# EPRI R&D on PMU Applications: Industry Case Studies & Vendor Engagement


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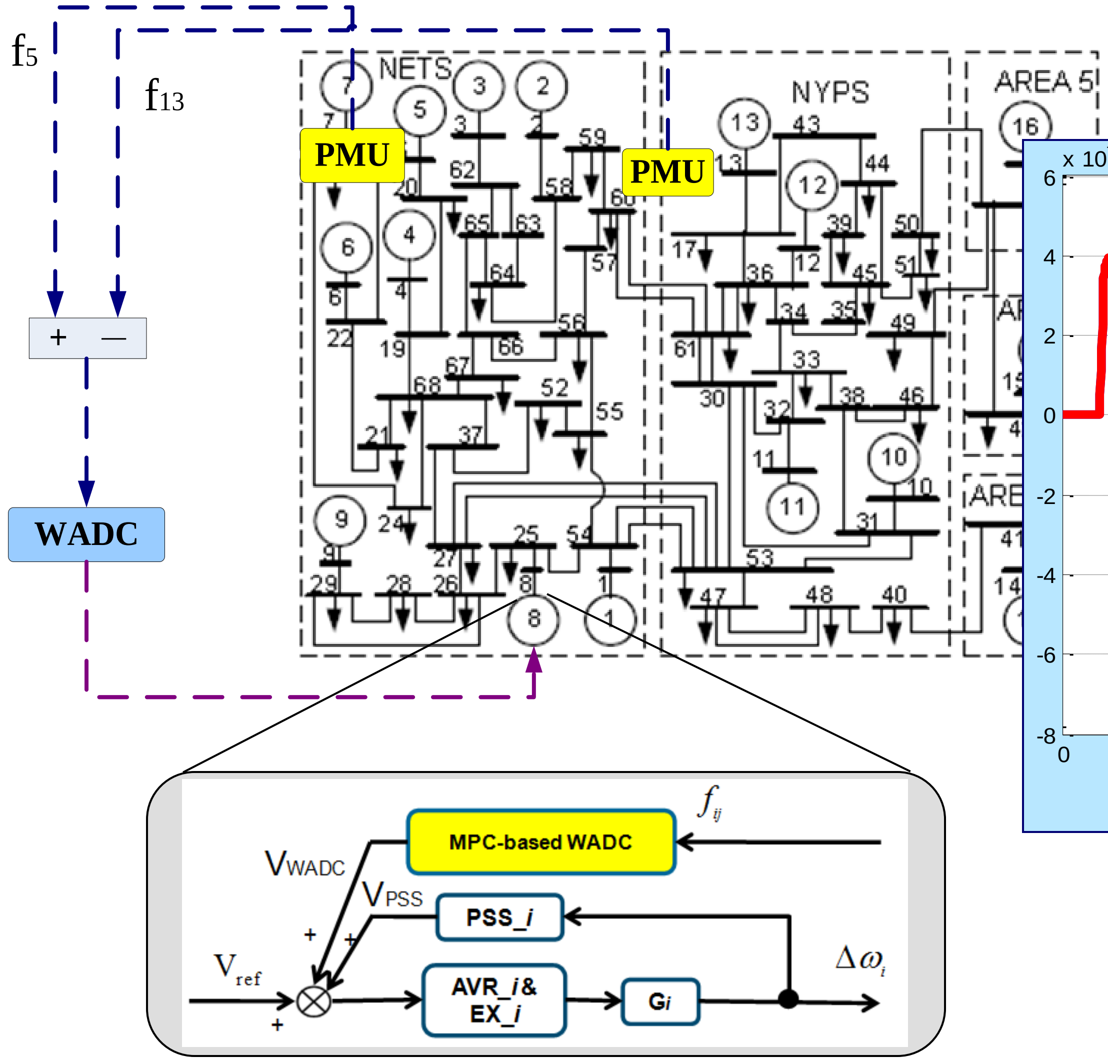
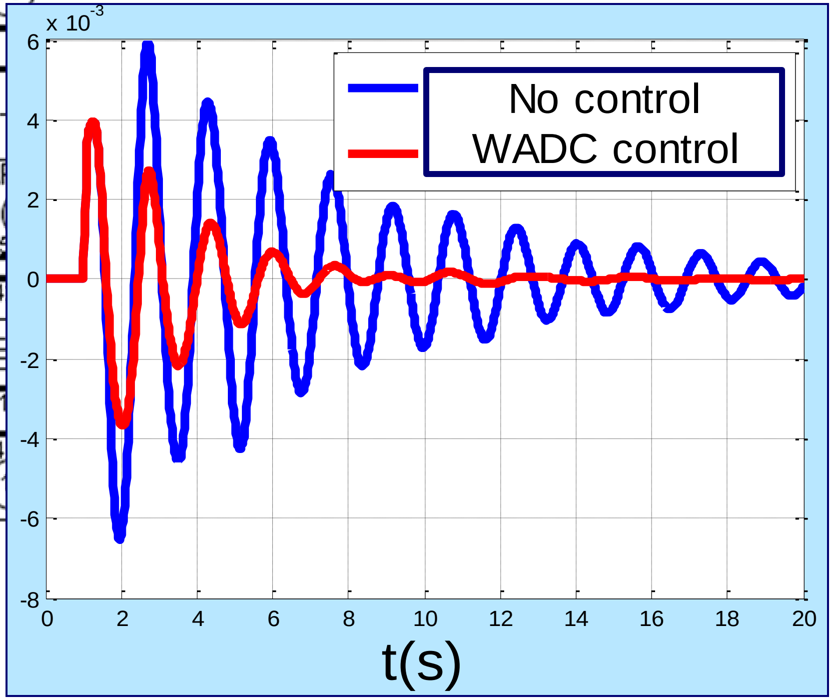
# 1. Synchrophasor-Based Wide Area Oscillations Damping Controller




***In collaboration with University Tennessee Knoxville (UTK)***

- **Improved Damping of Target Inter-area/Intra-area Oscillations Mode**
- **Application of Synchrophasor Technology in Closed Loop Wide Area Control**

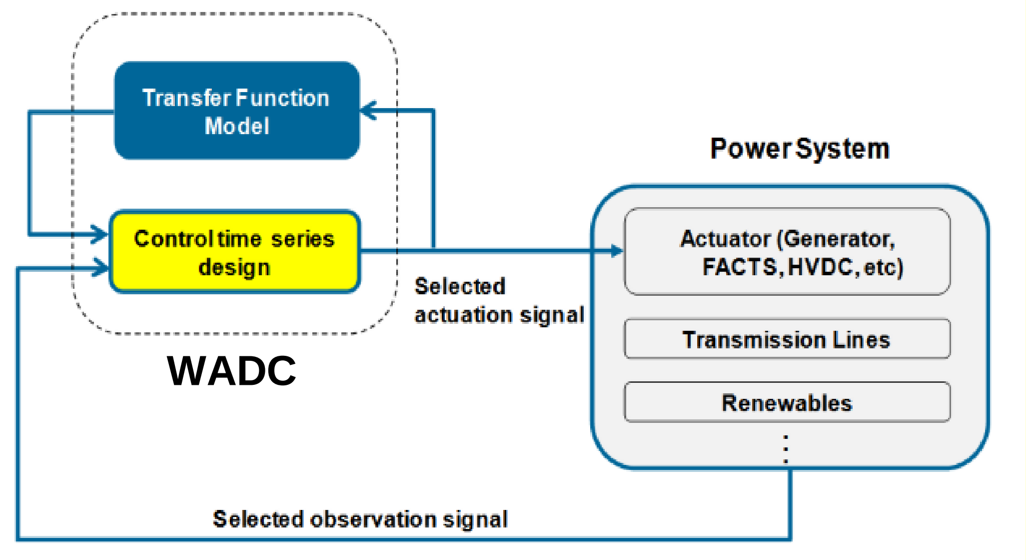
# Measurement Based Wide Area Damping Controller

**Offline Stage – WADC Design**

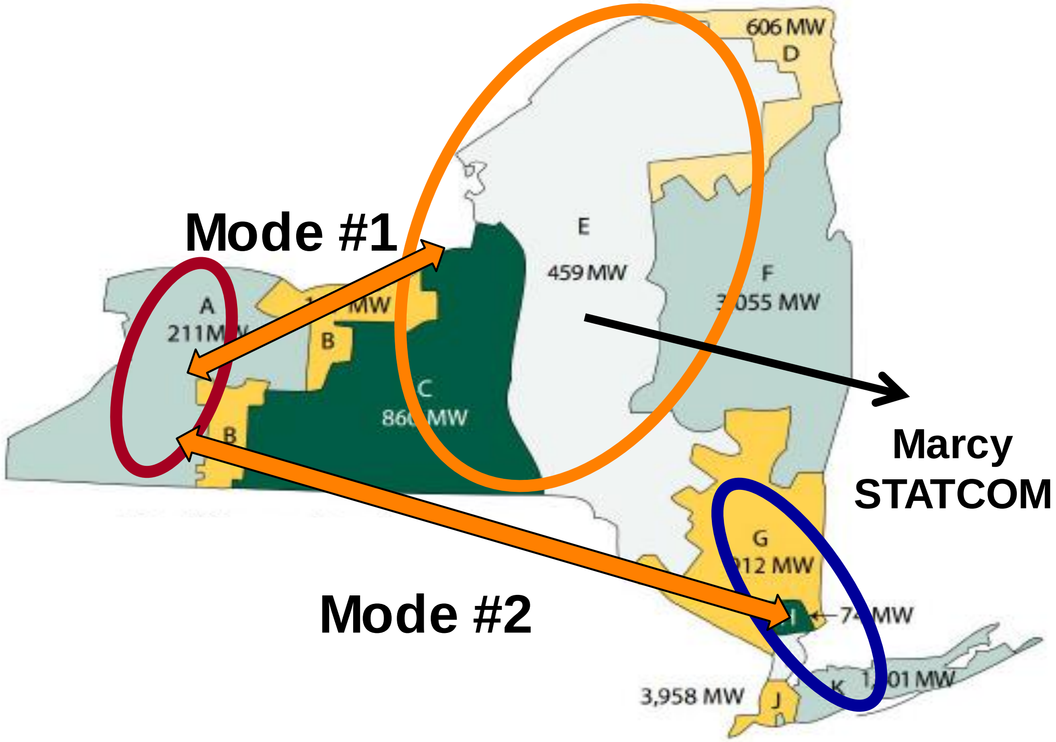
1. Modal Analysis
2. Selection of optimal observation signals
   - PMUs at selected locations for oscillation mode observability
3. Selection of optimal actuation signal
   - Actuators: Generator stabilizer/FACTS/HVDC
4. Model Identification and Validation
5. Control Design
6. Simulation-Based Testing
7. Hardware-In-the-Loop Testing

**Real-time Stage**

- Adaptive Controller
  - Model: Measurement-derived transfer function
- Controller Design



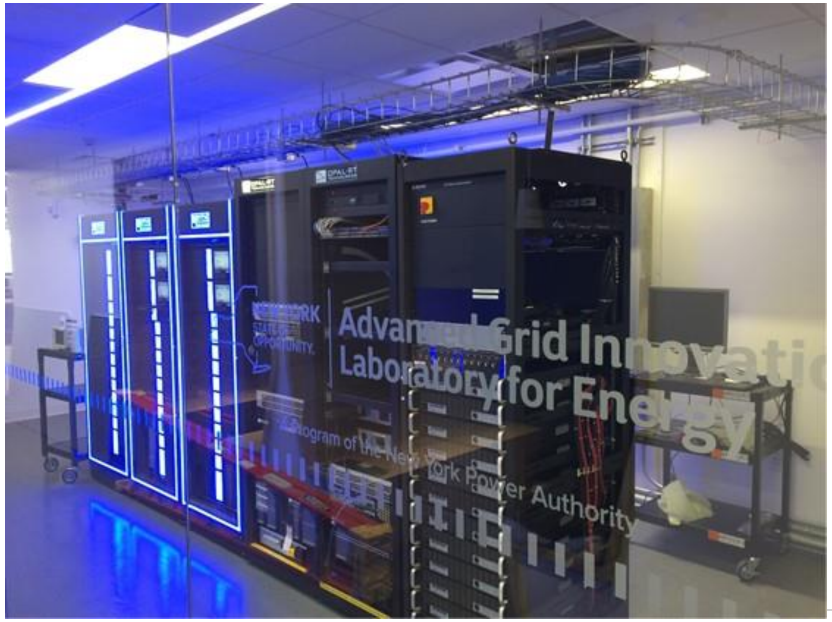
# NYPA Case Study




| Candidate actuator & observation | Case | Damping Improvement (Mode 1) | Damping Improvement (Mode 2) |
|---|---|---|---|
| Generator (Area A - Niagara) Frequency---A-E | Winter | +2.57% | +0.2% |
| | Summer | +10.04% | -0.54% |
| | Spring | +7.35% | -2.24% |
| | **Avg.** | **+6.65%** | **-0.86%** |
| STATCOM (Marcy) Frequency---E | Winter | +7.85% | +4.47% |
| | Summer | +5.38% | +6.82% |
| | Spring | +5.65% | +1.63% |
| | **Avg.** | **+7.21%** | **+5.73%** |

- 2019 NYISO planning models (light load, summer and winter)
- Modal analysis: Identified coherent groups and dominant modes
- Selection of optimal observation signals & actuator - Marcy STATCOM
- Demonstrating adaptive performance of WADC
  - Online model identification with ringdown data
  - Online model identification with probing data
- WADC design with backup signals and actuators
- Next: Hardware-in-the-Loop Implementation & Demo

# NYPA Advanced Grid Innovation Laboratory for Energy (AGILe)


- AGILe: electric power research laboratory with real-time simulation & modeling tools.
  - Target: conduct collaborative research with utilities and grid tech companies focused on facilitating stakeholders in solving grid related challenges
  - Lab established at NYPA's White Plains, NY office
  - RTDS & OPAL-RT simulators installed
  - NY state grid models under development

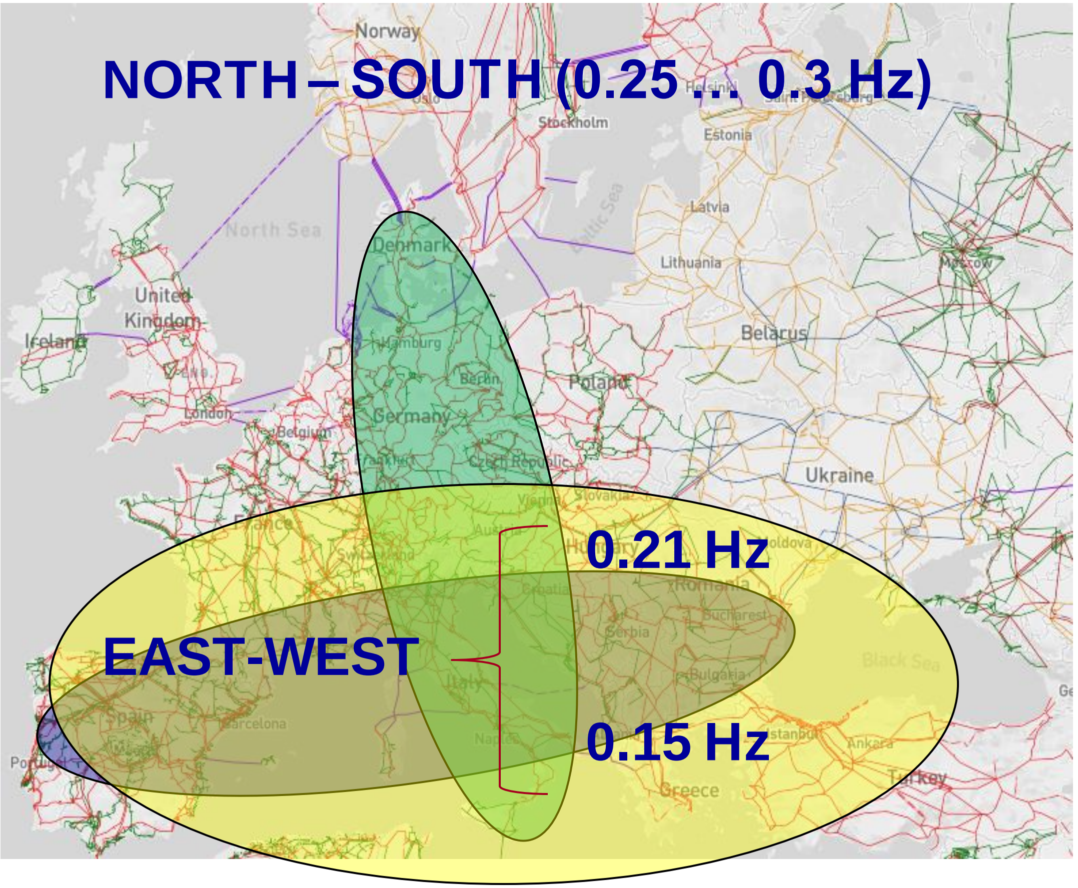
RTDS Technologies

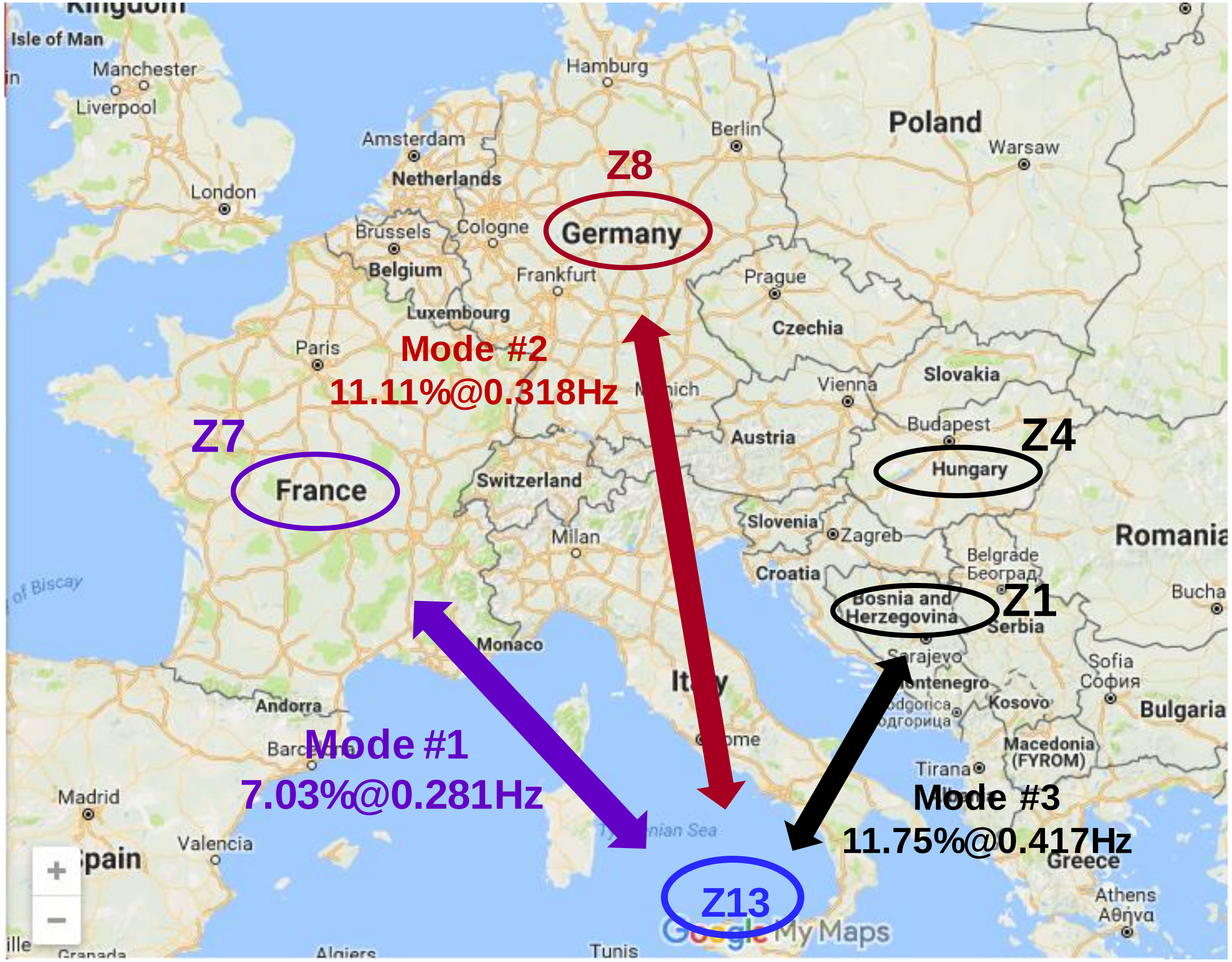
- 4 NovaCore chassis - 40-core processing power
- Simulation capability: ~600 3-phase buses
- RSCAD simulation software

OPAL-RT TECHNOLOGIES

- 1 8048B-TR4F Super Server - 40-core processing power
- Simulation capability: ~600 3-phase buses (transient simulation), ~10,000 single-phase buses (stability simulation)
- HYPERSIM and ePhasorSim simulation software

# TERNA Case Study

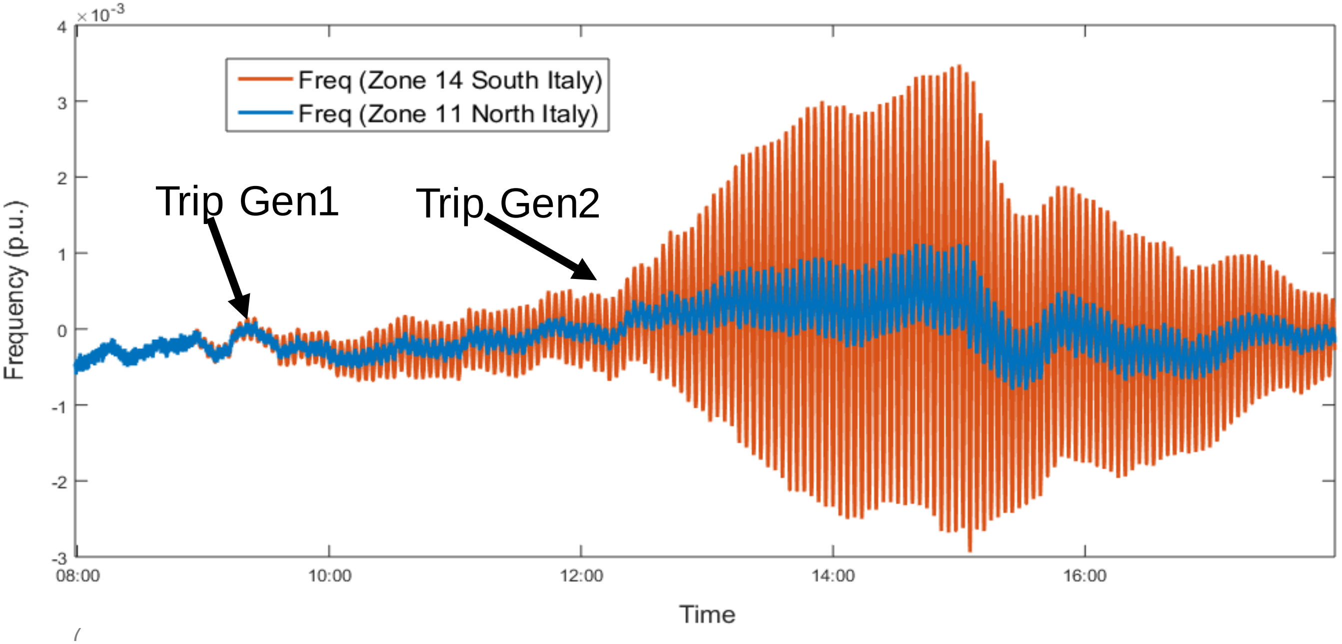


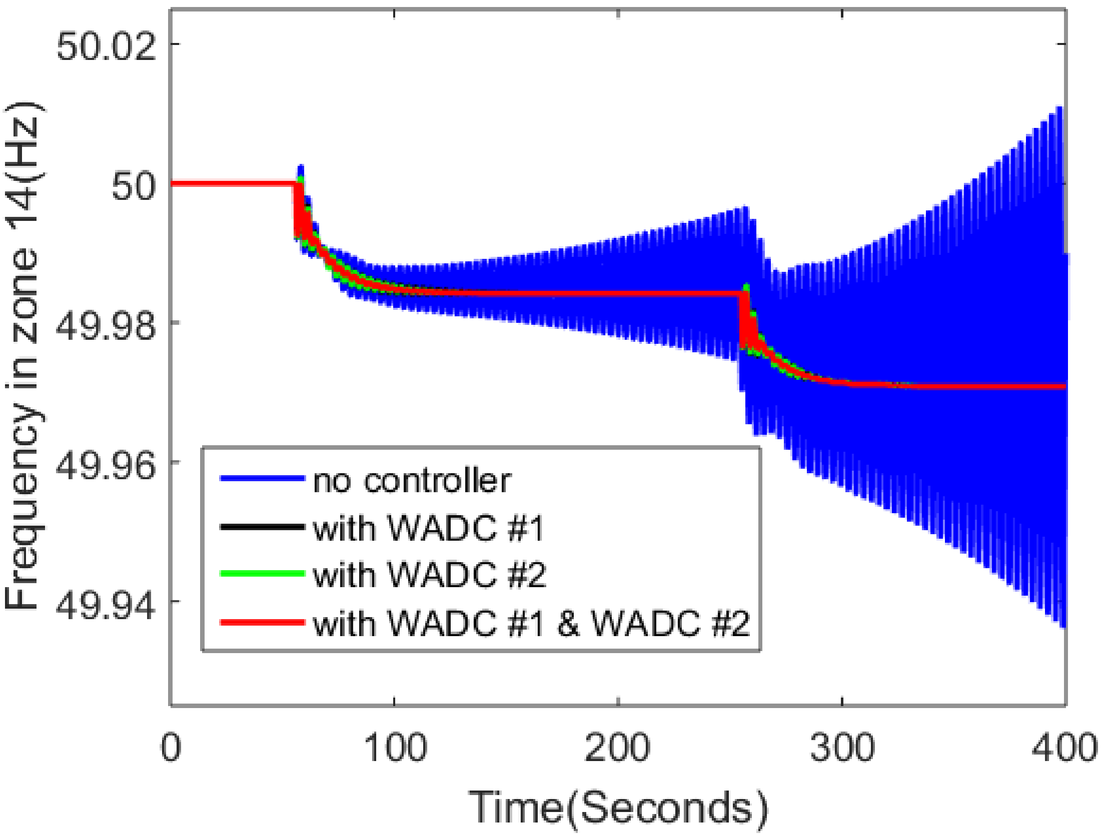




- Modal analysis: North-South Mode in TERNA model
- Observation signal selection: PMU1 South Italy – PMU2 North Italy (France area is optimal)
- Actuators: Two synchronous condensers in South Italy

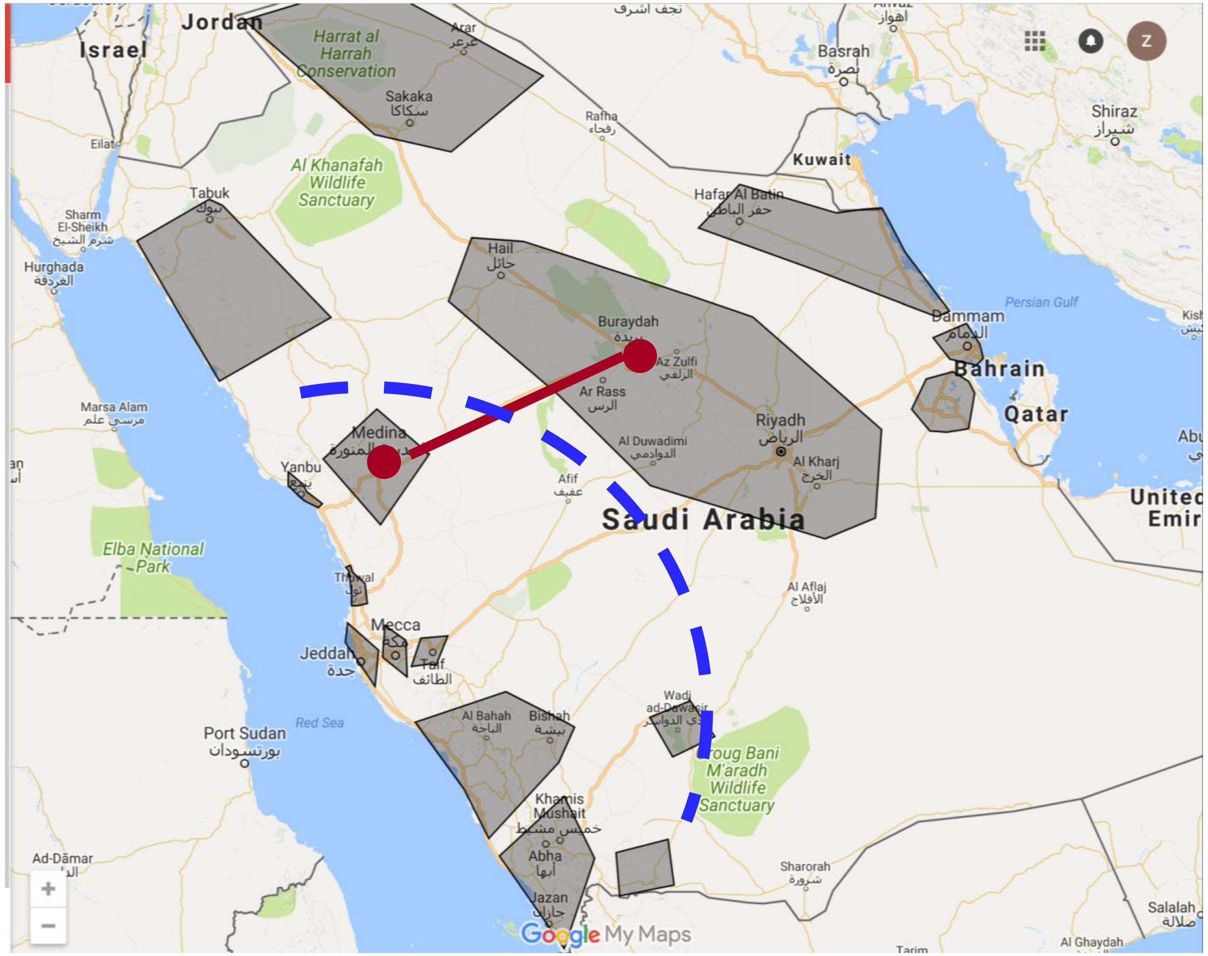
# WADC Design for an Actual 2017 Event

- PMU measurements provided by TERNA
- Two generator trips
- Event simulated and WADC designed
- Oscillations were damped by WADC
- Next: Hardware-in-the-Loop Implementation & Demo



# Saudi Electricity Company (SEC) Case Study




- Qassim – Medina: Double line, series compensated, separating West with Central/North/East SEC system
- 3 incidents since 2015 that resulted in tripping of the line
- Actuators:
  - STATCOMs in West
  - Additional STATCOM to be installed in Central area
- Study interaction of WADC with transmission line power swing protection



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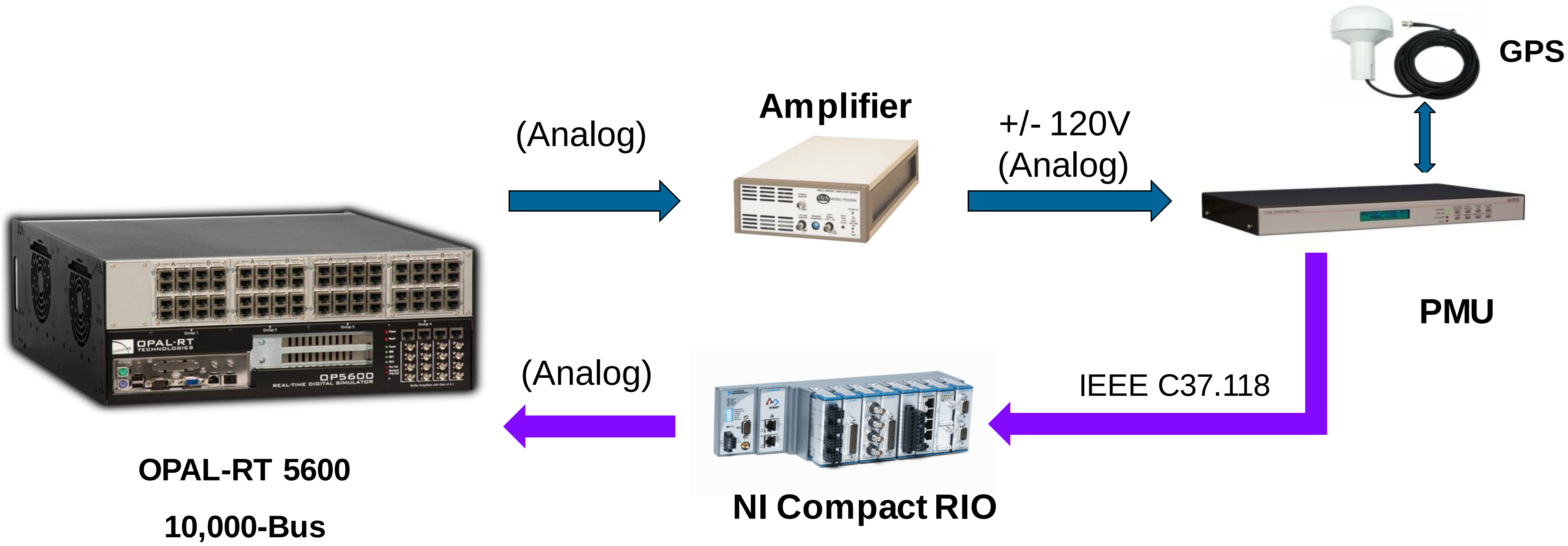
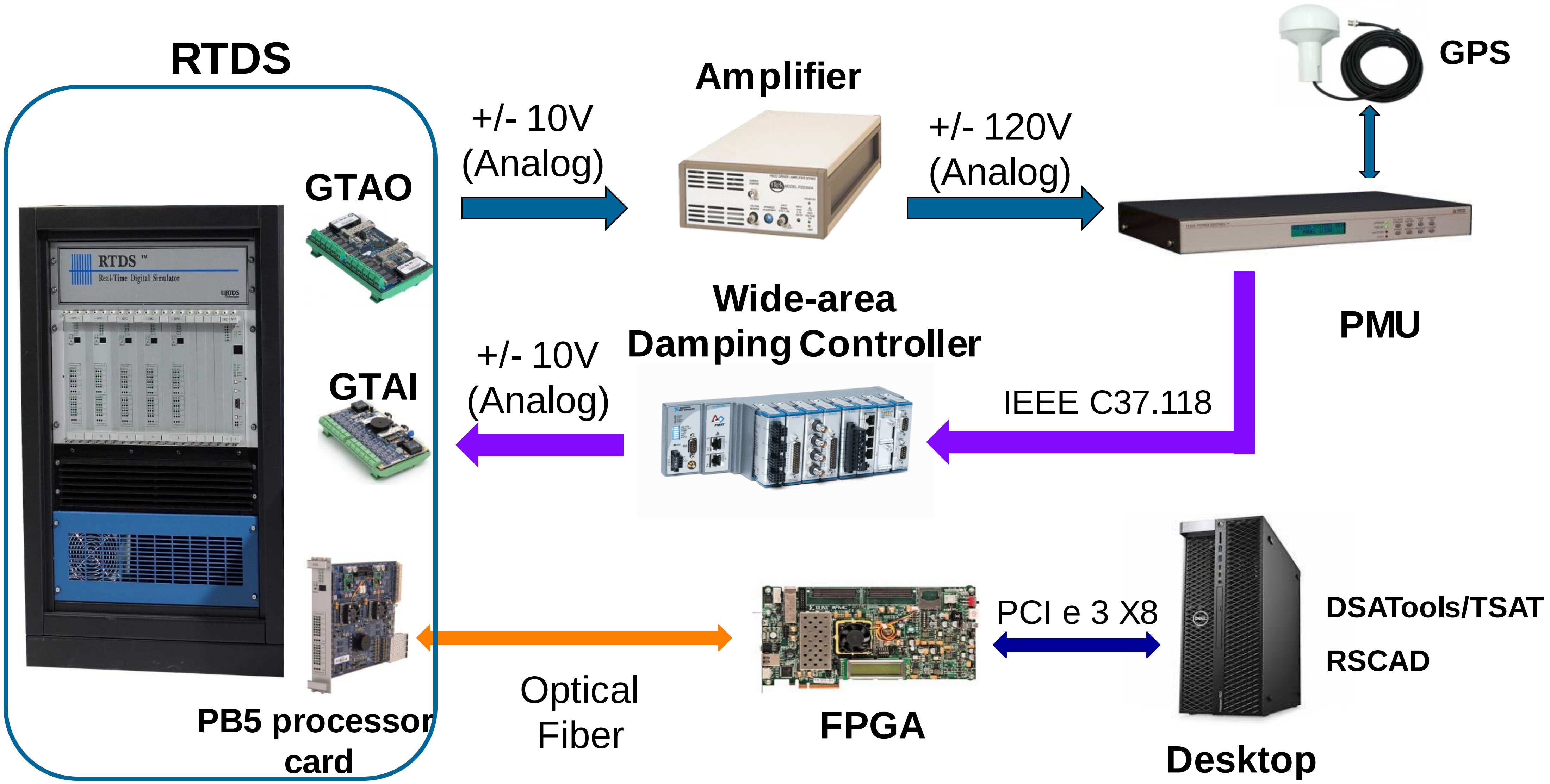
# WADC HIL - OpalRT

- OPAL-RT real-time simulator: Emulates grid
- PMUs: Collect real-time measurements
- National Instruments CompactRIO: WADC



# WADC HIL - Hybrid TSAT-RTDS Real-Time Simulation





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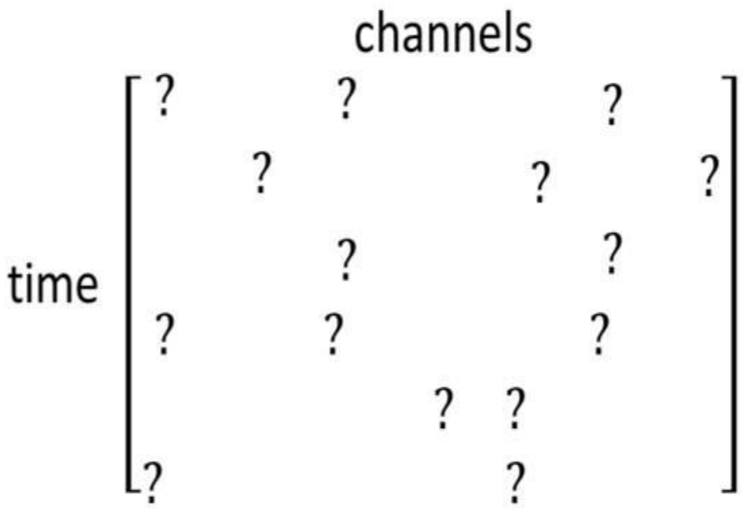
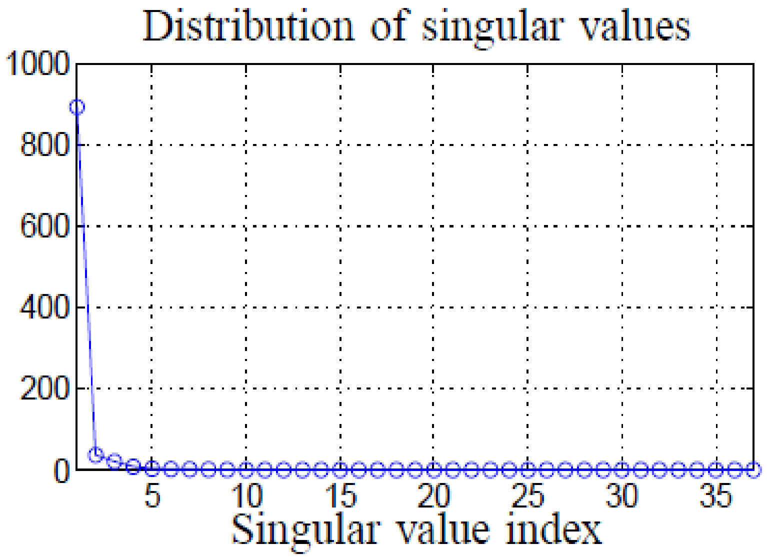
# 2. Data Quality Monitoring and Mitigation of Streaming Synchrophasor Measurements

- Target: Improve synchrophasor data quality by estimating missing data and replacing bad data in synchrophasor streams
- Model free technique, no need for topology information or system model/parameters
- Computationally efficient for real-time implementation
- Performs well for simultaneous & consecutive missing & bad data conditions




## Approach

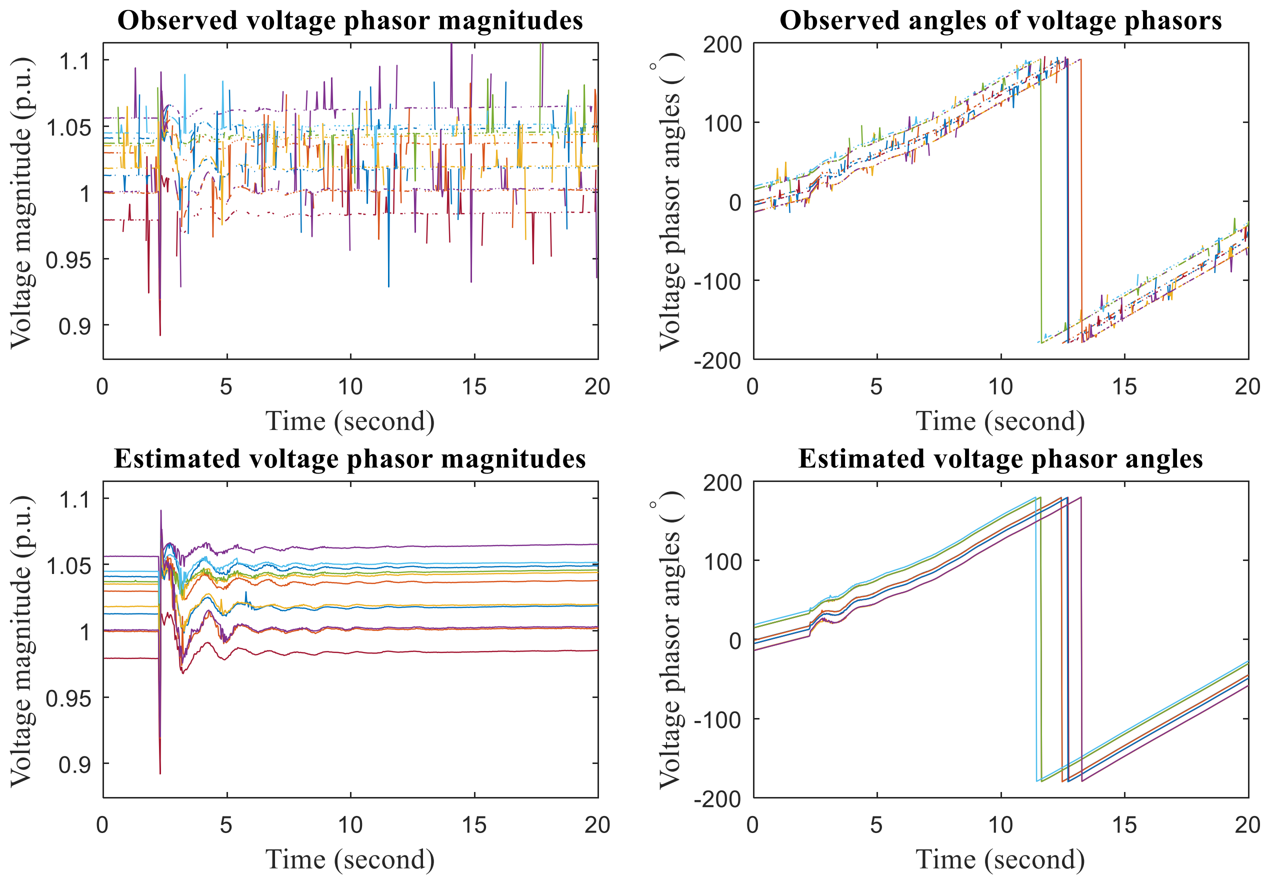
- Process *spatial-temporal blocks* of synchrophasor data collected from PMUs in electrically close regions
- Key feature: *low-rankness* of synchrophasor data blocks and their Hankel matrix.
- *Differentiation between event data and bad data*



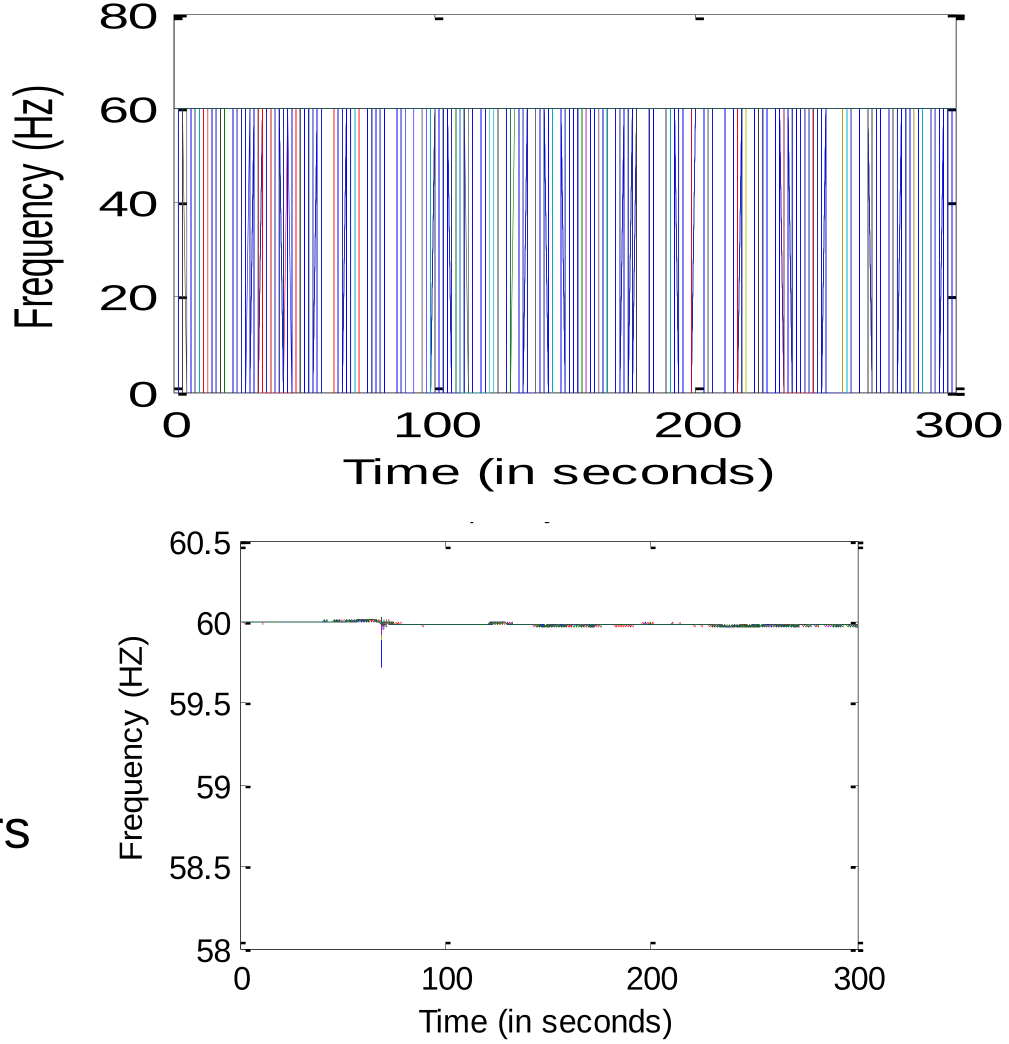

***In collaboration with RPI***

# Numerical Experiments with Missing & Bad Data

## Bad Data



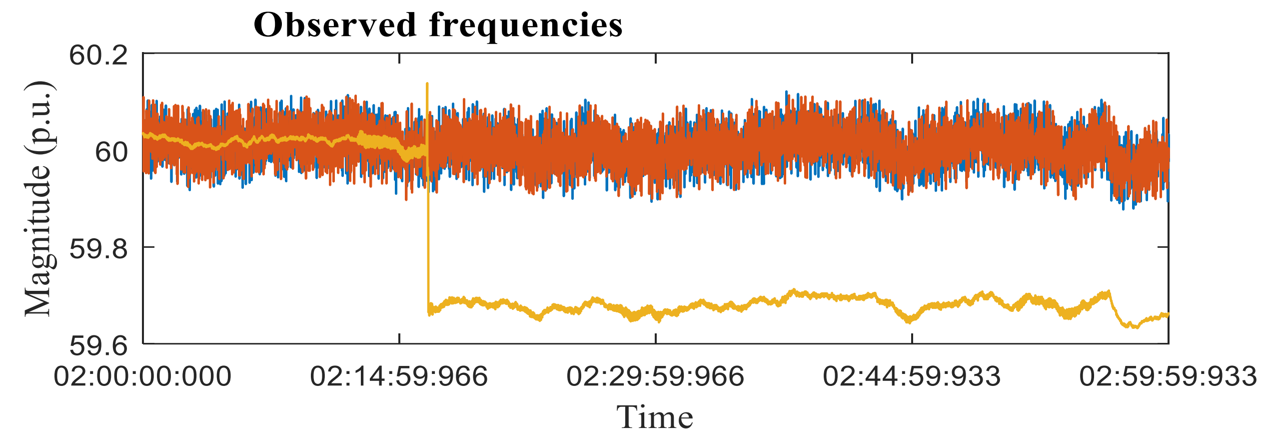

## Missing Data

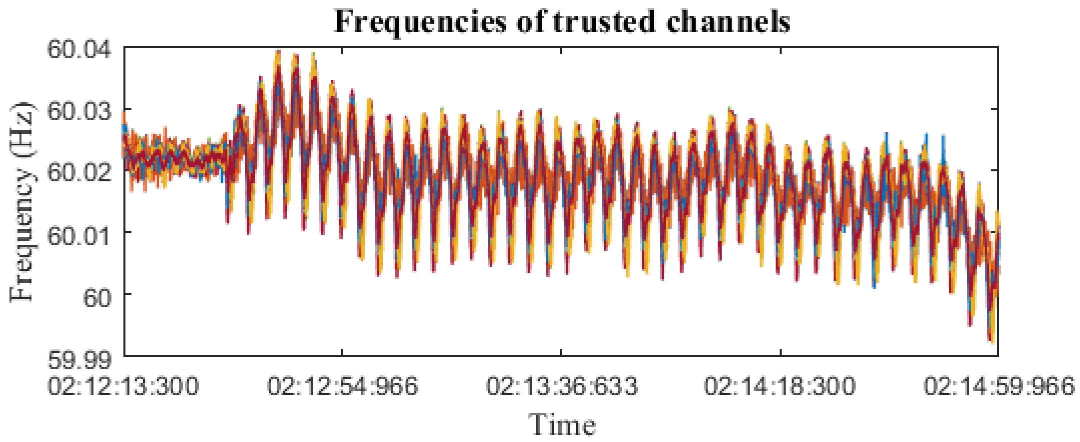


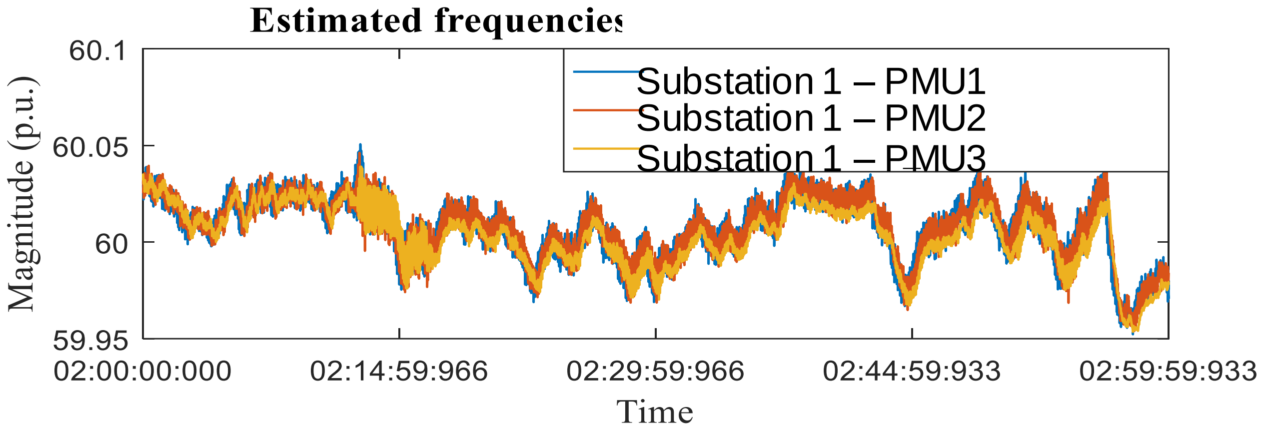

- SSDQ tested with various datasets provided by EPRI members
  - Bad measurements are identified and corrected effectively
  - Missing entries are filled in with high accuracy
  - Event data are not misidentified as bad data

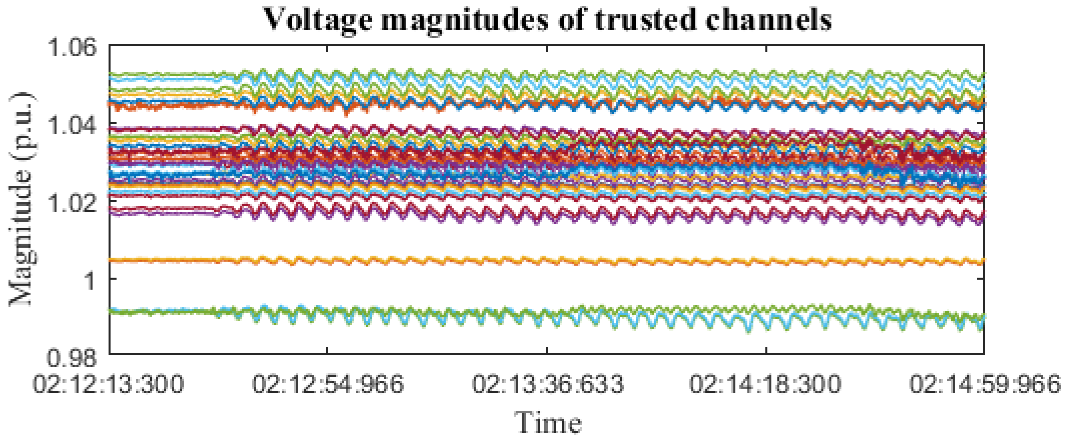
# SSDQ - Entergy Case Study

- Entergy provided 1 hour of recorded synchrophasor data during a 2017 oscillations event
- Event data were not misinterpreted as bad data



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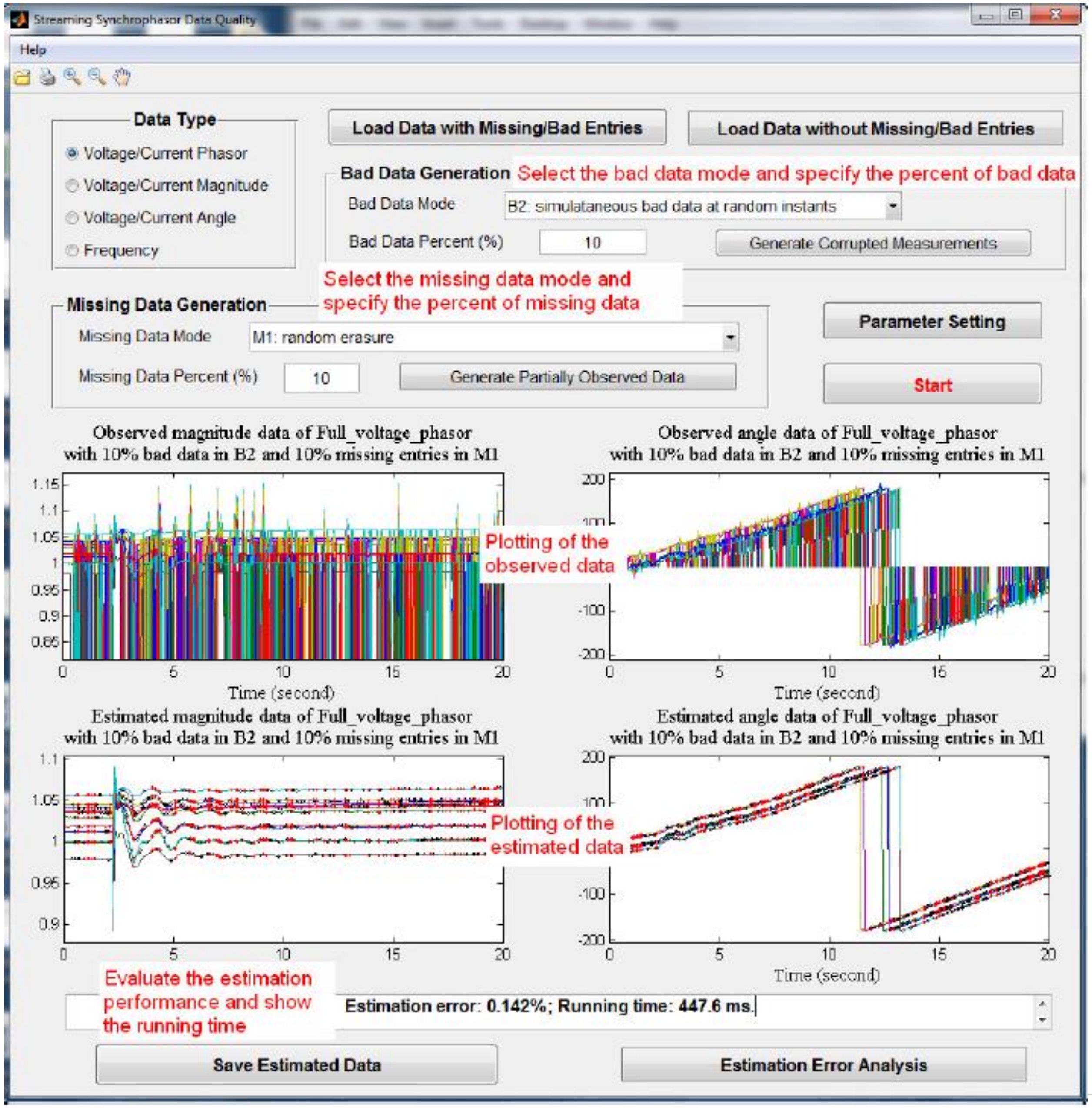
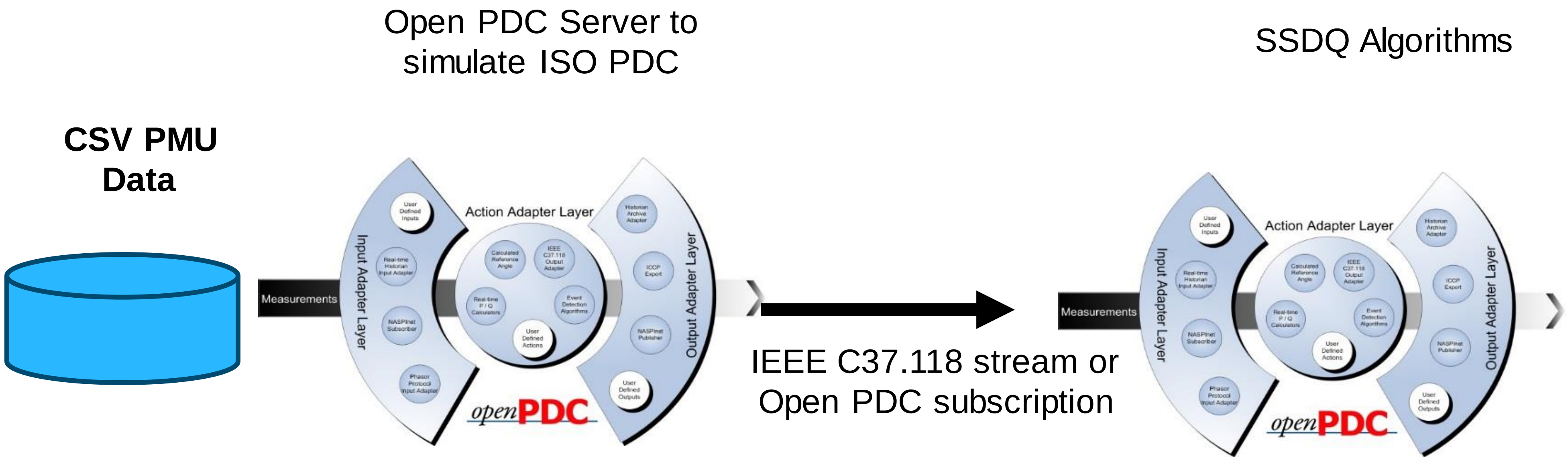
# SSDQ - Matlab Based Software for Offline Testing




- Streaming Synchrophasor Data Quality Tool (SSDQ) – Offline version
- Detecting missing and invalid bad data, and replacing it with accurate estimated data
- Value: improve results of off-line synchrophasor applications

# SSDQ – OpenPDC Implementation

- Streaming Synchrophasor Data Quality Tool (SSDQ) – Online version
- Algorithm implementation on Open PDC





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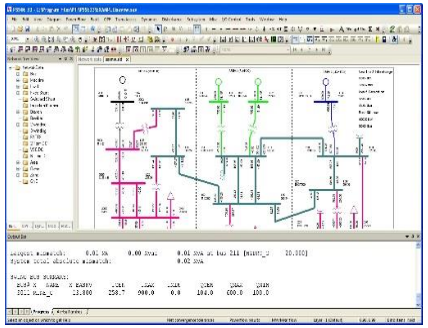
# 3. PMU Emulator

- Phasor values obtained from dynamic simulation tools may differ from synchrophasors measured by PMUs in the field
- How a PMU works:
  - – Analog signal sampling - A/D Conversion
  - – Digital filtering → magnitude attenuation & phase offset
  - – Phasor estimation
    - algorithm e.g. DFT
    - window length - P & M class PMUs
- PMU Emulator: interfaced with power system dynamics simulators, and produces “simulated synchrophasors” taking into account PMUs internal signal processing

**Dynamics Simulation Software (PSS/E, PSLF, TSAT etc)**

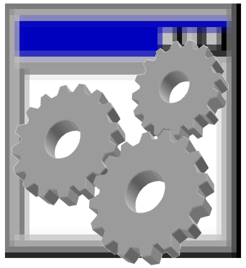


Simulated Phasors

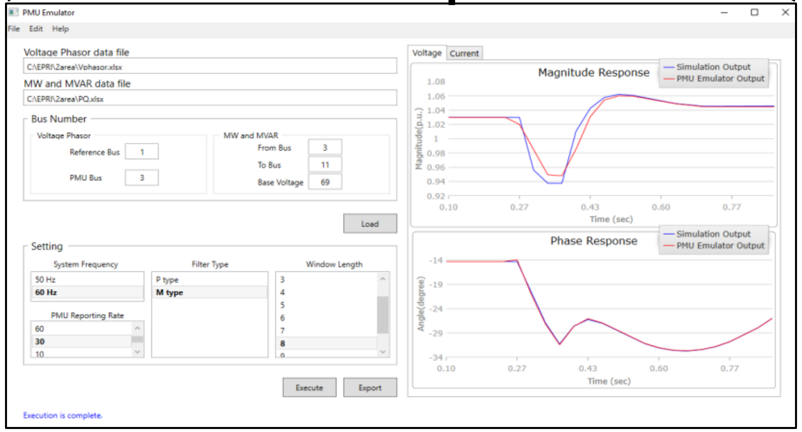
**PMU Emulator**

C37.118

**Synchrophasor Application**



**Proof-of-concept software**



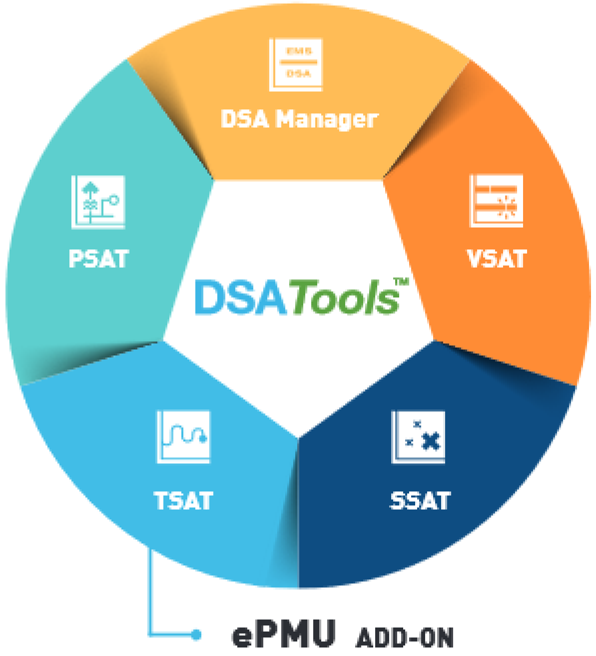

***In collaboration with WSU***

- Hardware-In-the-Loop benchmarking (RTDS & hardware PMUs)
- Use cases: Model validation, synchrophasor applications offline testing (especially control applications), operator training, etc

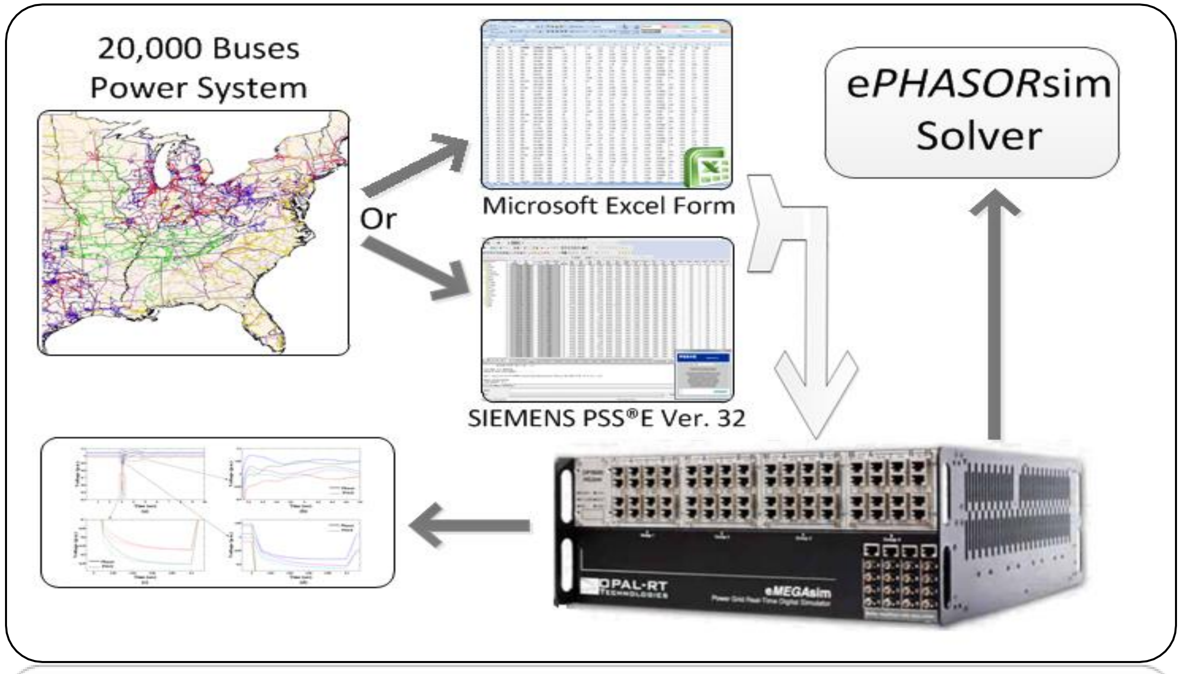
# Vendor Engagement & Case Studies

- Vendor Engagement: Collaboration with vendors for implementation of PMU Emulator in commercial platforms
- Coordinating with Powertech Labs and Opal-RT for implementation of PMU Emulator in ePMU and ePHASORsim respectively

**Powertech Labs - ePMU**




**OPAL-RT - ePHASORsim**





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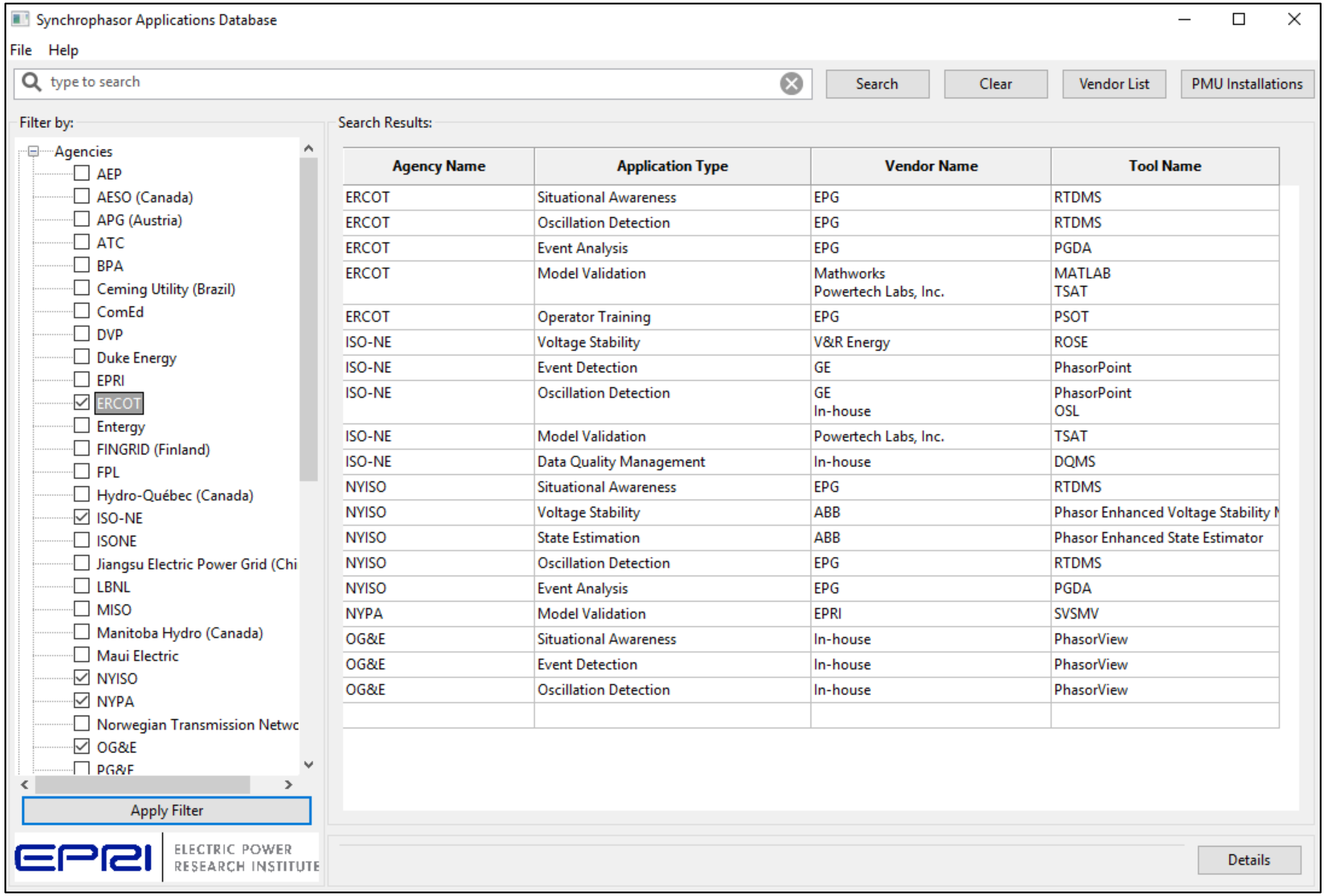
# 4. Synchrophasor Applications Database

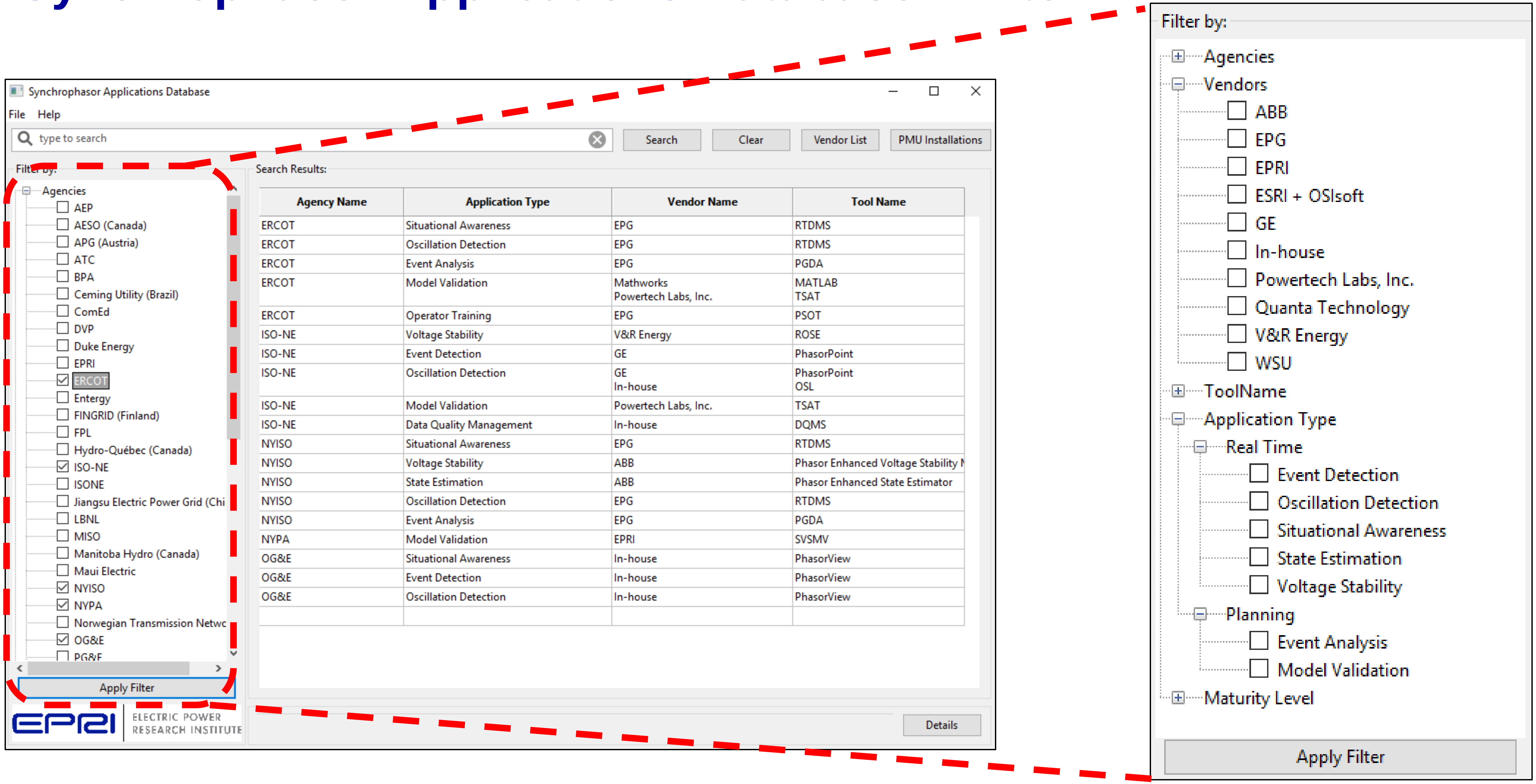



| Agency Name | Application Type | Vendor Name | Tool Name |
|---|---|---|---|
| ERCOT | Situational Awareness | EPG | RTDMS |
| ERCOT | Oscillation Detection | EPG | RTDMS |
| ERCOT | Event Analysis | EPG | PGDA |
| ERCOT | Model Validation | Mathworks<br>Powertech Labs, Inc. | MATLAB<br>TSAT |
| ERCOT | Operator Training | EPG | PSOT |
| ISO-NE | Voltage Stability | V&R Energy | ROSE |
| ISO-NE | Event Detection | GE | PhasorPoint |
| ISO-NE | Oscillation Detection | GE<br>In-house | PhasorPoint<br>OSL |
| ISO-NE | Model Validation | Powertech Labs, Inc. | TSAT |
| ISO-NE | Data Quality Management | In-house | DQMS |
| NYISO | Situational Awareness | EPG | RTDMS |
| NYISO | Voltage Stability | ABB | Phasor Enhanced Voltage Stability N |
| NYISO | State Estimation | ABB | Phasor Enhanced State Estimator |
| NYISO | Oscillation Detection | EPG | RTDMS |
| NYISO | Event Analysis | EPG | PGDA |
| NYPA | Model Validation | EPRI | SVSMV |
| OG&E | Situational Awareness | In-house | PhasorView |
| OG&E | Event Detection | In-house | PhasorView |
| OG&E | Oscillation Detection | In-house | PhasorView |

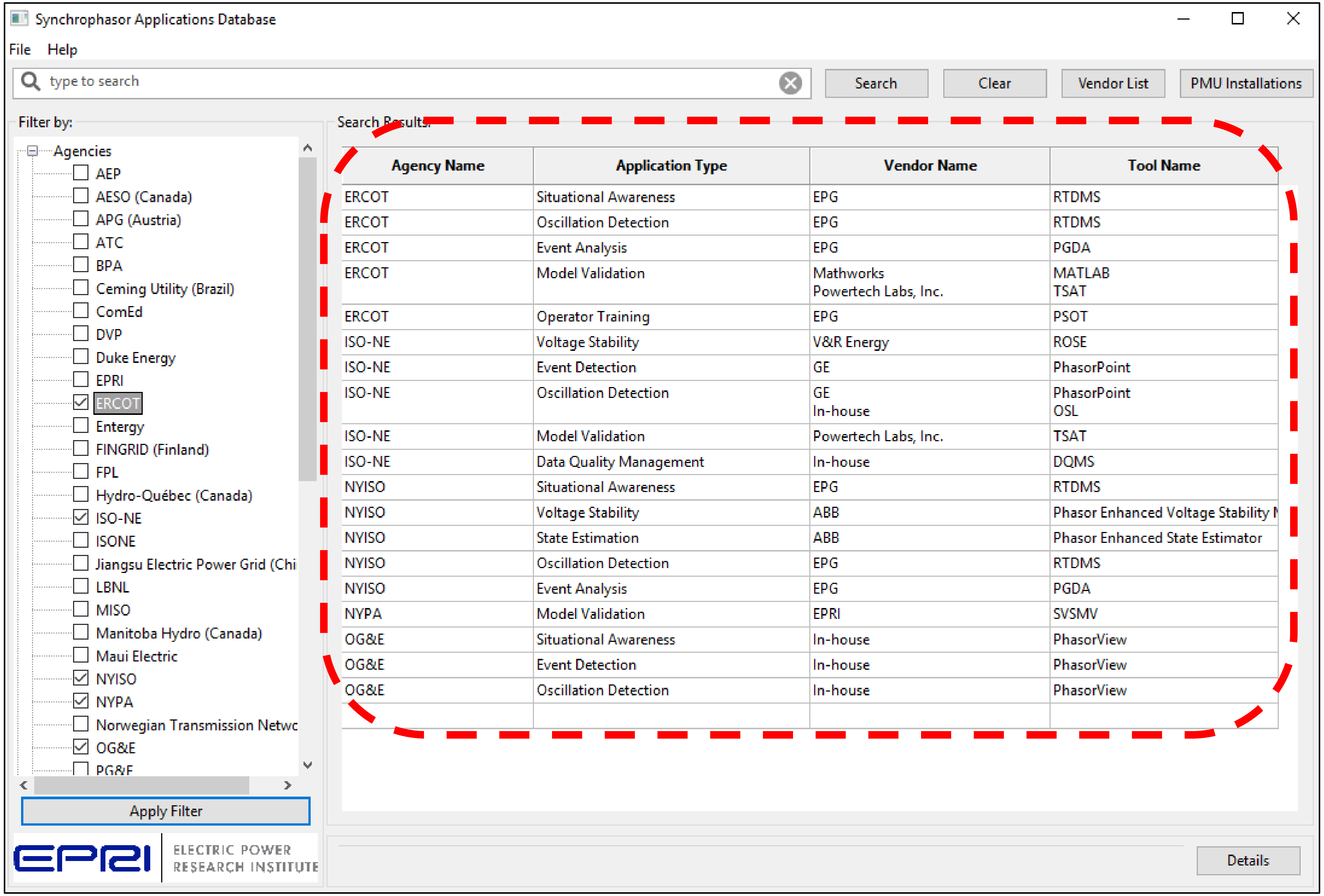
- Entries based on publicly available documents
- For each entry, summary description of application and related references

**Value: Inform utility/ISO engineers and executive management about uses cases and derived value of synchrophasor technology**

# Synchrophasor Applications Database - Filter



# Synchrophasor Applications Database – Entries Table

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| ISO-NE | Voltage Stability | V&R Energy | ROSE |
| ISO-NE | Event Detection | GE | PhasorPoint |
| ISO-NE | Oscillation Detection | GE<br>In-house | PhasorPoint<br>OSL |
| ISO-NE | Model Validation | Powertech Labs, Inc. | TSAT |
| ISO-NE | Data Quality Management | In-house | DQMS |
| NYISO | Situational Awareness | EPG | RTDMS |
| NYISO | Voltage Stability | ABB | Phasor Enhanced Voltage Stability N |
| NYISO | State Estimation | ABB | Phasor Enhanced State Estimator |
| NYISO | Oscillation Detection | EPG | RTDMS |
| NYISO | Event Analysis | EPG | PGDA |
| NYPA | Model Validation | EPRI | SVSMV |
| OG&E | Situational Awareness | In-house | PhasorView |
| OG&E | Event Detection | In-house | PhasorView |
| OG&E | Oscillation Detection | In-house | PhasorView |

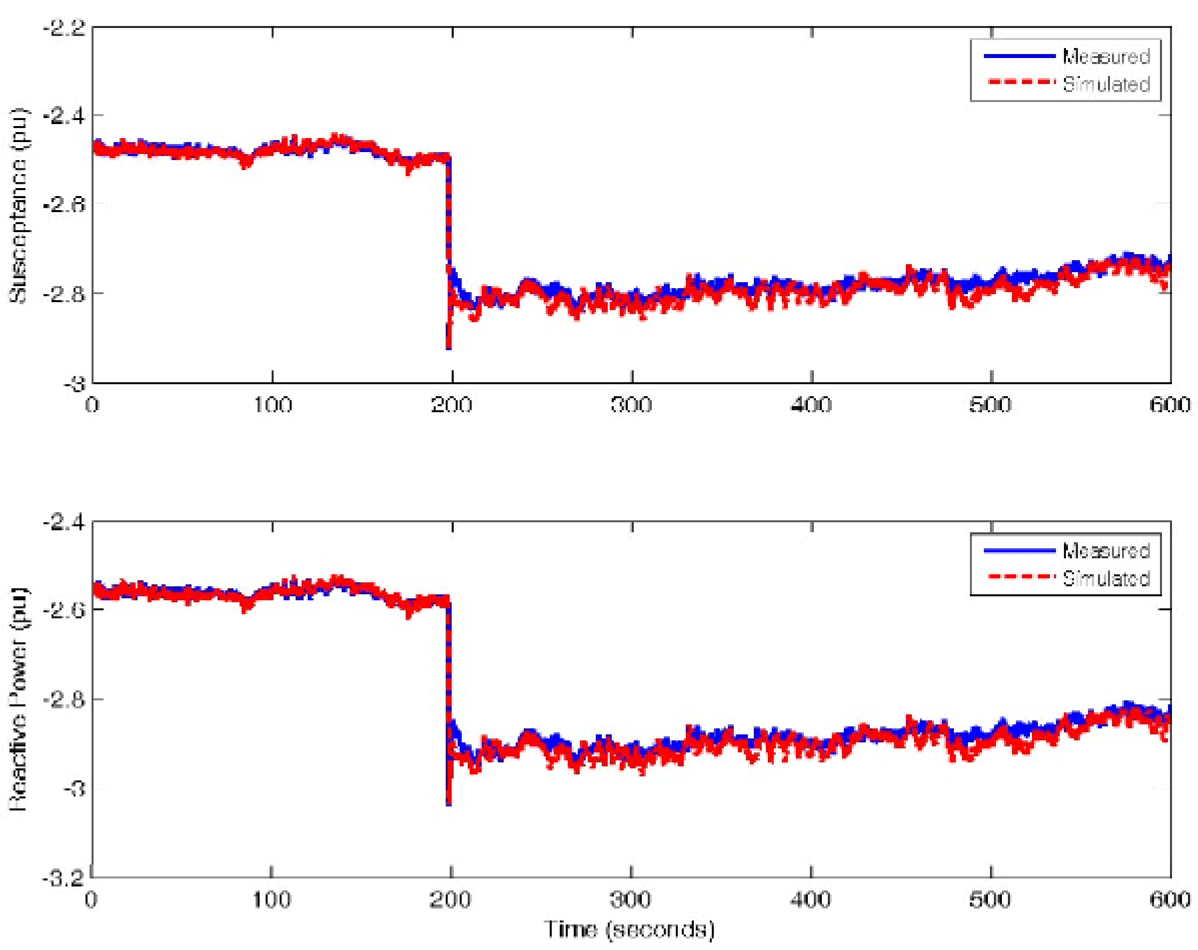
# Synchrophasor Applications Database – Detailed Entry Description

Model Validation at NYPA

Description:

NYPA has used EPRI's "Static Var System Model Validation" tool to validate the models of a STATCOM (Marcy substation) and an SVC. The generic dynamic Static Var Systems models (also developed by EPRI) were used to parameterize [1], [2]. Figure 1 [2] shows representative results of the model validation.

Figure 1: SVC Model Validation Using SVSMO1 Model at NYPA.



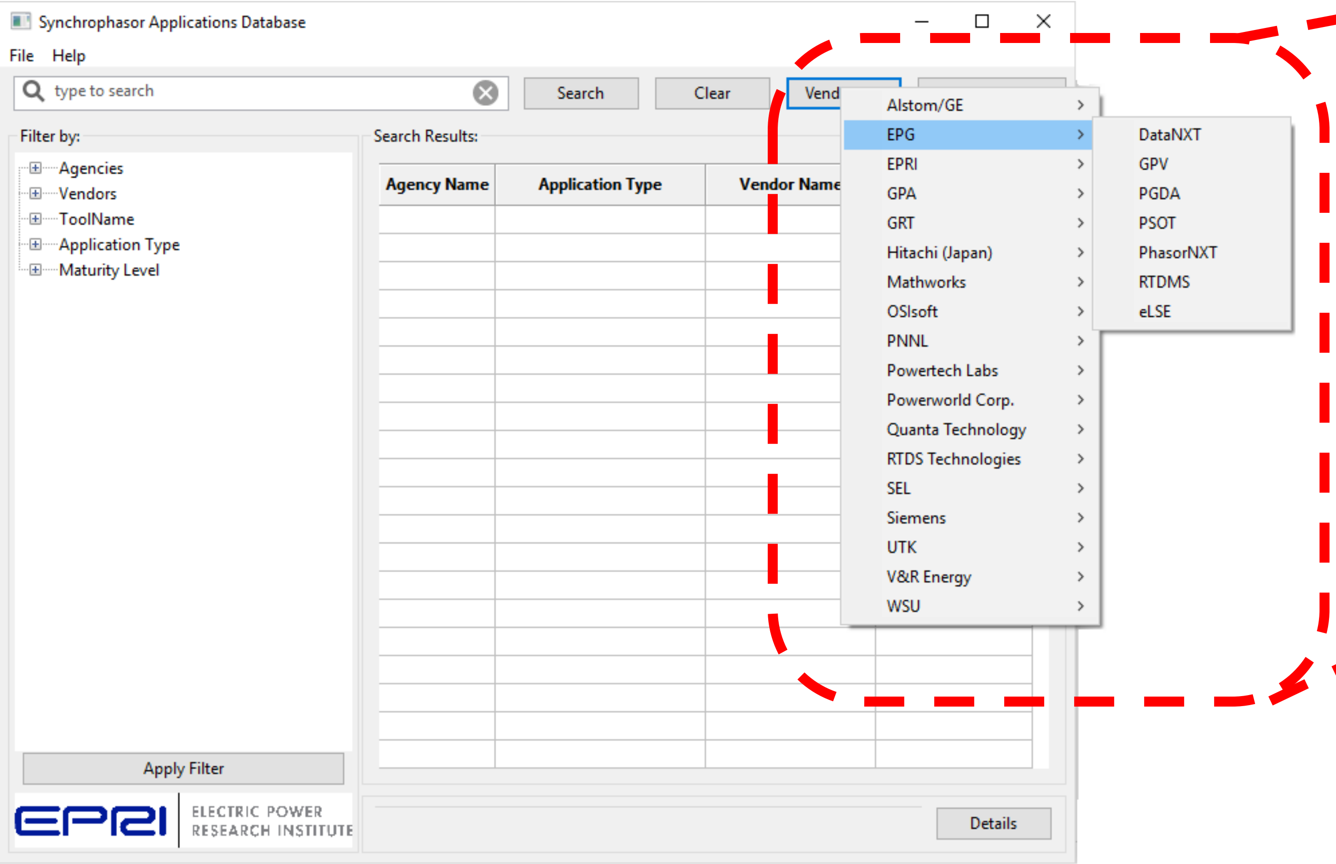

References:

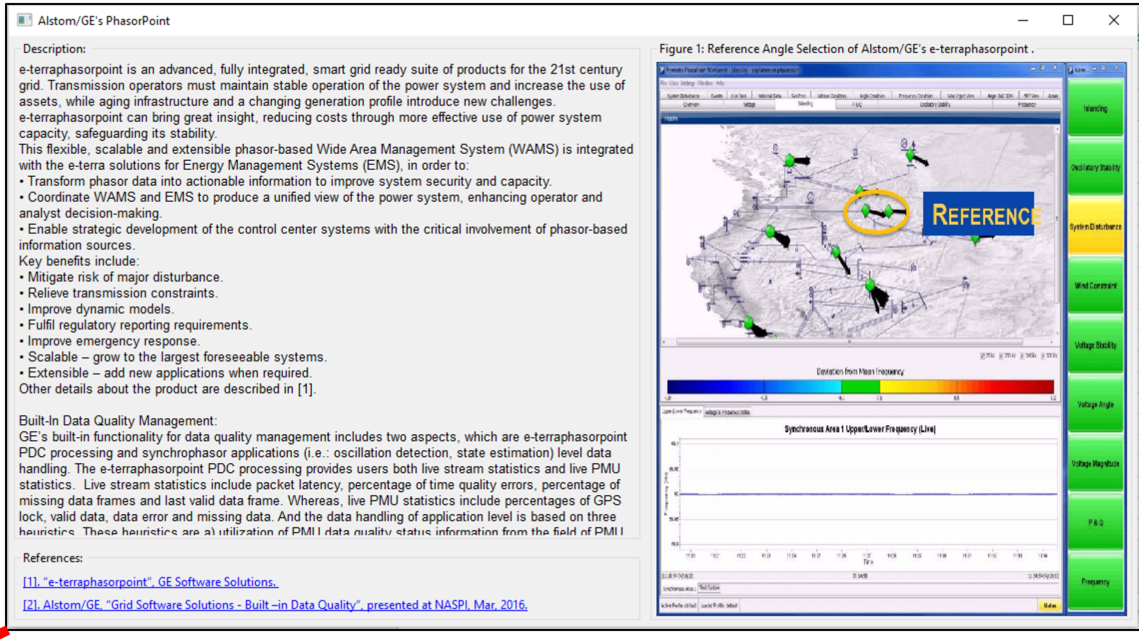

[1]. EPRI and NYPA, "Model Validation of SVC and STATCOM Using PMU Data", presented at N-ASPI, Oct, 2013.

[2]. EPRI and NYPA, "Validation of Generic Models for Stability Analysis of two Large St-atic Var Systems in New York using PMU Data", presented at IEEE PES GM, Apr, 2014.

# Together…Shaping the Future of Electricity

# Synchrophasor Applications Database – Vendor List



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# Synchrophasor Applications Database – PMU Installations