

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

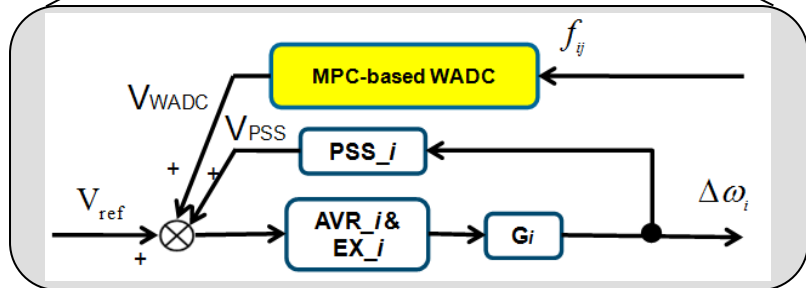
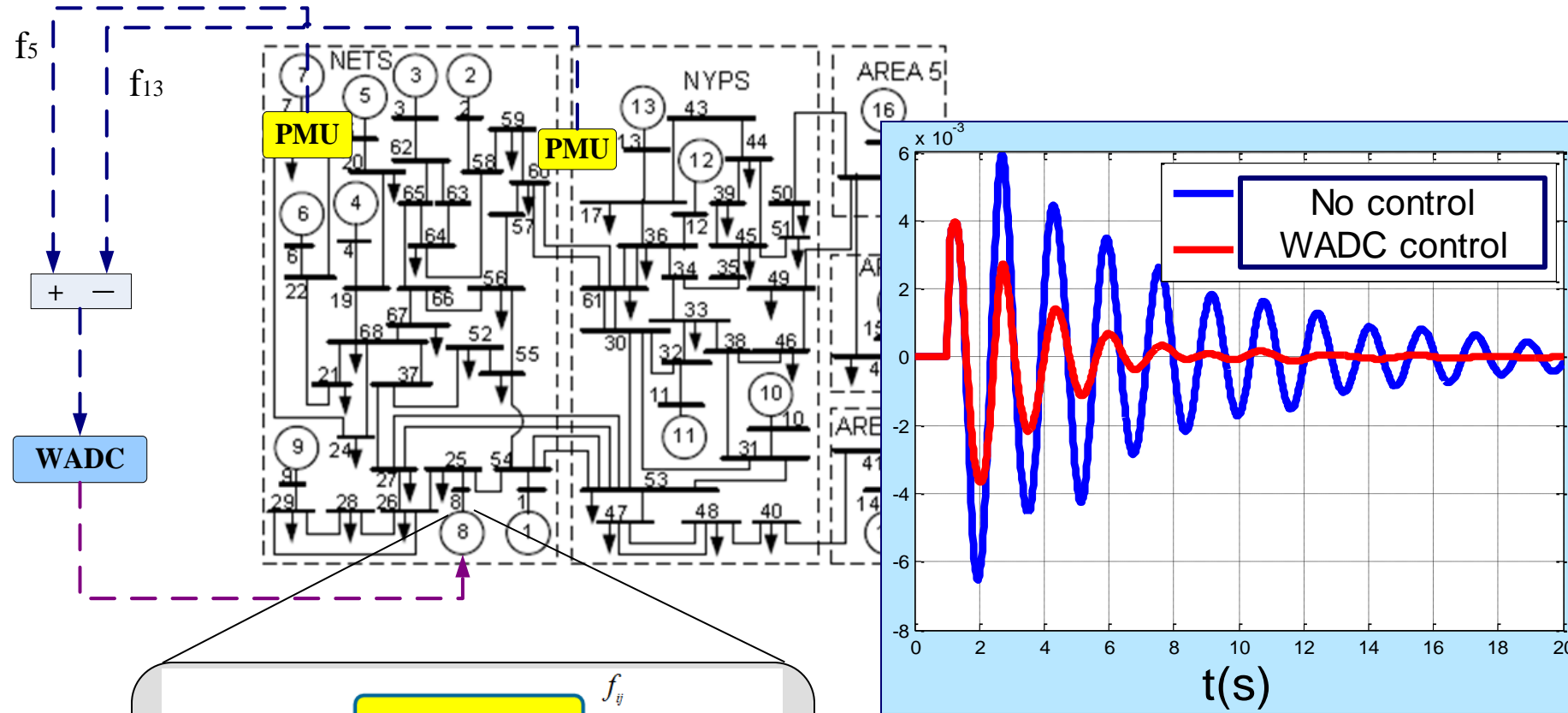
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Senior Technical Leader

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Technical Executive

NASPI WG Meeting
Philadelphia, PA
October 23, 2018



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

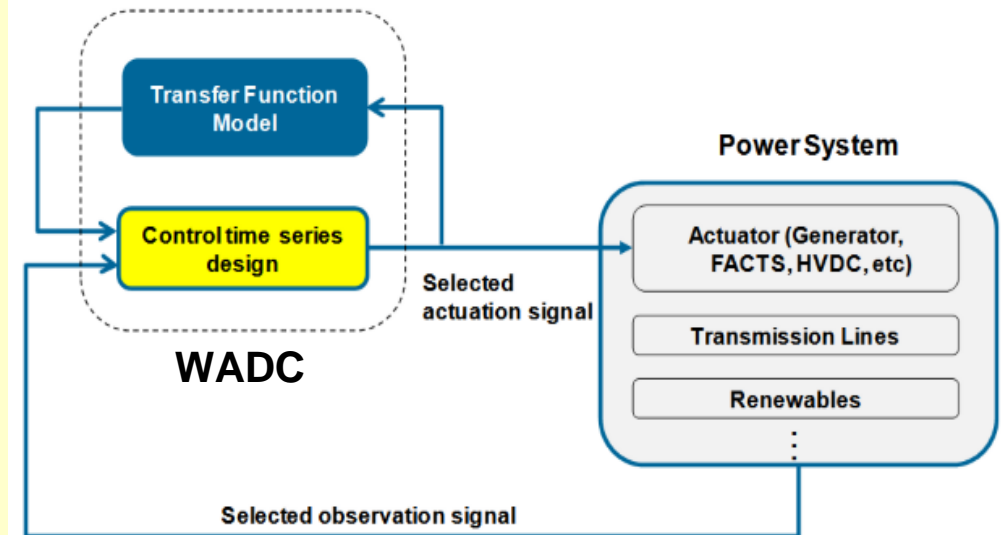
Measurement Based Wide Area Damping Controller

Offline Stage – WADC Design

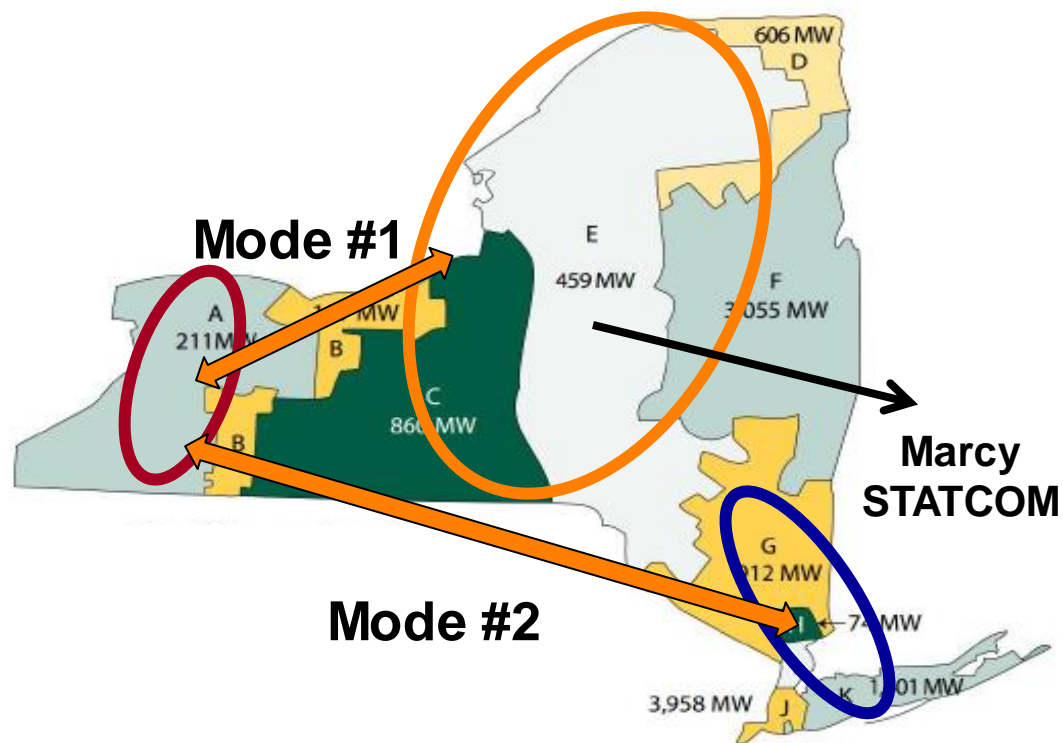
1. Modal Analysis
2. Selection of optimal observation signals
 - PMUs at selected locations for oscillation mode observability
3. Selection of optimal actuation signal
 - Actuators: Generator stabilizer/FACTS/HVDC
4. Model Identification and Validation
5. Control Design
6. Simulation-Based Testing
7.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

Real-time Stage

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



NYPA Case Study



- 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

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%

NYPA Advanced Grid Innovation Laboratory for Energy (AGILE)



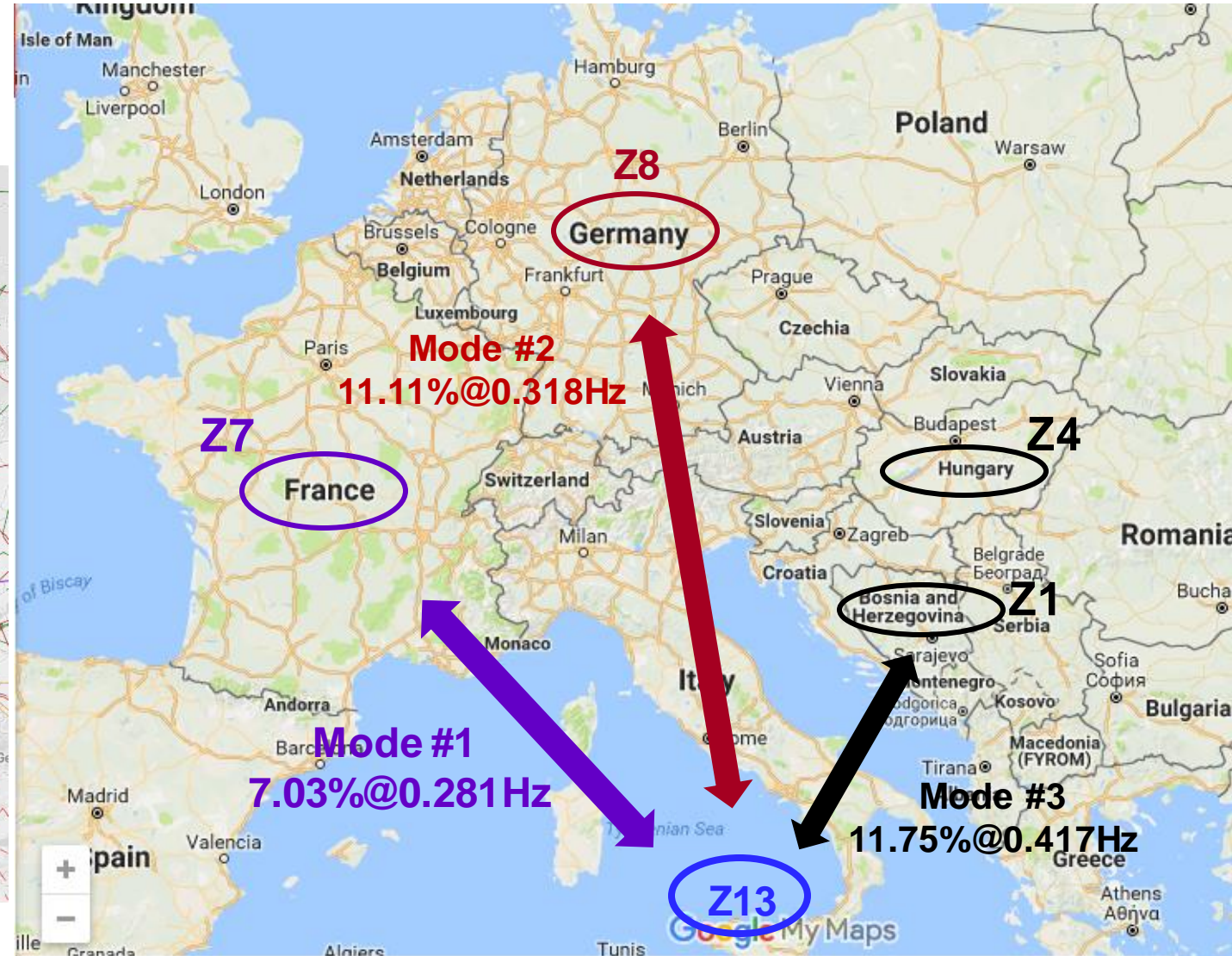
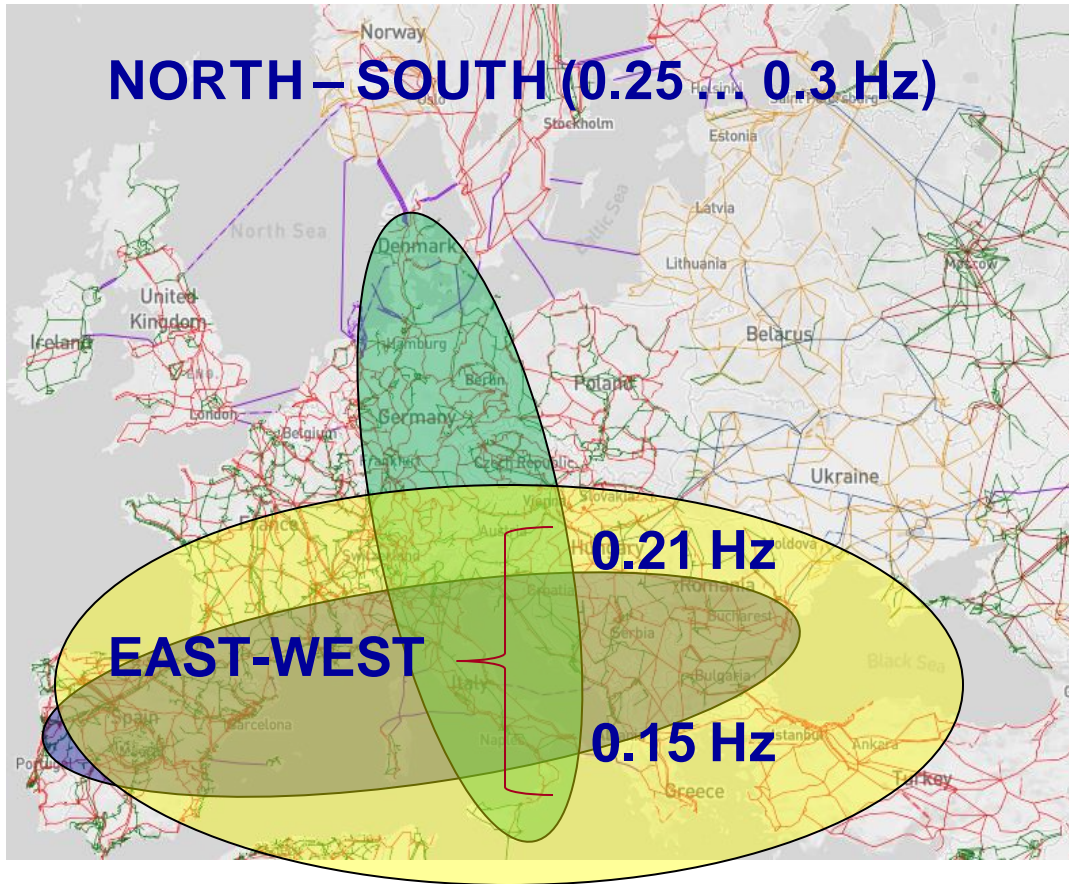
- AGILE: electric power research laboratory with real-time simulation & modeling tools.
- Target: conduct collaborative research with utilities and grid tech companies focused on facilitating stakeholders in solving grid related challenges
- Lab established at NYPA's White Plains, NY office
- RTDS &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



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

- 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

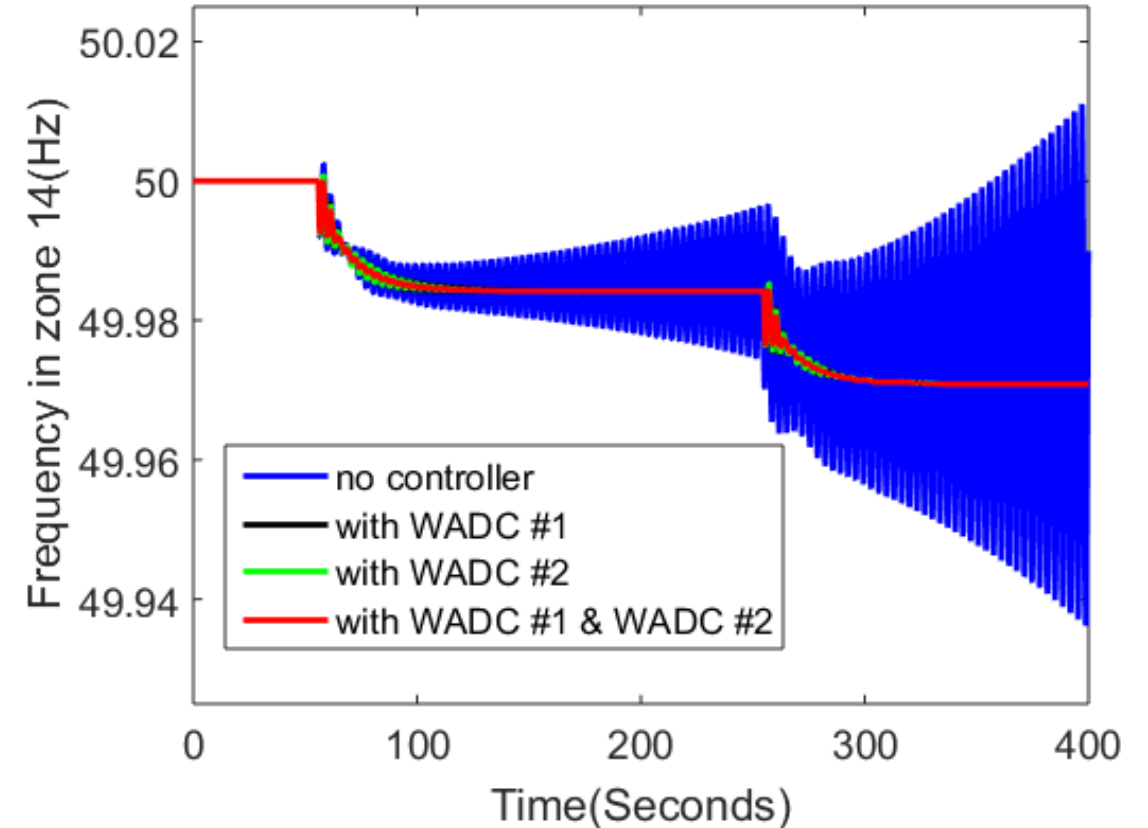
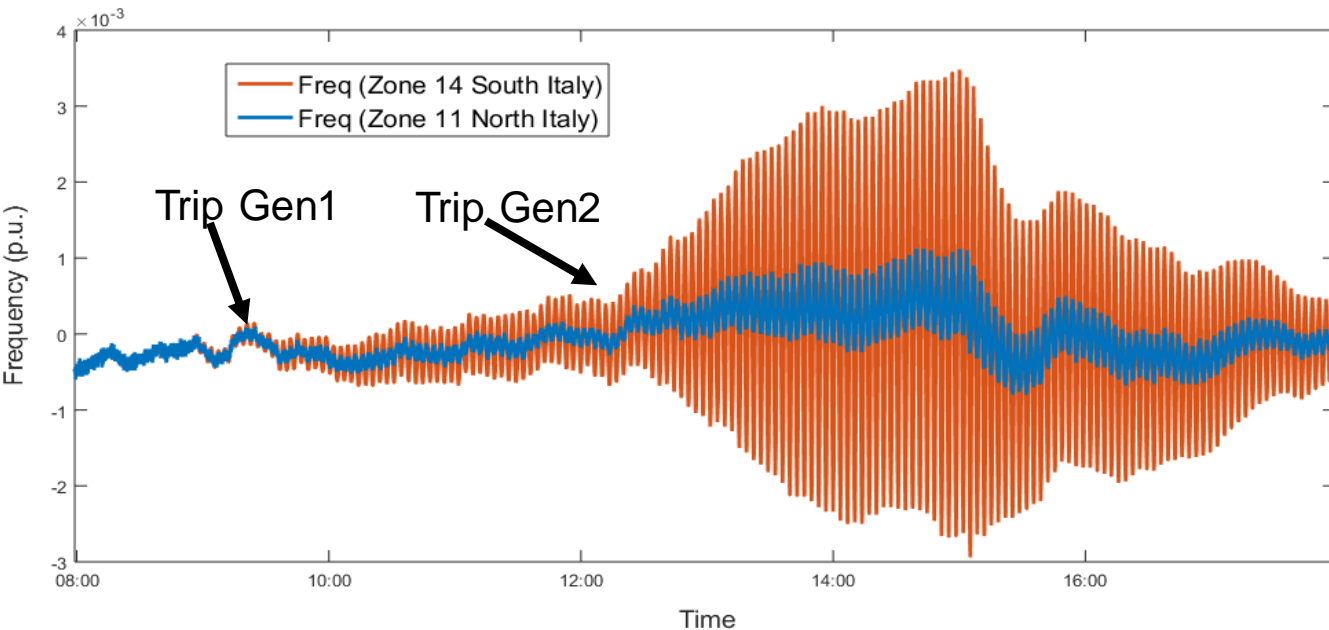
TERNA Case Study



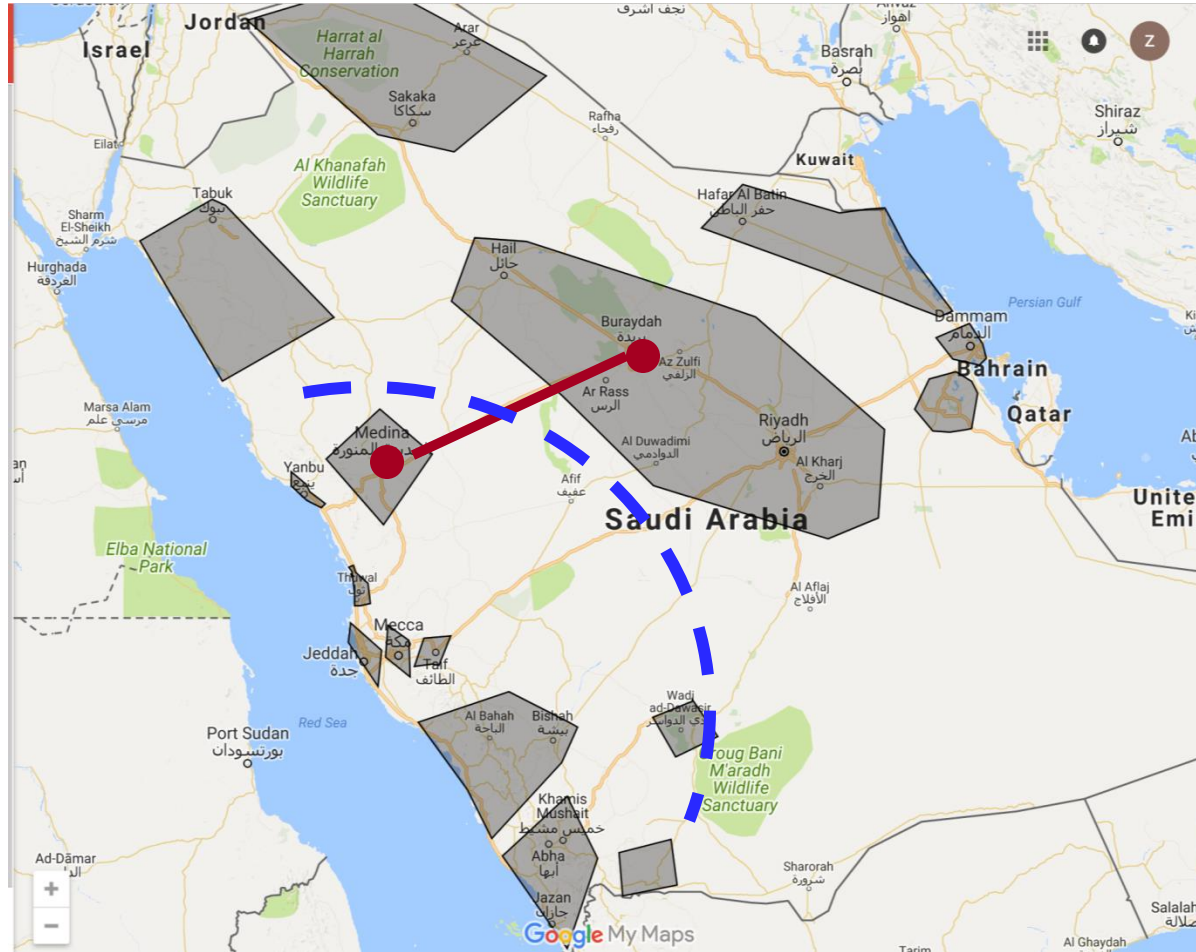
- Modal analysis: North-South Mode in Terna model
- Observation signal selection: PMU1 South Italy – PMU2 North Italy (France area is optimal)
- Actuators: Two synchronous condensers in South Italy

WADC Design for an Actual 2017 Event

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



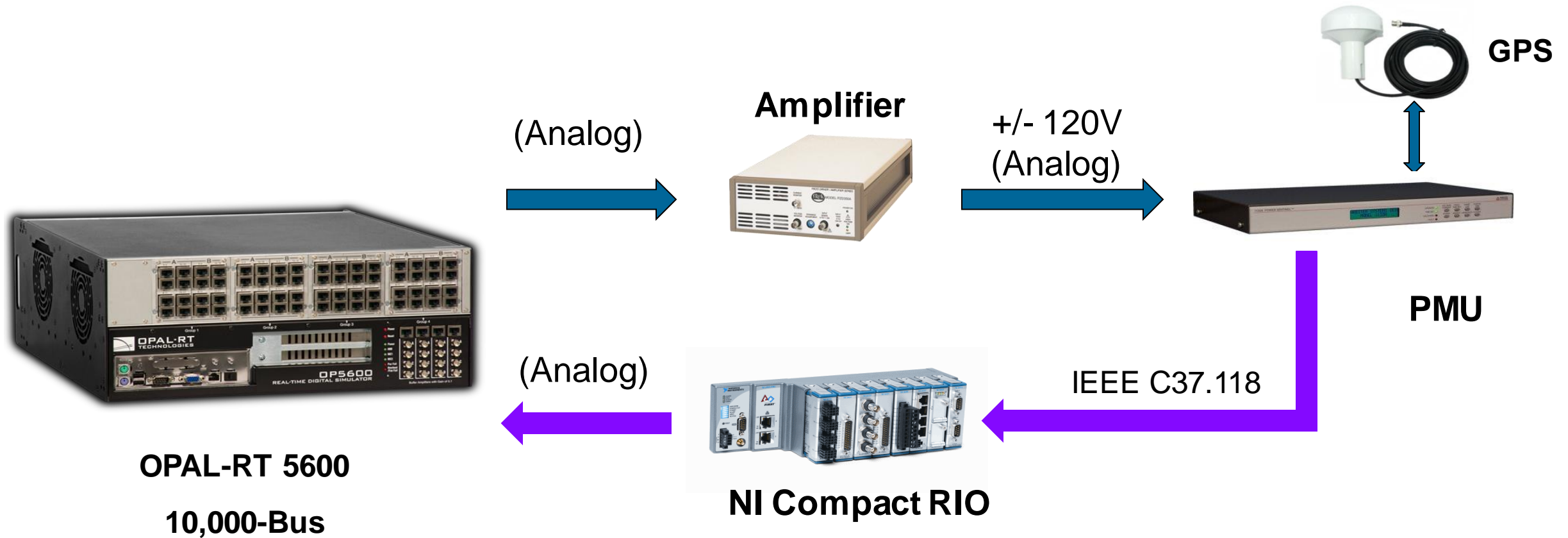
Saudi Electricity Company (SEC) Case Study



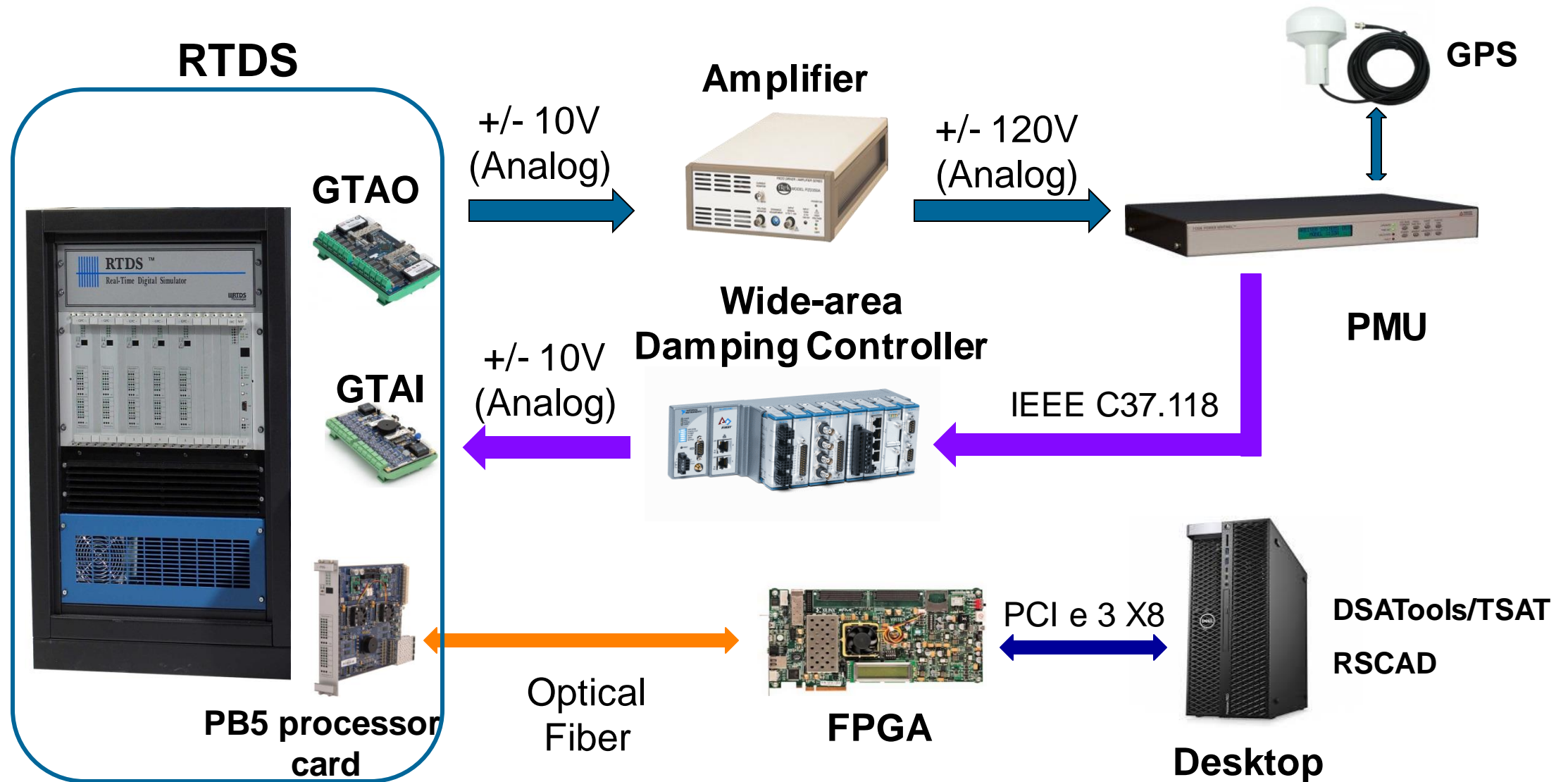
- Qassim – Medina: Double line, series compensated, separating West with Central/North/East SEC system
- 3 incidents since 2015 that resulted in tripping of the line
- Actuators:
 - STATCOMs in West
 - Additional STATCOM to be installed in Central area
- Study interaction of WADC with transmission line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

WADC HIL - OpaIRT

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

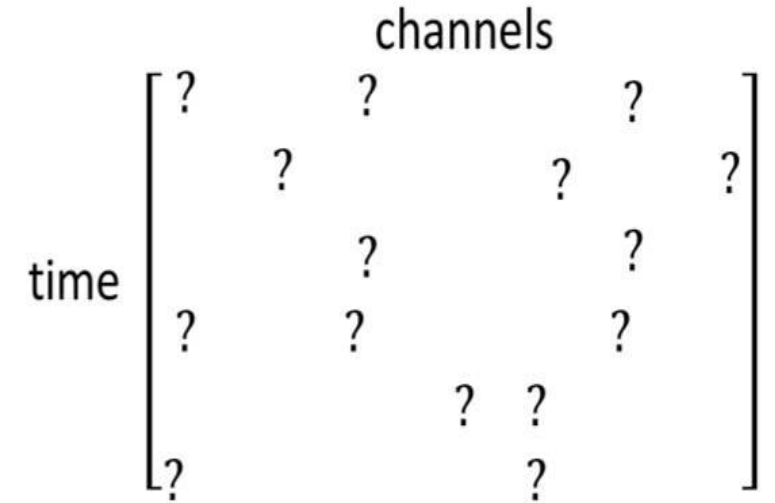


WADC HIL - Hybrid TSAT-RTDS Real-Time Simulation



2. Data Quality Monitoring and Mitigation of Streaming Synchrophasor Measurements

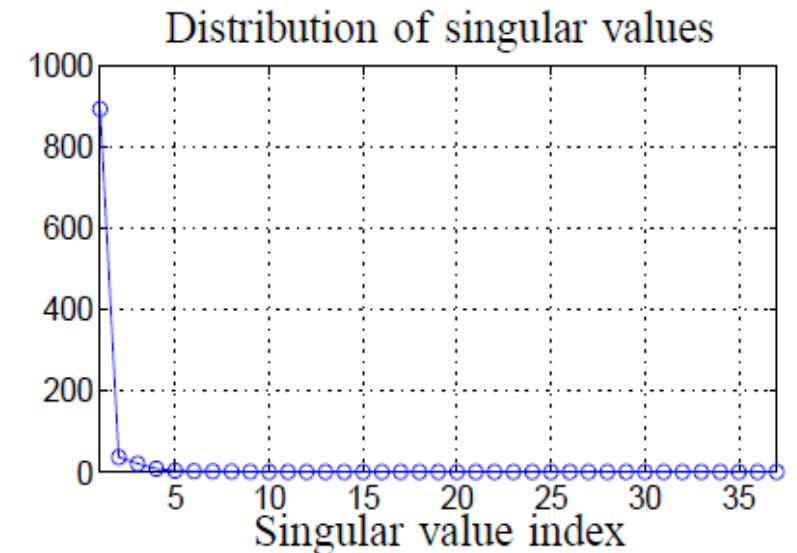
- Target: Improve synchrophasor data quality by estimating missing data and replacing bad data in synchrophasor streams
- Model free technique, no need for topology information or system model/parameters
- Computationally efficient for real-time implementation
- Performs well for simultaneous & consecutive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



Approach

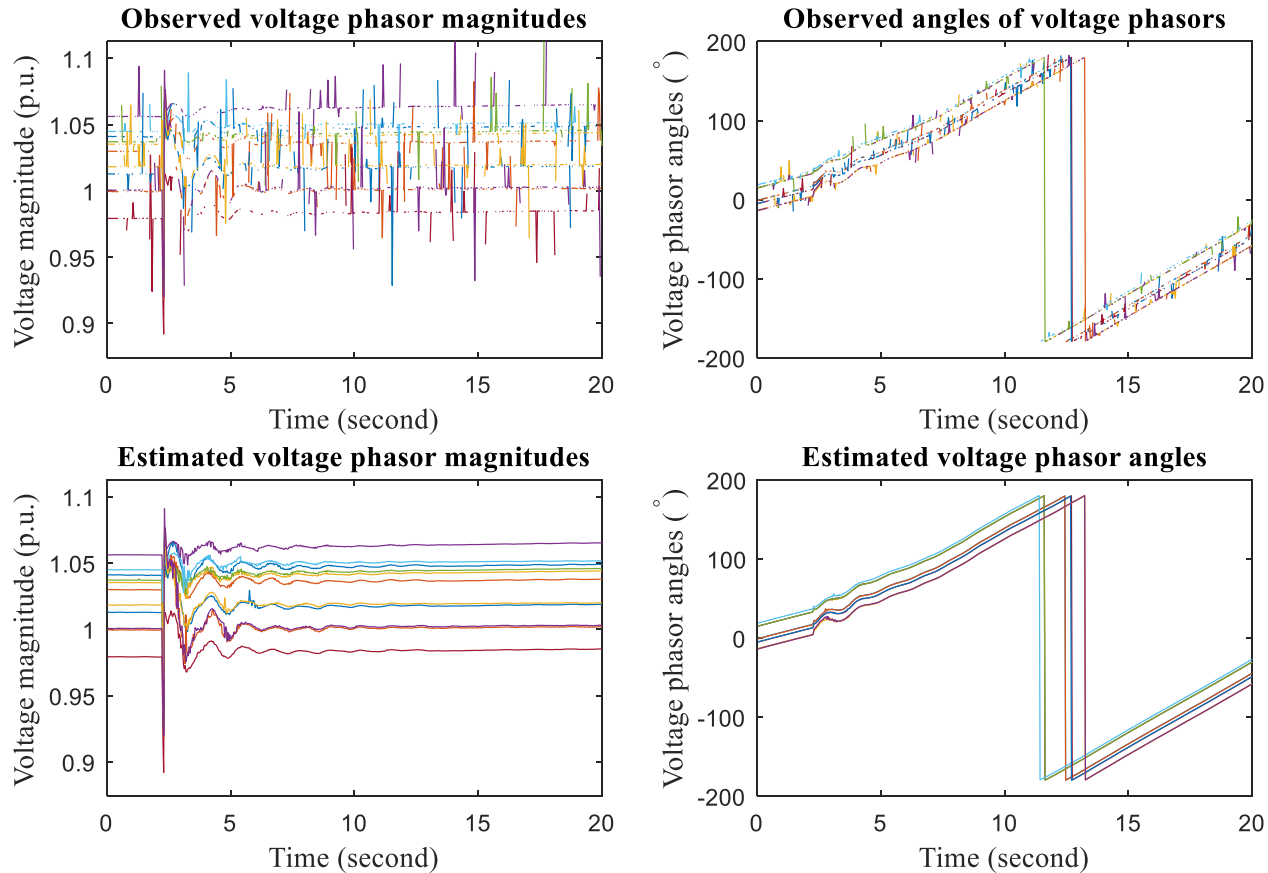
- Process *spatial-temporal blocks* of synchrophasor data collected from PMUs in electrically close regions
- Key feature: *low-rankness* of synchrophasor data blocks and their Hankel matrix.
- *Differentiation between event data and bad data*

In collaboration with RPI

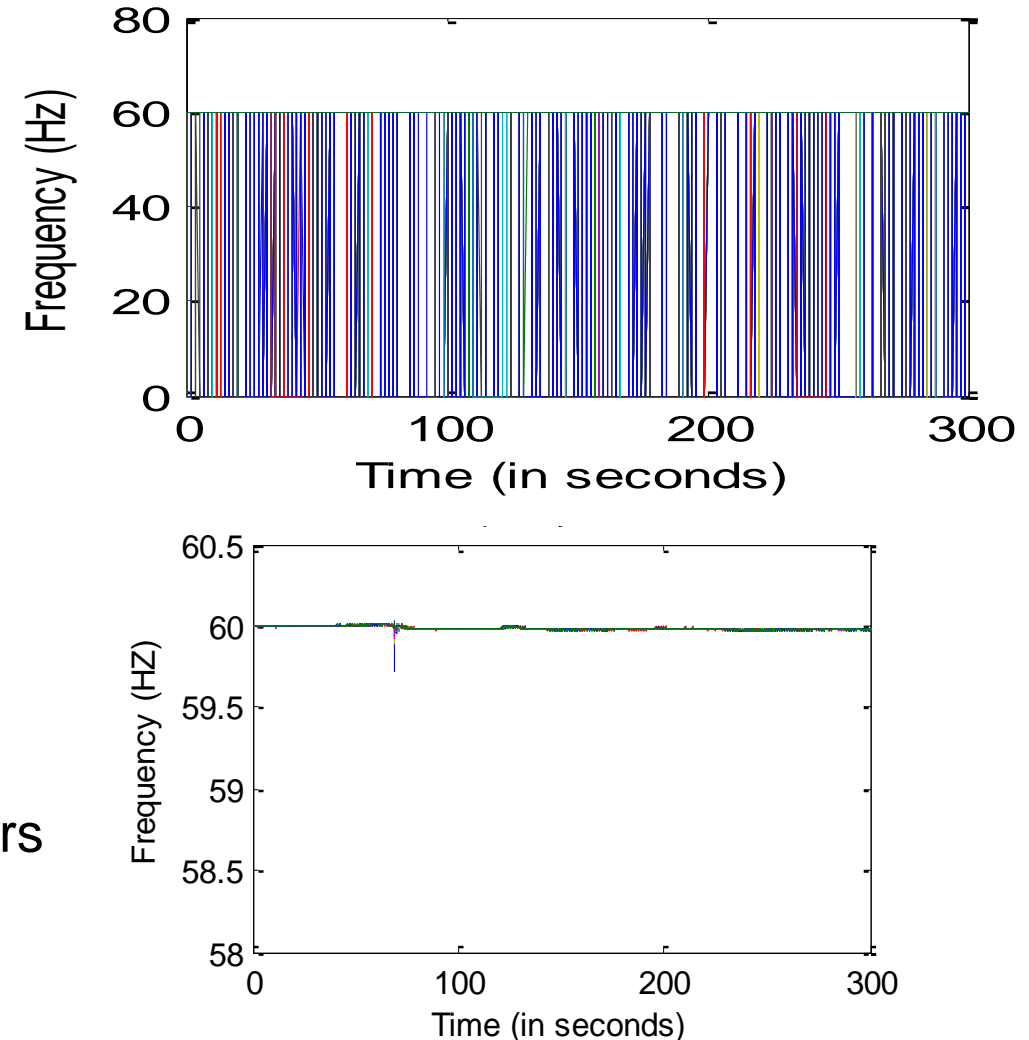


Numerical Experiments with Missing & Bad Data

Bad Data



Missing Data

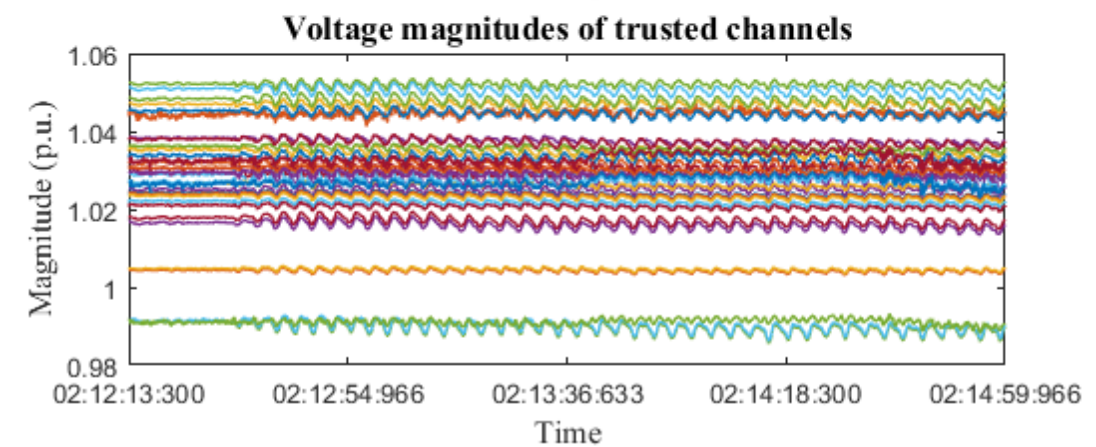
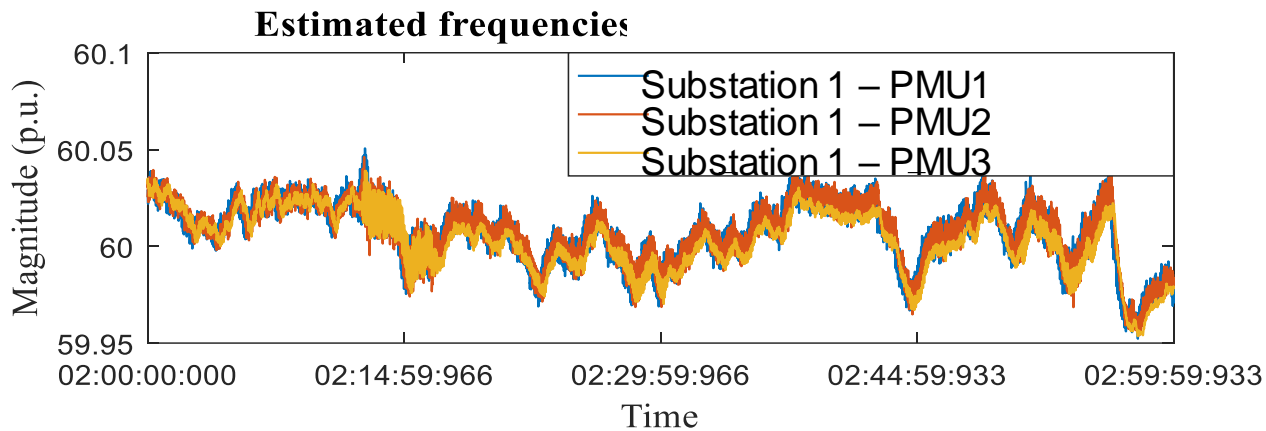
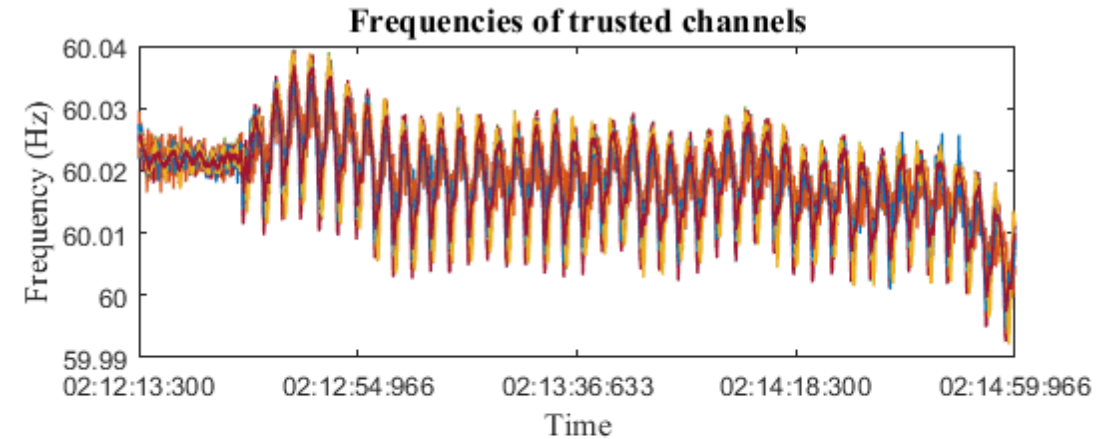
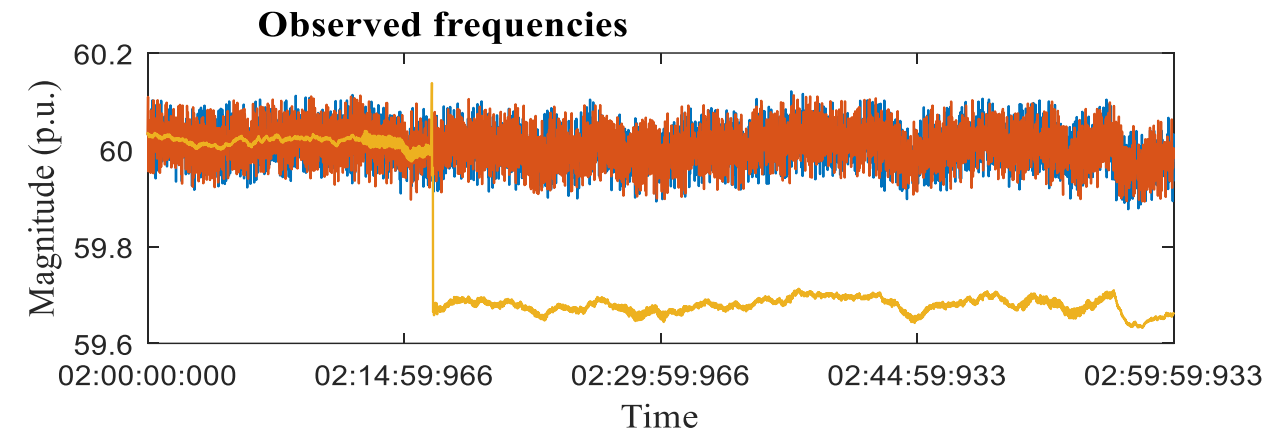


■ SSDQ tested with various datasets provided by EPRI members

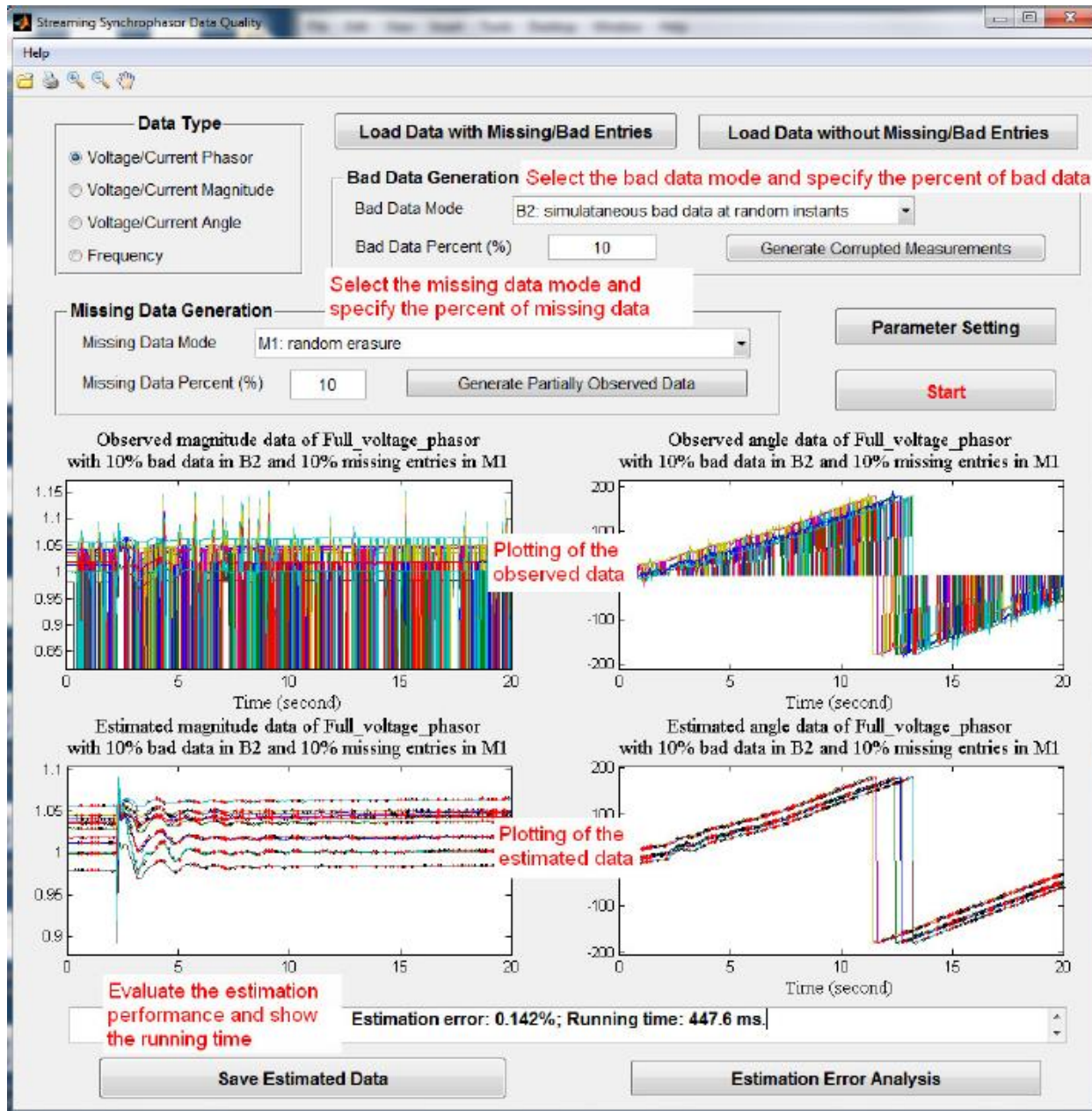
- Bad measurements are identified and corrected effectively
- Missing entries are filled in with high accuracy
- Event data are not misidentified as bad data

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



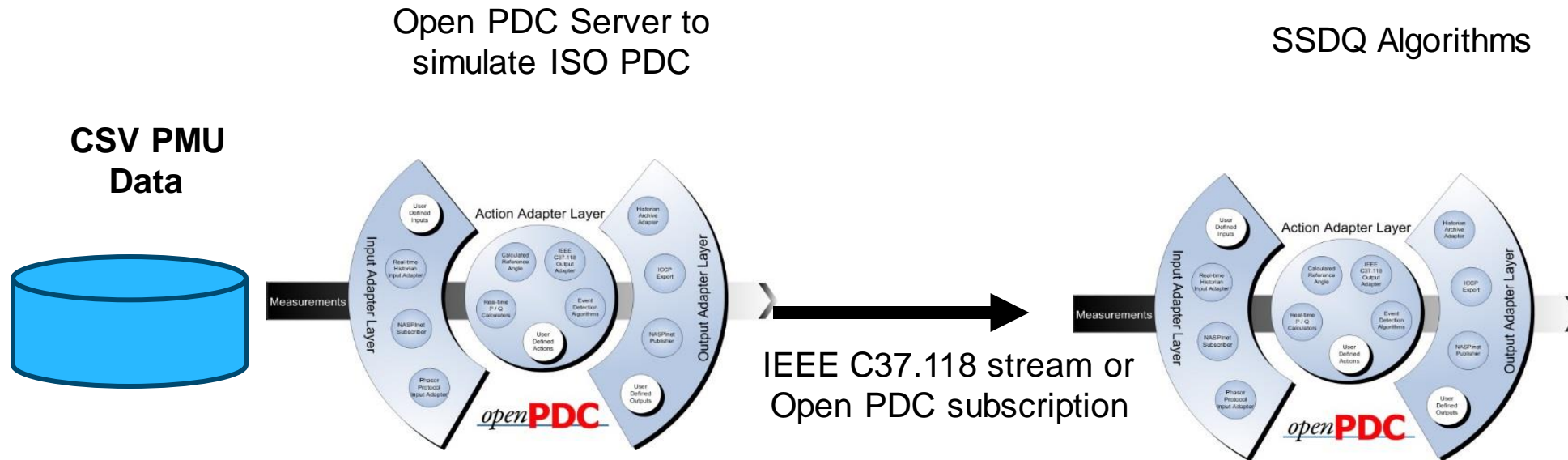
SSDQ - Matlab Based Software for Offline Testing



- 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

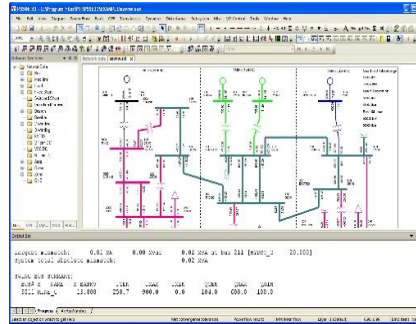
- Streaming Synchrophasor Data Quality Tool (SSDQ) – Online version
- Algorithm implementation on Open PDC



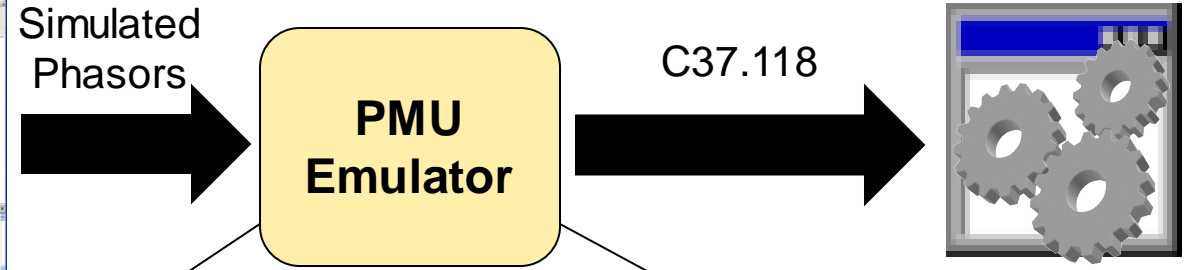
3. PMU Emulator

- 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

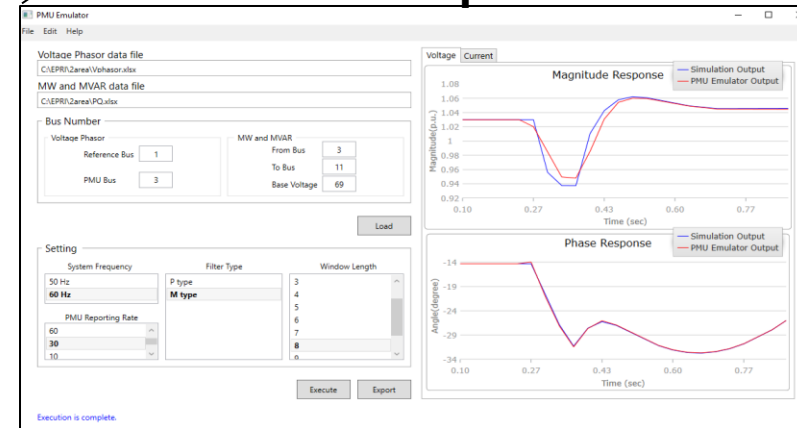
Dynamics Simulation Software (PSS/E, PSLF, TSAT etc)



Simulated Phasors



Proof-of-concept software



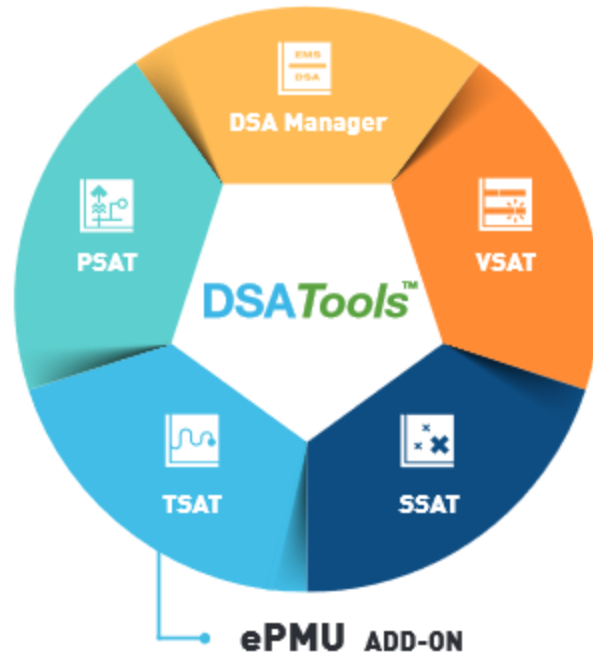
In collaboration with WSU

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

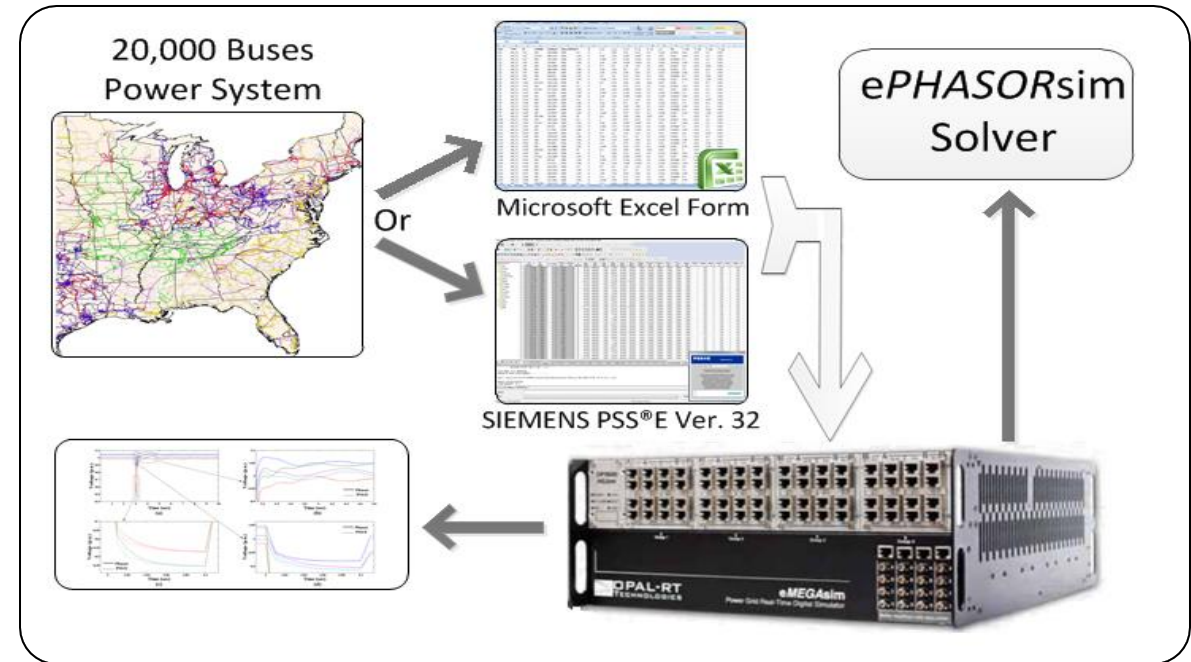
Vendor Engagement & Case Studies

- 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



4. Synchrophasor Applications Database

The screenshot shows the 'Synchrophasor Applications Database' interface. On the left, there is a 'Filter by:' section with a tree view of agencies, including ERCOT, NYISO, and NYPA, which are checked. Below the filter is an 'Apply Filter' button. The main area displays 'Search Results:' in a table format. The table has four columns: Agency Name, Application Type, Vendor Name, and Tool Name. The data rows include various agencies like ERCOT, ISO-NE, NYISO, and NYPA, with application types such as Situational Awareness, Oscillation Detection, and Model Validation, and tools like RTDMS, MATLAB, and PhasorView.

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 Powertech Labs, Inc.	MATLAB 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 In-house	PhasorPoint 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
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

File Help

type to search

Search Clear Vendor List PMU Installations

Filter by:

- Agencies
 - AEP
 - AESO (Canada)
 - APG (Austria)
 - ATC
 - BPA
 - Ceming Utility (Brazil)
 - ComEd
 - DVP
 - Duke Energy
 - EPRI
 - ERCOT
 - Entergy
 - FINGRID (Finland)
 - FPL
 - Hydro-Québec (Canada)
 - ISO-NE
 - ISONE
 - Jiangsu Electric Power Grid (Chi
 - LBNL
 - MISO
 - Manitoba Hydro (Canada)
 - Maui Electric
 - NYISO
 - NYPA
 - Norwegian Transmission Netwoc
 - OG&E
 - PG&F

Search Results:

Agency Name	Application Type	Vendor Name	Tool Name
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ERCOT	Oscillation Detection	EPG	RTDMS
ERCOT	Event Analysis	EPG	PGDA
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NYISO	State Estimation	ABB	Phasor Enhanced State Estimator
NYISO	Oscillation Detection	EPG	RTDMS
NYISO	Event Analysis	EPG	PGDA
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OG&E	Situational Awareness	In-house	PhasorView
OG&E	Event Detection	In-house	PhasorView
OG&E	Oscillation Detection	In-house	PhasorView

Apply Filter

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Details

Filter by:

- Agencies
- Vendors
 - ABB
 - EPG
 - EPRI
 - ESRI + OSIssoft
 - GE
 - In-house
 - Powertech Labs, Inc.
 - Quanta Technology
 - V&R Energy
 - WSU
- ToolName
- Application Type
 - Real Time
 - Event Detection
 - Oscillation Detection
 - Situational Awareness
 - State Estimation
 - Voltage Stability
 - Planning
 - Event Analysis
 - Model Validation
- Maturity Level

Apply Filter

Synchrophasor Applications Database – Entries Table

Synchrophasor Applications Database

File Help

type to search [X] Search Clear Vendor List PMU Installations

Filter by:

- Agencies
 - AEP
 - AESO (Canada)
 - APG (Austria)
 - ATC
 - BPA
 - Ceming Utility (Brazil)
 - ComEd
 - DVP
 - Duke Energy
 - EPRI
 - ERCOT
 - Entergy
 - FINGRID (Finland)
 - FPL
 - Hydro-Québec (Canada)
 - ISO-NE
 - ISONE
 - Jiangsu Electric Power Grid (Chi
 - LBNL
 - MISO
 - Manitoba Hydro (Canada)
 - Maui Electric
 - NYISO
 - NYPA
 - Norwegian Transmission Netwc
 - OG&E
 - PG&F

Apply Filter

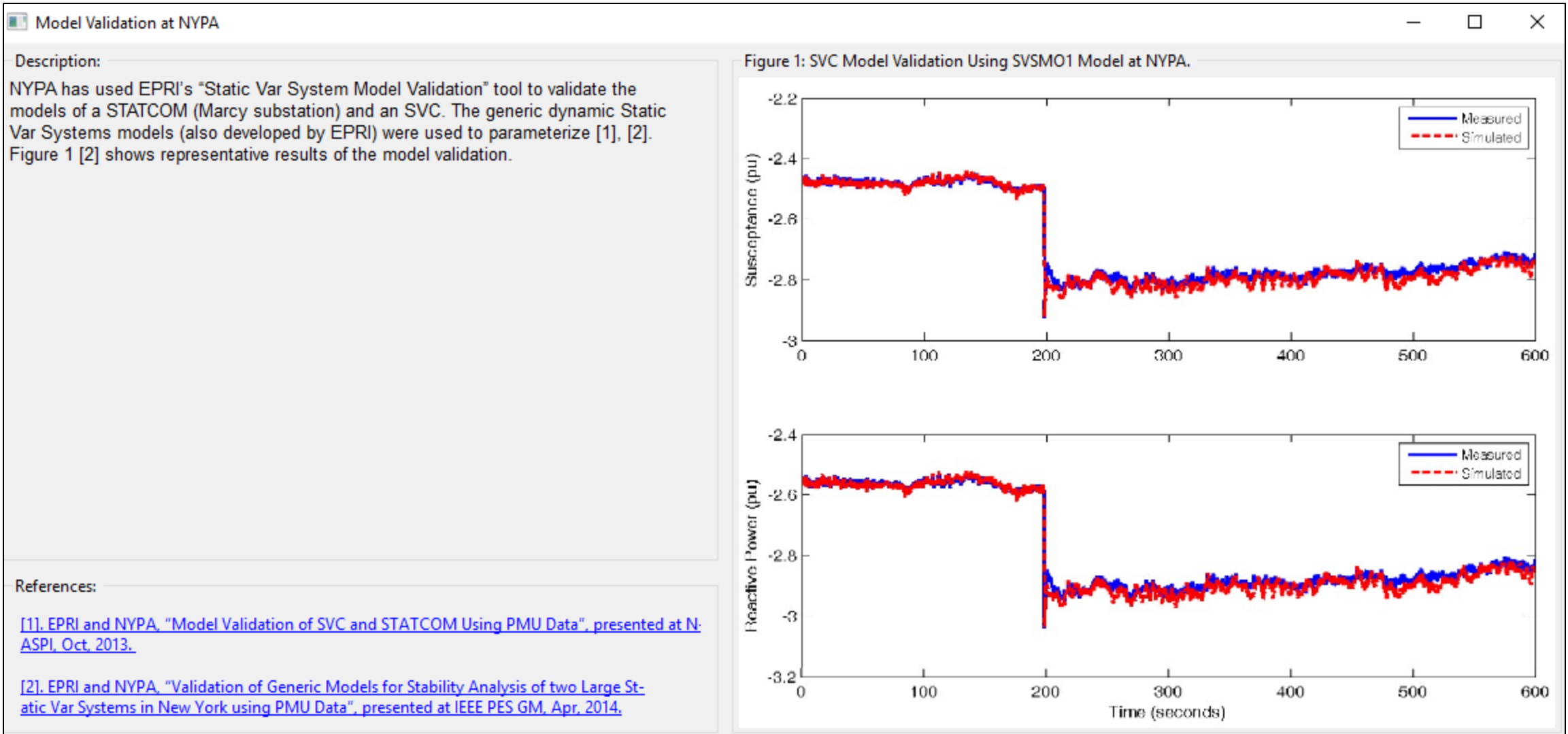
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NYISO	Oscillation Detection	EPG	RTDMS
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OG&E	Situational Awareness	In-house	PhasorView
OG&E	Event Detection	In-house	PhasorView
OG&E	Oscillation Detection	In-house	PhasorView

Details

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Synchrophasor Applications Database – Detailed Entry Description





Together...Shaping the Future of Electricity

Synchrophasor Applications Database – Vendor List

The screenshot displays the Synchrophasor Applications Database interface. On the left, a search bar contains the text "type to search". Below it, a "Filter by:" section includes expandable categories for Agencies, Vendors, ToolName, Application Type, and Maturity Level. The main area shows a "Search Results:" table with columns for Agency Name, Application Type, and Vendor Name. A "Vendor" dropdown menu is open, listing various vendors such as Alstom/GE, EPG, EPRI, GPA, GRT, Hitachi (Japan), Mathworks, OSIsoft, PNNL, Powertech Labs, Powerworld Corp., Quanta Technology, RTDS Technologies, SEL, Siemens, UTK, V&R Energy, and WSU. A red dashed line highlights the "Alstom/GE" entry in the dropdown menu, which is linked to a detailed view of the "Alstom/GE's PhasorPoint" software.

Alstom/GE's PhasorPoint

Description:
 e-terraphasorpoint is an advanced, fully integrated, smart grid ready suite of products for the 21st century grid. Transmission operators must maintain stable operation of the power system and increase the use of assets, while aging infrastructure and a changing generation profile introduce new challenges. e-terraphasorpoint can bring great insight, reducing costs through more effective use of power system capacity, safeguarding its stability.
 This flexible, scalable and extensible phasor-based Wide Area Management System (WAMS) is integrated with the e-terra solutions for Energy Management Systems (EMS), in order to:
 • Transform phasor data into actionable information to improve system security and capacity.
 • Coordinate WAMS and EMS to produce a unified view of the power system, enhancing operator and analyst decision-making.
 • Enable strategic development of the control center systems with the critical involvement of phasor-based information sources.
 Key benefits include:
 • Mitigate risk of major disturbance.
 • Relieve transmission constraints.
 • Improve dynamic models.
 • Fulfill regulatory reporting requirements.
 • Improve emergency response.
 • Scalable – grow to the largest foreseeable systems.
 • Extensible – add new applications when required.
 Other details about the product are described in [1].

Built-In Data Quality Management:
 GE's built-in functionality for data quality management includes two aspects, which are e-terraphasorpoint PDC processing and synchrophasor applications (i.e.: oscillation detection, state estimation) level data handling. The e-terraphasorpoint PDC processing provides users both live stream statistics and live PMU statistics. Live stream statistics include packet latency, percentage of time quality errors, percentage of missing data frames and last valid data frame. Whereas, live PMU statistics include percentages of GPS lock, valid data, data error and missing data. And the data handling of application level is based on three heuristics. These heuristics are a) utilization of PMU data quality status information from the field of PMU I

References:
 [1]. "e-terraphasorpoint", GE Software Solutions.
 [2]. Alstom/GE, "Grid Software Solutions - Built-in Data Quality", presented at NASPI, Mar. 2016.

Figure 1: Reference Angle Selection of Alstom/GE's e-terraphasorpoint.

The figure shows a screenshot of the Alstom/GE's e-terraphasorpoint software interface. It features a map of a power system with a 'REFERENCE' label and a graph titled 'Synchroscop Area 1 Upper-Lower Frequency (Line)'. The graph displays a blue line representing the frequency over time, with a color scale at the bottom ranging from 0.8 to 1.2. The interface includes various navigation and control elements on the right side.

