PMU Data Analytics for Power System Planning and Operations

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Outline

- Introduction
- Automated Event Mining – Automated PMU Data Analysis
- PMU Data Analytics - Use Cases for Planning and Operations
  - Oscillation Detection and Monitoring
  - Asset Health Monitoring
  - Automated Generator Model Validation
  - Linear State Estimator
- Q&A, Discussion

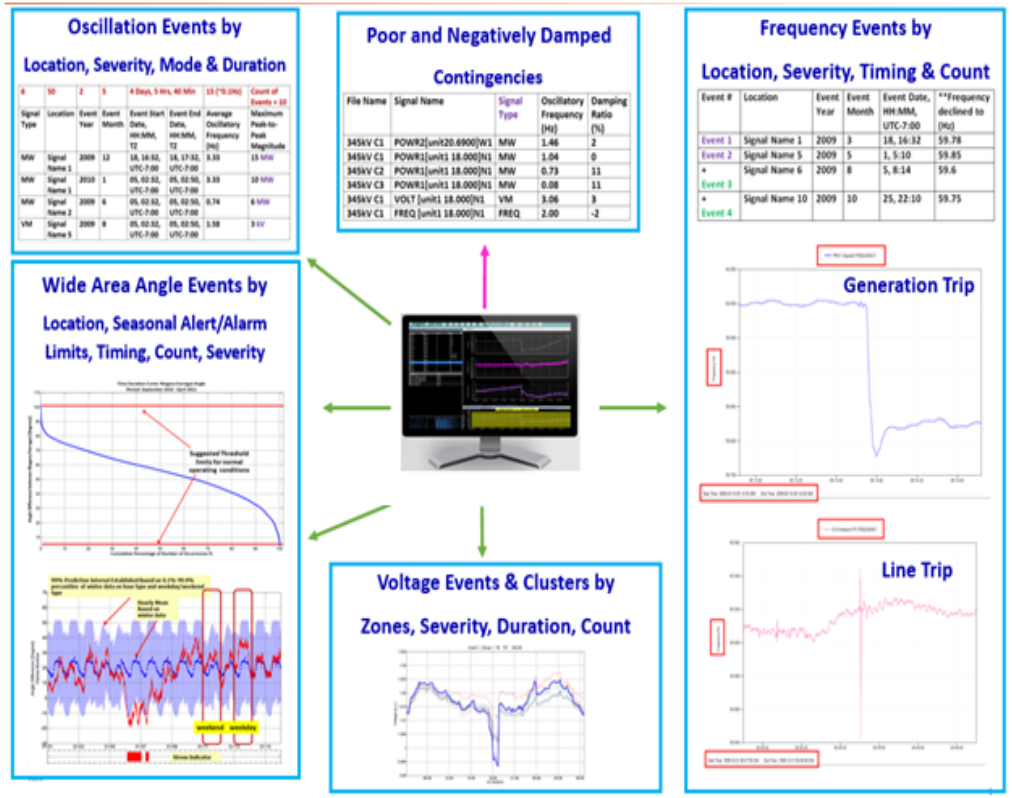
Introduction

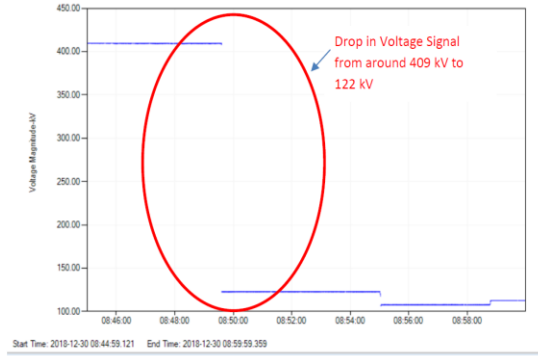
- Rapid Adoption of Synchrophasor Technology and deployment of PMUs
- Utilities, ISOs and RCs have Terabytes of Synchrophasor data being archived
- High-resolution (30 frames/second or higher) and time-synchronized data from PMUs provides unprecedented visibility into grid dynamics
- Need for PMU Data Analysis
  - Extract value from large archives to guide planning and operations
  - Assess Grid Performance
    - How Many Events: Where, When, How Severe?
    - Identify weak spots in the grid to guide capital investments and update operating procedures
    - Identify indicators of potential equipment failure and device malfunctions
  - Validate and Set Alarm Thresholds for Real-Time Operations

Automated Event Mining (AEM)

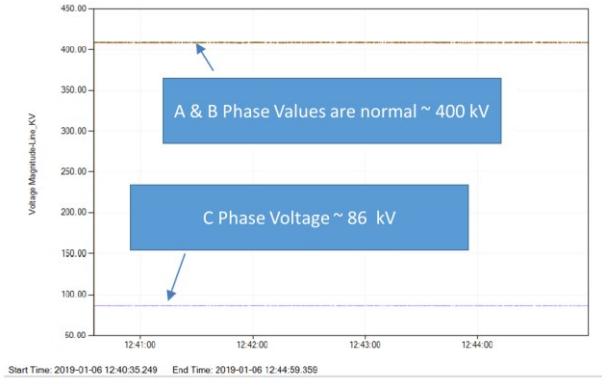
Automated Analysis of Large amounts of PMU data (weeks, months, years)

- Oscillations
- Generation & Load Trip
- Faults
- Line Trips
- Extended Low voltage events including FIDVR
- Device Calibration Issues
- Equipment Failure
- Grid Stress (Phase Angle Differences)



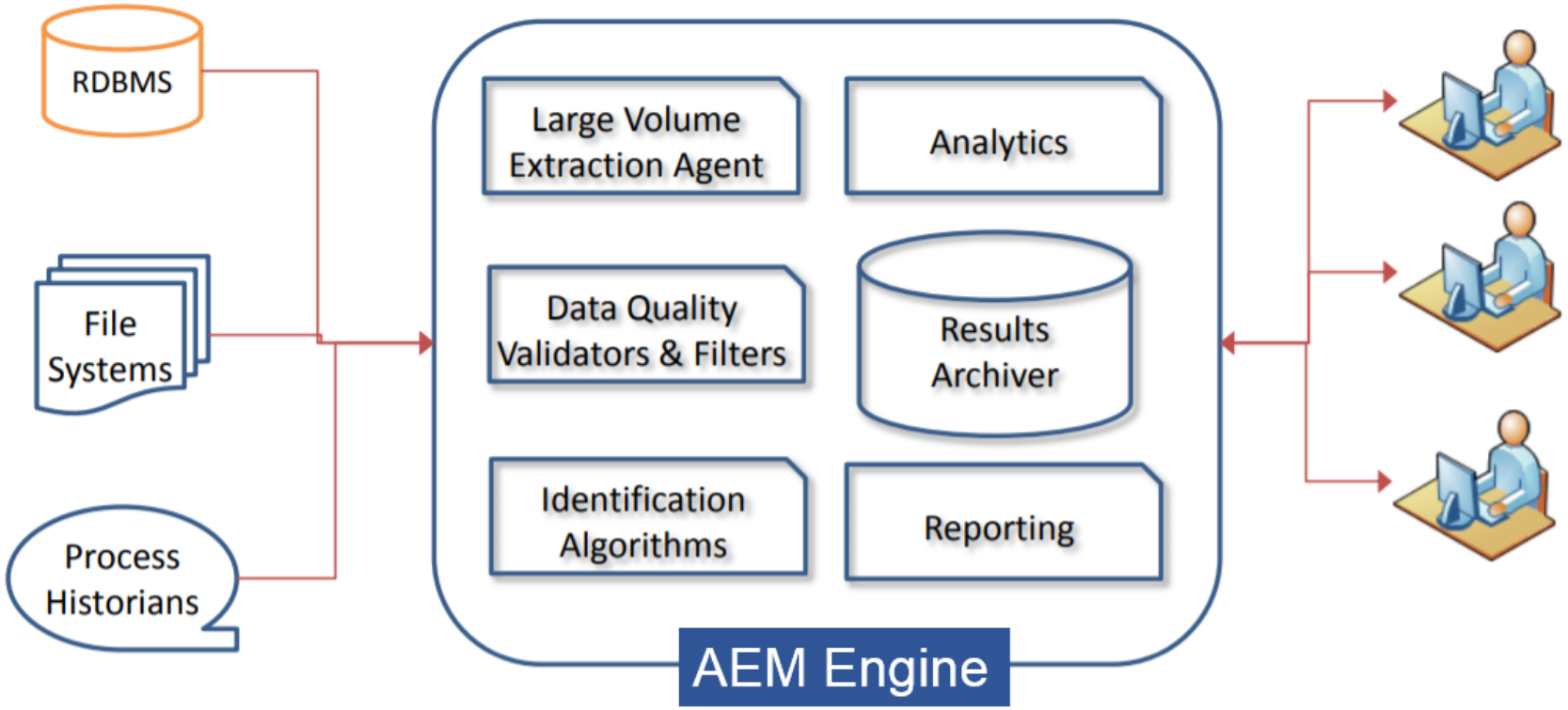


Potential Transformer (PT) Failure



Device (PT, CCVT) Calibration Issue

Architecture - Overview



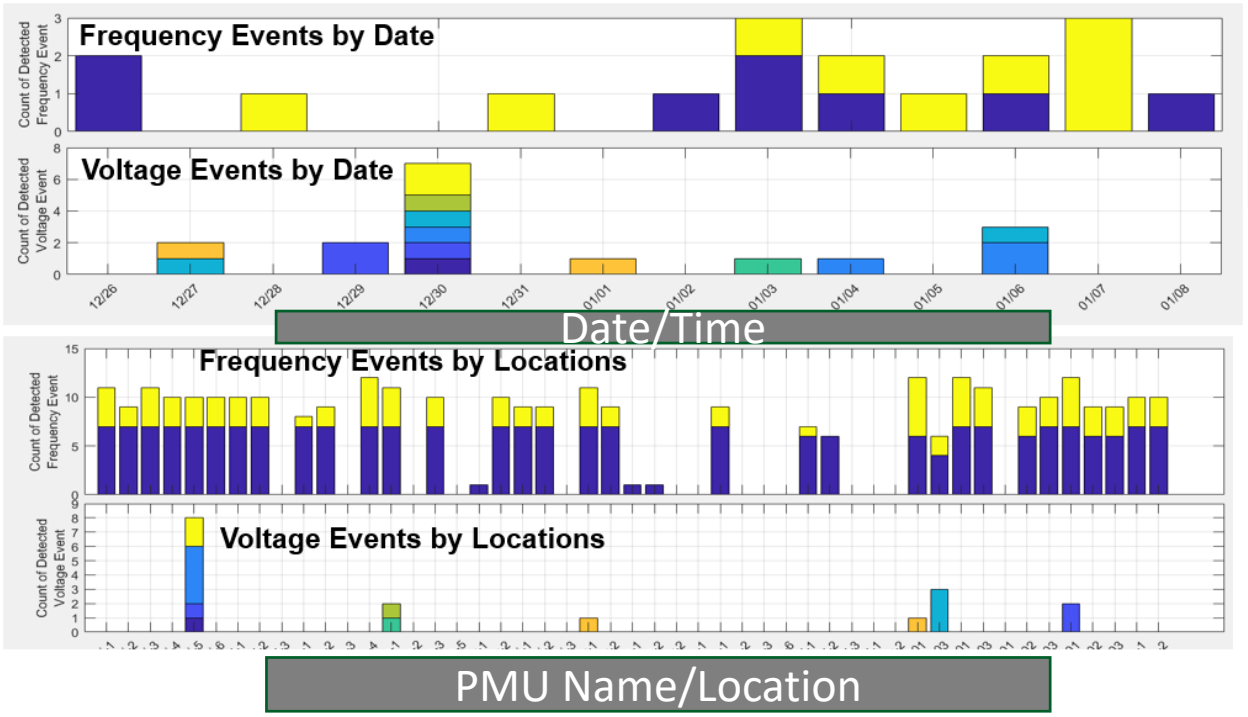
Data Sources

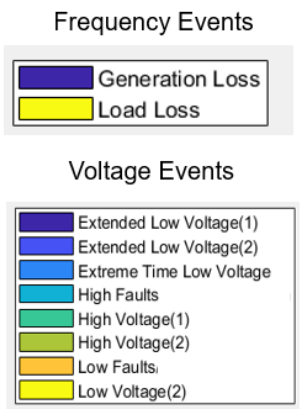
Visualization

Reports

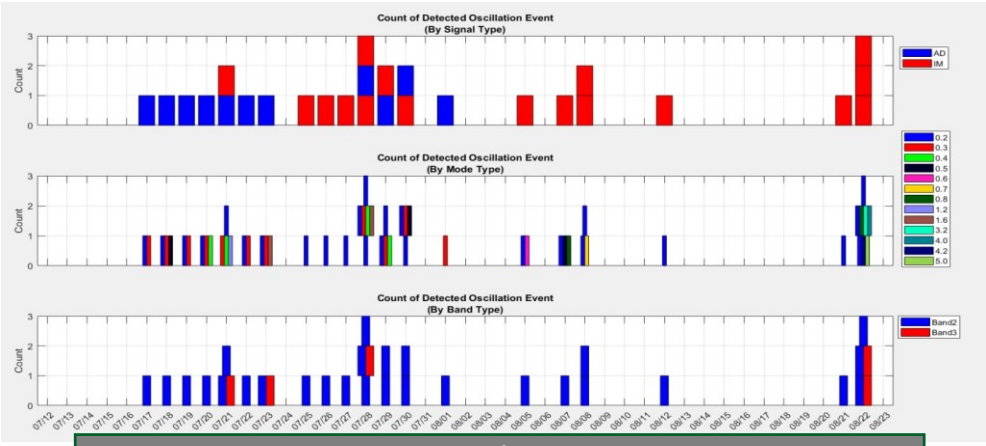
Events By Date and PMU Location/Substation

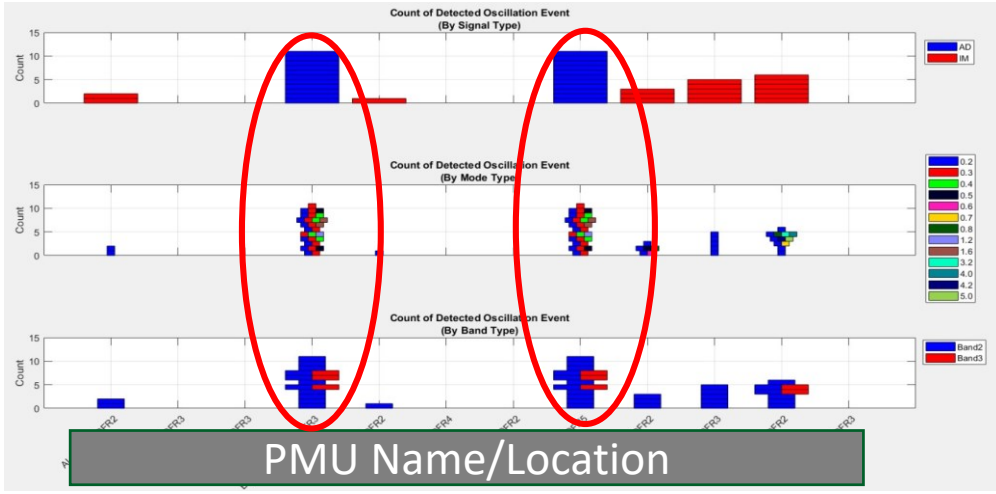
Frequency and Voltage Events





Oscillations



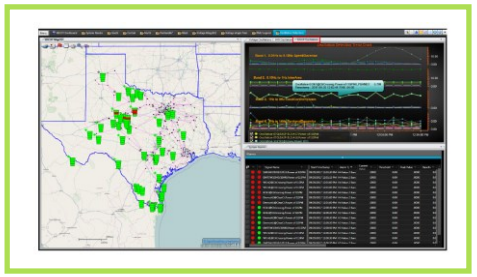


Value of Grid Performance Analysis for Planning & Operations

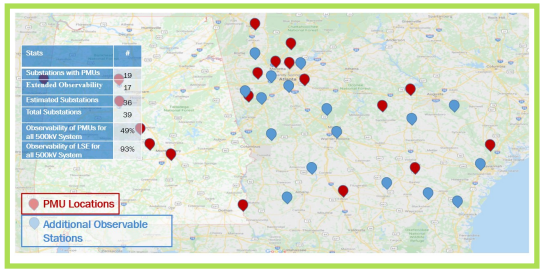
- **Planning & Operation Management**
  - System dynamic performance assessment
  - Identify emerging problem areas that threaten reliability
  - Actionable Information to guide goals and programs
- **Operations Support & Analysis**
  - Assessment of Events using multiple perspectives such as time-of-day, season, severity, etc.
  - Identification and Analysis of Oscillations for improved monitoring and mitigation
- **Planning & Modeling**
  - Identify Weak Spots in the system to guide capital investments
  - Support Model Validation using PMU data
- **PMU Engineering**
  - Verify Event detection and Alarm operation, fine tune Alarm thresholds
  - Identify unreliable Equipment and measurement system problem areas

PMU Data Analytics - Use Cases for Planning & Operations

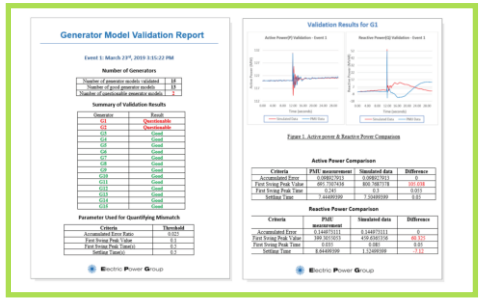
Oscillation Detection and Source Location



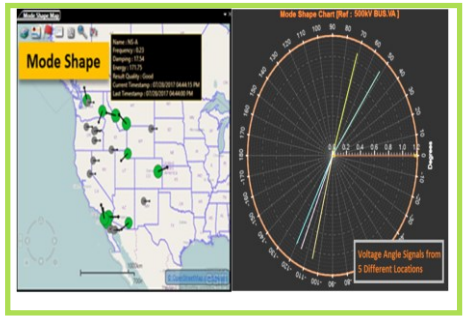
Linear State Estimation for Grid Resiliency



Generator Model Validation



Oscillations Monitoring



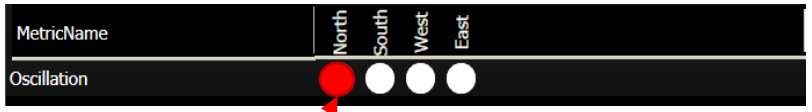
Asset Health Monitoring

Oscillation Detection and Monitoring with Synchrophasors

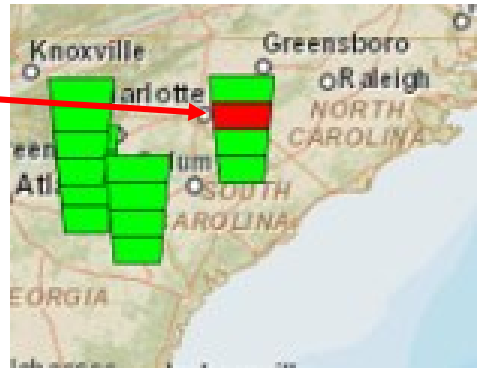
- Oscillations may reveal issues in the power grid, may causes equipment damage and in severe cases system wide oscillations could cause backouts (e.g., Aug 1996 in Western Interconnection)
- **Monitoring Natural System Oscillations (Mode Meter)** – Continuous Monitoring of Natural Oscillation Modes and their damping
- **Oscillation Detection** – Quick and Accurate Detection of forced Oscillations
- **Oscillation Source Location** – Identify source of oscillations such as source region/area or generating power plants

Oscillation Detection & Monitoring

Detection – Alarms



Oscillation Detected

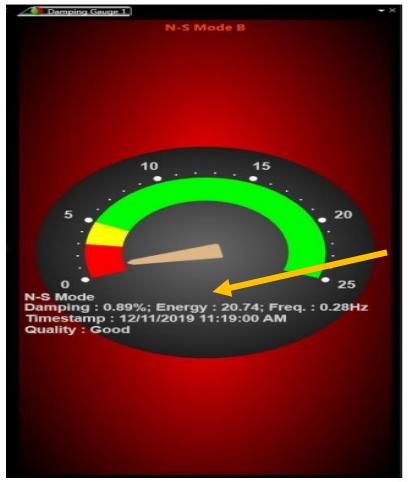


Severity

Forced : Amplitude

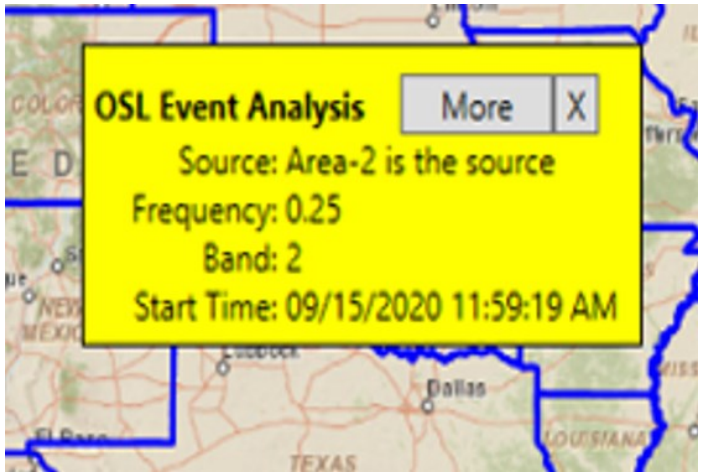
130 MW peak to peak amplitude

Natural : Damping

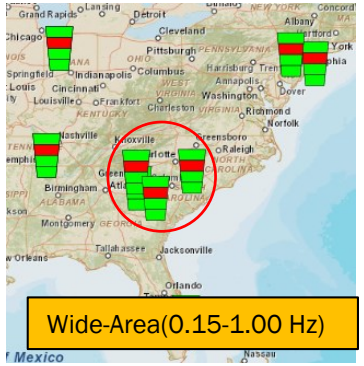


Low Damping

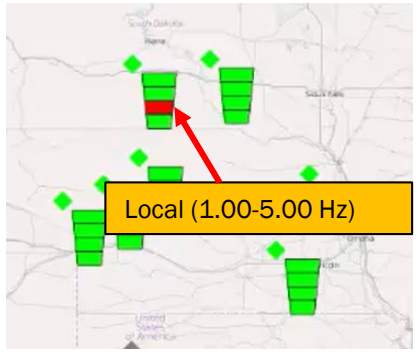
Source Location (Identify Source Area or Source Generator)



Type



Wide-Area



Local

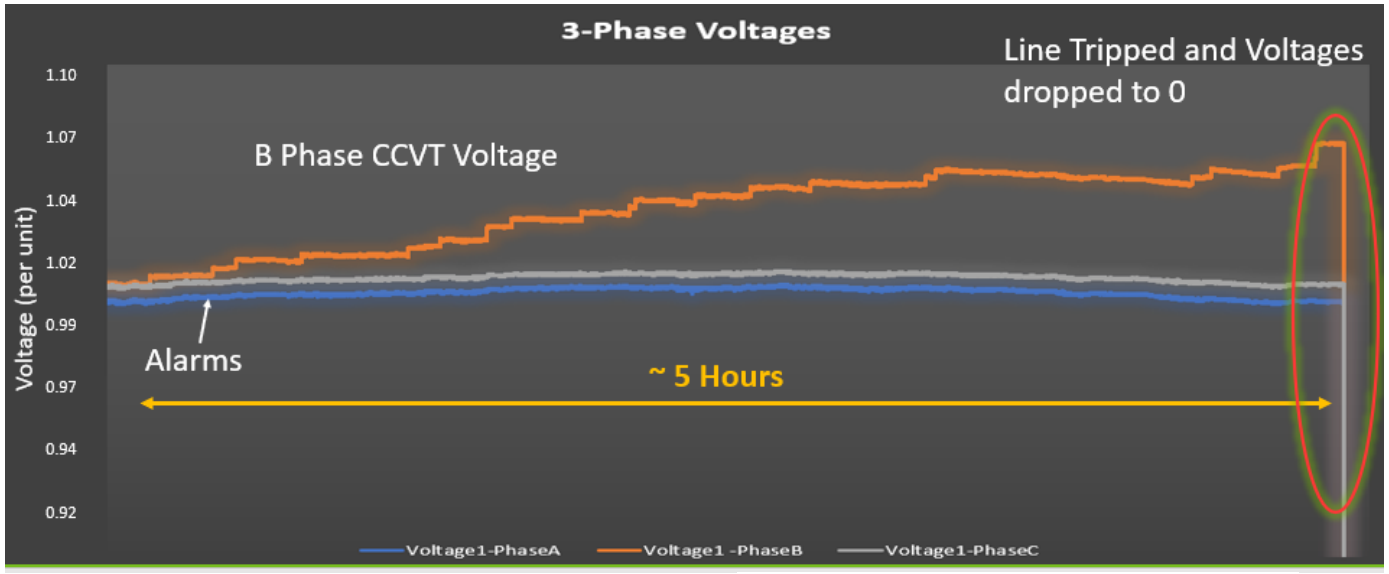
Root Cause Diagnosis and Remedial Actions

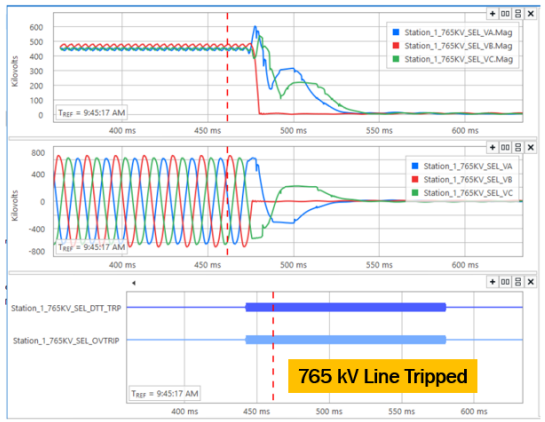
- Forced Oscillation from Generation Plant
- Contact Plant Operators
- Generation Redispatch
- Check Controller Settings

Asset Health Monitoring

Using PMU Data to detect precursors to Equipment Failure

- Transmission Equipment is Aging
- Failures of substation equipment have led to damage and/or explosions at substations, compromising personnel safety, affecting reliability, and causing outages
- Instrument Transformers such as PTs, CTs, and CCVTs are not monitored in substations
- Electrical Signatures in PMU data can be analyzed in real-time to detect precursor to equipment failure

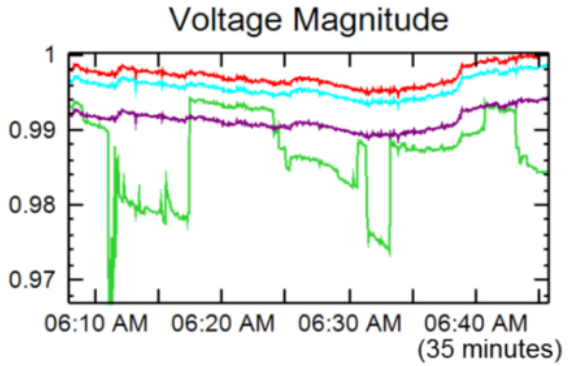




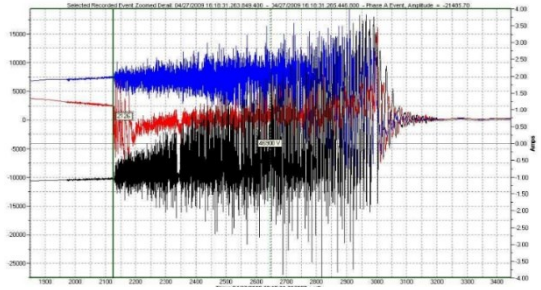
Source: Qiushi Wang et. al, 'CCVT Modelling Failure Mode Investigation and Impact on Relay Operation', CIGRE-US, 2020.

PMU Data for Detecting Equipment Failures

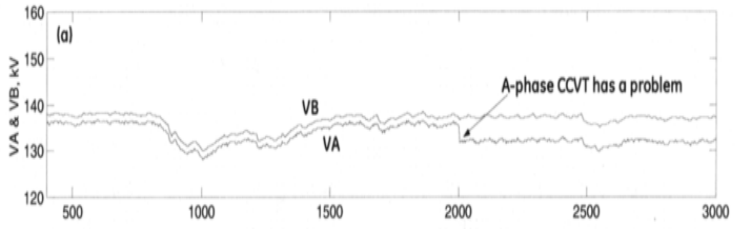
Loose Fuse Connections in CCVT Safety Switch

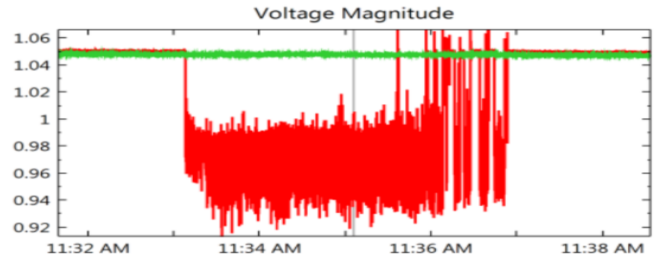


Switching Transients due to Ferroresonance

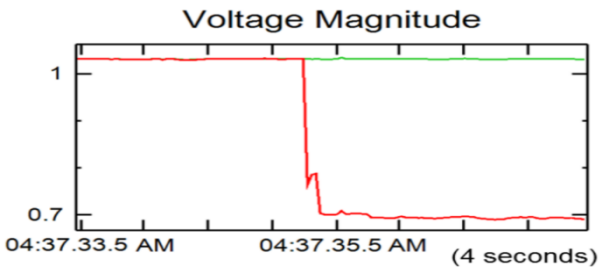


A - Phase CCVT Issue

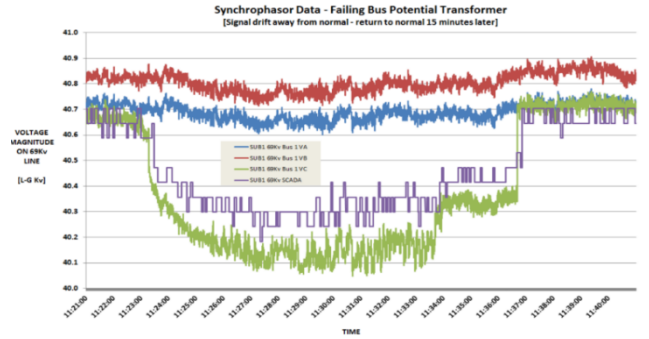




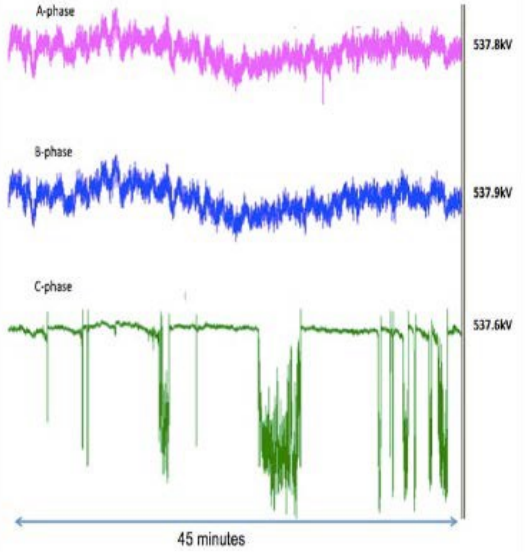
Loose Connection at PT feeding the PMU



Blown fuse on One Phase of PT



Internal Primary Winding Issue



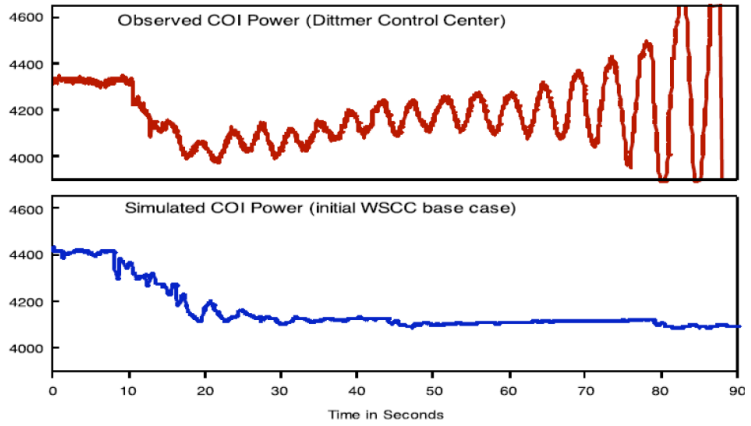
CCVT Failure example – PMU Data showed precursors 4 days before alarms from SCADA system

References:

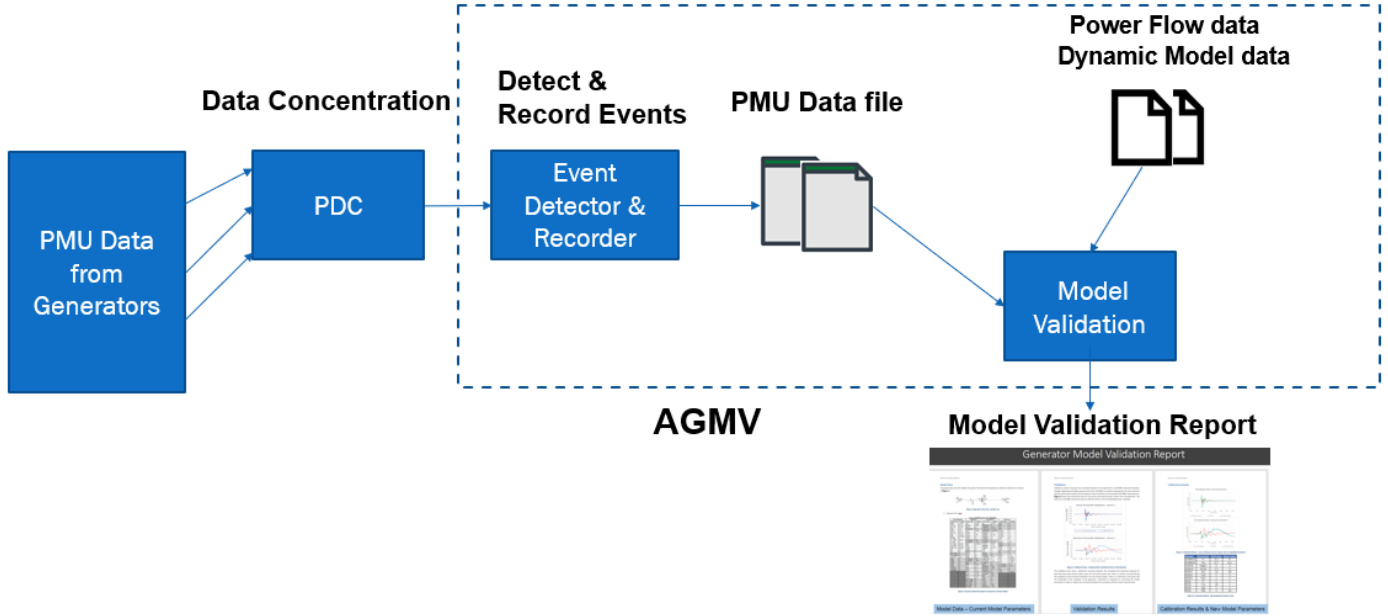
1) NASPI Technical Report, "Diagnosing Equipment Health and Mis-operations with PMU data", May 2015
2) Bogdan Kasztenny and Ian Stevens, "Monitoring Ageing CCVTs – Practical Solutions with Modern Relays to Avoid Catastrophic Failures", March 2007
3) David Shipp and Thomas Dionise, IEEE Tutorial, " Switching Transients, Transformer Failures, Practical Solutions", Feb 2016

Automated Generator Model Validation (AGMV)

- Inaccurate models can lead to incorrect assessment of system response
- Traditional staged tests require generators to be taken out of service, can be expensive and time consuming
- PMU data can be used to validate models without taking units offline
- Can be repeated frequently for multiple event types
- Automated Process to validate models and assess performance



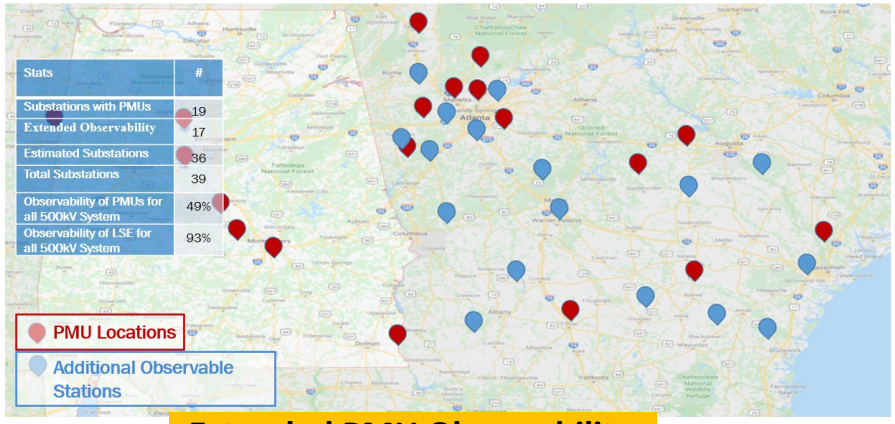
Source: NERC Reliability Guideline, "Power Plant Dynamic Model Verification using PMUs", September 2016



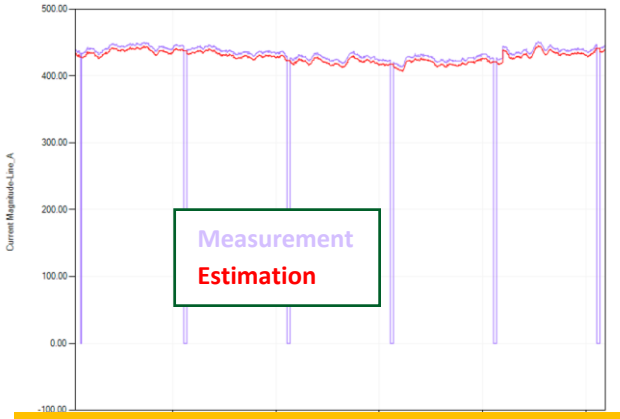
Linear State Estimation

Extending PMU Observability and Improving Grid Resiliency

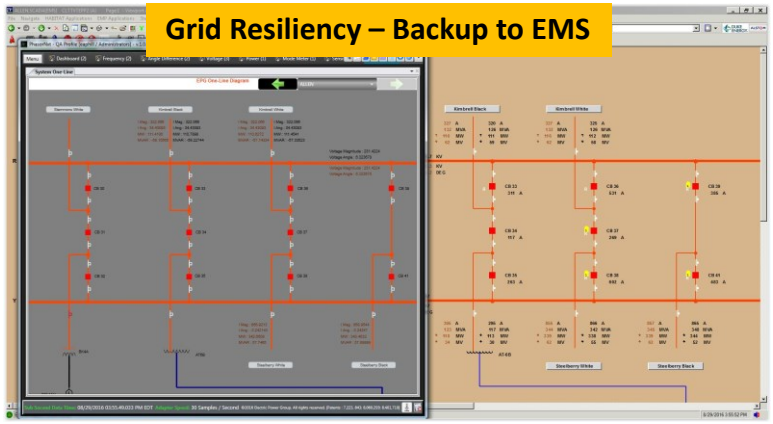
Challenges	LSE Solution
State Estimator Not Solving	Always Solves
Iterative and Slow (every few minutes)	Linear Solution, Solves at sampling rate (25 or 50 frames/sec)
Data Quality	Real-time data conditioning
Costly PMU Deployment	Expands Real-Time Observability beyond current PMU coverage
Grid Resiliency / Independent from EMS	Provides backup to EMS resulting from equipment failure, physical and cyber attacks



Extended PMU Observability



Addresses Data Quality issues in Real-Time



Source: L. Zhang *et al.*, "Benefits of using linear state estimation for synchrophasor applications," *2017 IEEE Power & Energy Society General Meeting*, 2017

THANK YOU