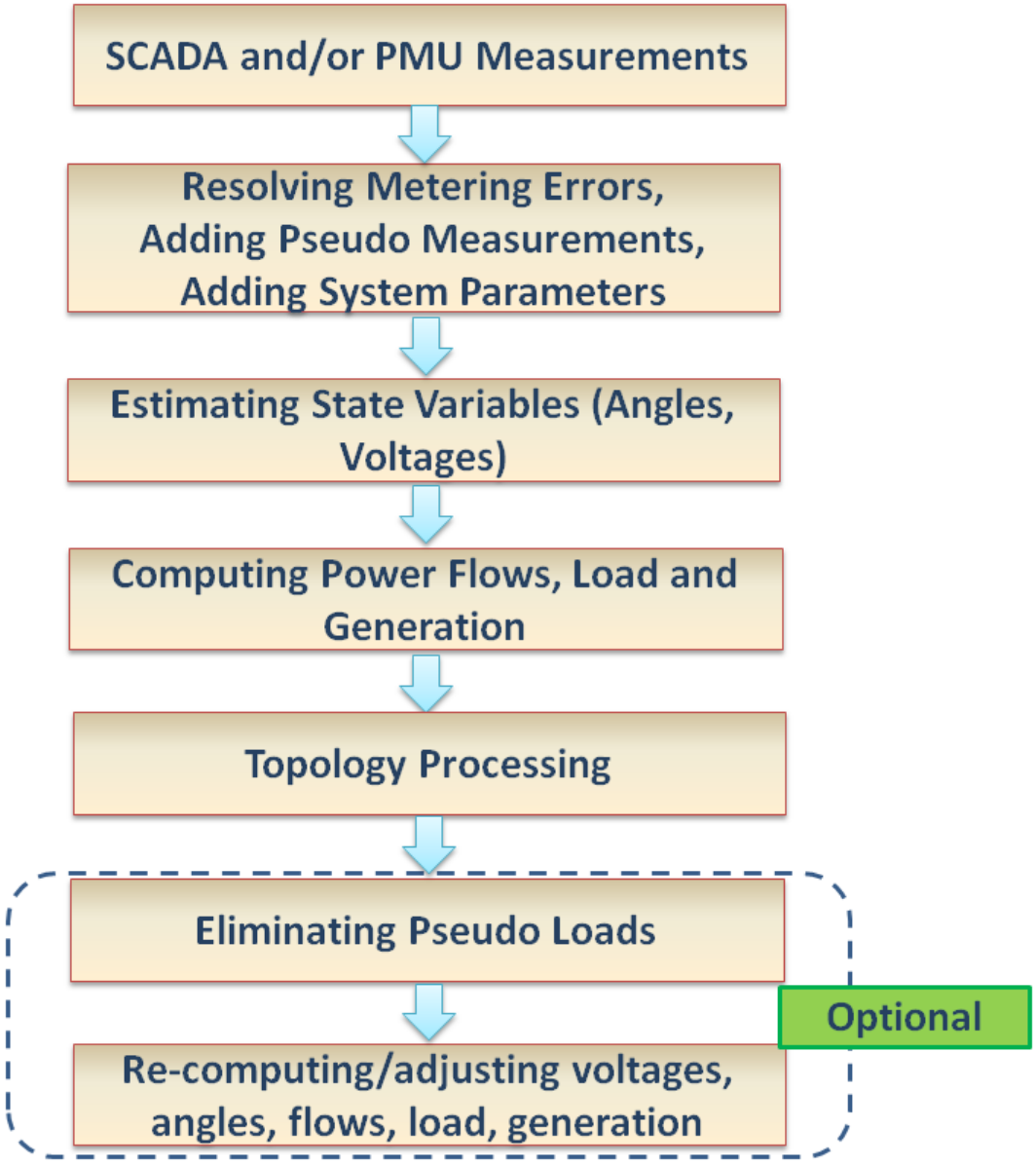
Real-Time Operational Toolset



Purpose of State Estimator (SE)

- Main tool to assess reliability and stability of a power system in real-time environment at a utility/ISO:
  - Basis for all advanced applications and market applications
- Designed to **produce a system state** based on the "best estimate" of the system voltages and phase angles:
  - Provided that there are errors in the measured quantities; and
  - That there is a redundancy in measurements
- Minimizes the sum of squares of the differences between the estimated and the measured values of variables
  - The computation of least square estimation in use since early 19th century
- Purpose of State Estimator is the same regardless of input measurements: SCADA, PMU, or both

State Estimation Process

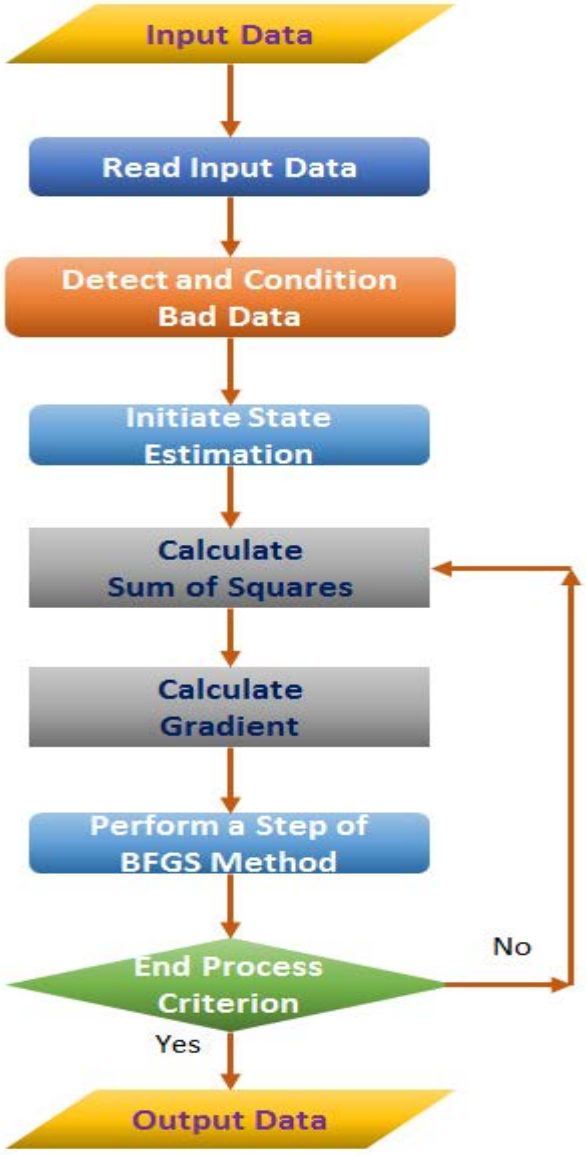


Using PMUs in State Estimation

- Two types of state estimation use PMUs:
  - Hybrid State Estimator
  - Linear State Estimation

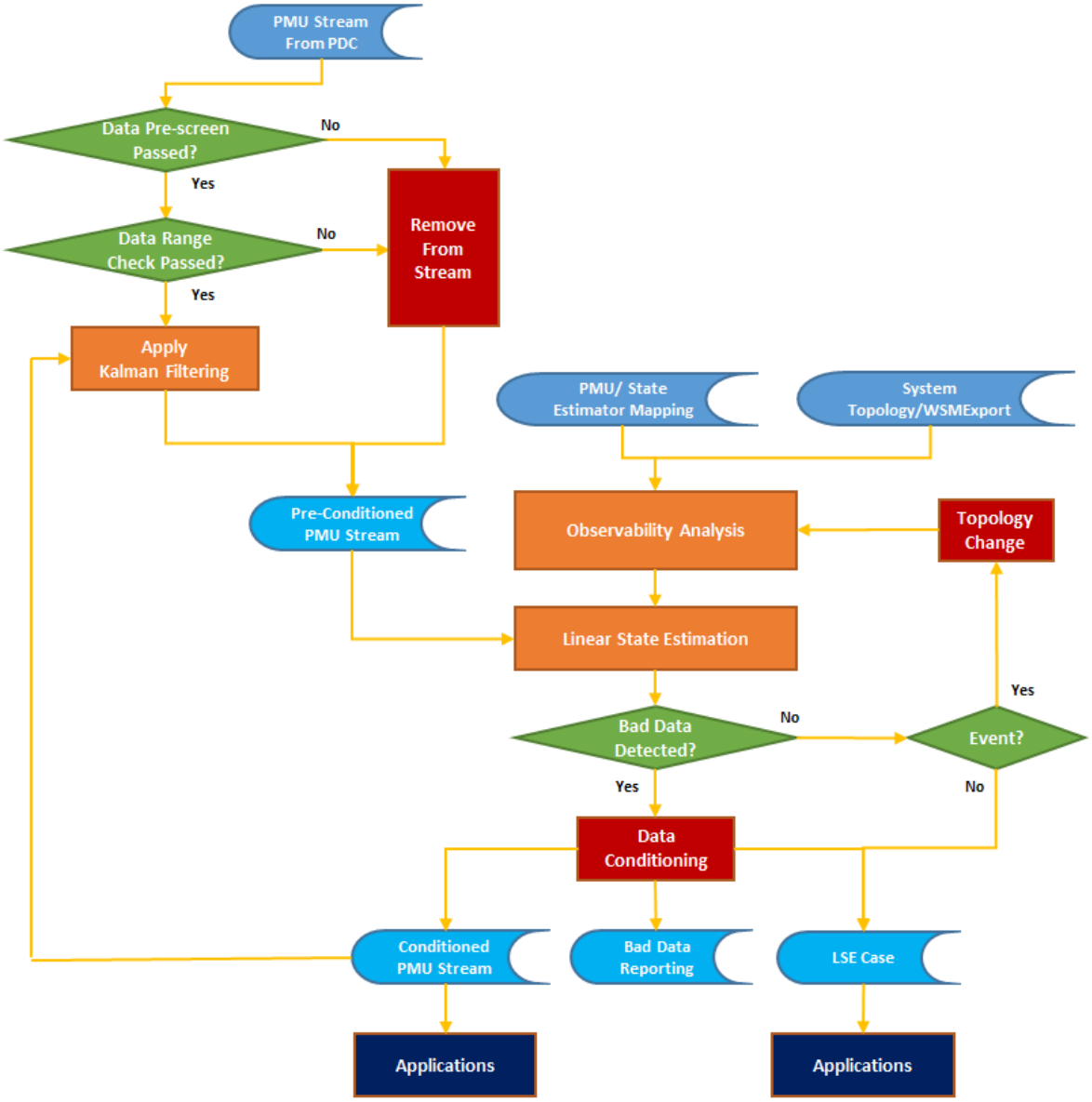
Hybrid State Estimator

- Hybrid State Estimator:
  - A nonlinear state estimator using SCADA and PMU measurements
  - As any nonlinear SE, uses an optimization algorithm, such as Newton method, BFGS quasi-Newton method, etc.
    - BFGS method (right) performs optimization steps in a cycle
    - At each optimization step, objective function and its gradient are computed multiple times



Linear State Estimation

- Uses synchronized voltage and current phasor measurements from PMUs
- A complex multi-step process



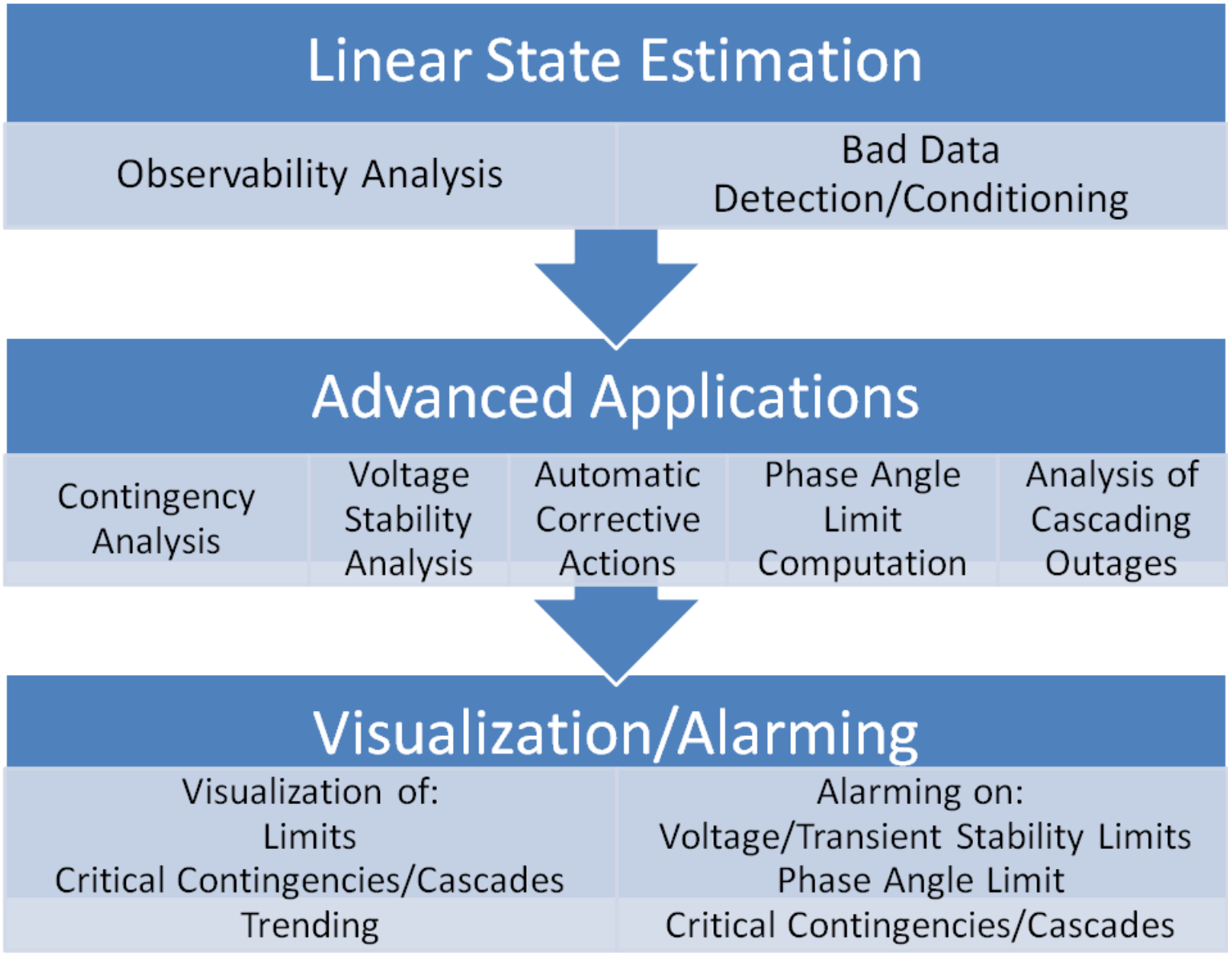
Advantages of Using PMU Measurements for State Estimation

- Hybrid State Estimator:
  - PMUs add redundancy;
  - Uses phase angle measured by PMUs vs. estimated value
  - PMUs may increase observability (if installed at locations not observable by SCADA)
- Linear State Estimator:
  - Improves real-time resilience:
    - A backup to the conventional SE solution if it fails to solve or SCADA data is not available
  - Improves real-time reliability:
    - A check/validation for the quality of conventional state estimator
  - High speed of state estimation due to using a direct non-iterative solution
    - Solves at PMU sample rate (30 times/sec or 60 times/sec)

Output of State Estimator

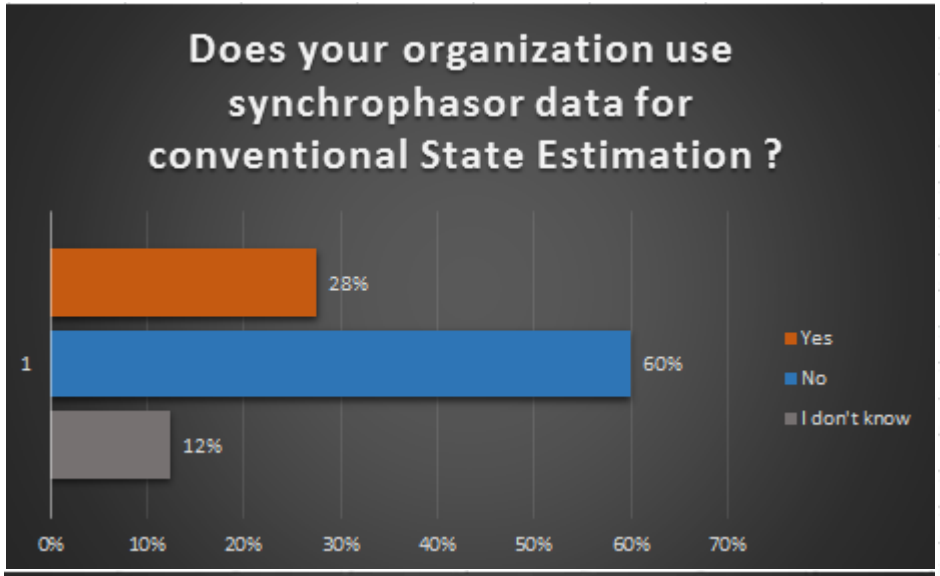
- Regardless of the type of input measurements (SCADA and/or PMU), the output should be the same
- Output of any State Estimator is a system state:
  - Usually, a node-breaker model
  - This case is used to compute power flow and perform advanced calculations:
    - Real-time contingency analysis, voltage stability analysis, transient stability analysis, analysis of cascades, etc.
  - Conditioned PMU stream is one of the outputs of LSE
- Any state estimator is used for bad data detection/conditioning

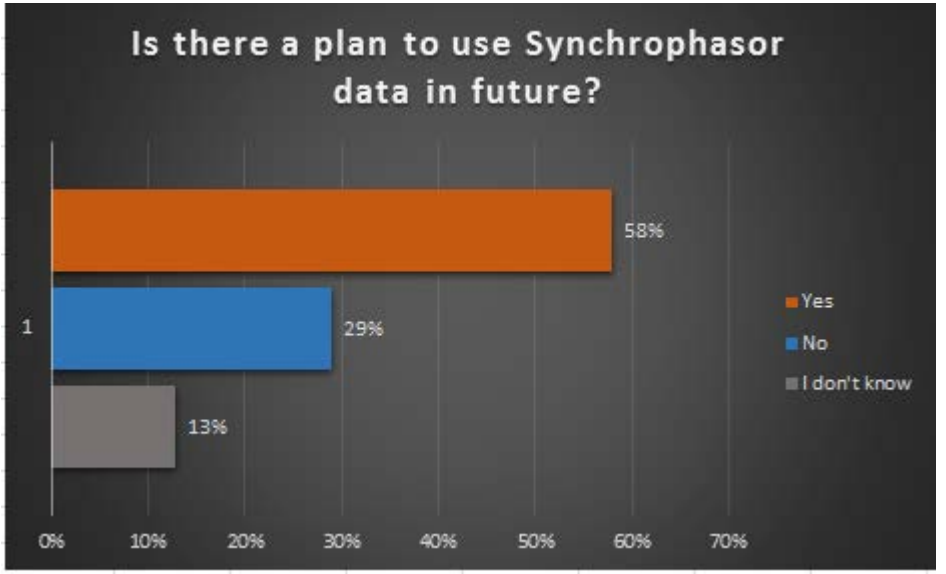
LSE as the Foundation of Advanced Apps

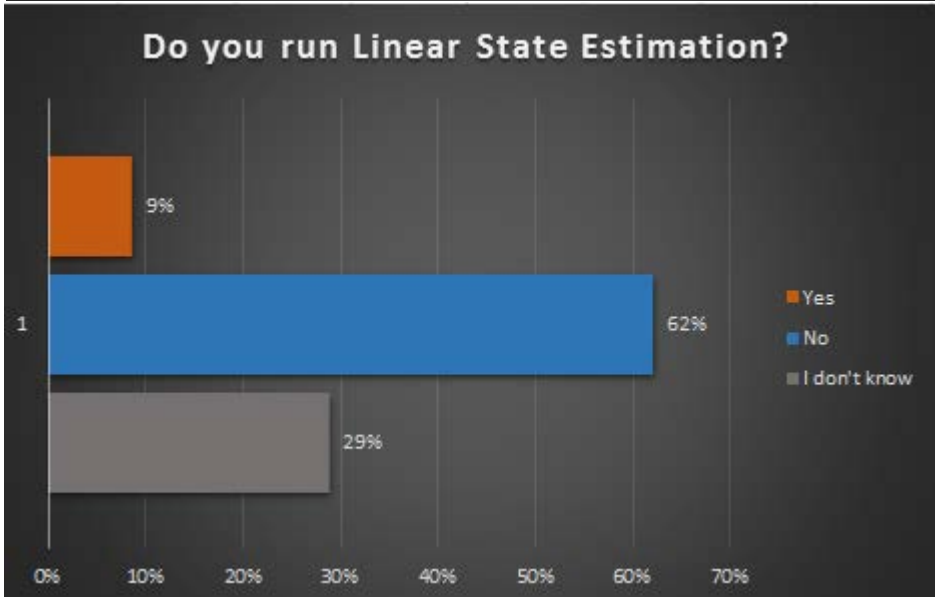


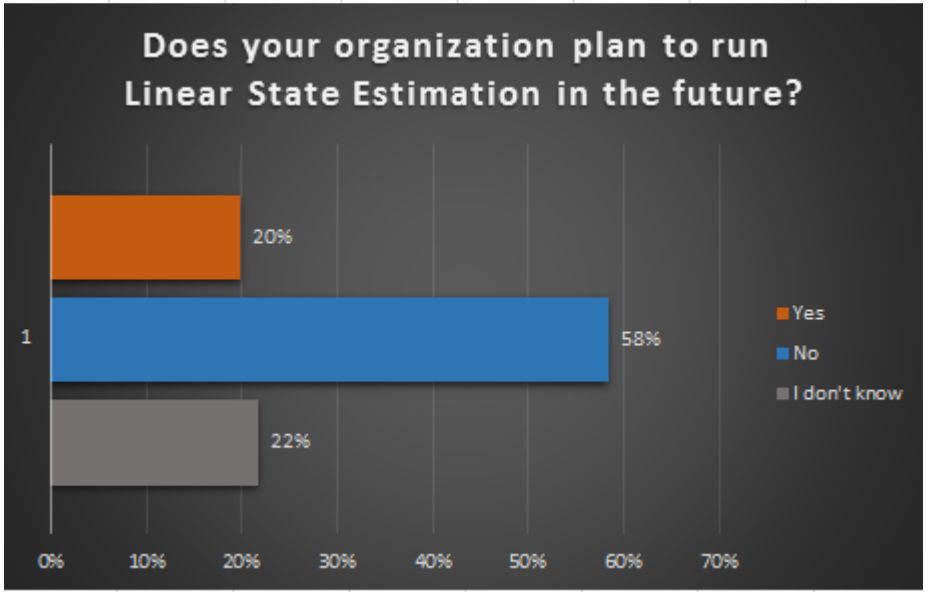
Acceptance of PMUs for State Estimation

- Results of 2016 IEEE/CRSTT survey









Integrating Enhanced State Estimation into the Operational Toolset

- Control room acceptance:
  - Hybrid SE is becoming an accepted tool in control room
  - LSE is still being viewed as a new tool that needs to become more mature and requires further validation
- Limitations of LSE today include:
  - Limited number of PMUs; therefore, limited observability and significantly smaller size (in term of the number of nodes/buses) of “PMU case” as compared conventional SCADA-based SE case
  - No need and capability to run advanced apps at PMU sampling rate, so no need to have a case 30 times/s

What Needs to be Done to Bring LSE to Control Room?

- Questions to answer:
  - Conventional SE is a reliable, proven, mature tool. If SE, a trusted tool that we rely on works, why do we need anything else, like LSE?
  - If PMU data and SCADA data are close, but LSE and SE results differ, which tool to trust? How to verify which solution is correct?
  - When using the LSE output as the state estimator case for advanced apps, how accurate are the results of these apps compared to results from the conventional apps?

Discussion