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AMERICAN ELECTRIC POWER
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Study Committee C2

Power System Operation and Control

10230_2022

A KDE-based Methodology for PMU Data Management and Real-time Event Detection summary

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Motivation

- Increase in renewable penetration has contributed to more frequent system oscillations.
- PMU enabled real-time monitoring overwhelms operators with a massive amount of data.
- A methodology to differentiate vigorous and prolonged oscillations from common grid dynamics is necessary for maintaining situational awareness.

Methodology

- **Recording**-Vendor-supplied PMU application used to capture real-time oscillatory dynamics
- **Estimation**-Kernel Density Estimation (KDE) applied to depict bi-variate probability density function with regard to oscillation amplitude and decay time.
- **Refining**-Maximum Likelihood Cross Validation (MLCV) adopted to refine estimation of density function.
- **Training**-Heuristic training with input of historical event data deployed to customize cut-off probability for each PMU stream
- **Visualization**-Outlying observation picked by cut-off probability and highlighted on scatter plots
- **Configuration**-Individualize oscillatory alarm settings based on scatter plots

Implementation

- **Data Extraction**-over five million observations extracted for each of the 289 PMU signals.
- **Data Processing**-cross validated KDE applied to baseline each signal and locate outliers that are observations of harmful oscillations.
- **Setting Configuration**-Alarm setting customized for each PMU signal.
- **Validation**-Proposed methodology compared with empirical-based oscillation detection in offline event re-identification and real-time event detection.
- **Deployment**-Proposed methodology replaces empirical-based oscillation detection in facilitating multiple control room functions

Demonstration

- Historical Event Re-identification in Texas Valley Area

Methodology	Event Total	False Alarm
KDE	28	0
Empirical	29	16

- Real-time Event Detection in ERCOT and SPP

Region	Method	Time	Event Total	False Alarm %
ERCOT	KDE	3 Mo.	49	6%
ERCOT	Empirical	3 Mo.	60	48%
SPP	KDE	1 Mo.	15	0%
SPP	Empirical	1 Mo.	10	50%

Deployment

- Despite system updates, the KDE-based event detection remains robust

Area	Since	False Alarm %		Critical Event Missed
		after	before	
ERCOT	07/20	≈6%	50%	0
SPP	09/20	<5%	45%-50%	0
PJM	10/20	<5%	50%	0

Contributions

- Innovation of a KDE-based methodology to accurately baseline PMU signals and initialize alarm settings.
- Establishment of a real-time event detection mechanism that has demonstrated system-wide adaptability, enhanced sensitivity, and long-term reliability.
- Development of a generalized approach to enhance situational awareness and control room preparedness against increasing renewable penetrations

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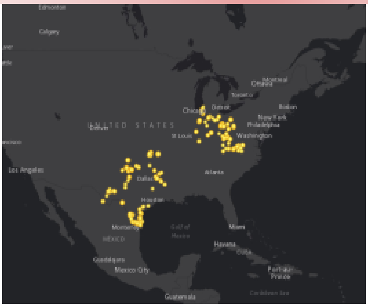
Details

AEP's PMU Deployment

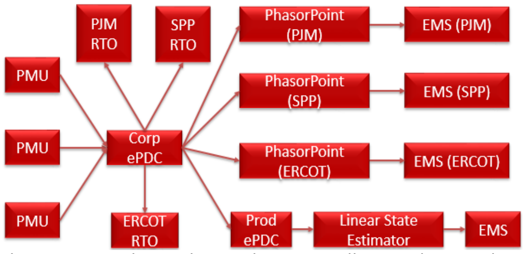


AEP operates in 11 states constituting parts of ERCOT, SPP and PJM's footprints.

AEP has deployed more than 450 PMUs across three footprints

The PMUs have been used in real-time detection and offline analysis of oscillation events.

AEP's PMU Configuration



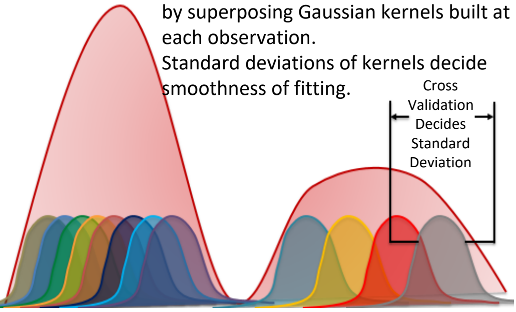
Phasor Point decouples real-time oscillatory data and feeds them to control rooms.

Million of historical data points stored during past 3 years of operations; events triggered by empirical stored

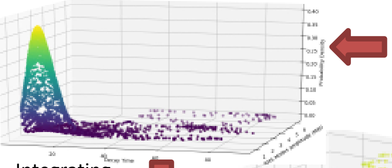
Gaussian Kernel Density Estimation

Distribution of recorded oscillation fitted by superposing Gaussian kernels built at each observation.

Standard deviations of kernels decide smoothness of fitting.

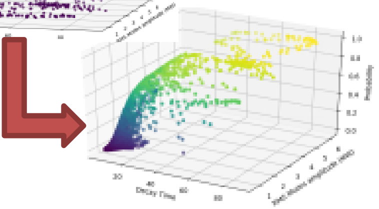


Distribution Function Estimated



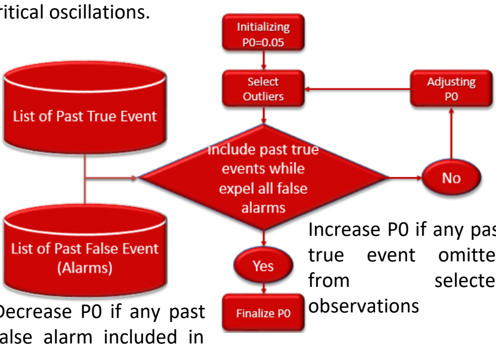
Density Function Estimated

Integrating density function to obtain distribution function



Heuristical Training

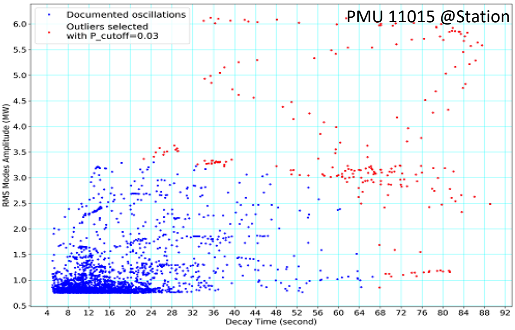
P0 is the cut-off probability, it decides how many observations are picked as outliers, thus observations of critical oscillations.



Increase P0 if any past true event omitted from selected observations

Decrease P0 if any past false alarm included in selected observations

Visualizing Outliers



Each dot represents an observation. Observations occurred within 5 min are considered to represent the same event.

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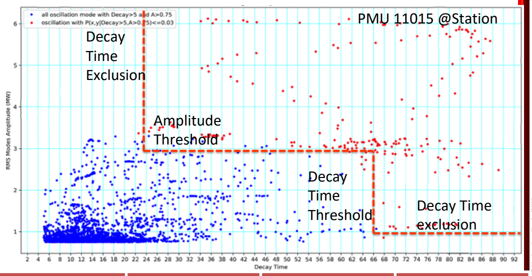
Details Continued

Configuring Alarms

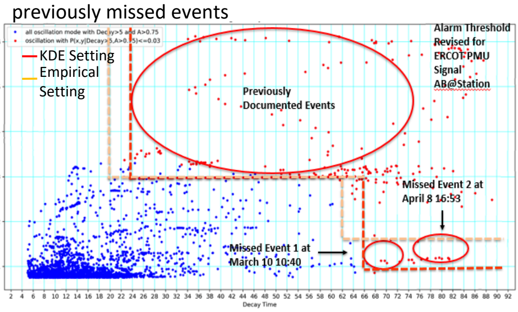


Decay Time Exclusion	Decay Time Threshold	Amplitude Exclusion	Amplitude Threshold
24 S	66 S	1.0MW	3MW

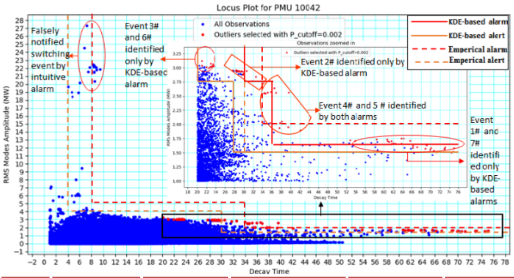
Event Detection Enhancement-Sensitivity

The KDE-based methodology baselines each PMU signal and individualizes their oscillation alarms

As a result, alarms are revised more accurately, flagging previously missed events



Event Detection Enhancement Reliability



No.	Date	Lasted	Max RMS Amplitude	Max Decay	False Alarm
1	2-23-20	3.5 min	1.75 MW	66 Sec	No
2	2-25-20	3 min	2.95 MW	34 Sec	No
3	3-09-20	50 Sec	3.25 MW	24 Sec	No
4	3-12-20	5 min	2.56 MW	40 Sec	No
5	3-13-20	4.5 min	2.05 MW	42 Sec	No
6	3-15-20	15 Sec	3.12 MW	21 Sec	No
7	3-30-20	3 min	1.66 MW	75 Sec	No

Event Detection Enhancement Summary

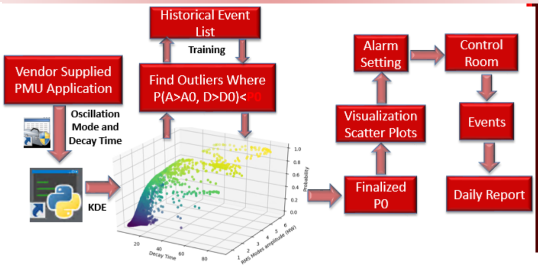
Historical Event Re-identification-most eventful PMUs

PMU#	Empirical Alarm		KDE Alarm		True event by KDE-only
	True	False	True	False	
10042	2	1	6	0	4
11015	4	7	7	0	3
11025	2	0	3	0	1
10059	5	6	7	0	2
10040	2	2	5	0	3

Real-time Event Detection-with tri-weekly EMS update

Area	Method	Time	False Event	Event Total	Rate %
ERCOT	KDE	3Mo.	3	49	6%
ERCOT	Empirical	3Mo.	29	60	48%
SPP	KDE	1Mo.	0	15	0%
SPP	Empirical	1Mo.	5	10	50%

Deployment



Conclusion and Future Work

- The KDE-based methodology enhances sensitivity and reliability of real-time oscillation event detection
- The proposed methodology demonstrated robustness despite constant EMS database update.
- Long term grid development plan will be carried out based on event information collected by the KDE-based scheme.

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