From EMS to WAMS to WAMPAC

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NASPI Work Group Meeting
Charlotte, NC
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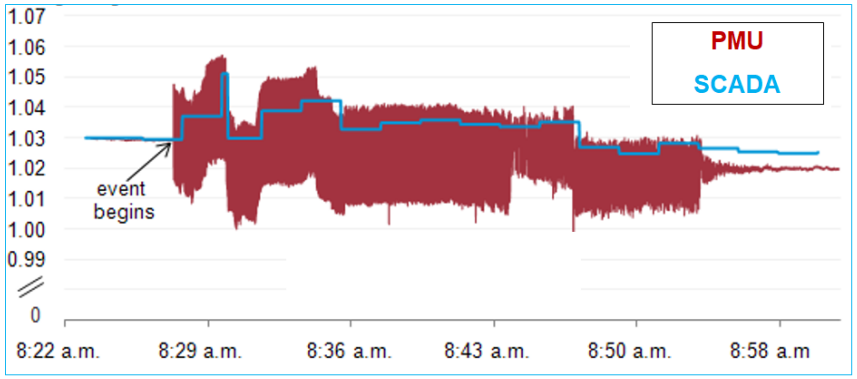
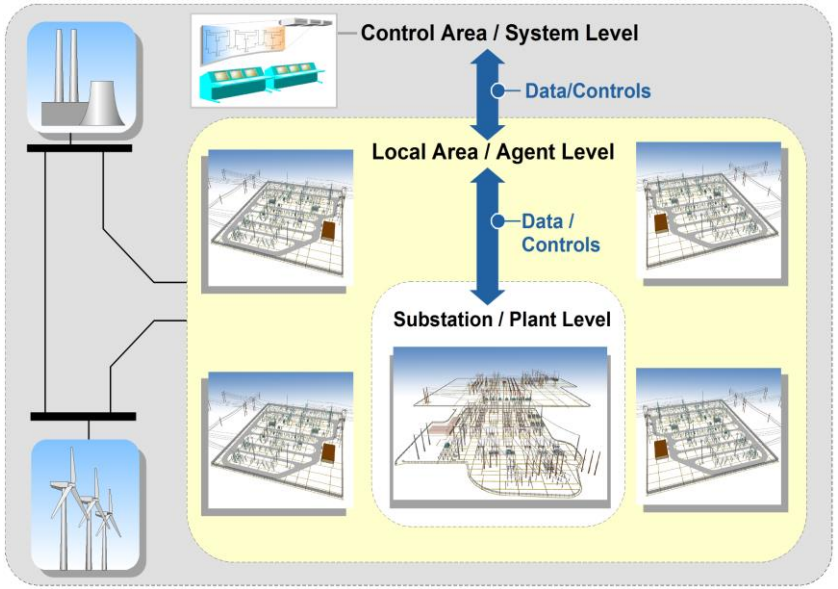
Next Generation Grid Monitoring & Control for IBR Dominated Grids





Monitoring

SCADA → PMU/Synchrophasors → Synchro-Waveform Data

Analysis

Model Based → Measurement & Model Based

Control

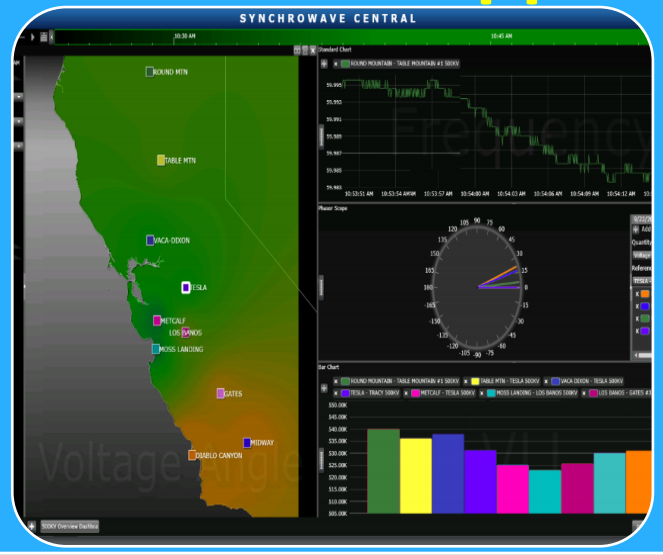
Centralized Control → Hierarchical Decentralized Control

- Local Area Controls: Mitigate disturbance locally & fast
- Centralized Controls: Optimize grid efficiency (slower outer layer)

Control Room Operations: Human Control → Supervision of Automated Systems

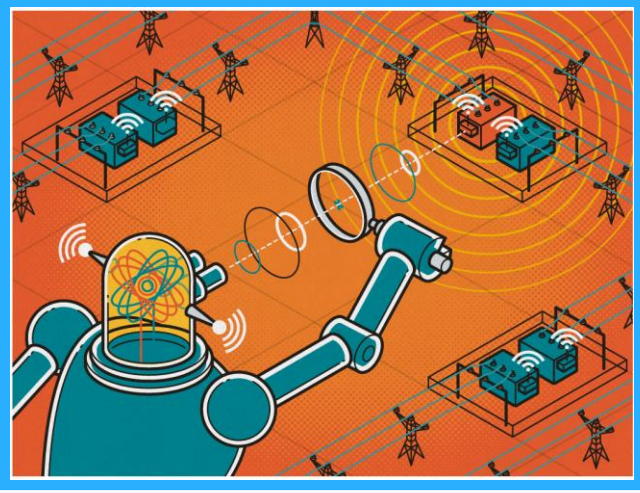
Synchrophasor/PMU Applications

State-of-the-Art Applications



- Wide Area Situational Awareness/Visualizations
- PMU Based State Estimation
- Event Detection
- Oscillations Monitoring & Analysis

Emerging Applications



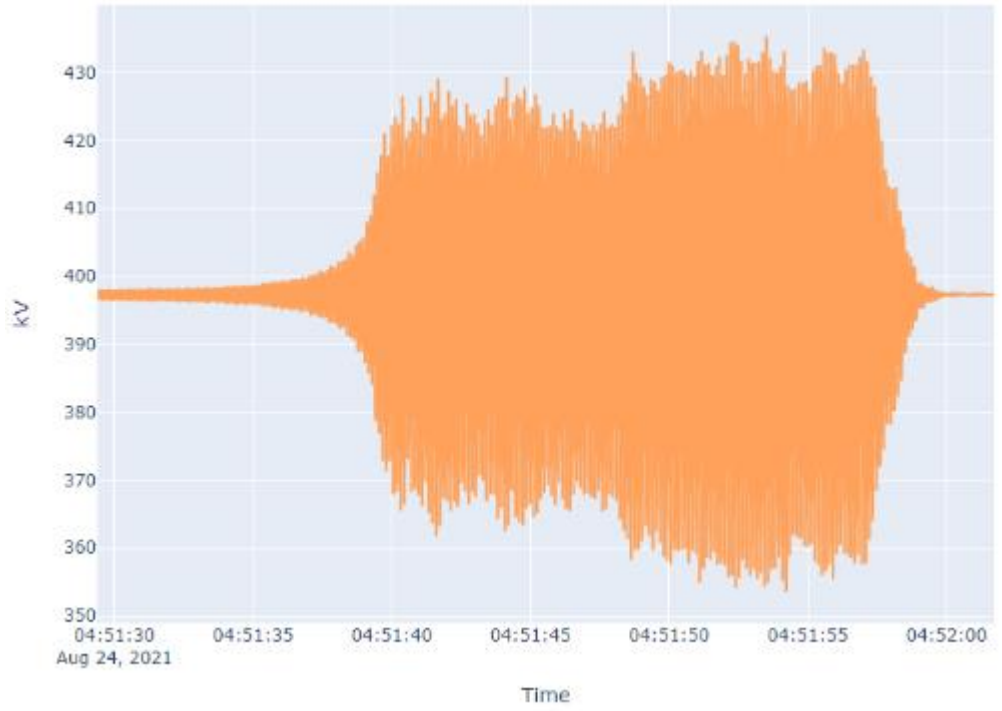
- Sub-synchronous Oscillations
- Inertia Estimation
- Artificial Intelligence/Machine Learning
- Grid Control

Sub-synchronous Oscillations

- Inverter controls might create sub-synchronous oscillations due to control interactions and/or network resonance
- Such oscillations are usually in the frequency band of 5.0-50.0 Hz

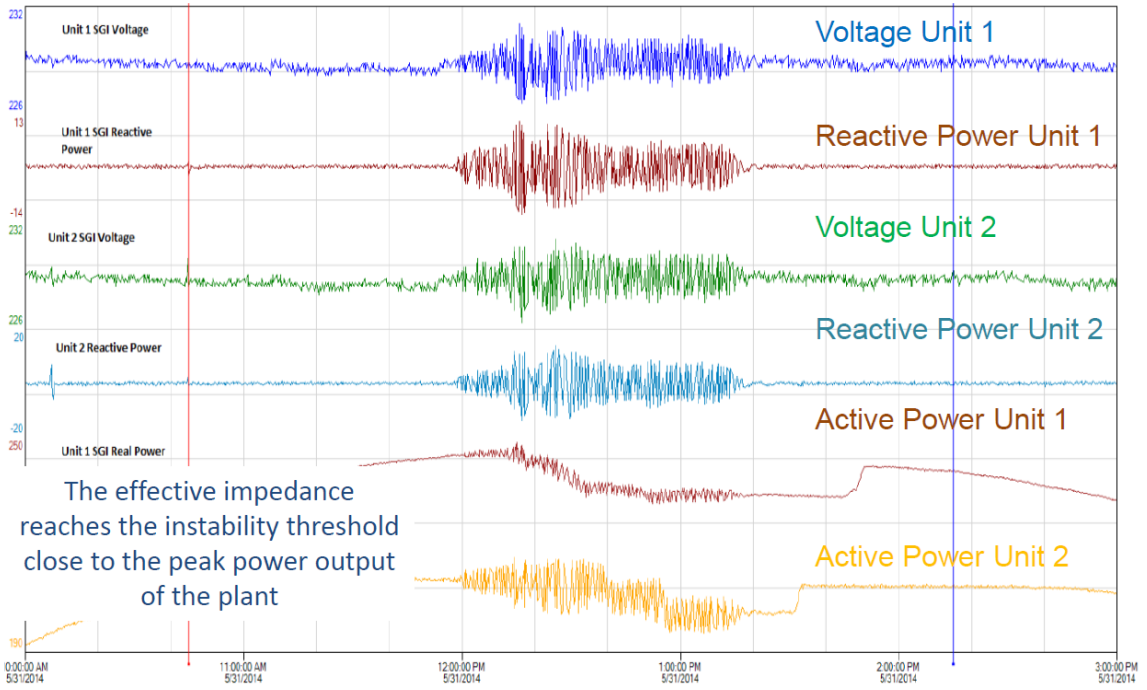
Scotland 2021 Event

~8Hz Oscillation



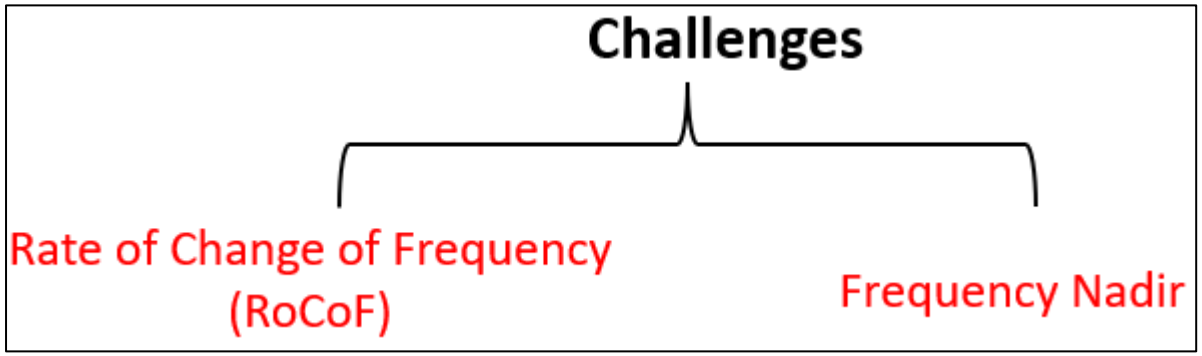
California, US

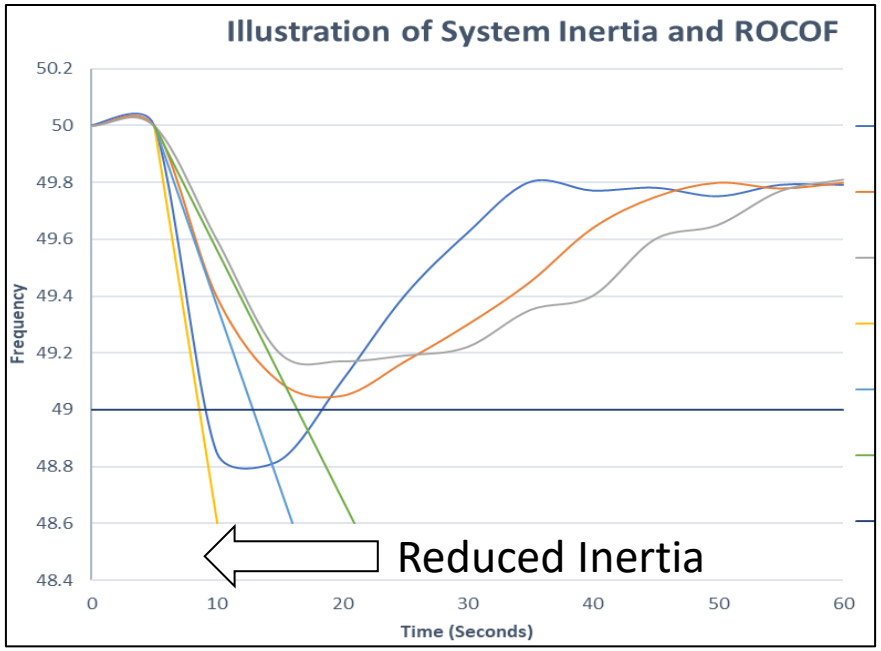
PV Plant – ~7 Hz Oscillation

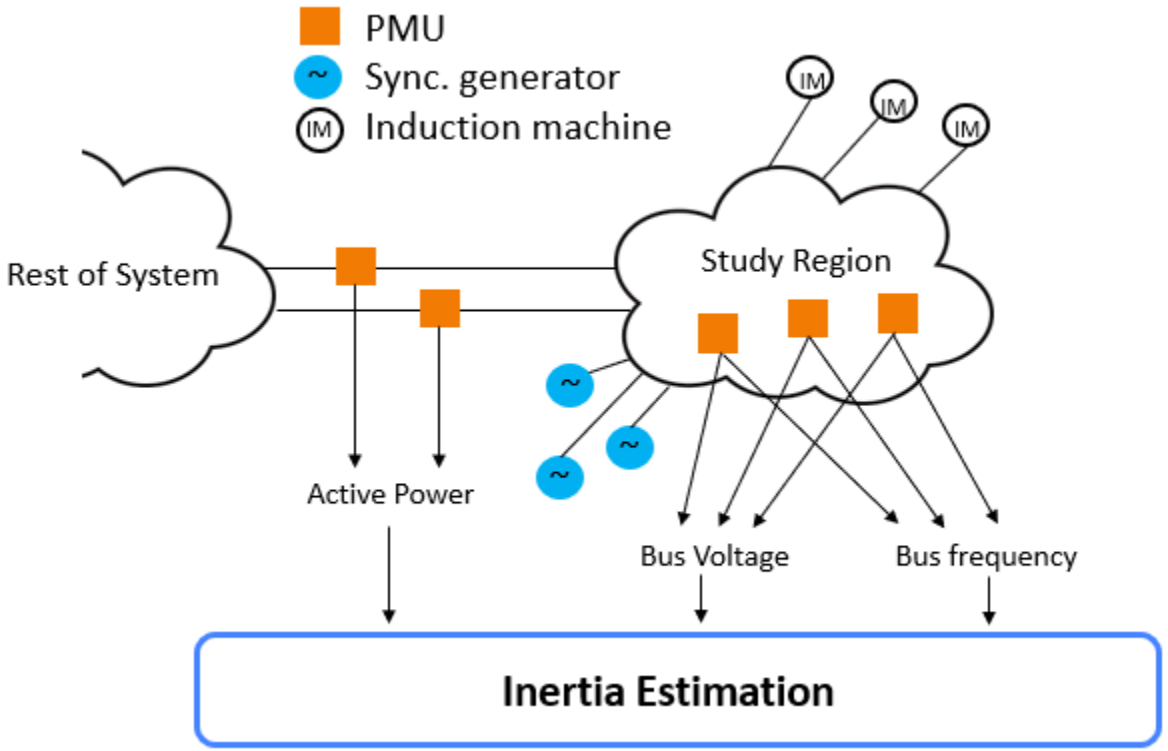


PMU Based Inertia Estimation/Monitoring

Increasing integration of renewable generation displaces synchronous generation → system inertia reduction

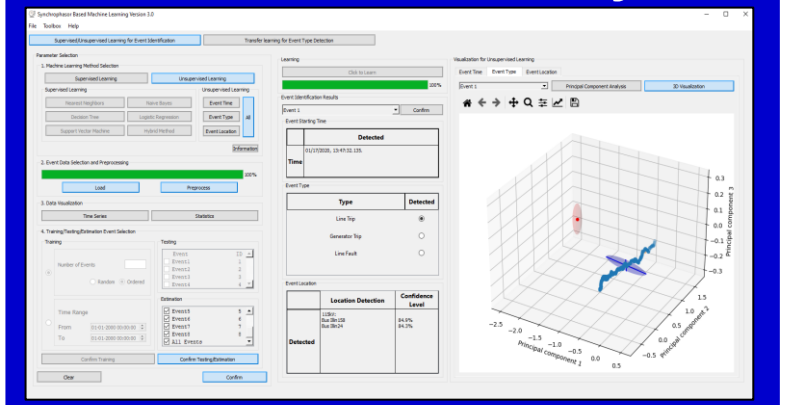






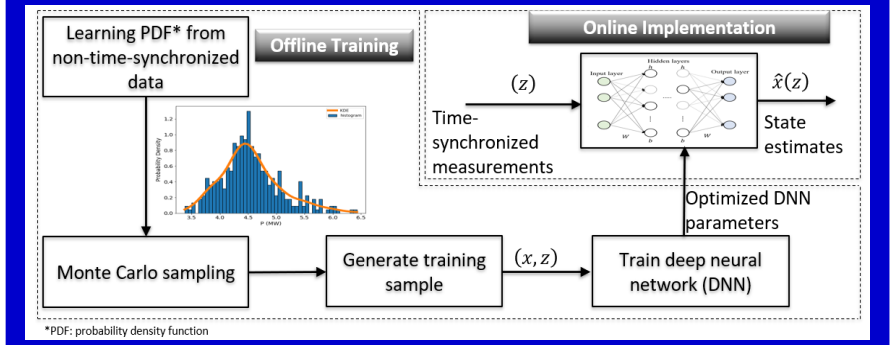
AI Applications with Synchrophasors

ML Based Event Analysis



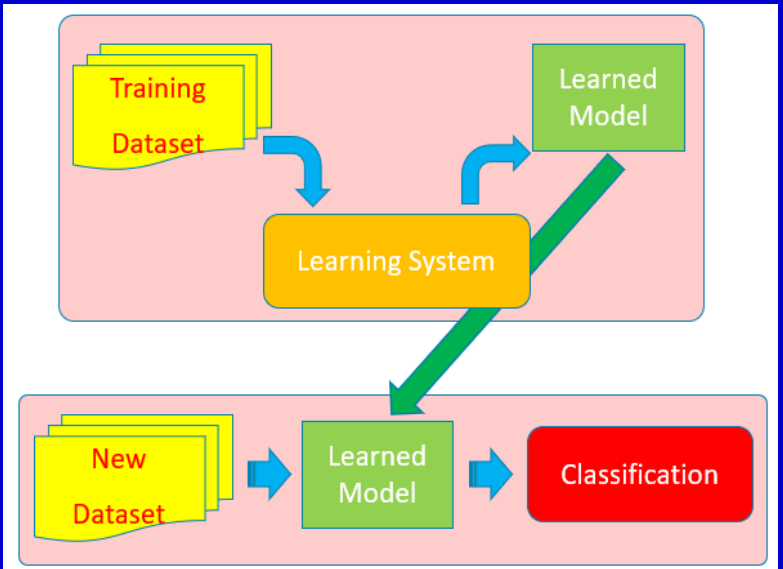
- Event Identification
  - Time
  - Type
  - Location
- ML Techniques
  - Supervised Learning
  - Unsupervised Learning
  - Transfer Learning

ML Based State Estimation



- Model Independent
- Independent of Measurement Error Distribution
- Overcomes SCADA/PMU Synchronization Issues
- Full System Observability with Limited Number of PMUs
- High Speed

ML Based Security Assessment

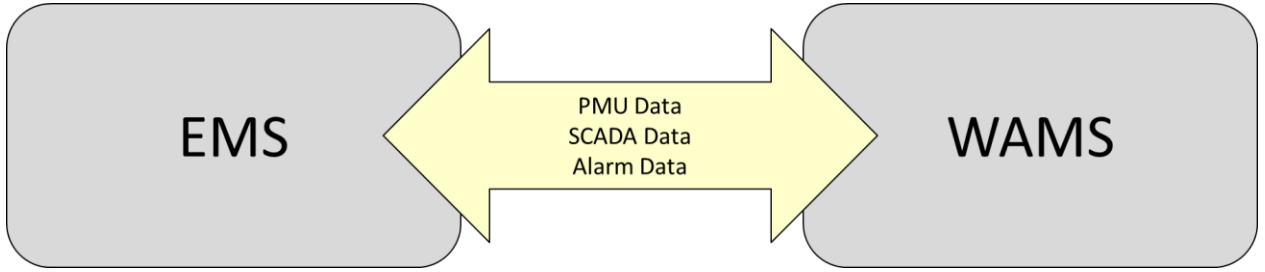


- Precursor/Pre-event Analysis
- Grid Health Index
- Leverage all available data in the control room

Situational Awareness & Security Assessment Using AI & PMU Measurements

EMS-WAMS Integration

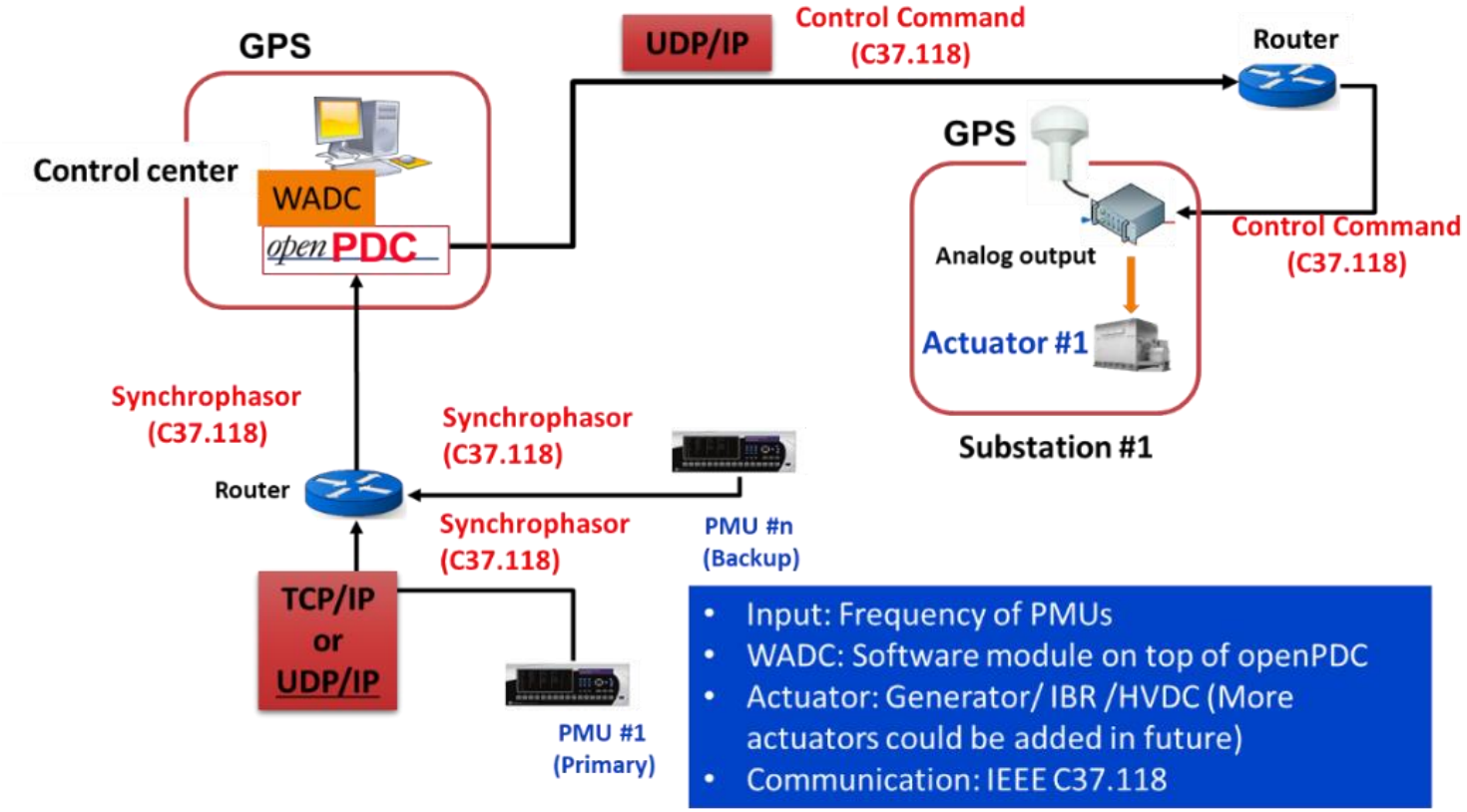
- Summarize techniques, protocols and architectures for integration of EMS/SCADA with WAMS
- Inform transmission operators and assess value of integrated EMS & WAMS
- Surveys
  - Utilities & ISOs
  - EMS Vendors
  - WAMS Vendors

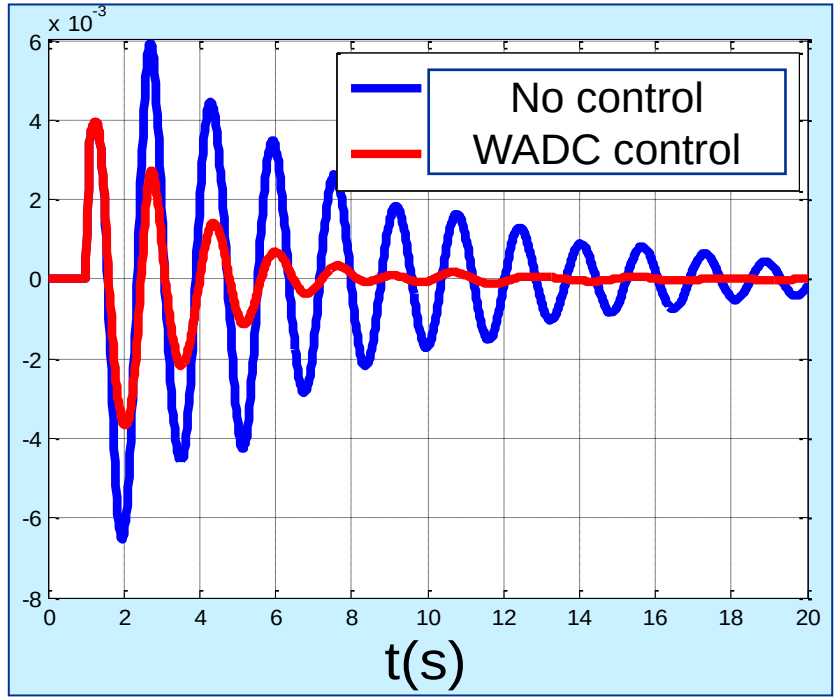


Survey Questions

Data	• e.g. : Data flow of integration?
Communication Protocols	• e.g. : Communication protocols used?
Applications	• e.g. : EMS applications using PMU data?

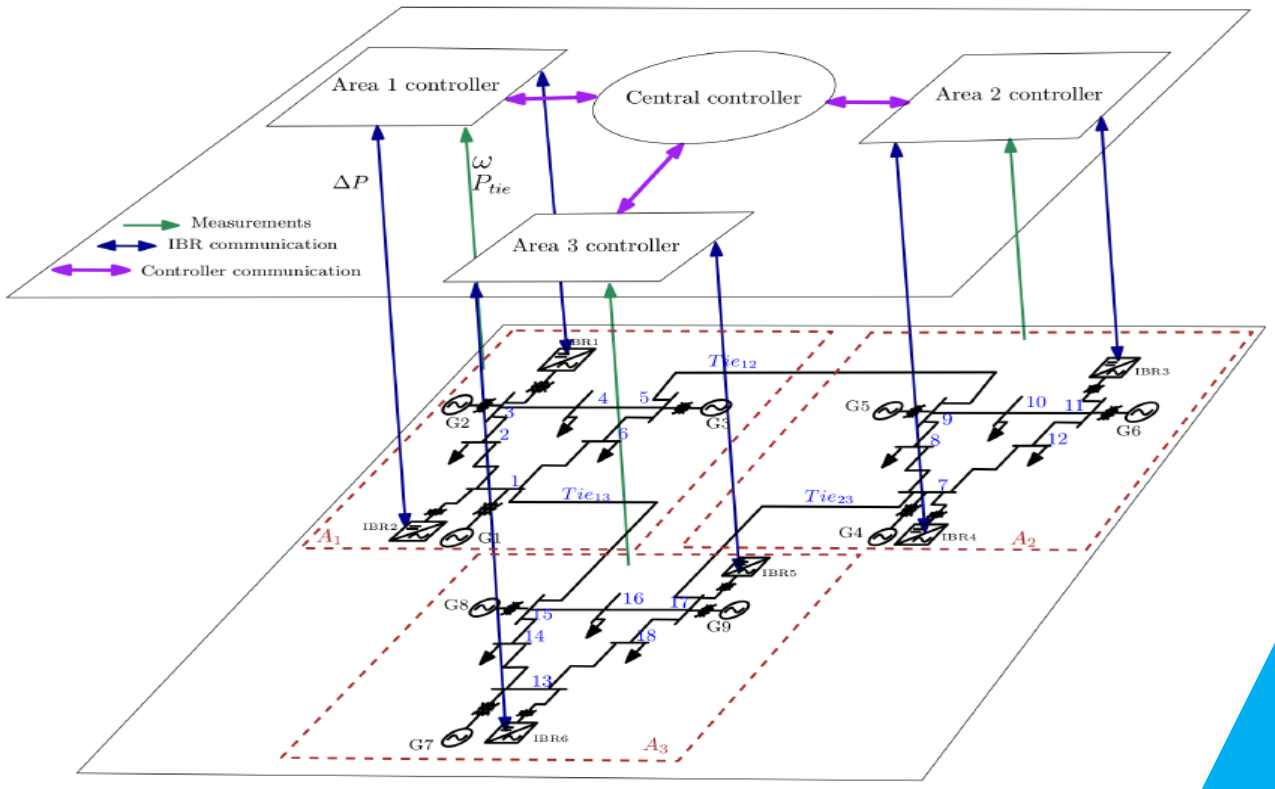
Wide Area Oscillations Damping Control





Hierarchical Decentralized Frequency Control

Frequency control layers



Central Controller

- Coordinates local area controllers
- Slower global response

Local Area Controllers

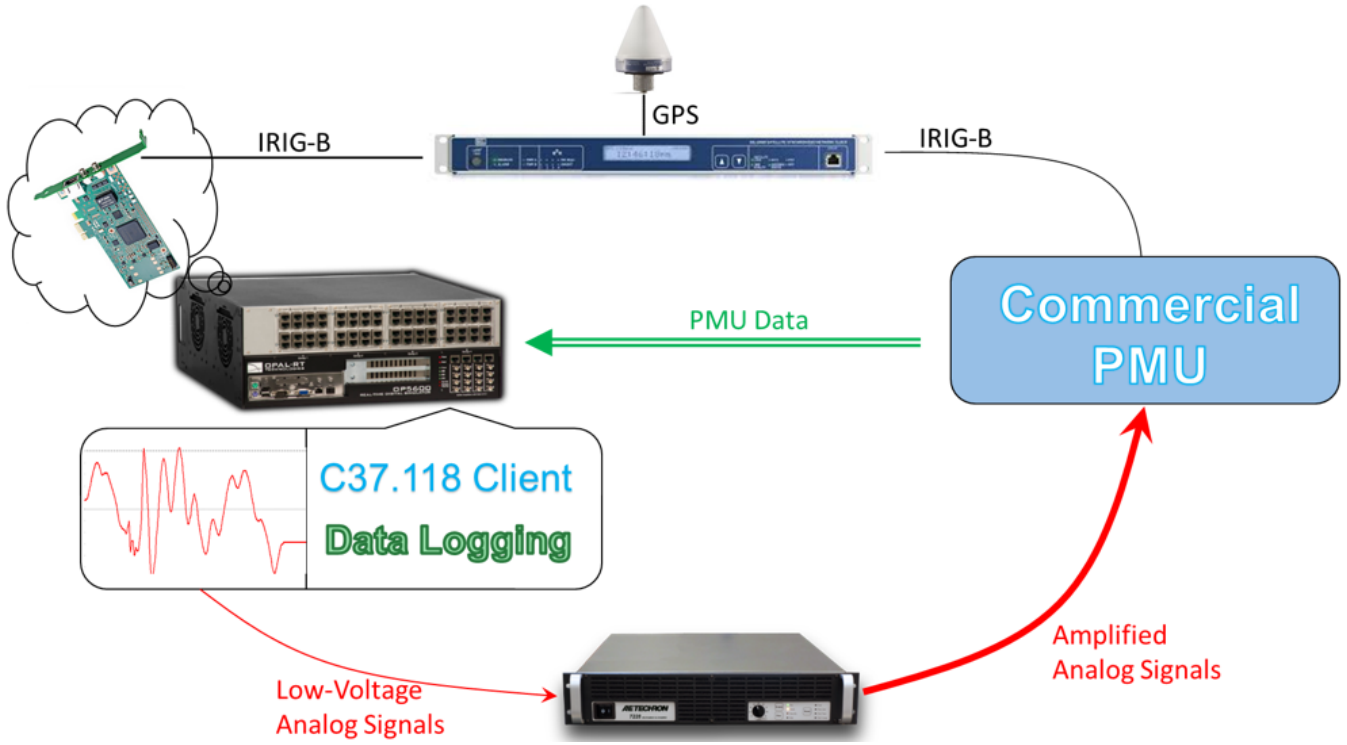
- Monitoring and control signals only from/to area resources
- Faster local area response

IBR Constant Frequency Control

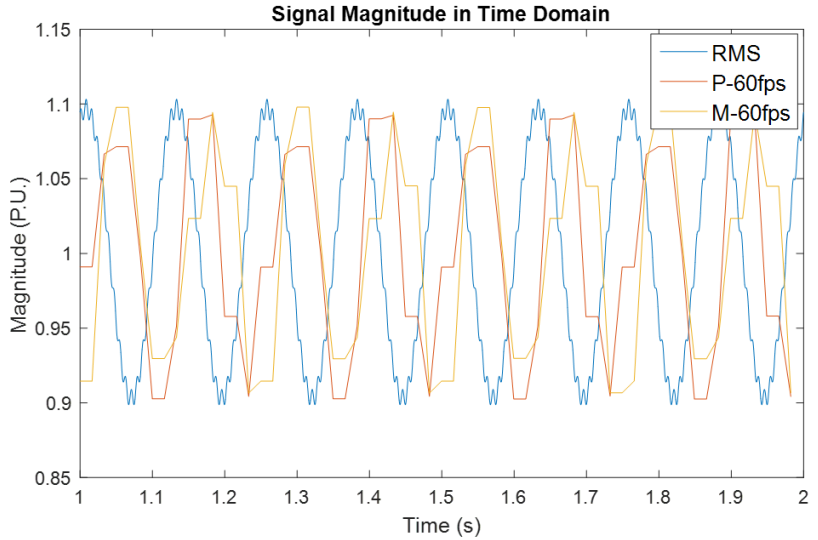
- Fast frequency control
- Using only local frequency measurements for expedited response

Use of PMU data

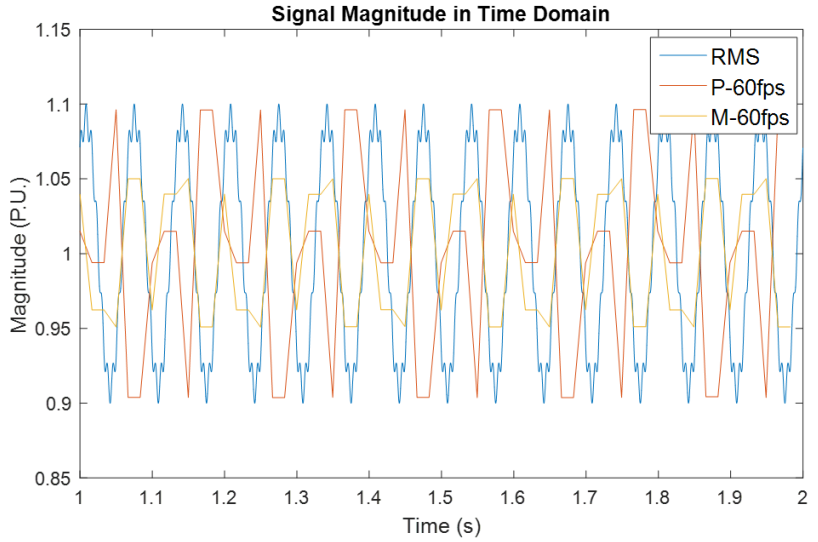
PMU Limitations in Monitoring Fast Dynamics



8 Hz

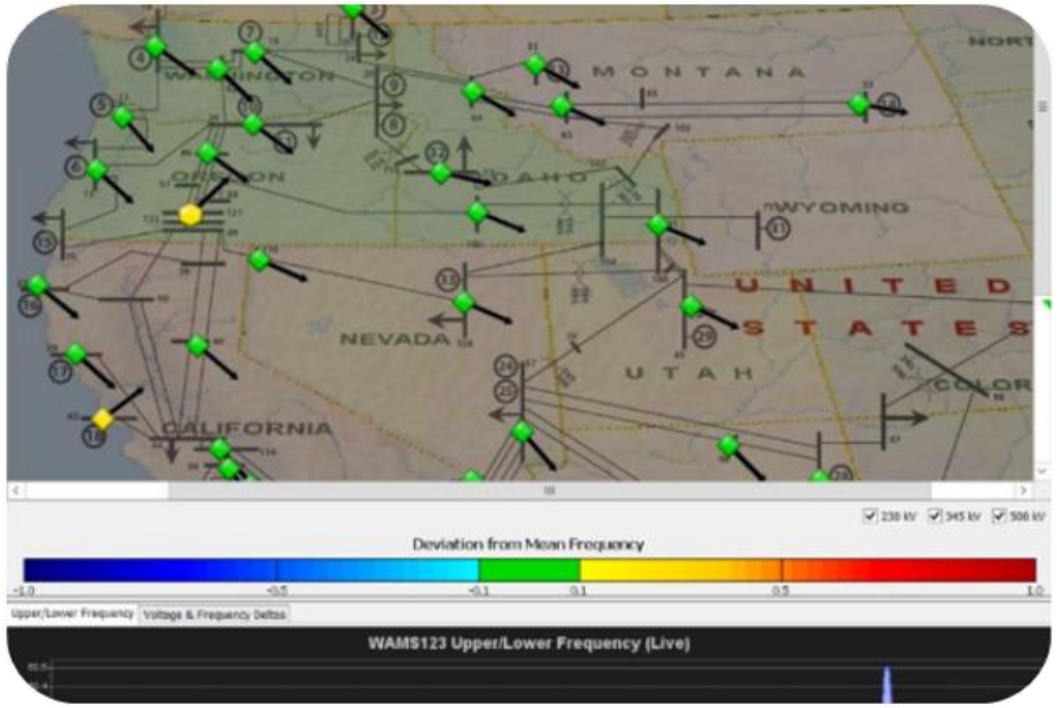


15 Hz

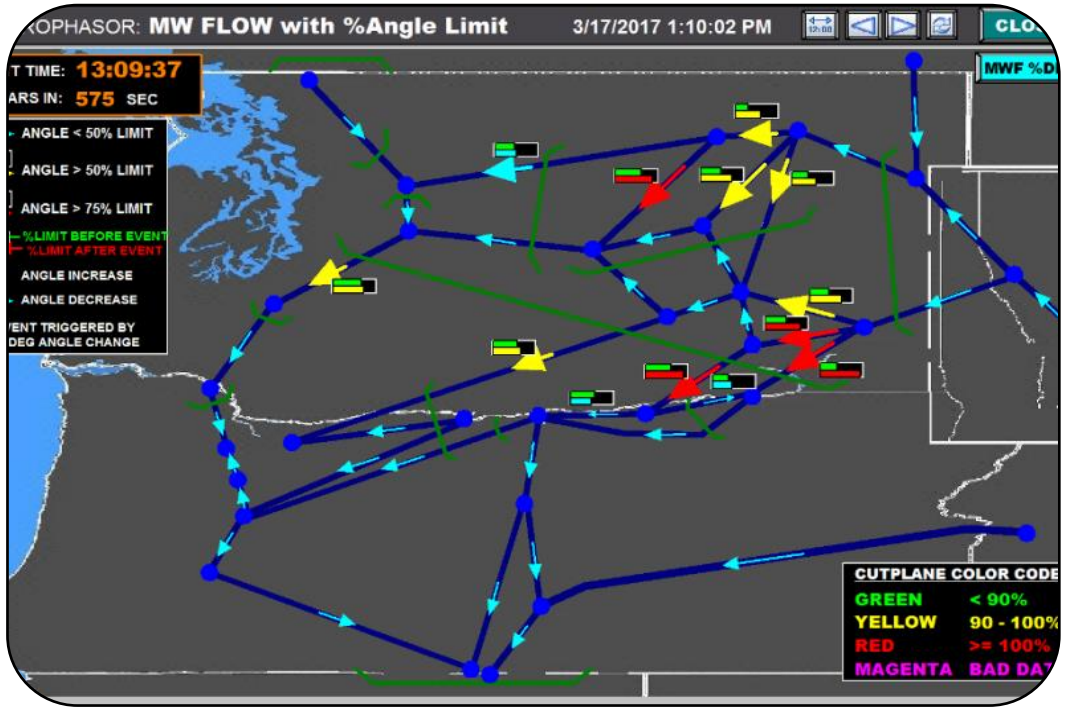


Wide Area Situational Awareness & Visualization

Vendor Tools



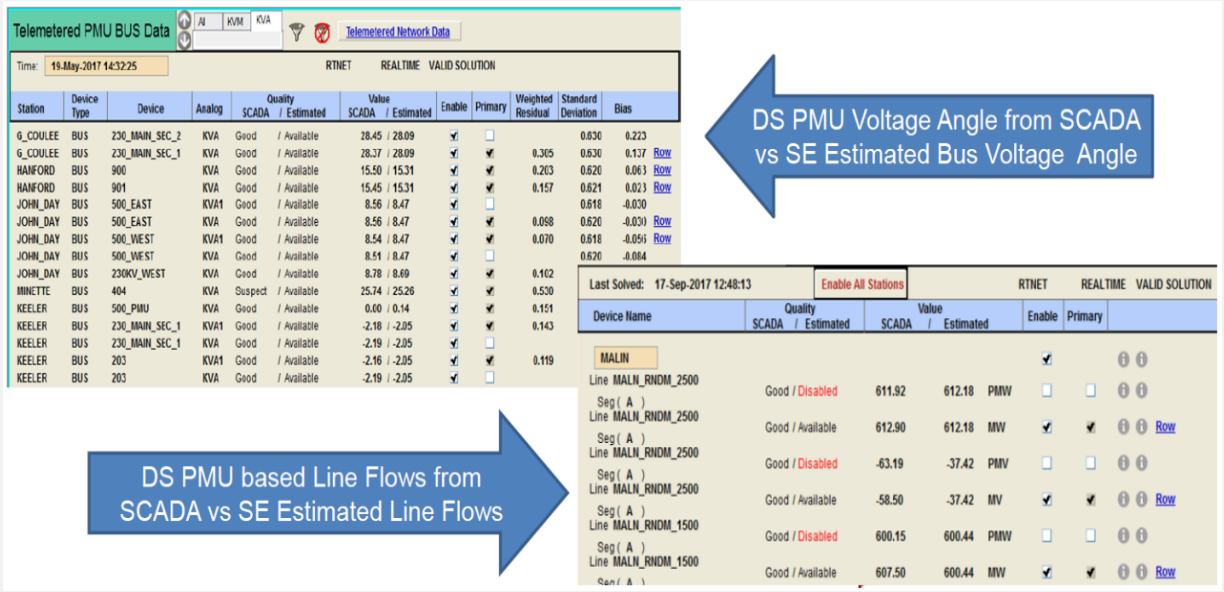
In-House Tools



- Geospatial displays
- Chart trends
- Phasor diagrams
- Line flows
- Voltage contours
- Phase angle differences
- Alerts/Alarms
- Color codes
- Arrows

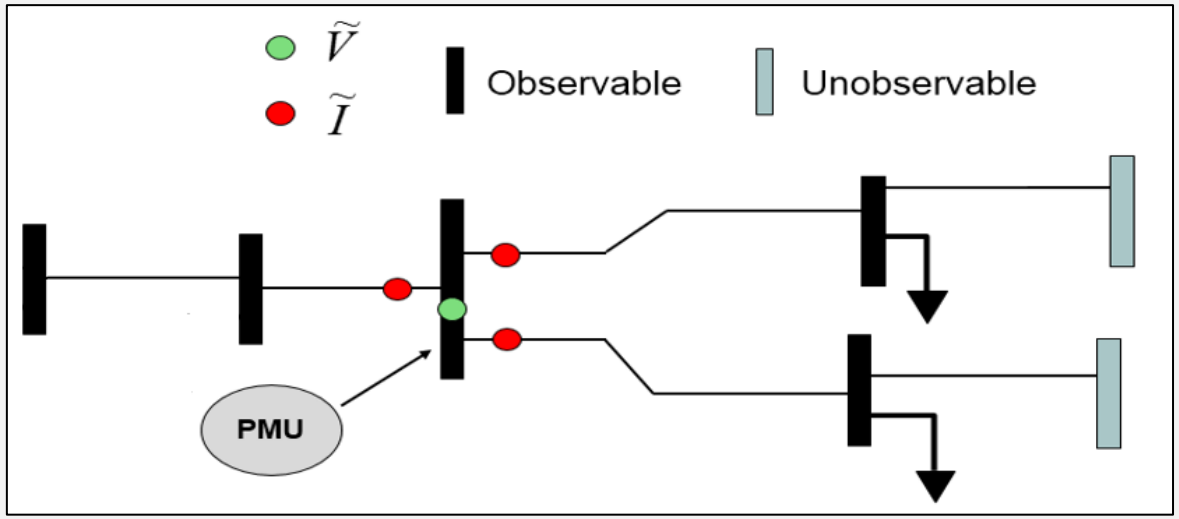
PMU Based State Estimation

Hybrid State Estimation



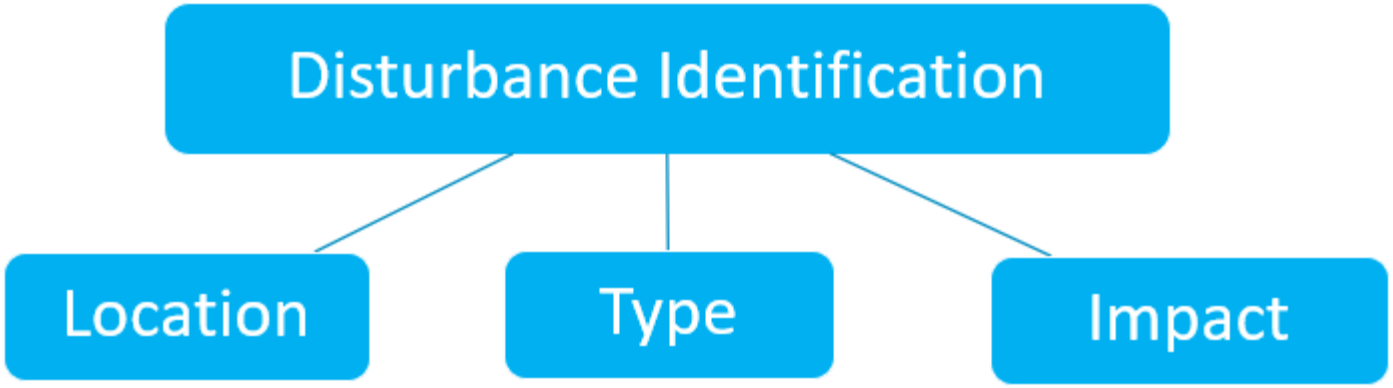
- Incorporation of Synchrophasor Data into EMS/SCADA State Estimator

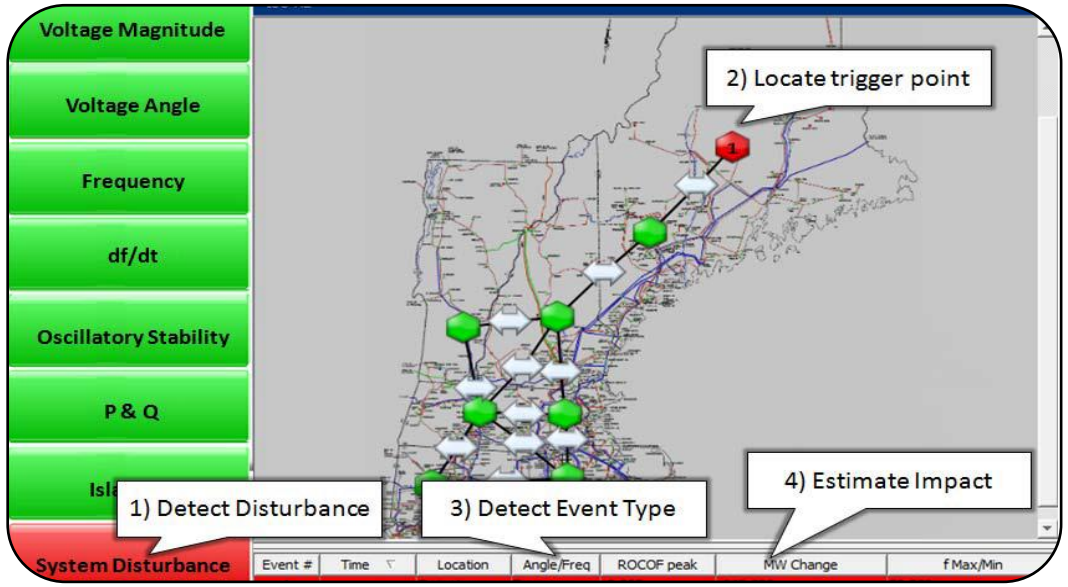
Linear State Estimation



- PMU-Only Based State Estimator
- Complementary or Backup to EMS/SCADA State Estimator

Event Detection

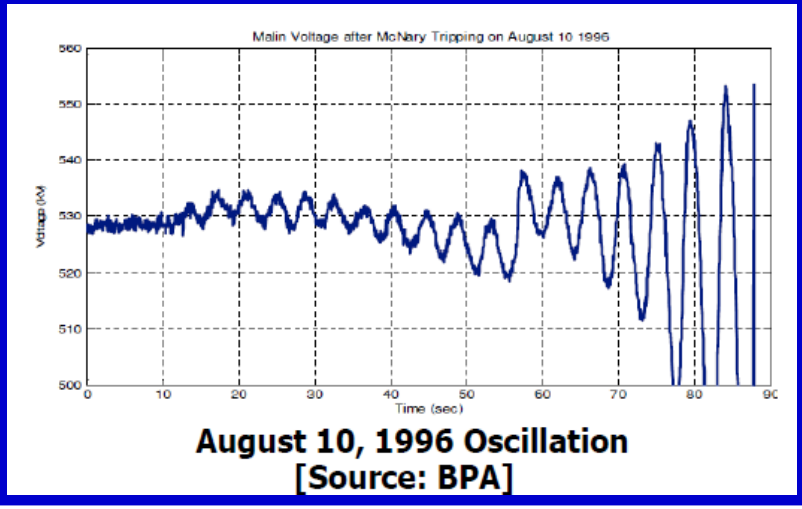




- Event detection logic typically based on heuristics (e.g. frequency threshold)
- Alarm Triggering

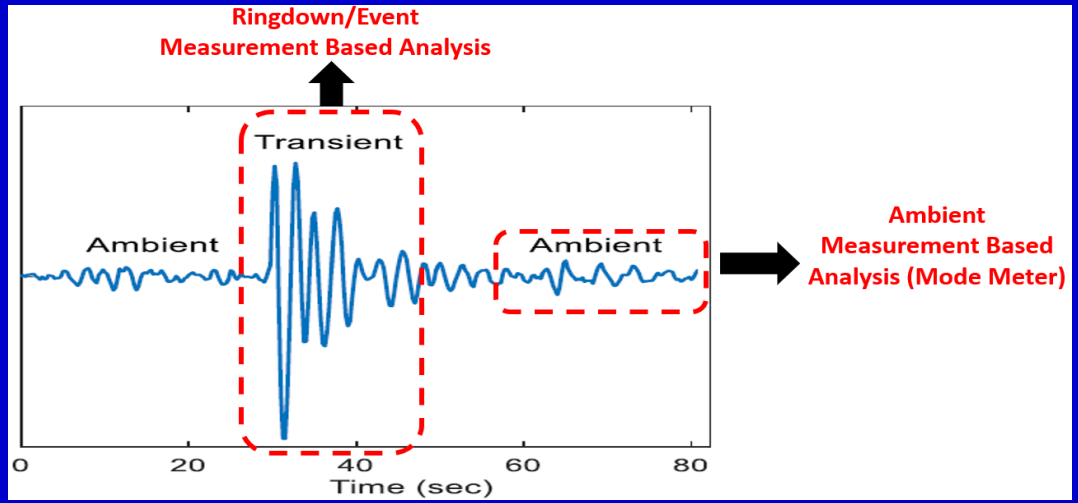
Oscillations Monitoring & Analysis

Past Events

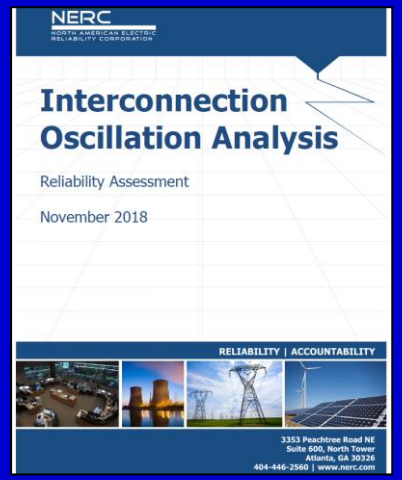


August 10, 1996 Oscillation
[Source: BPA]

Real-Time Analysis



Offline Grid Analysis

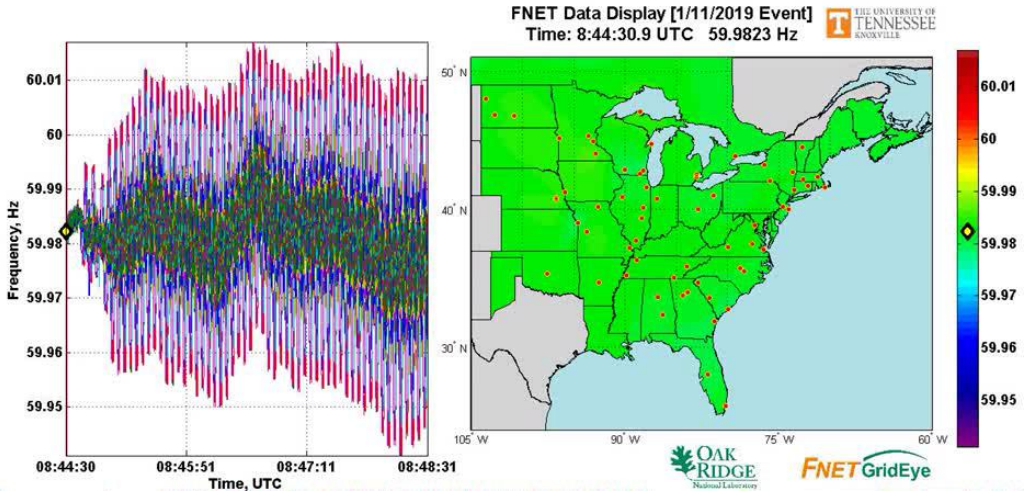


ISO-NE has observed 2000+ oscillatory events since 2012

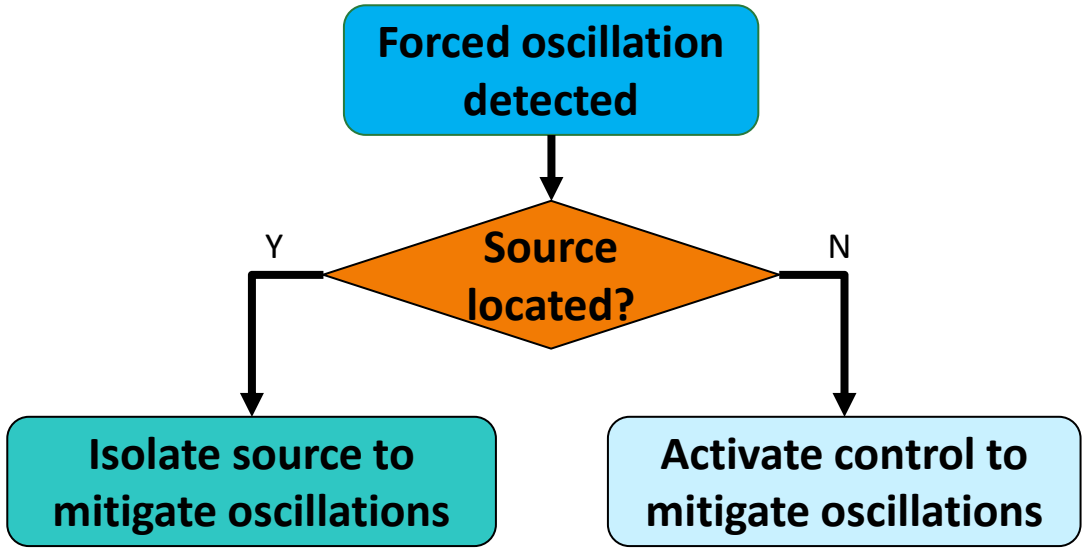
Vendor Tools

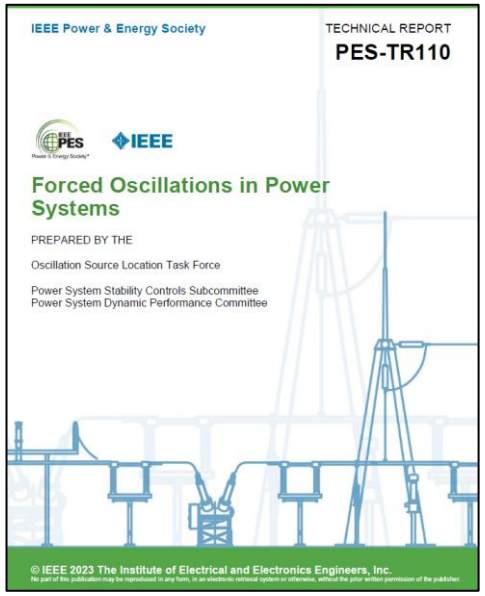
Forced Oscillations

January 2019 Event

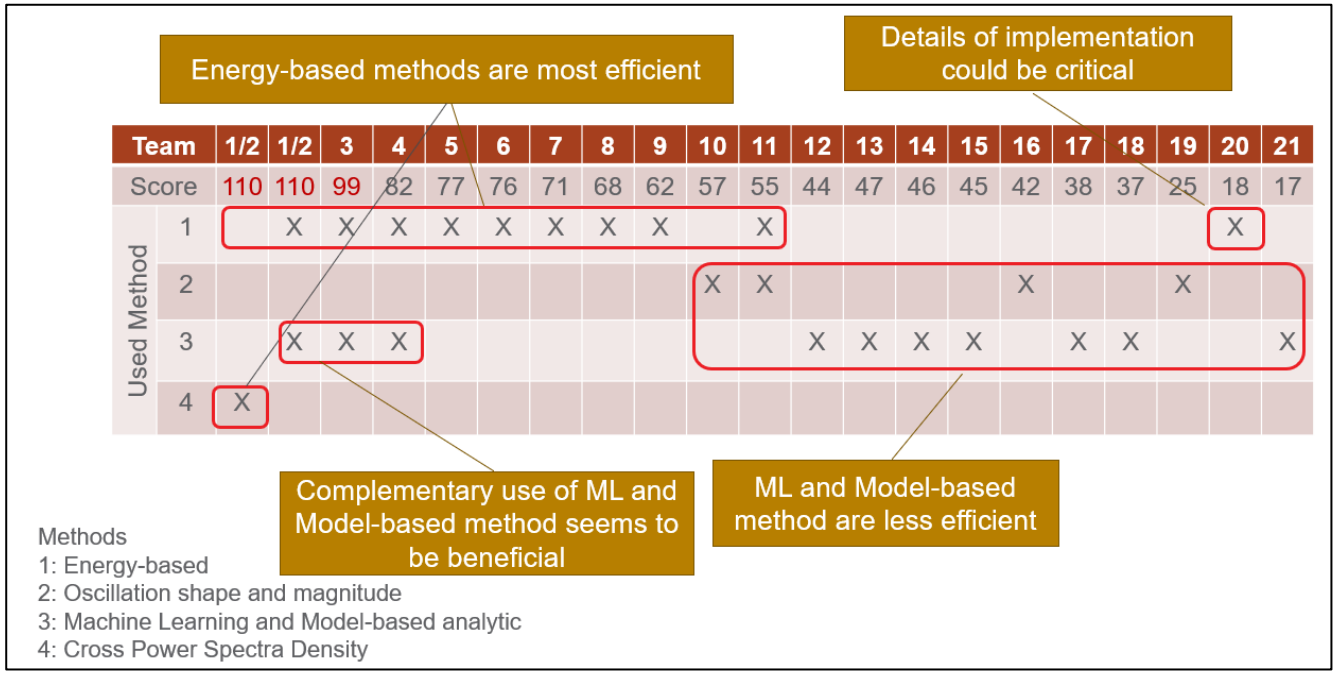


Forced Oscillations Mitigation





IEEE/NASPI Oscillation Source Location Contest



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Score	110	110	99	82	77	76	71	68	62	57	55	44	47	46	45	42	38	37	25	18	17
Used Method 1		X	X	X	X	X	X	X	X		X									X	
Used Method 2										X	X					X			X		
Used Method 3		X	X	X								X	X	X	X		X	X			X
Used Method 4	X																				