Machine Learning Based State Estimation for Transmission Systems

Evangelos Farantatos
Principal Team Leader
Transmission Operations & Planning R&D Group
EPRI

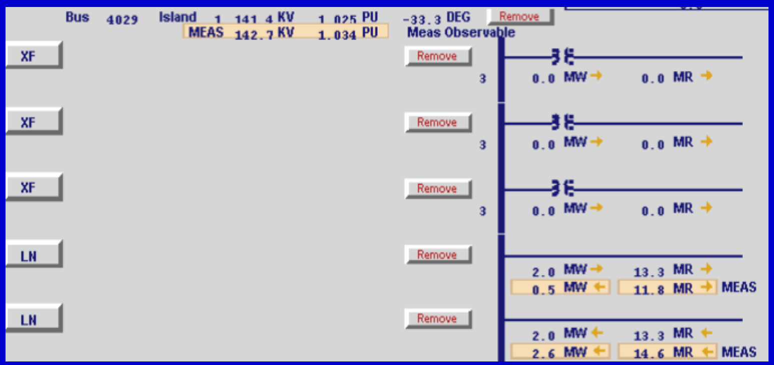
Panel Session: "Application of Big Data and AI/ML in Monitoring, Operations, Planning and Protection"
IEEE PES General Meeting
Orlando, FL
July 19, 2023

Acknowledgments: Prof. Anamitra Pal (ASU)

State Estimation

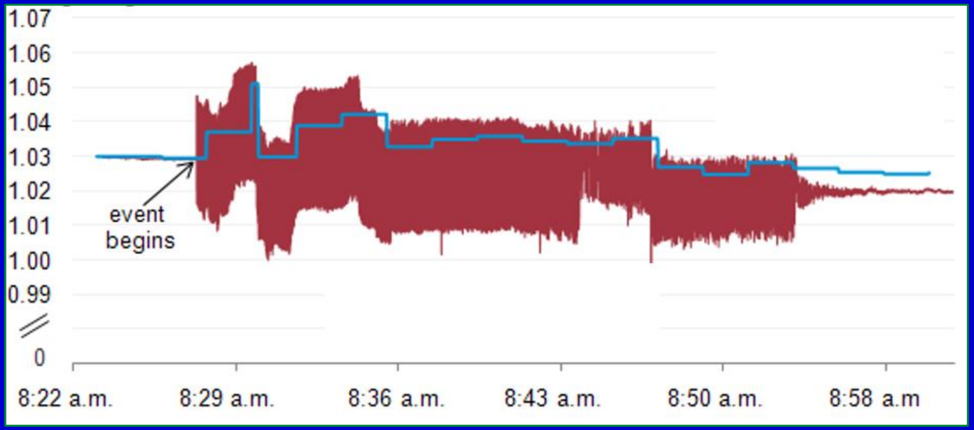
Backbone EMS Function for Situational Awareness

SCADA/EMS State Estimation



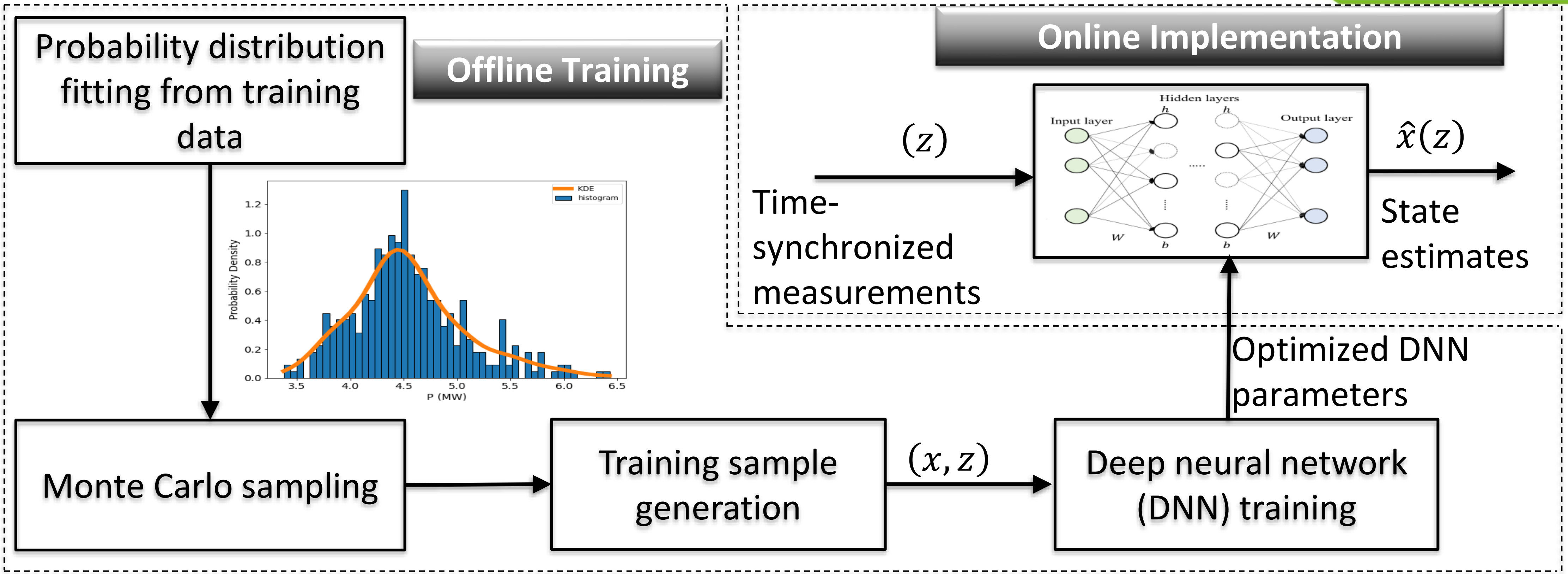
- **State Definition**: Positive sequence voltage phasors (bus voltage magnitudes and angles) of system's buses
- **Measurement Set**: SCADA data
  - Voltage magnitude, current magnitude, real & reactive power flows and injections
  - Measurement model: Nonlinear
  - Gaussian distribution of measurement error
- **Solution Algorithm:** Weighted Least Squares
  - Iterative Solution

PMU Based State Estimation



- a.k.a Linear State Estimation
- **Measurement Set**: Phasor Measurement Unit (PMU)
  - Voltage and current phasors
  - Measurement model: Linear
  - Gaussian distribution of measurement error
- **Solution Algorithm**: Weighted Least Squares
  - Direct Solution

Machine Learning Based State Estimation

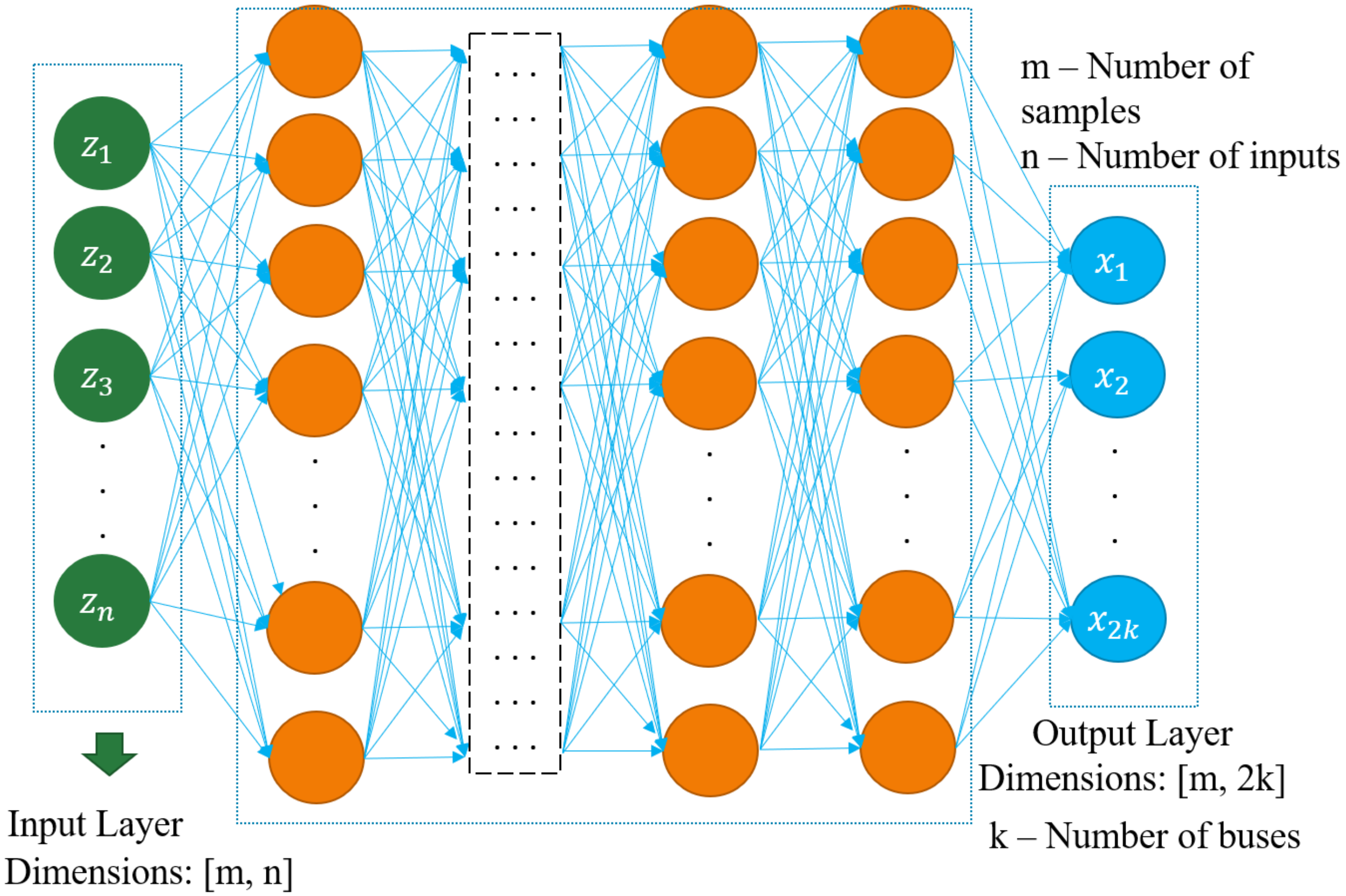


Features

- Model Independent
- Independent of Measurement Error Distribution
- Overcomes SCADA/PMU Synchronization Issues
- Achieves Full System Observability with Limited Number of PMUs
- High Speed

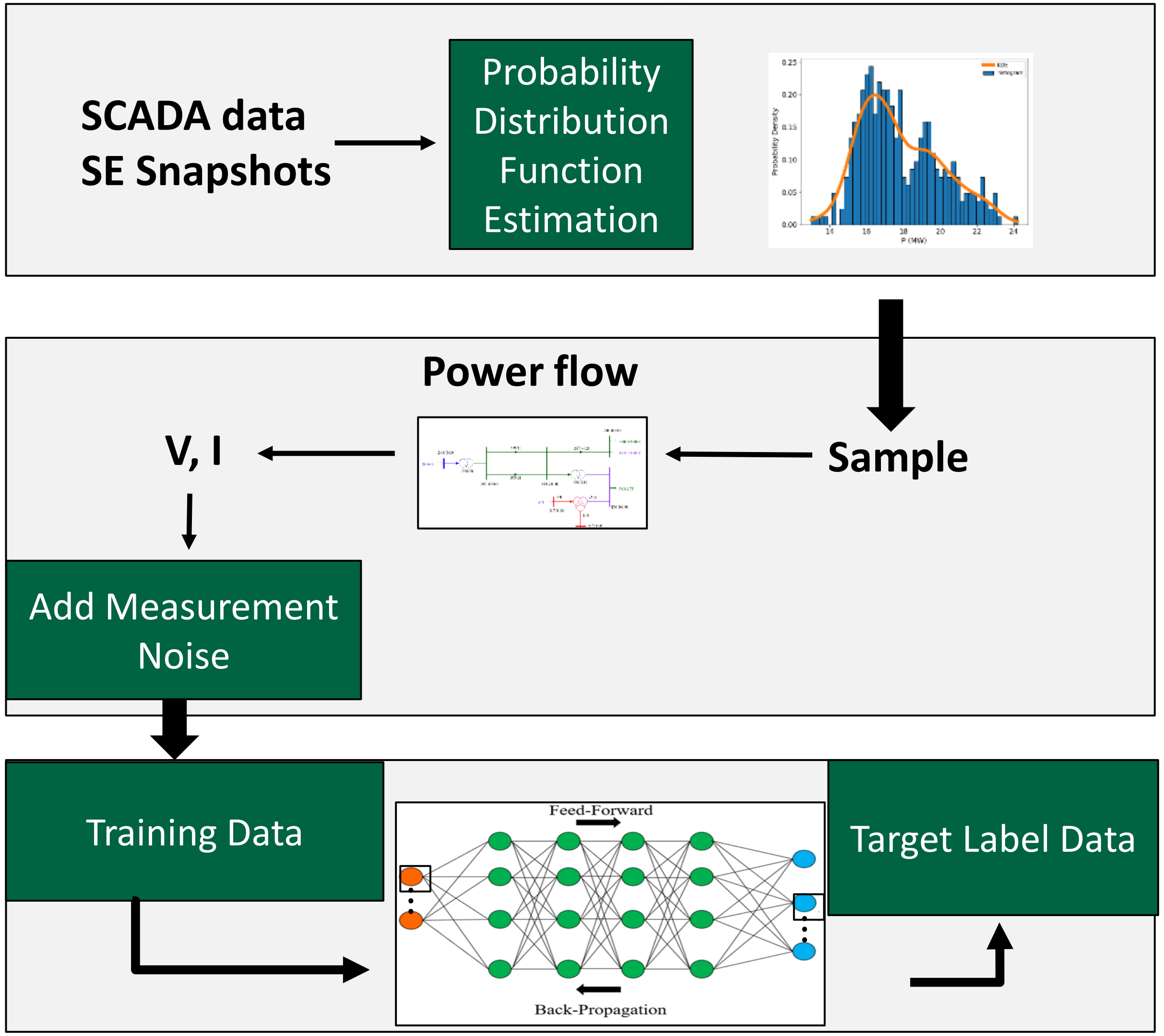
Deep Neural Network (DNN)

- DNN Input: PMU measurements
- DNN Output: States of the system
- Target accuracy:
  - <0.1% error in magnitude
  - <0.5° error in angle



DNN Training

- Collect historical SE data (Load, generation, system model)
- Probability distribution function fitting
- Monte Carlo sampling and PF/OPF solution
- Embed noise functions to mimic instrumentation errors: “Synthetic Measurements”
- Identify dominant topologies
- Train DNN hyperparameters for base topologies and specific PMU placement

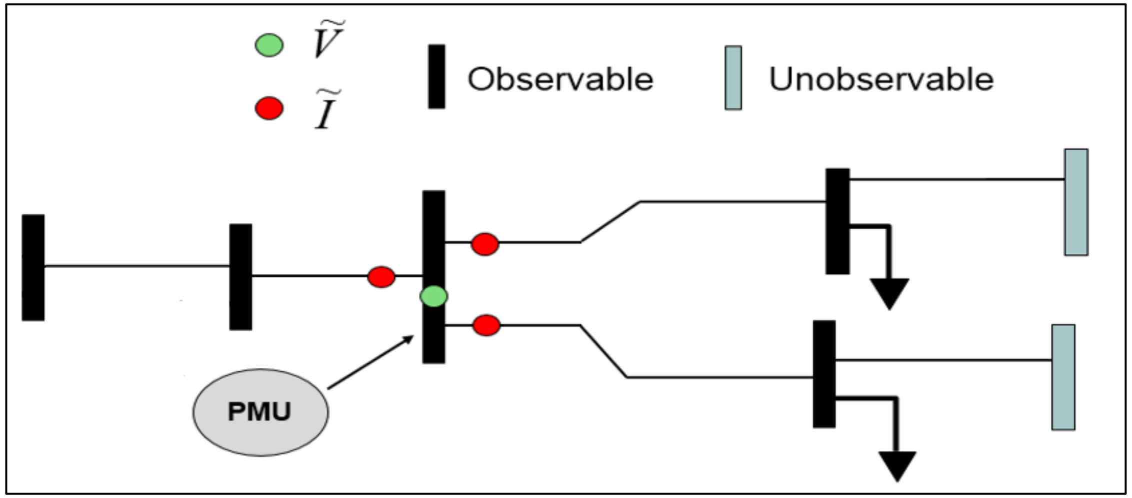


LSE vs ML-SE - Topological Observability

Full Grid Observability with Limited Number of PMUs

- Linear State Estimation (LSE): number of estimated states depends on topological observability from PMUs
- ML based SE: entire system state estimation without need for topological observability

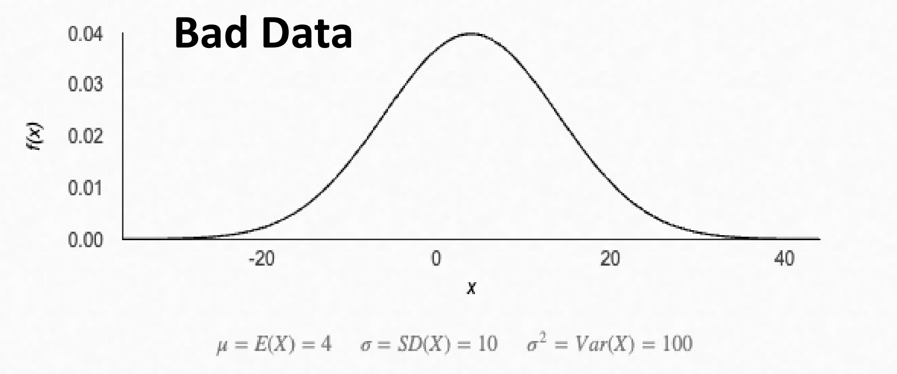
PMU Observability

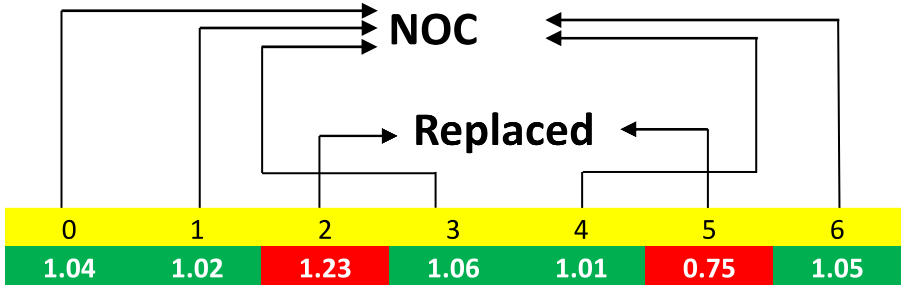


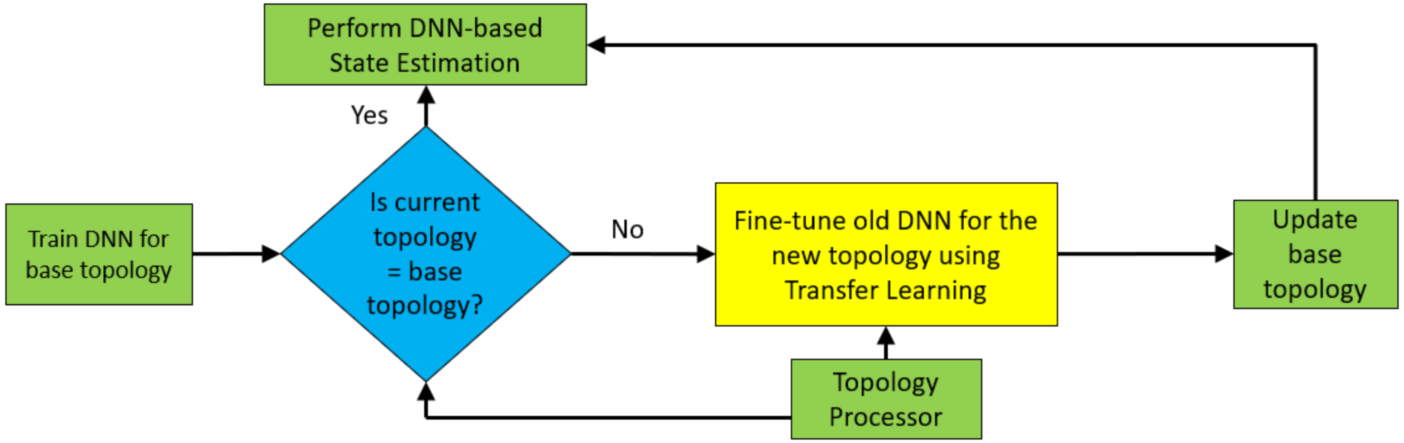
118 Bus System – Estimation Error		
Scenario / Metric	LSE 32 PMUs	ML-SE 13 PMUs
Voltage Magnitude	0.001 p.u.	0.001 p.u.
Voltage Angle	0.00199 rad	0.0020 rad

Bad/Missing Data & Topology Changes

- Bad/Missing data detection based on Wald Test
- Bad/Missing data replacement with Nearest Operating Condition (NOC) from training dataset
- Transfer Learning used for DNN update when topology changes





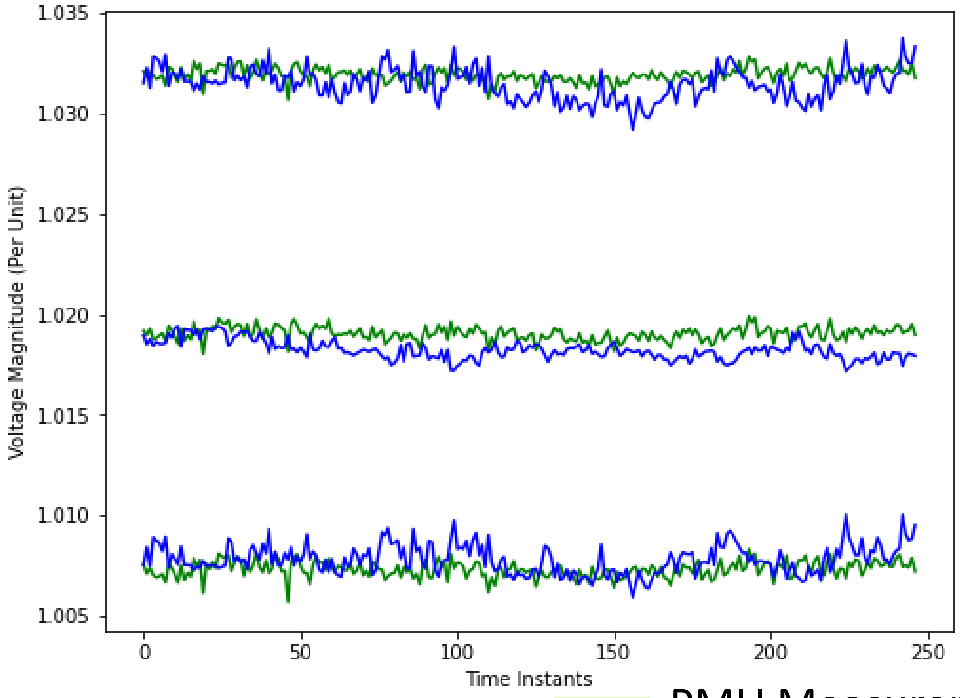


TVA Case Study – Preliminary Results

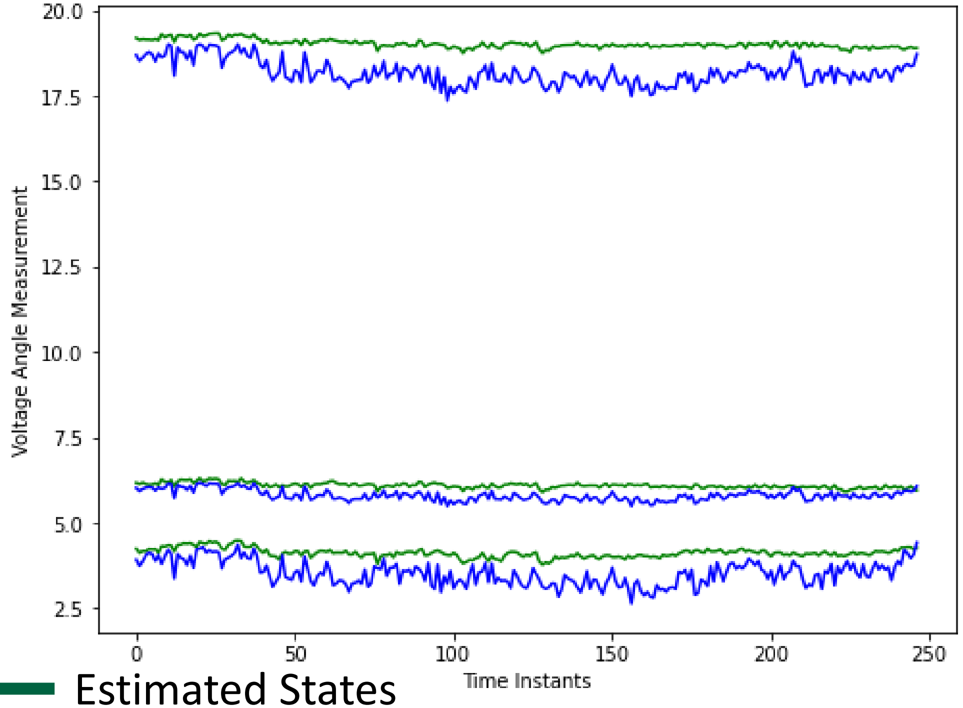
- **Provided data:**
  - EMS SE snapshot files (PSS/E format): July 1 to December 31, two files per day
  - PMU data: 709 PMUs. 1 hour for 15th day of August-December

kV Level	# of PMUs
500	130
345	3
230	15
161	517
<=135	44

Voltage magnitude (Per unit)



Voltage angle (Degrees)



PMU Measurements Estimated States