AMERICAN ELECTRIC POWER
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AEP's WAMS Experiences with Synchrophasor Applications

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AEP Transmission Operations Advanced Applications

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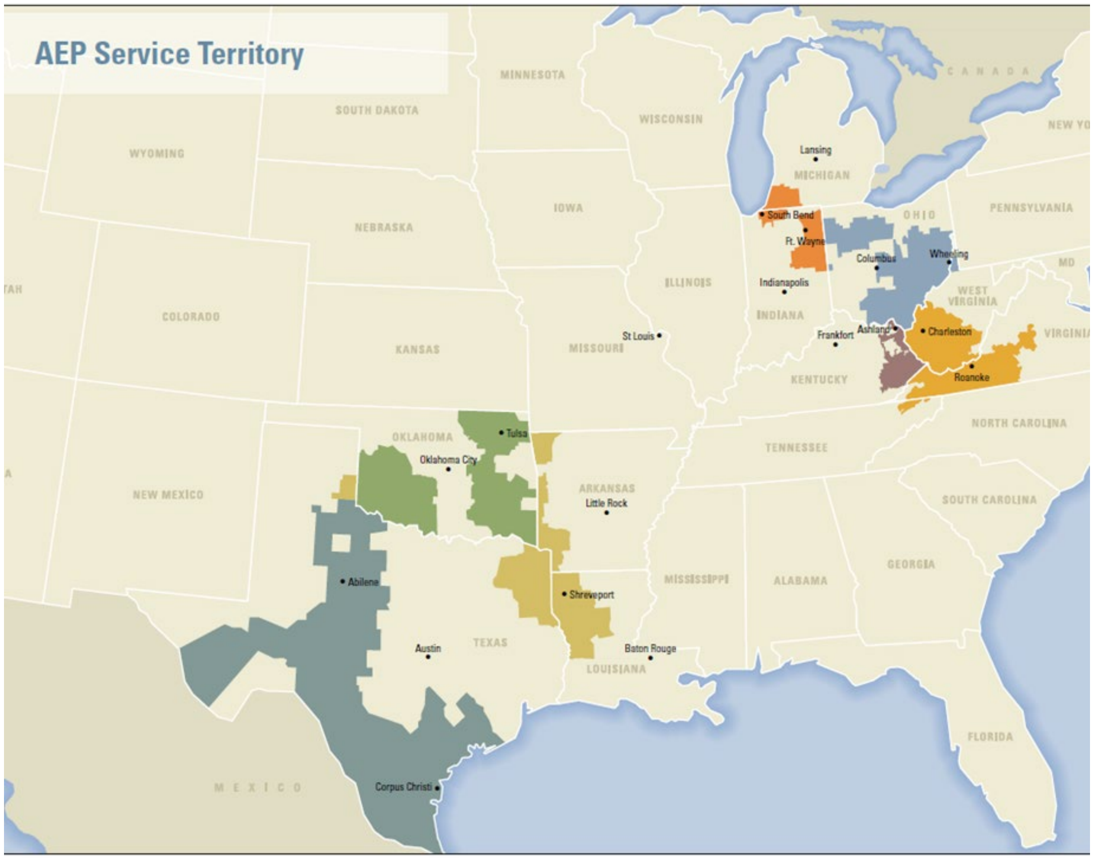
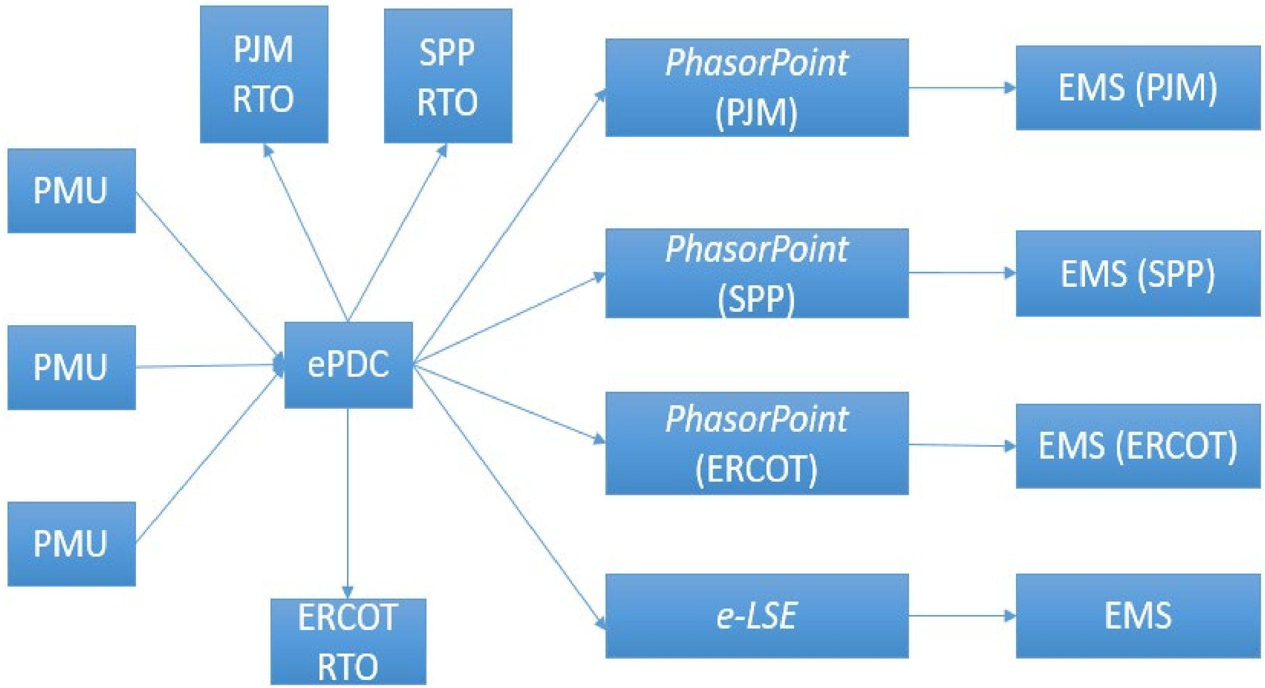
AEP's Service Territory



- AEP operates in 11 states constituting parts of ERCOT, SPP and PJM's footprints
- AEP has by far deployed more than 430 PMUs across three footprints (PJM, ERCOT, SPP)
- The PMUs has been used in real-time detection, offline analysis of oscillation event and linear state estimation

AEP PMU System Architecture



AEP's Oscillation Detection Statistics

- **Methodology Applied in PhasorPoint**

1. Probability based event detection established
2. New alarm configuration deployed in all three footprints
3. Performance on event detection enhanced dramatically

- **AEP Auto Daily PMU Report**

1. System Average Frequency & PMU Data Quality monitored
2. Poor Quality PMUs identified and listed
3. Oscillation event summary listed with charts of event details

- **Linear State Estimator**

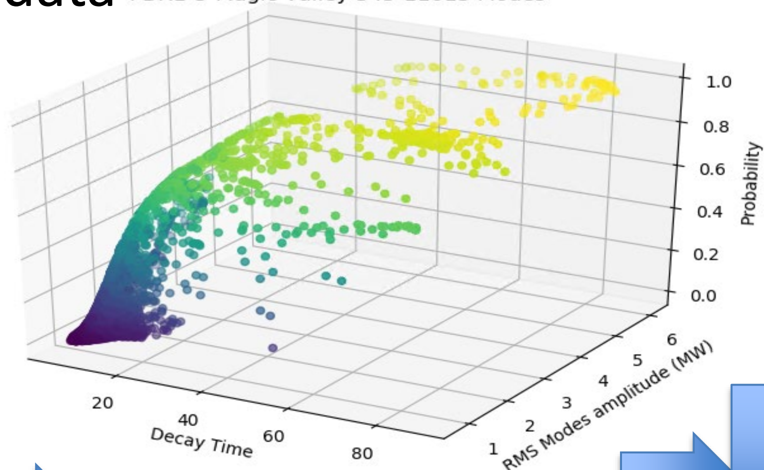
Methodology-Probability based Event Detection

Kernel Density Estimation used to delineate the distribution of oscillatory data

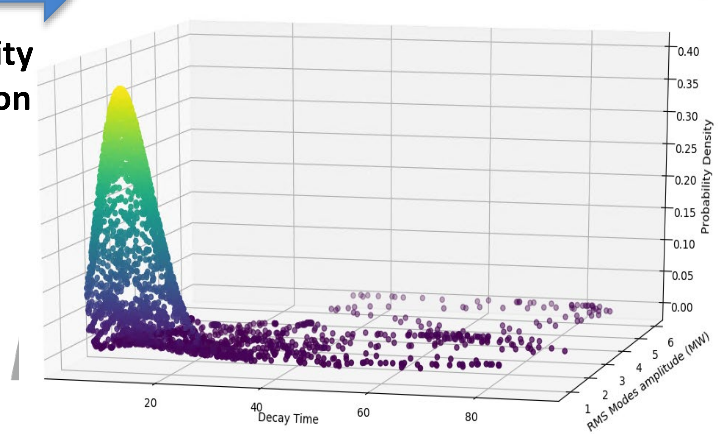
Oscillation Mode and Decay Time

Probability Estimation

PDX1-3-Magic Valley 345-11015 Modes



PDX1-3-Magic Valley 345-11015 Modes



P0 Decides how many events we notify operators

Event List

Validation

Find Outliers Where P(A>A0, D>D0)<**P0**

Alarm Setting

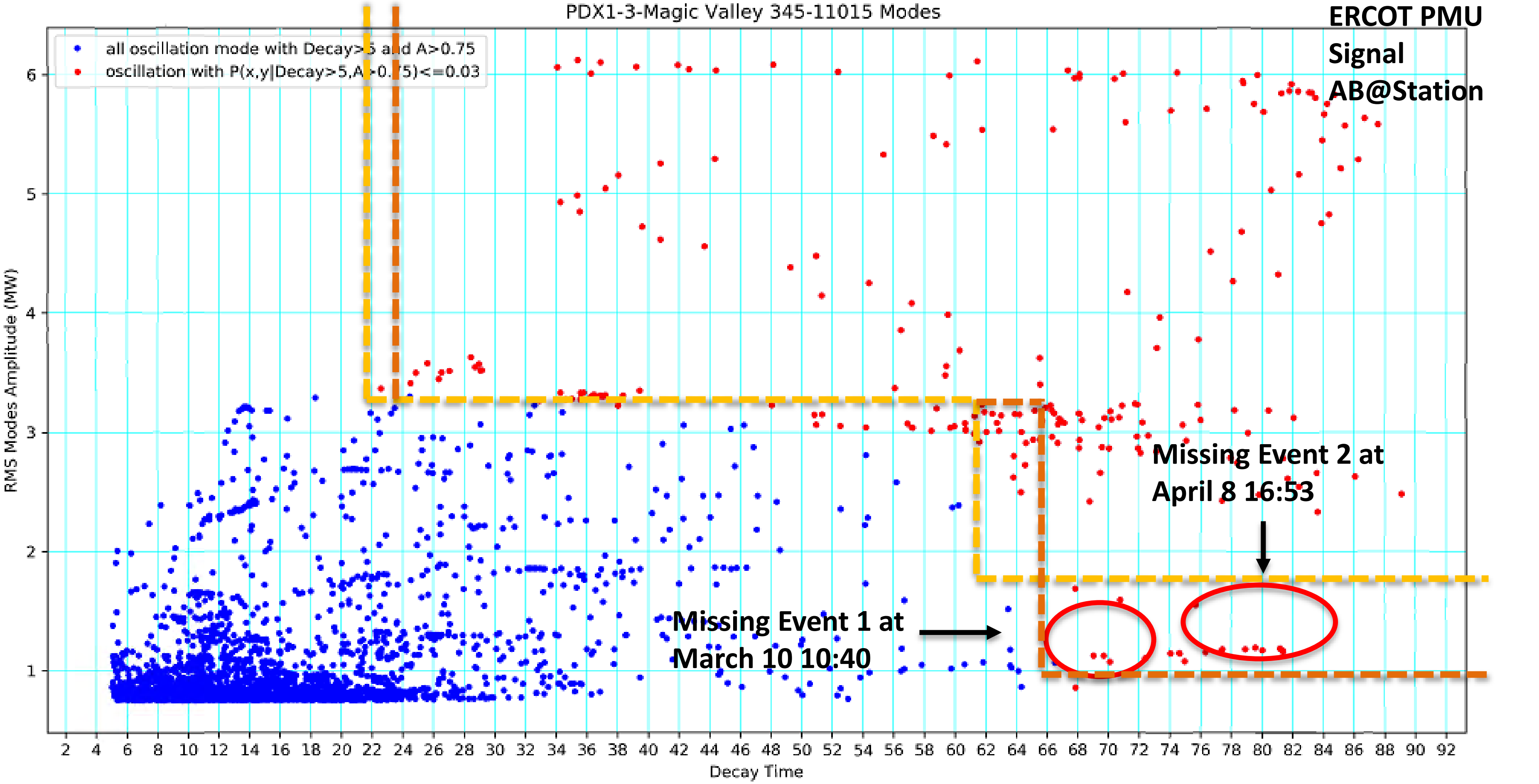
Daily Report

Adjustment

Methodology-Sensitivity Enhancement

	Decay Time Exclusion	Decay Time Threshold	Amplitude Exclusion	Amplitude Threshold
Old Alarm	Around 20 seconds	Around 62 seconds	1.5MW	3MW
New Alarm	22 seconds	66 seconds	0.75MW	3MW

Alarm Threshold Revised for ERCOT PMU Signal AB@Station



Methodology Performance

Table I Performance Overview of KDE-based event detection					
Footprint	**Production Deployment**	**False Alarm Count**	**False Alarm Rate (after)**	**False Alarm Rate (before)**	**Footprint**
ERCOT	07/2020	<30	Around 6%	50+%	ERCOT
SPP	09/2020	<10	Less than 5%	45%–50%	SPP
PJM	10/2020	<20	Less than 5%	50+%	PJM

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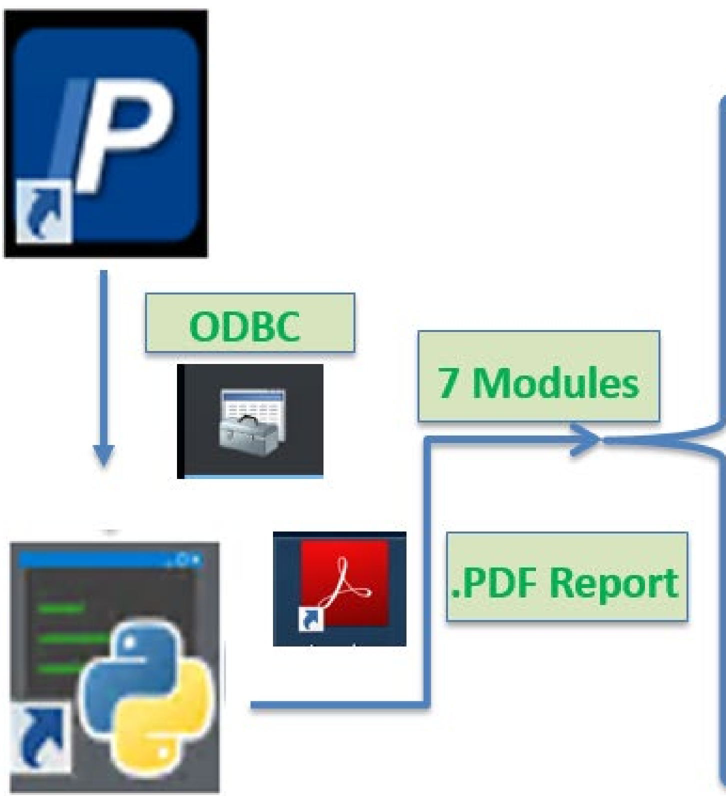
- **Analysis Completed in e-PhasorAnalytics and Matlab**

1. Oscillation energy on critical events calculated

AEP Auto Daily PMU Report

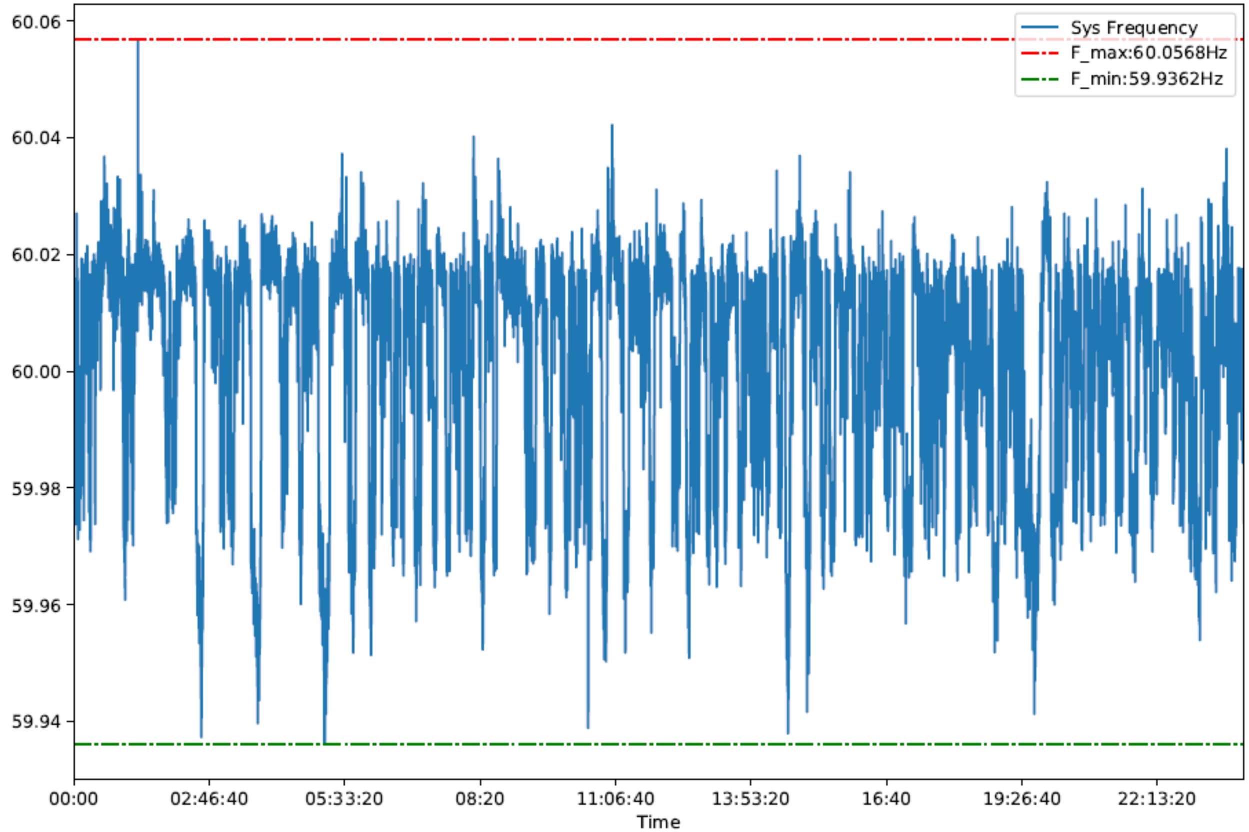


1. System Daily Average Frequency Chart
2. Daily PMU Data Quality Statistics Pie Chart
3. Daily Poor Quality PMU List
4. Monthly PMU Data Quality Statistics Pie Chart
5. Monthly Poor Quality PMU List
6. Daily Oscillation Alarm Events Summary
7. Event Details

AEP Auto Daily PMU Report

System Daily Average Frequency Chart Example

- Sys. Daily Average Frequency
- Max Frequency
- Min Frequency



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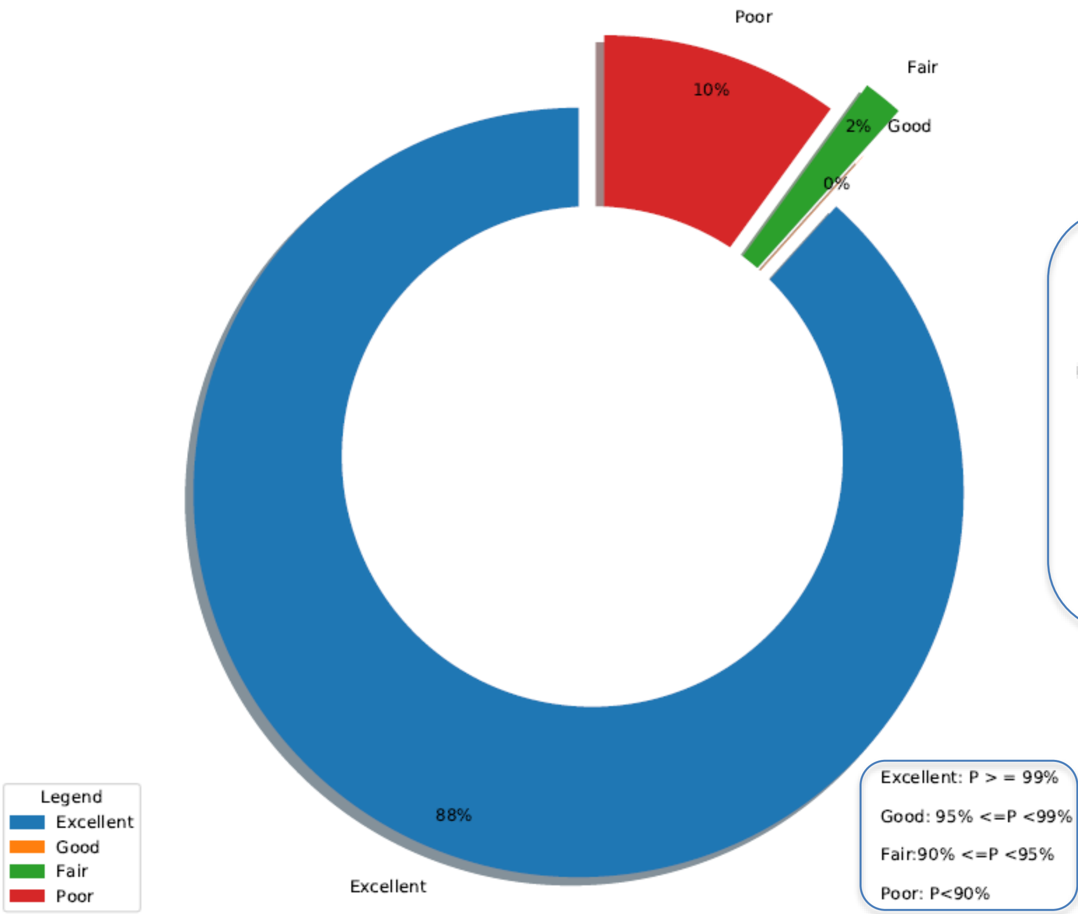
AEP Auto Daily PMU Report

Daily PMU Data Quality Statistics Pie Chart Example



Excellent: P > = 99%

Good: 95% <=P <99%

Fair:90% <=P <95%

Poor: P<90%

AEP Auto Daily PMU Report

Daily Poor Quality PMU List

Index	PMU ID	PMU Name	Validity/%
1	1	A	0.0
2	2	B	0.0
3	3	C	0.0
4	4	D	0.0
5	5	E	0.0
6	6	F	0.0
7	7	G	0.0
8	8	H	0.0
9	9	I	0.0
10	10	J	0.0
11	11	K	0.0
12	12	L	81.93399810791016

AEP Auto Daily PMU Report

Daily Oscillation Alarm Events Summary Example

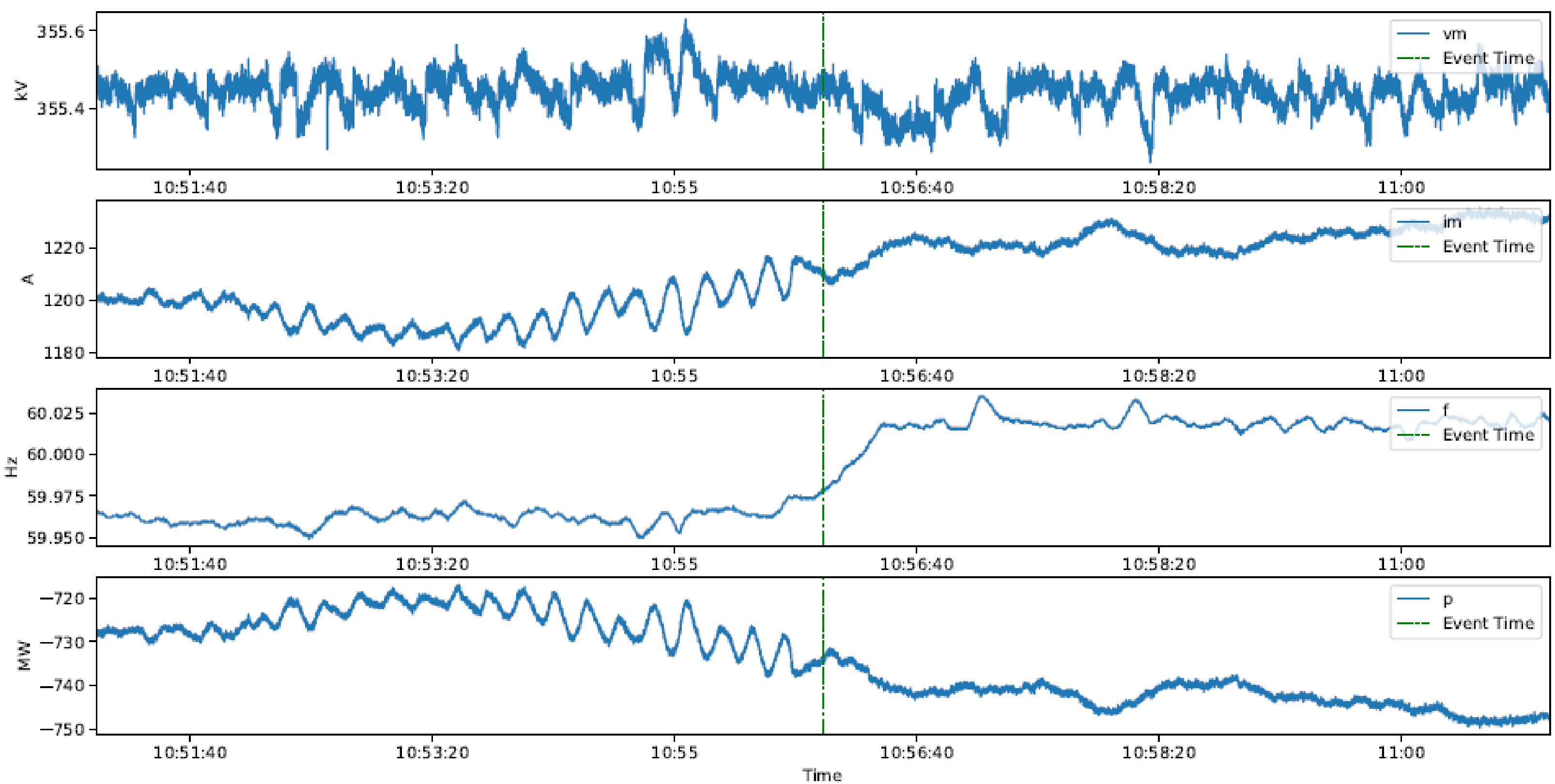
Index	Date	Time	measurement_group	measurement	parameter	message
1	2021-04-29	10:56:01	RH	12345 (ABC@RH)	P	PDX1-3 event status alarm

Index	Date	Time	measurement_group	parameter	message
1	2020-04-29	01:48:48	WF	f	PDX1-3 event status alarm
2	2020-04-29	01:48:48	WF	f	PDX1-3 event status alarm
3	2020-04-29	02:03:37	WF	f	PDX1-3 event status alarm
4	2020-04-29	02:03:37	WF	f	PDX1-3 event status alarm
5	2020-04-29	02:32:11	WF	f	PDX1-3 event status alarm
6	2020-04-29	02:32:11	WF	f	PDX1-3 event status alarm
7	2020-04-29	04:35:58	WF	f	PDX1-3 event status alarm
8	2020-04-29	04:35:58	WF	f	PDX1-3 event status alarm

AEP Auto Daily PMU Report

Event Details Example

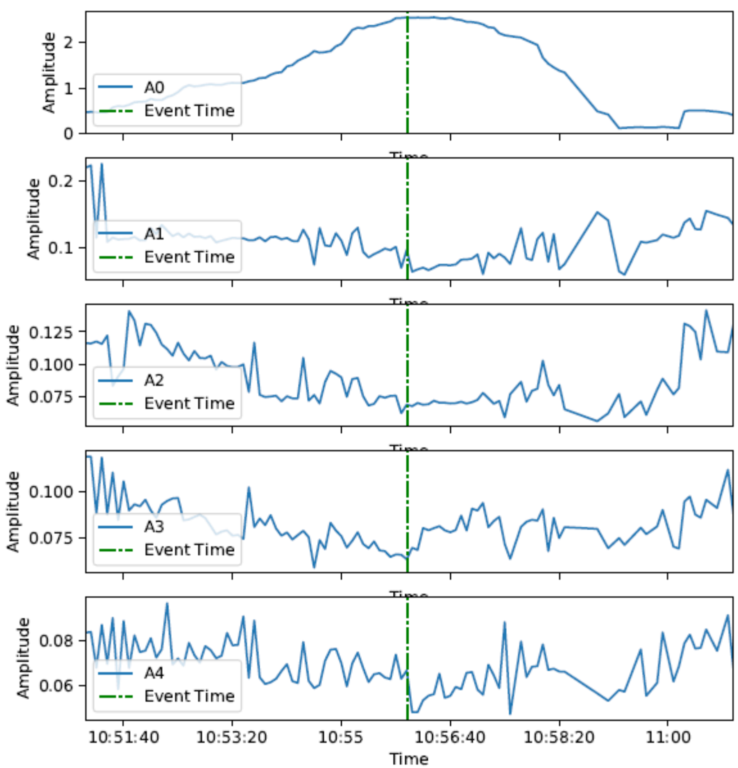
Event 1 PMU Measurements



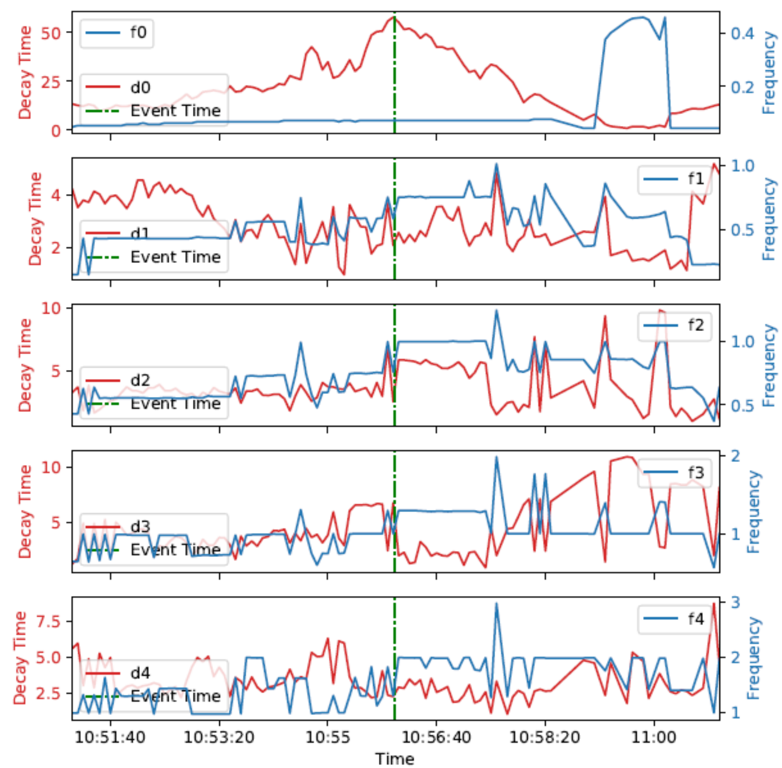
AEP Auto Daily PMU Report

Event Details Example

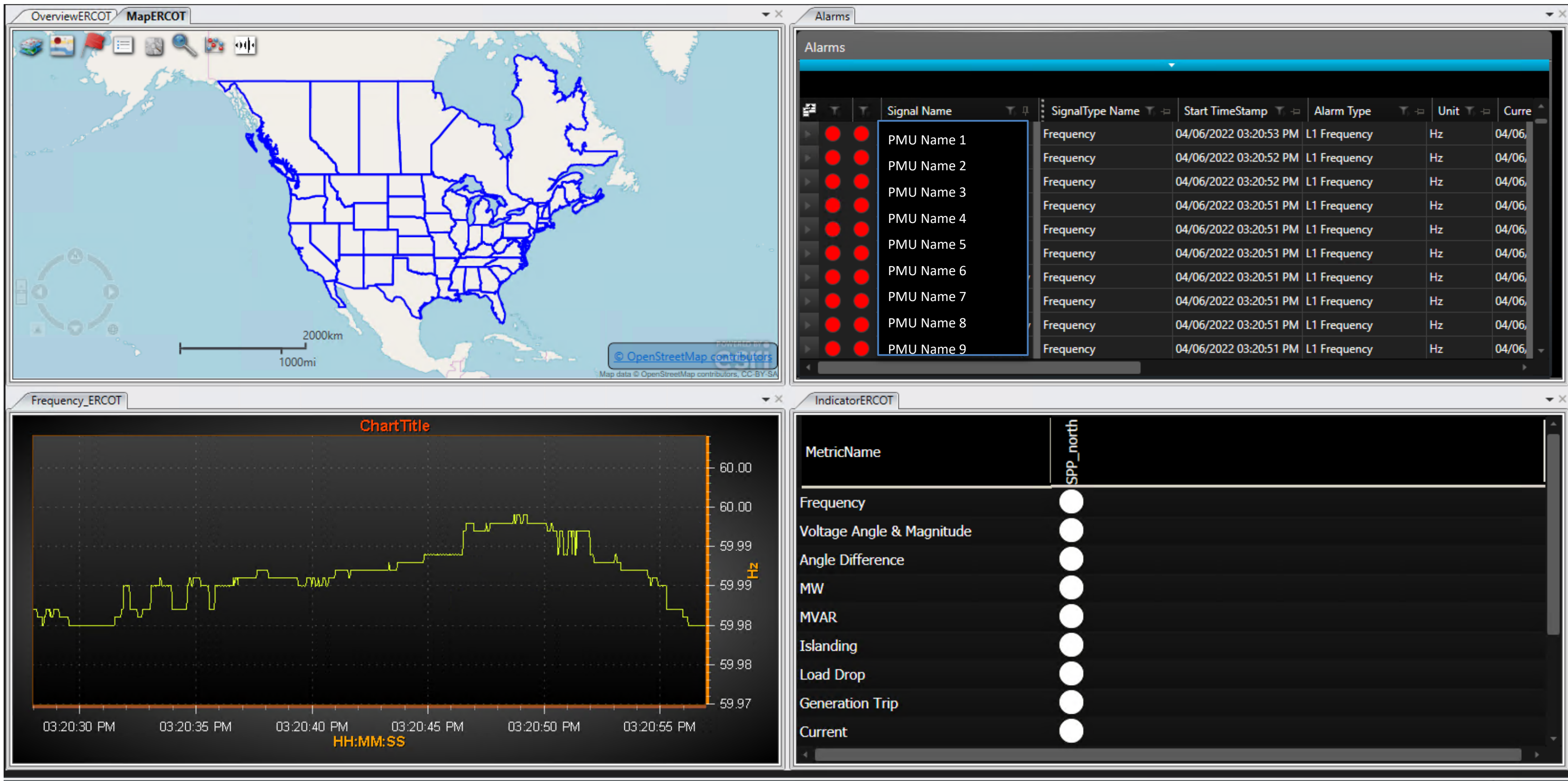
Mode Amplitude



Mode Decay Time & Mode Frequency



Linear State Estimator



Linear State Estimator

- The objective of AEP's LSE deployment is to provide additional observability and situational awareness capability using Phasor Measurement Unit (PMU)data for oscillation analysis, and to enhance grid resiliency by providing a backup solution when the traditional Energy Management System (EMS) / State Estimator (SE) system fails.

- The project was initiated in 2020. AEP is currently working with Electric Power Group (EPG) to deploy this LSE project. The LSE at AEP currently uses measurements from 430 PMUs, with an expected increase in coverage of up to 720 PMUs in the next few years.

Linear State Estimator

- The mathematical advantage of the LSE enables it to **solve the estimation problem at the synchrophasor rate** (30 samples per second for this deployment), providing situational awareness at high resolution, as compared to the traditional SE which provides one snapshot every minute.

- Solving state estimation at the synchrophasor rate enables **detection of fast power system dynamics**, such as power oscillations, which are expected to appear more often with the increase in renewable integration. AEP is planning to supply the LSE output to their real-time oscillation detection tools as part of the next steps after commissioning the production LSE environment.

- Another key benefit of the LSE implementation in AEP's situational awareness strategy is **increased coverage** of the monitored footprints. The LSE expands the real-time observability beyond the existing coverage of physical PMUs deployed in the field. This reduces the investment cost associated with installing physical PMUs, while still providing situational awareness capability.

Summary

- Probability based event detection deployed to monitor oscillatory behaviors in power, frequency and voltage signals
- Auto Daily event report generated automatically by python script to monitor PMU quality and archive all the events detected
- Future work: Linear state estimator deployment

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QUESTIONS??

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