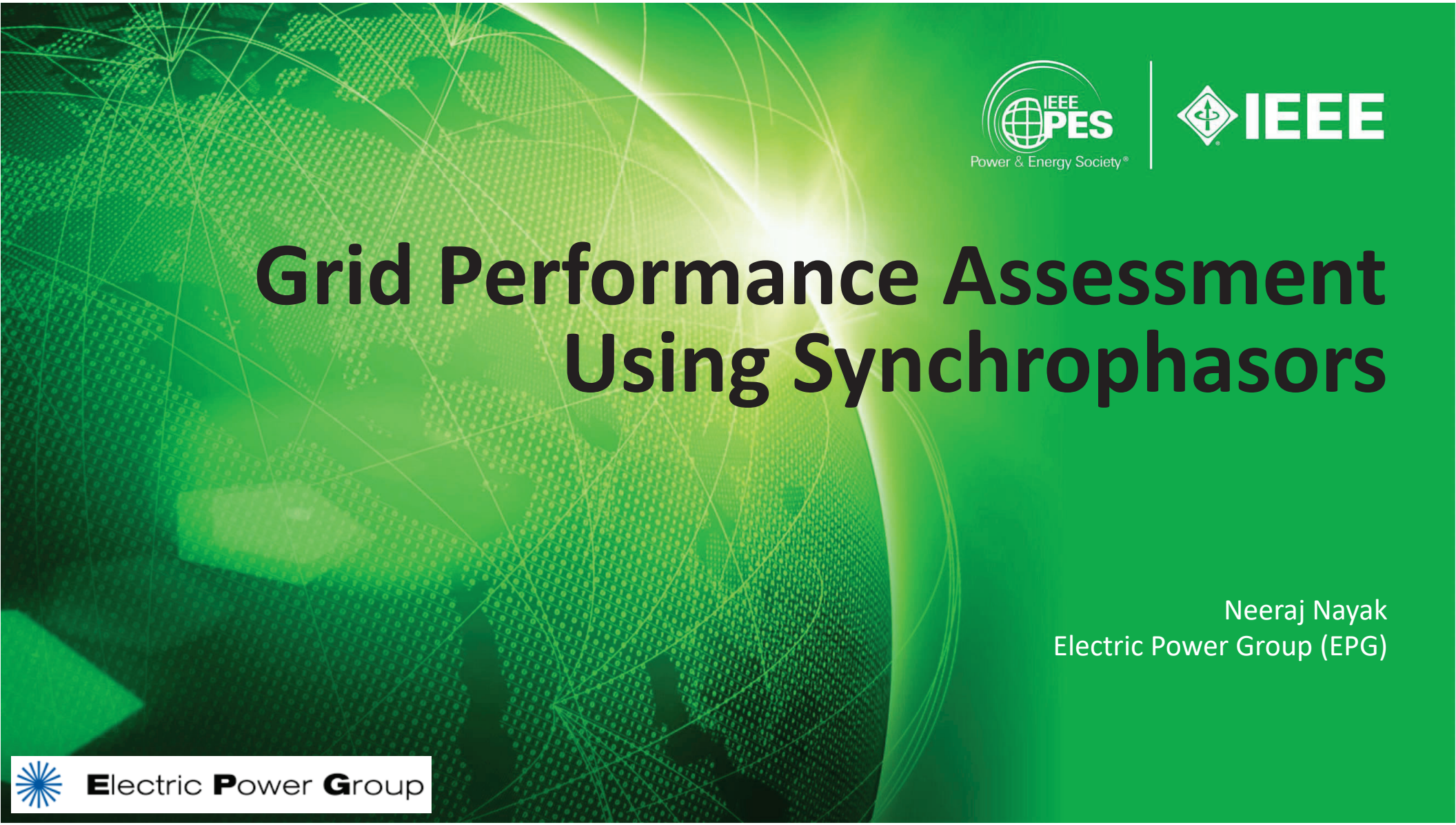

Grid Performance Assessment Using Synchrophasors

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Electric Power Group

Outline

- Introduction
- Automated Event Mining (AEM)
- Grid Event Signatures using PMU Data
- Use Case Examples
- Reporting
- Data Quality Assessment
- Summary

Introduction

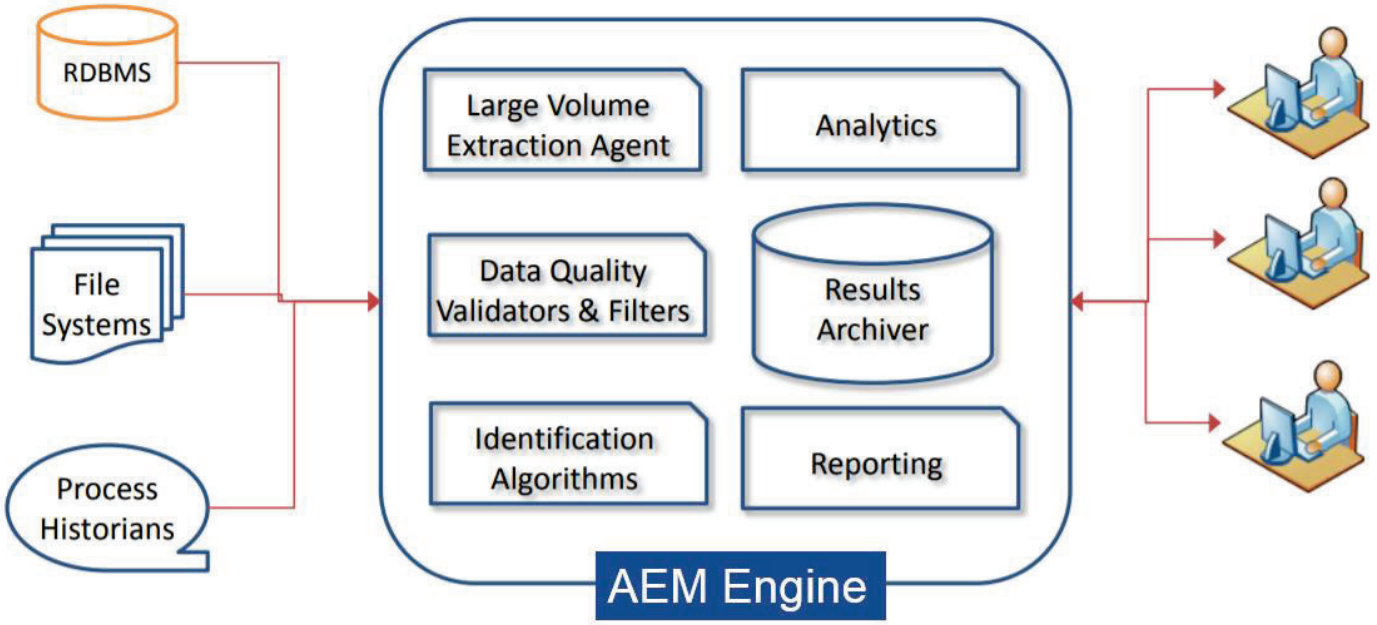
Why PMU Data Analysis?

- 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 Tool for PMU data Mining
- Scans through large PMU data archives
  - Data Sources: Flat Files (*.csv, COMTRADE), Databases (MySQL, MSSQL, PI, OpenHistorian)
- Used AEM extensively for PMU data analysis for major Grid Operators, Reliability Coordinators and Utilities
- Key Functionality and Capabilities
  - Automated Mining and Identification of Oscillations, Generation trip and load trip, faults and low voltage events
  - Measurement Anomalies and Device Calibration Issues
  - Data Quality Assessment Summary
  - Automated Report Generation

Architecture - Overview

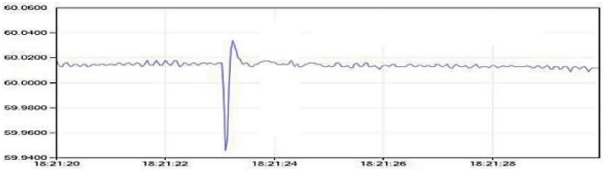


Data Sources

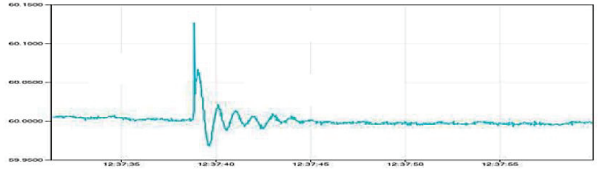
Visualization

Grid Event Signatures

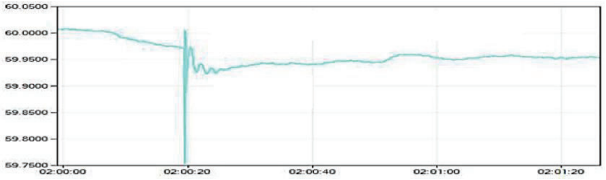
A: Drop, Rebound and Slow Recovery - Generation Trip



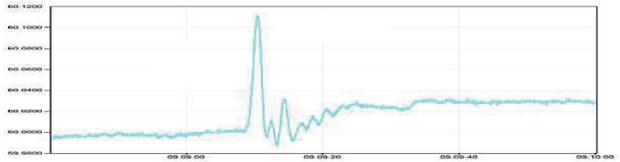
B: Sharp Change and Immediate Recovery - Fault



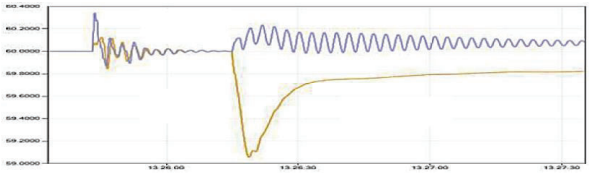
C: Transient and Ringdown - Line Trip



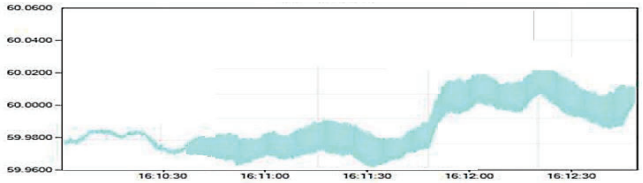
D: Transient and Drop - Line Trip and Generation Trip



E: Rise and Slow Recovery - Load Trip



F:Separation – 2 Signals : Islanding



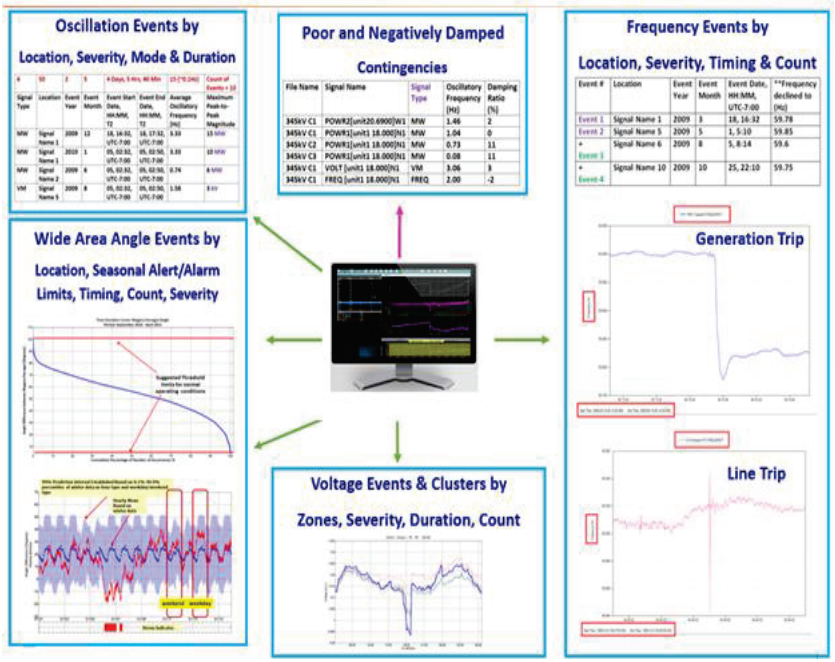
G: Oscillations

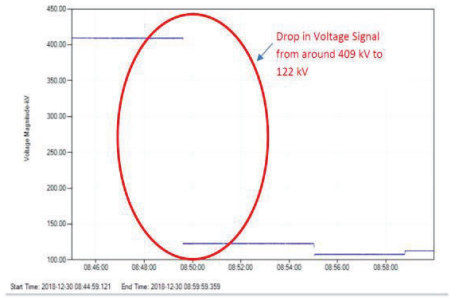
High Resolution PMU Data allows us to monitor grid dynamics and Event Signatures

Event Types

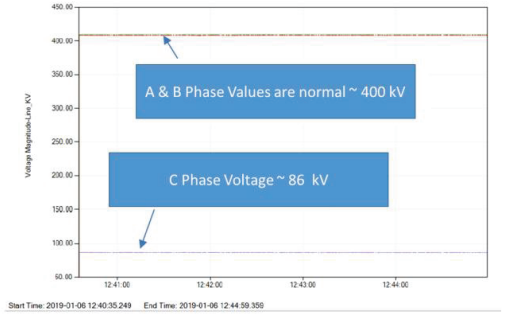
Automated Analysis of Large amounts of PMU data (weeks, months, years)

- 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



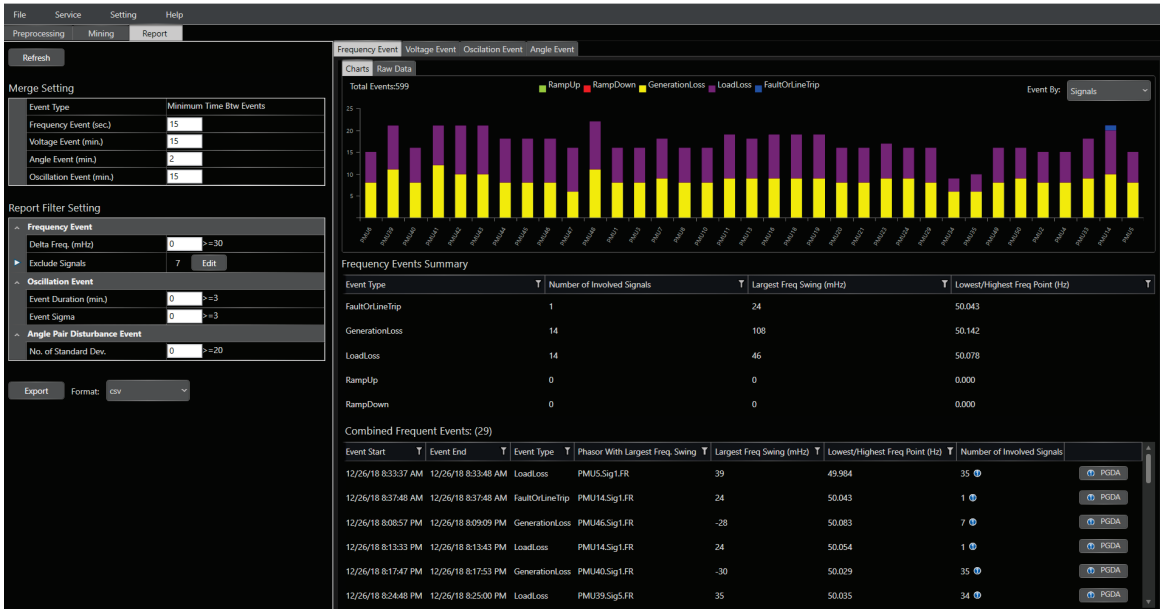
Device (PT, CCVT) Calibration Issue

Event Detection Criteria - Examples

- Default criteria or user-defined criteria for detecting events:
  - Faults with voltage below 0.9 per unit for less than 1 second
  - Low voltage events with voltage below 0.9 per unit for more than 1 second
  - Extended low voltage events with voltage below 0.9 per unit for more than 15 minutes
  - Generation and Load trip events with frequency change greater than 30 mHz over a time window of 15 seconds
  - Oscillation Energy exceeding 3 standard deviations of RMS energy in voltage, real and reactive power flows
  - Phase Angle Differences exceeding 10 standard deviations
  - Composite Events with combination of the above criteria

Example

- PMUs: 50
- Signals: 1500
- Events Identified: 49
  - Frequency Events – 17
  - Voltage Events – 17
  - Oscillations – 15



Classification of 49 Events

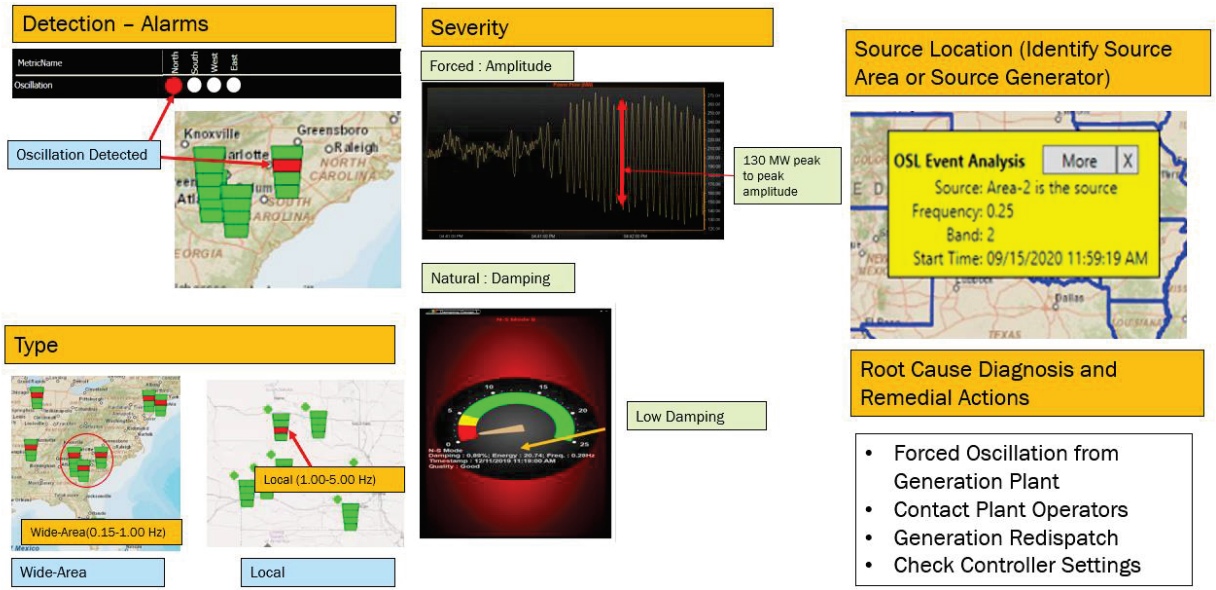
Frequency Events: Total 17 Events			
Event Type	**Count of Events**	**Largest Frequency Swing (mHz)**	**Estimated Generation/Load Loss**
Fault/Line Trip	0	-	-
Generation Loss	8	94	423 MW
Load Loss	9	108	486 MW

Oscillation Events : Total 15 Events			
Type	**Count of Events**	**Largest Amplitude**	**Event Duration (Mins)**
Inter-Area Oscillations	1	80 Amps	5
Local/Forced Oscillations	4	60 MVAR	120
Local Plant Controller Systems	6	15 MVAR	15
Fast Acting Controllers/HVDC/SSCI	4	3 kV	10

Voltage Events : Total 17 Events			
Type	**Count of Events**	**Duration**	**Largest Voltage Change**
Faults	5	<1sec	0.5 pu
Extended Low Voltage including FIDVR	6	> 1 sec – > 1 Minute	0.3 pu
Over Voltage	4	> 1 sec – > 1 Minute	0.2 pu
Device/Equipment Failure	1	Several Minutes - Hours	0.7 pu
Device Calibration/Scaling Issues	1	Several Minutes - Hours	0.78 pu

Oscillation Events

- Grids experience several oscillations events
- Most oscillation events have small amplitude and may not have a significant impact on reliability and stability
- Challenge is to identify the oscillation events that are significant



Oscillation Events

Number of Events detected can be sensitive to Thresholds

Energy/Amplitude Setting (Peak-Peak Amps)	No. of Oscillation Events
5	5230
10	2058
15	666
30	142
50	15
100	3

Intelligent Criteria to Detect Events Based on Change in Energy rather than absolute amplitude values

Root Cause Analysis of Oscillation Events

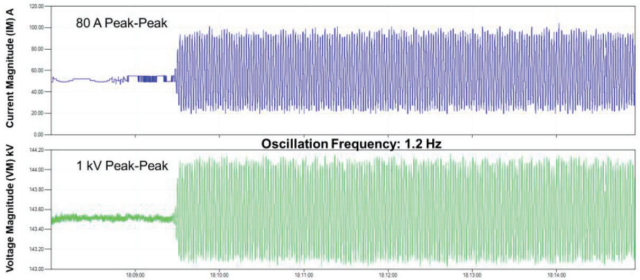
Band	Oscillation Type/Category	Frequency Range (Hz)	No. of PMU Locations	No. of Events	Highest Peak-Peak Amplitude	Most Severe Location
1	Speed Governor	0.01 to 0.15	-	-	-	-
2	Inter-area or Local Forced Oscillations	0.15 to 1.0	10	5	80 Amps	Substation B
3	Local Plant Control Systems	1 to 5.0	7	6	15 MVAR	Substation K
4	Fast Acting Controllers, HVDC, SSCI	5 to 15	4	4	3 kV	Substation L

Event Details

Local Plant Control System Oscillations (1-5 Hz) - Root Cause	Frequency	Stations
1. Faulty PSS Card/Settings	1. 1.2 Hz	1. Substation A
2. Malfunctioning AVR Controls	2. 1.2 Hz	2. Substation K
3. Bad Control Card/Settings – Hydro Plant	3. 1.8 Hz	3. Substations R, P
4. Type 3 & 4 Wind Turbine connected to weak grid	4. 3 Hz	4. Substation S
5. Bad Controller settings – Wind Plant	5. 3.3 Hz	5. Substation L
6. Loss of 2 500/230-kV Transformers (Weak Grid) and Control Malfunction	6. 4 Hz	6. Substation T

Oscillation Events

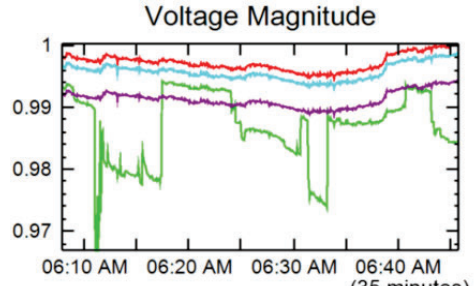
Excitation System Issue



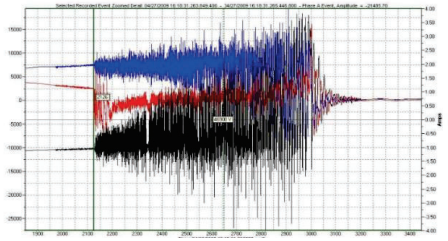
This material is based upon work supported by the Department of Energy under Award Number DE-OE0000916

Equipment Failure Detection using PMU data

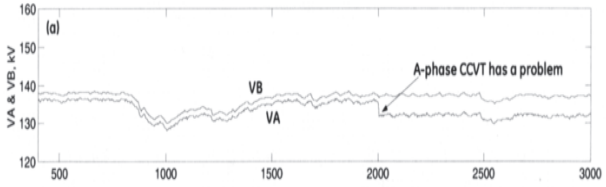
Loose Fuse Connections in CCVT Safety Switch

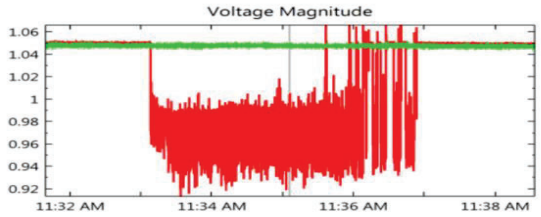


Switching Transients due to Ferroresonance

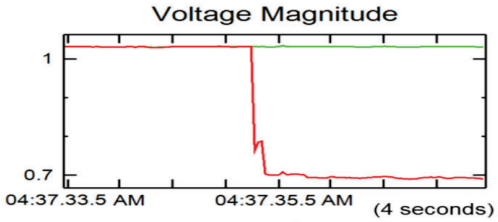


A - Phase CCVT Issue

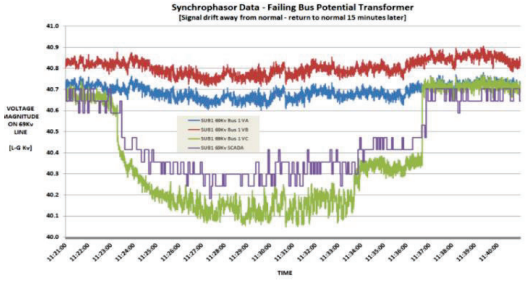




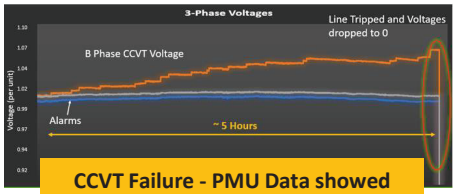
Loose Connection at PT feeding the PMU



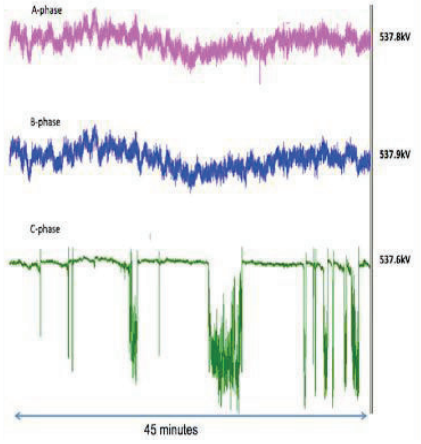
Blown fuse on One Phase of PT



Internal Primary Winding Issue



CCVT Failure - PMU Data showed precursors 5 hours before line outage



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

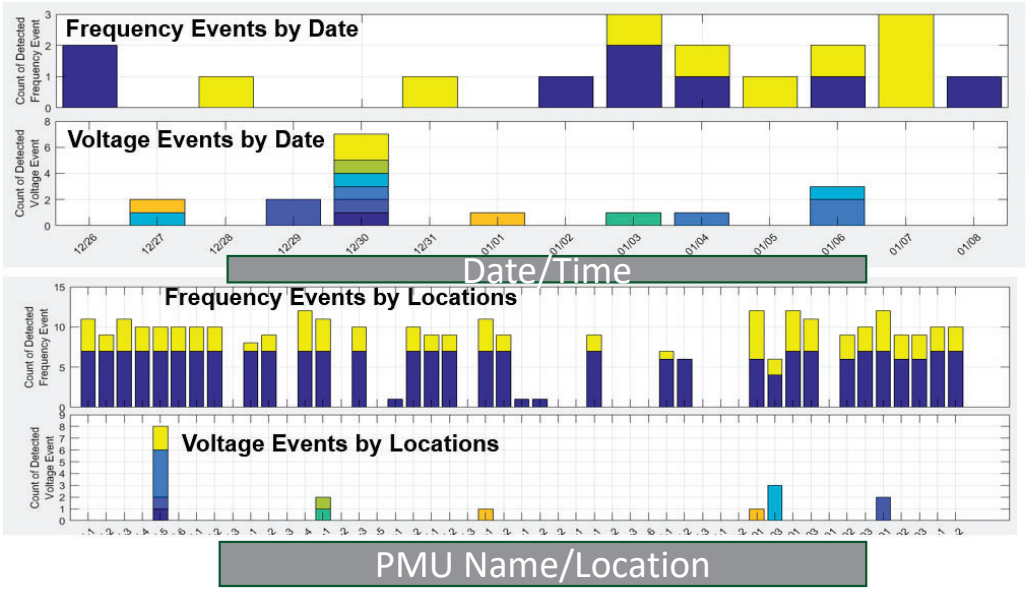
References:

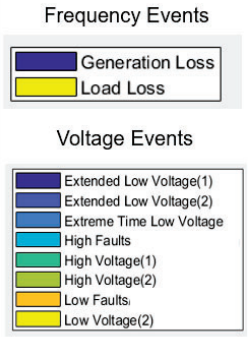
1) NASPI Technical Report, "Diagnosing Equipment Health and Mis-operations with PMU data", May 2015
2) Bogdan Kasztenny and Ian Stevens, "Monitoring Ageing CCVTs – Practical Solutions with Modern Relays to Avoid Catastrophic Failures", March 2007
3) David Shipp and Thomas Dionise, IEEE Tutorial, " Switching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

Reporting

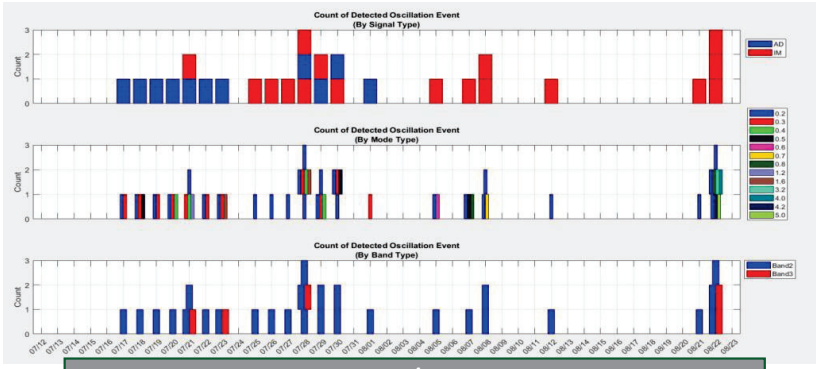
Events By Date and PMU Location/Substation

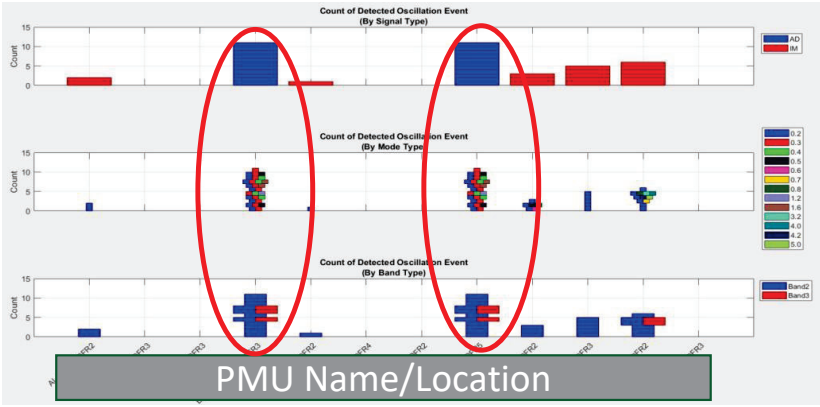
Frequency and Voltage Events





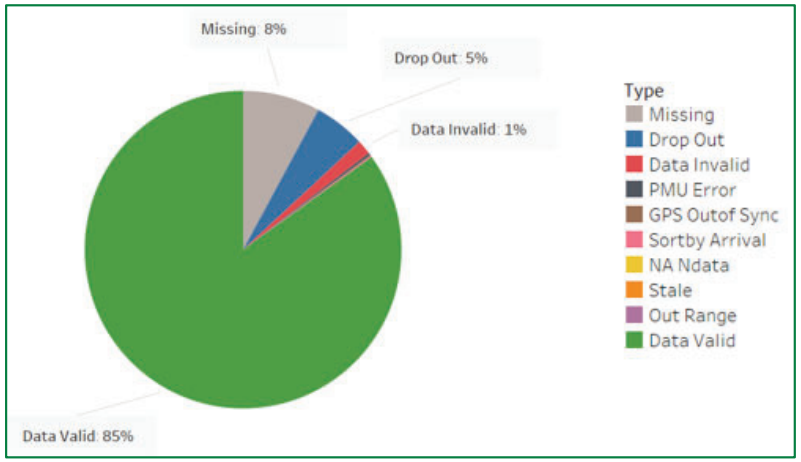
Oscillations



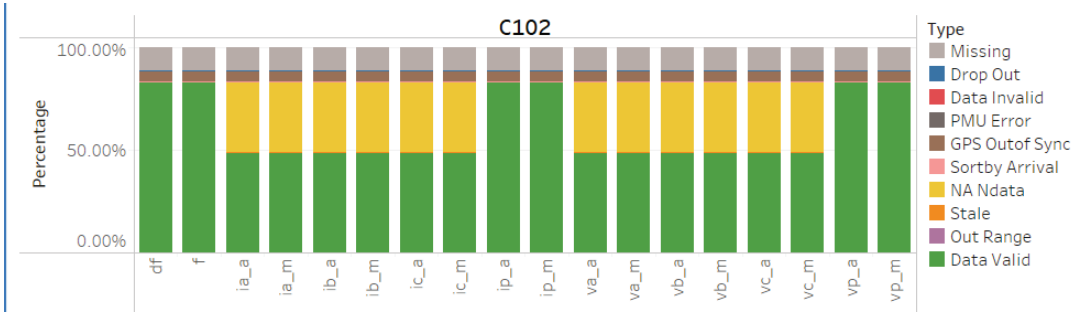


Data Quality Assessment

PMU Level and Signal Level Data Quality Checks



PMU level	Signal Level
• Data Invalid	• Out of Range
• GPS Out of Synch	• Stale
• PMU Error	• NaN
• Sort by Arrival	• Data Invalid
• Drop Out	• GPS Out of Synch
• Missing Data	• PMU Error
• Data Valid	• Sort by Arrival
	• Drop Out
	• Missing Data
	• Data Valid



This material is based upon work supported by the Department of Energy under Award Number DE-OE0000916

Summary

- Extract value from large archives of synchrophasor data
- Automated process to assess grid performance
- Assist planning and operation engineers to mine historical data
  - Review of Grid Performance & Reporting
  - Identify Device Calibration and Equipment Anomalies
  - Statistics analysis for baselining
  - Establish Alarm limits for Real-Time Operations
  - Develop Event Library for Training

Thank You