
AEP's Experience in Configuring and Deploying Linear State Estimator to Enhance Grid Resilience

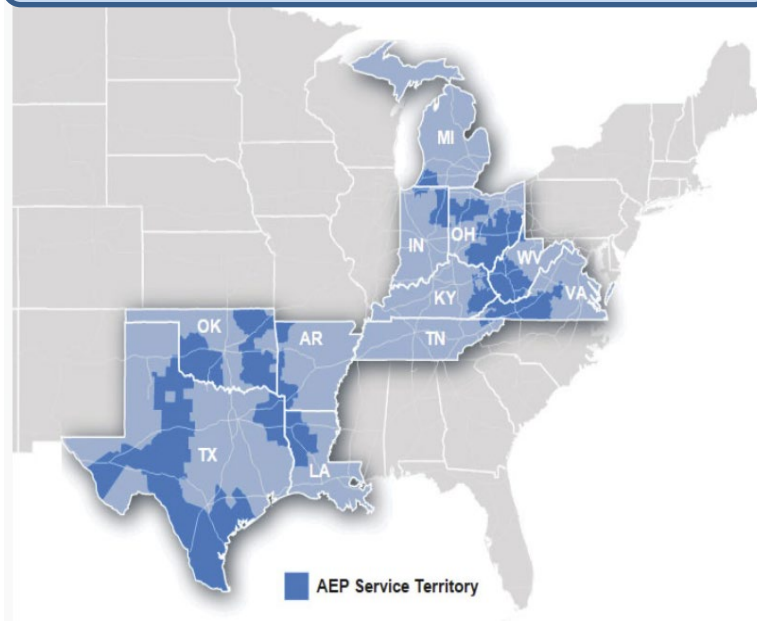
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Introduction — American Electric Power (AEP)

- Largest transmission system consisting of over 40,000 mile network
- 8000+ miles of EHV network rating 345kV and above
- Serving 11 states and majorly participates in three RTOs: PJM, SPP, and ERCOT
- Currently runs three EMS systems with approximately 530 PMUs deployed.

AEP is one of the largest electric utilities in the US



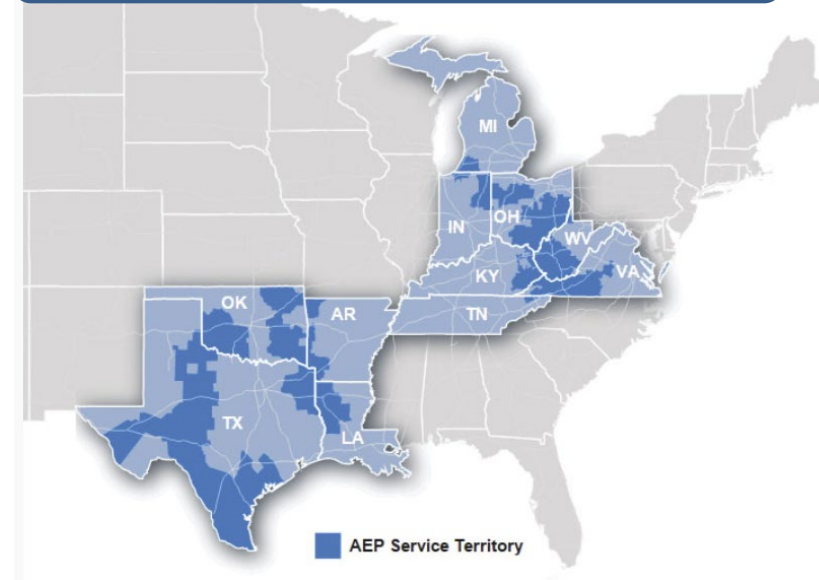
Introduction — LSE Project

Motivation: To improve grid resilience

Goals

- To provide more observability and situational awareness using the existing PMU data to support advanced real-time analysis
- To provide a backup solution when traditional State Estimator fails.

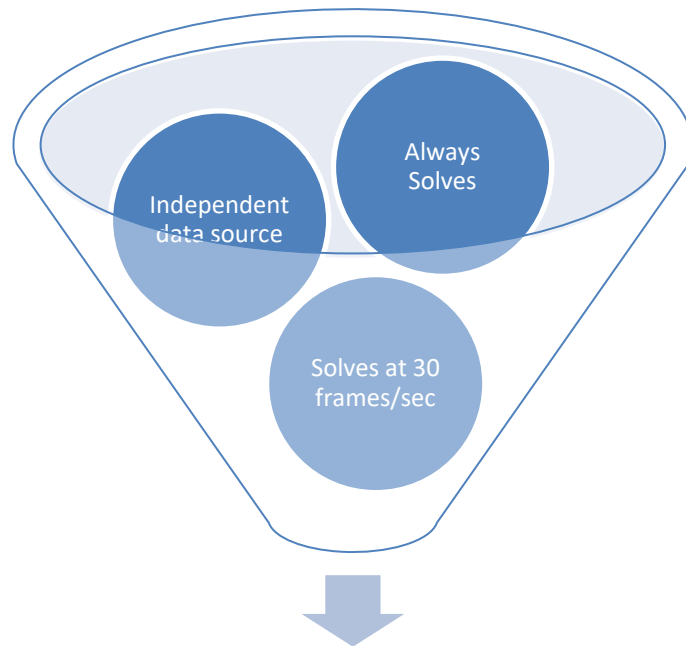
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Benefits — Enhanced Resilience

Backup to AEP's EMS and Real-time Data Archive

Challenges	LSE Solution
State Estimator Not Solving	Always Solves
Iterative and Slow (every few minutes)	Linear Solution, Solves at sampling rate (30 or 60 frames/sec)
Data Quality	Real-time data conditioning
Costly PMU Deployment	Expands Real-Time Observability beyond current PMU coverage
Backup for real-time PMU data viewing and data archiving	Document events up to 30 days
Grid Resiliency / Independent from EMS	Provides backup to EMS resulting from equipment failure, wide area measurement faults, physical and cyber attacks



Improved Grid Resiliency

Benefits — Expanded Observability

Increased Observability in all three footprints

Status/Footprints	PJM	SPP	ERCOT
Total Number of Substations	96	39	57
Substations Observable with PMU	47	24	30
Substations Observable with LSE	81 (+19 non-AEP)	34(+8 non-AEP)	49(+29 non-AEP)
PMU Coverage	49%	62.5%	52.6%
LSE-enabled Extended Coverage	84.4%	87.2%	86%

Table 1. Observability Extension in EHV level of AEP footprints

Saves O&M cost and avoid outages on ultra-high voltage transmission

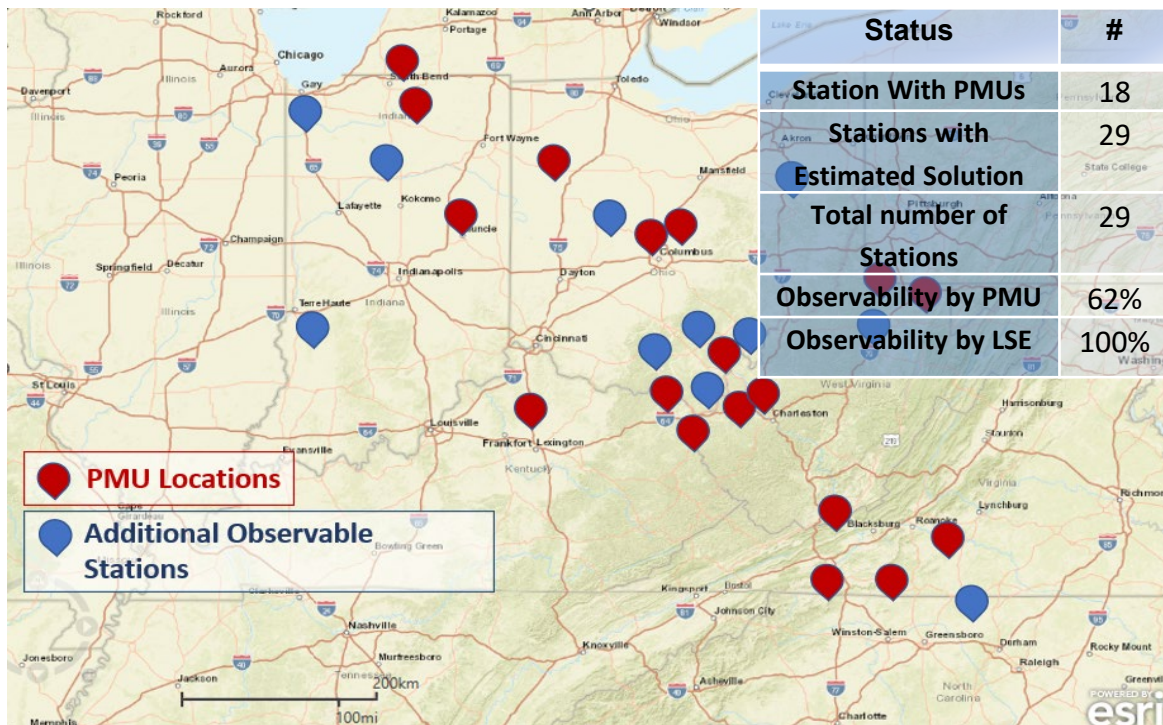
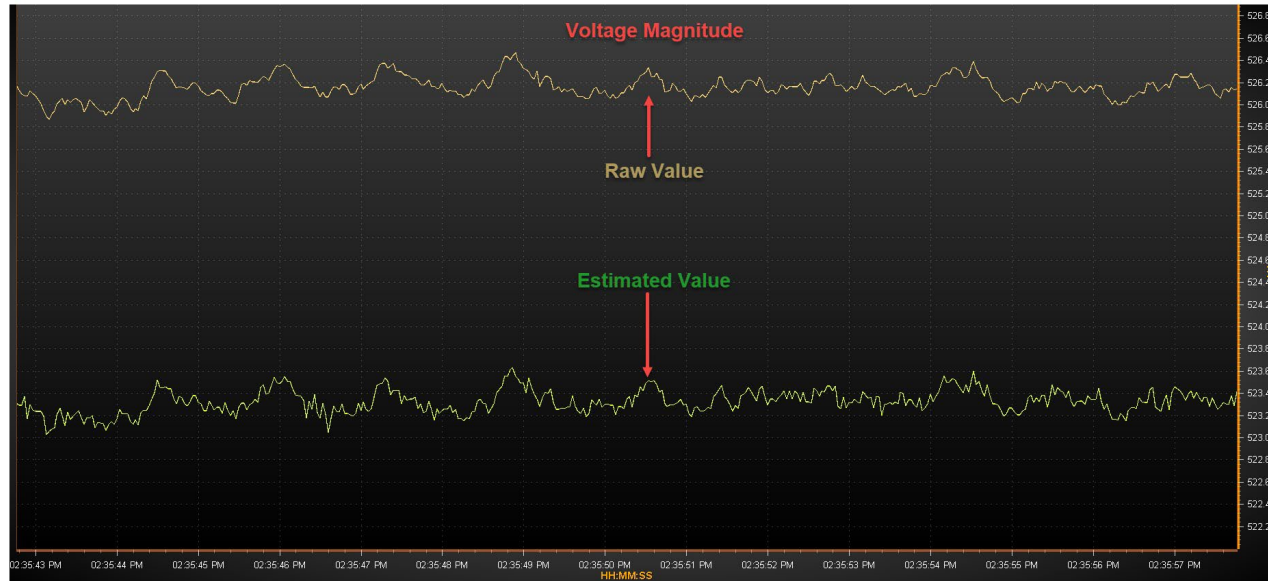


Fig. 1. 765kV PJM System Reaches full Observability by LSE

Benefits — Enhanced Reliability



- Accurate Estimations
- Filters out data problems
- High resolution for oscillation monitoring

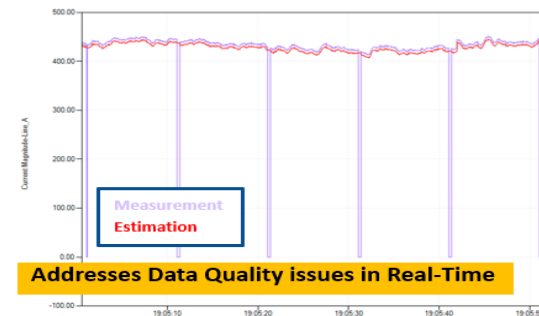


Fig. 2. Example of comparison trend between raw and estimated voltages

Architecture — Infrastructure

Power System

- 530+ AEP owned PMUs streaming at 30 samples/s
- PMU data sent to control rooms and RTOs
- Voltage levels: from 12 kV to 765 kV

Data Centers

- Two Data Centers (East and West)
- Highly Available
- Send data to RTOs
- Send data to LSE Servers
 - Testing environment
 - Staging environment
 - Training environment
 - Production A and Production B

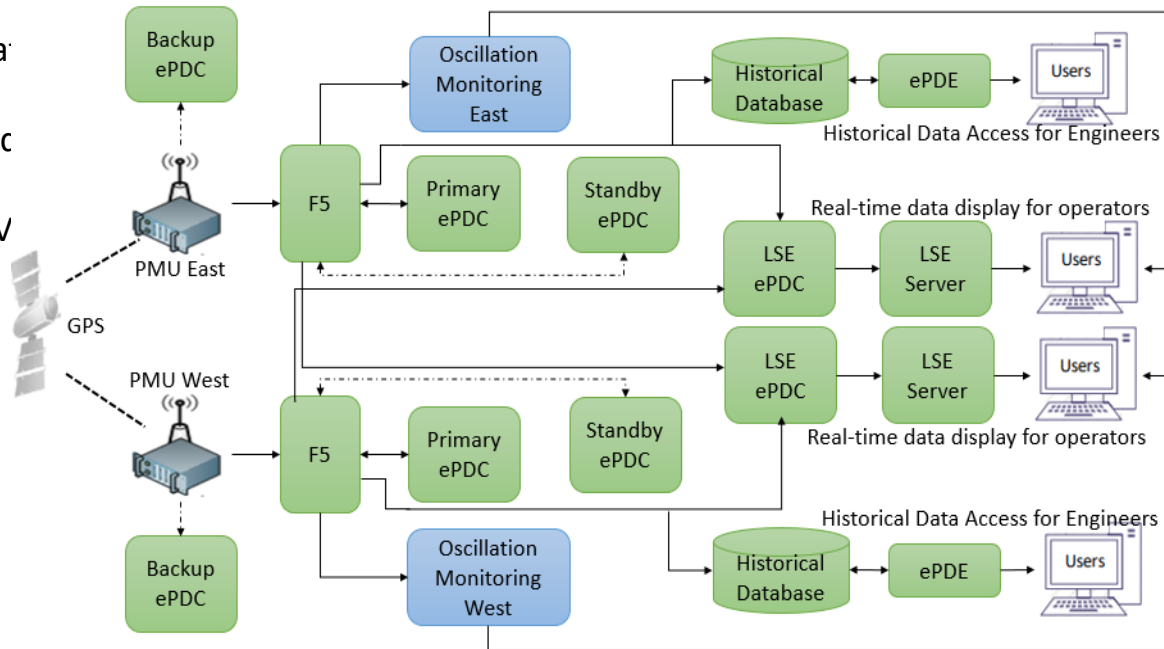


Fig. 3. AEP's PMU Infrastructure

Architecture — Deployment

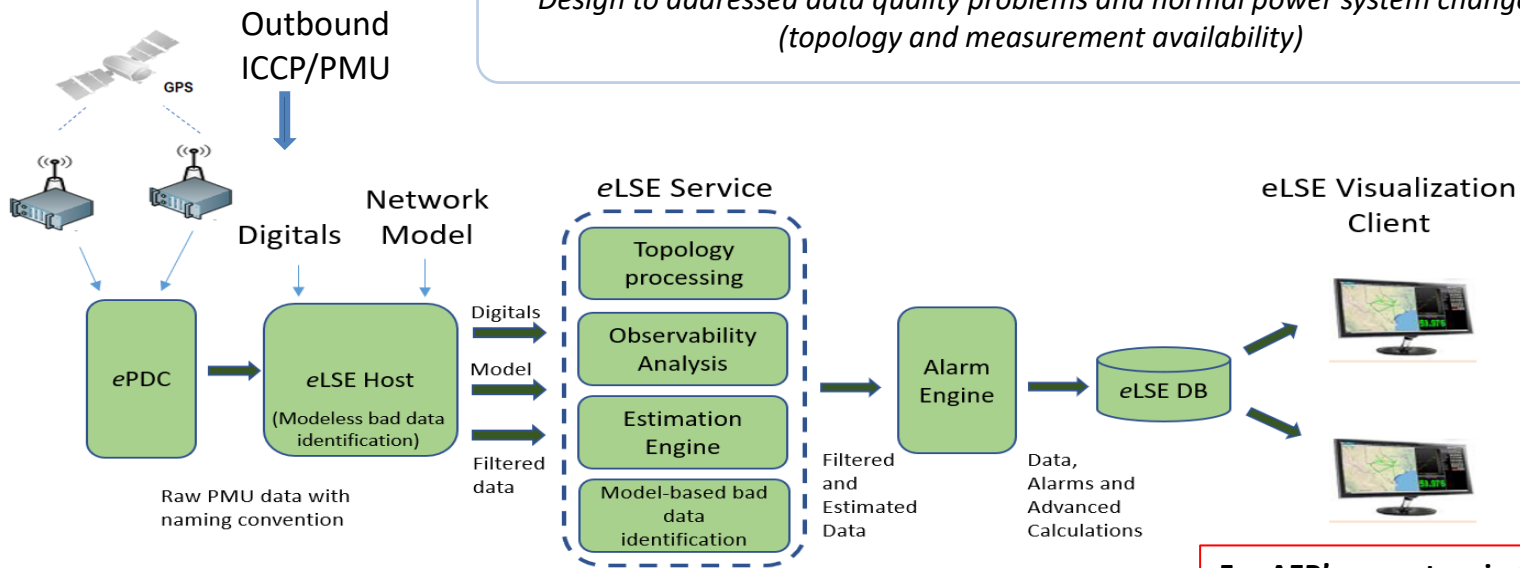
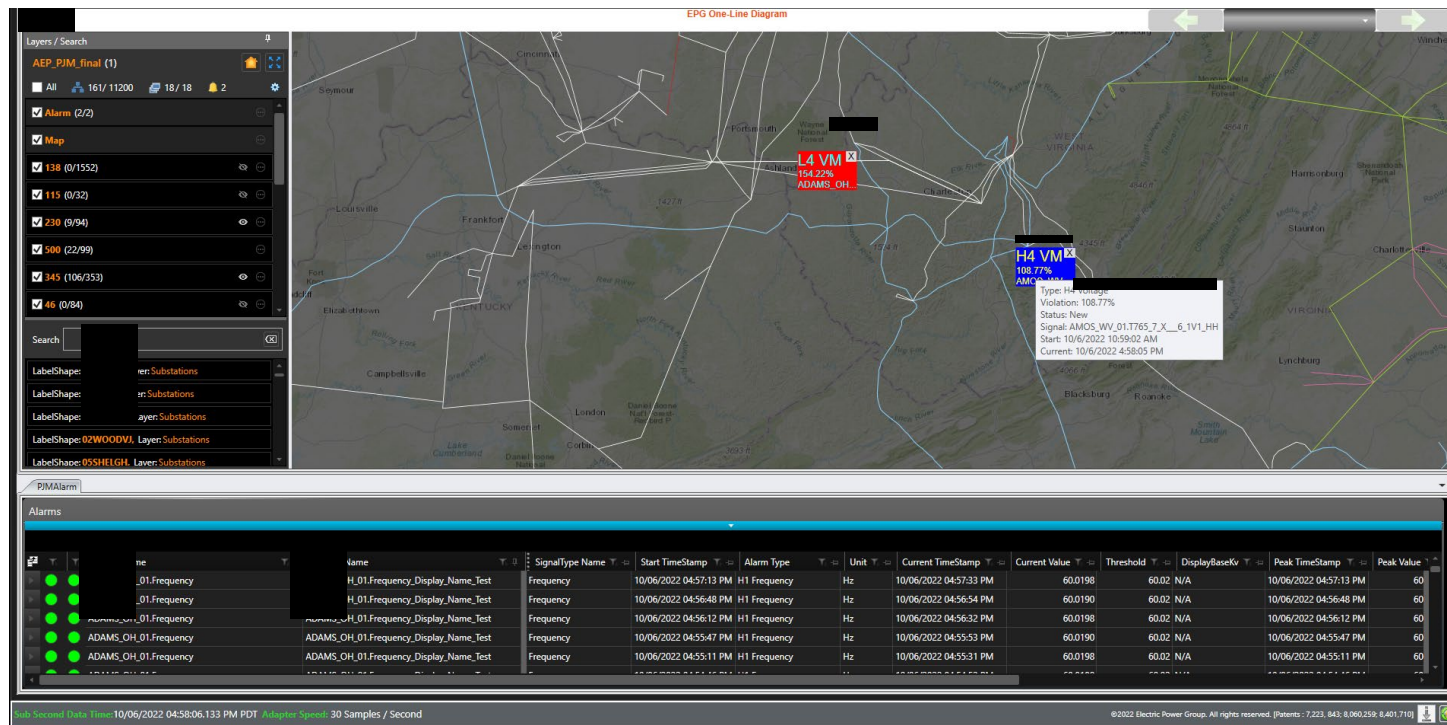


Fig. 4. LSE Architecture Diagram

For AEP's operators in Control Room and Engineers

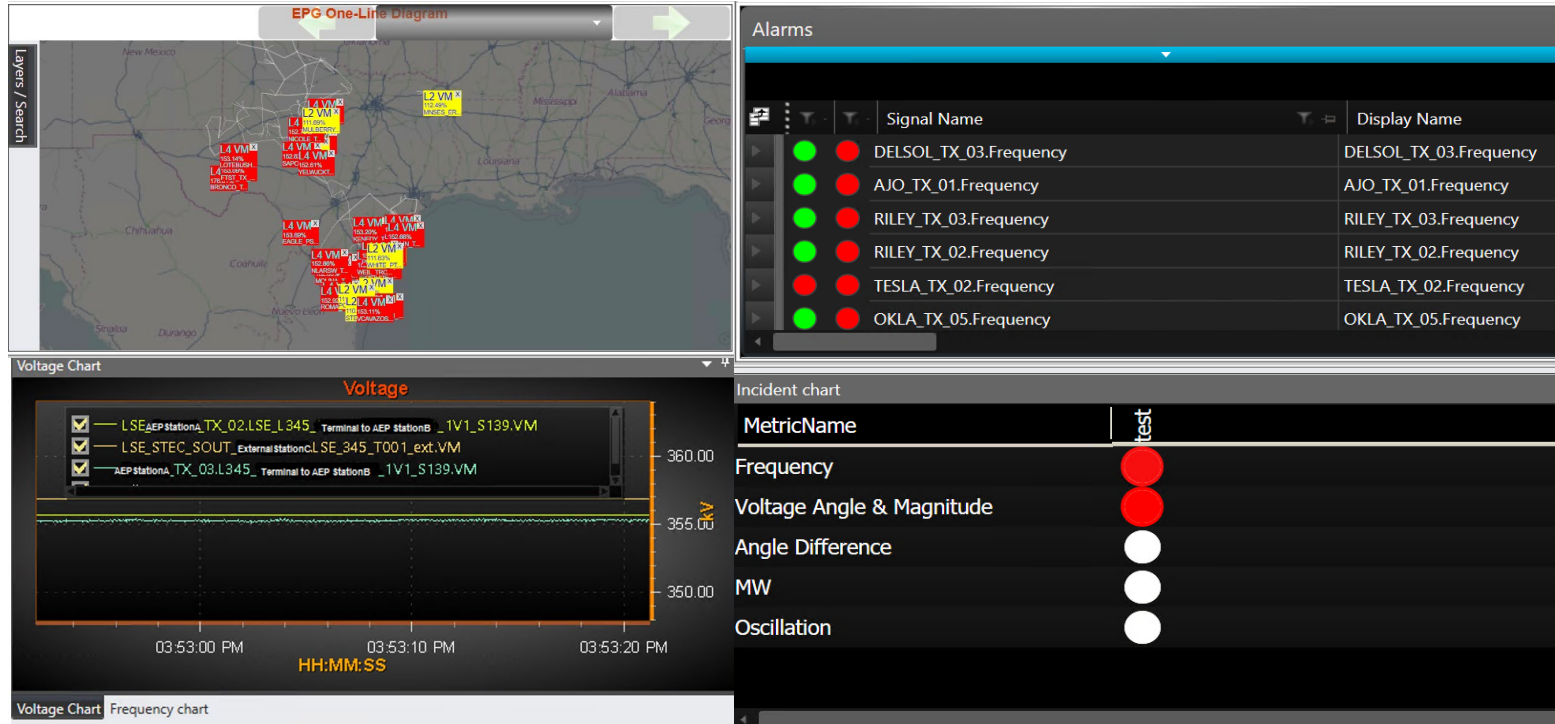
Functionalities — Visualizations



- Geospatial map
- Layered Overview diagram
- Pop-ups notifications
- Alarm Panel
- Customized Display
- High-speed trending capabilities

Fig. 5. Example of LSE Display used in the control room

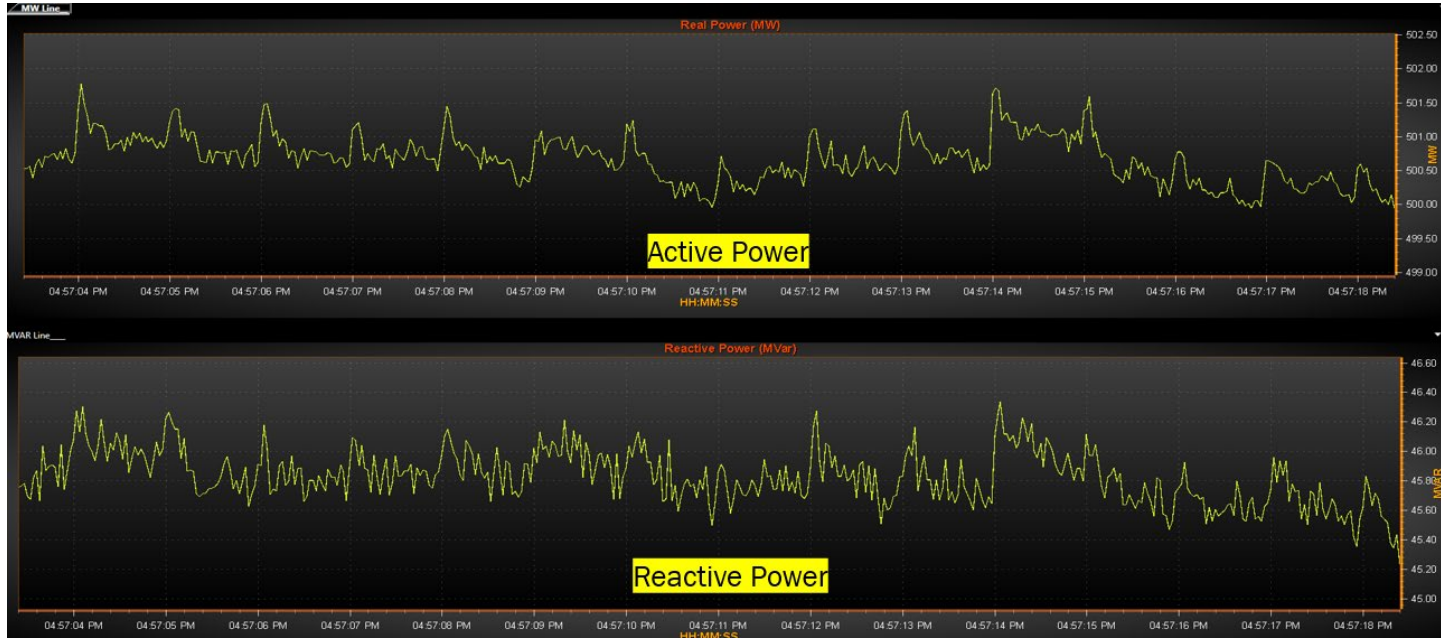
Functionalities — Visualizations



- Geospatial map
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- **Alarm Panel**
- **Customized Display**
- High-speed trending capabilities

Fig. 6. Example of Customized Display on Workstation

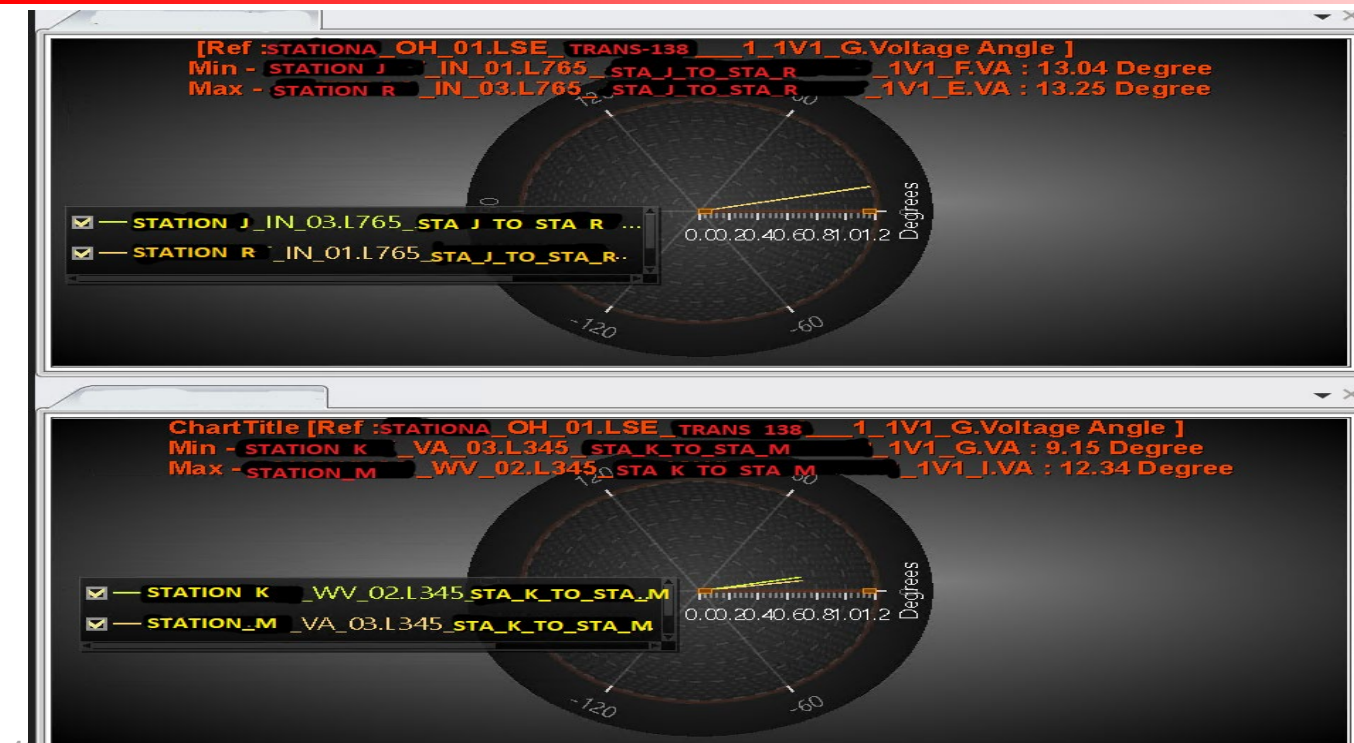
Functionalities — Visualizations



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- **High-speed trending capabilities**

Fig. 7. Example of High-speed trend used in the control room

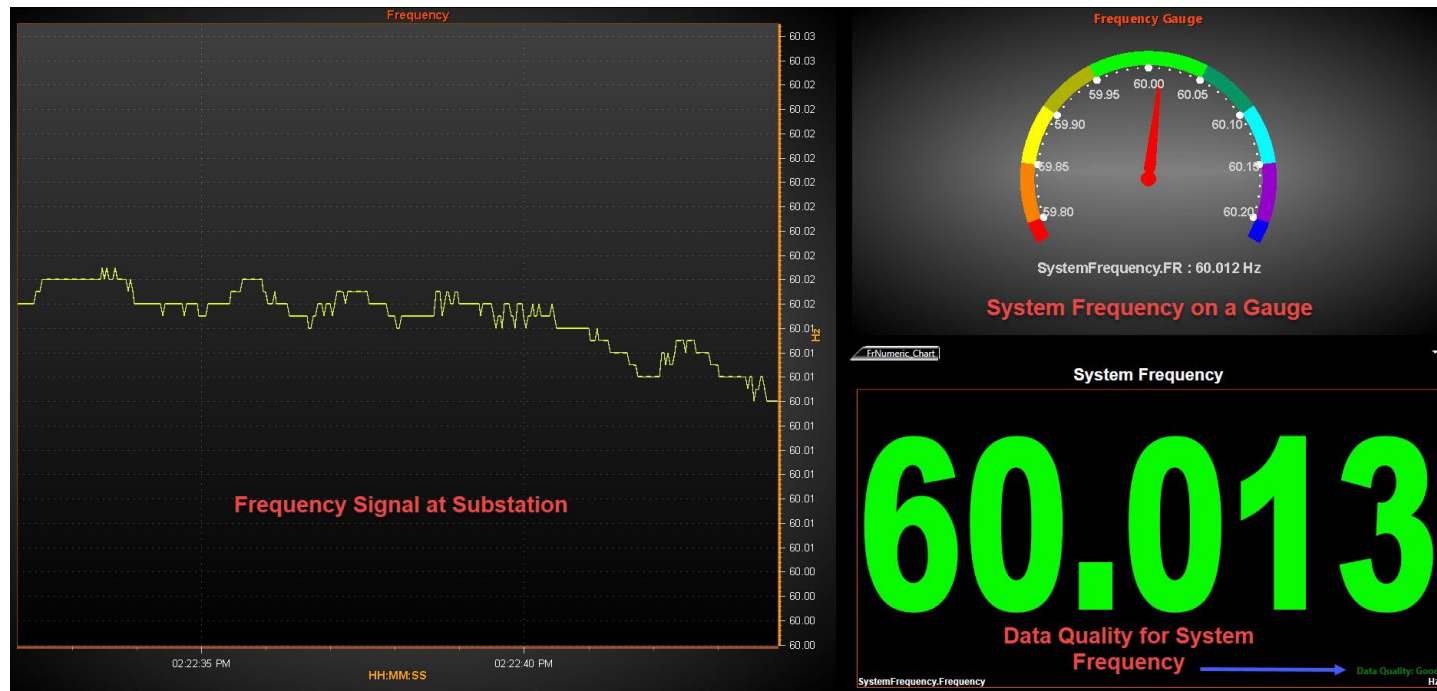
Functionalities-Visualizations



- Geospatial map
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- Customized Display
- **High-speed trending capabilities**

Fig. 8. Example of Angle Difference Chart

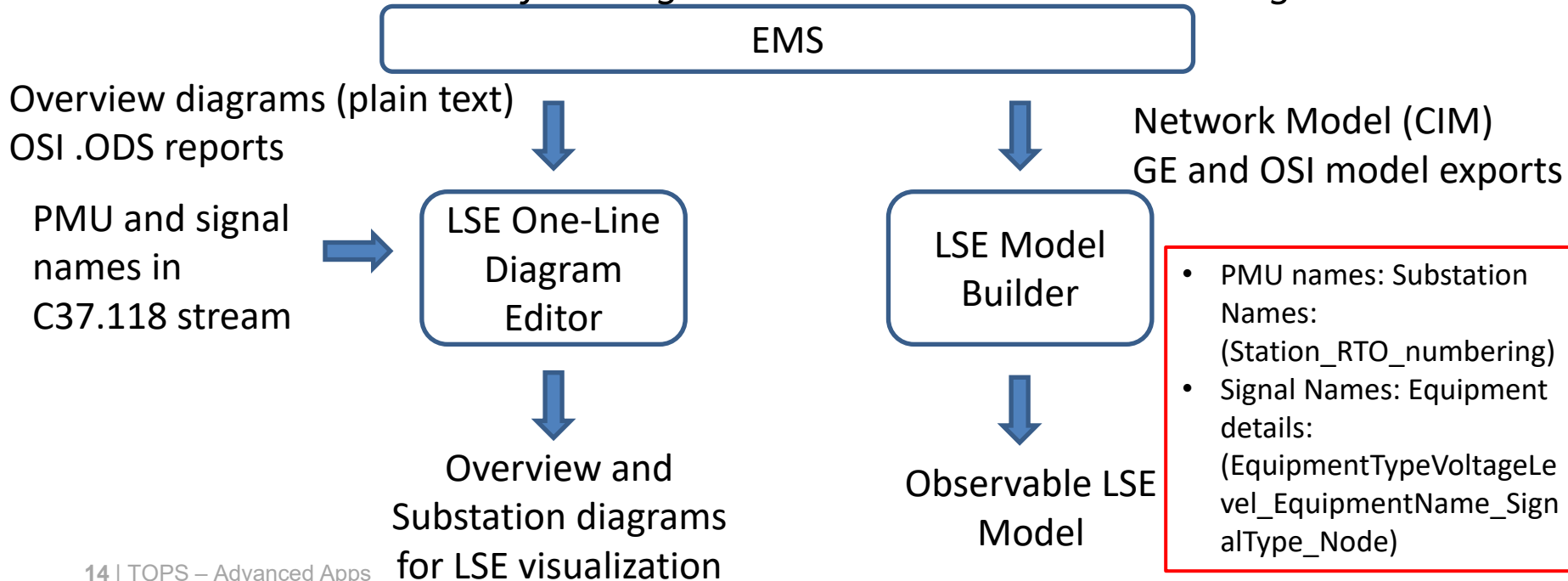
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Functionalities — Automated Model Promotion

Automated Conversion for Integration with EMS Models and Diagrams



Summary

- LSE was deployed at AEP with an architecture to enable high availability and automatic model/diagram promotion and customizable visualization
- LSE provides high resolution state estimation solution that is granular enough to track fast system dynamics
- LSE provides redundancy for traditional SE, enhancing grid resilience
- LSE expands the scope of high-resolution monitoring beyond PMU coverage, benefiting real-time analysis such as oscillation source location

Questions

