

Let's Talk About Synchrophasors, PMUs & Applications

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Outline

- Synchrophasor Technology
 Background
- State-of-the-Art PMU Applications & Use Cases
- Trending PMU Applications
- Synchrophasor/PMU Limitations -Towards Synchronized Sampled Value Measurements





Electric Power Research Institute (EPRI)

Mission

Advancing safe, reliable, affordable and environmentally responsible electricity for society through global collaboration, thought leadership and science & technology innovation

Independent

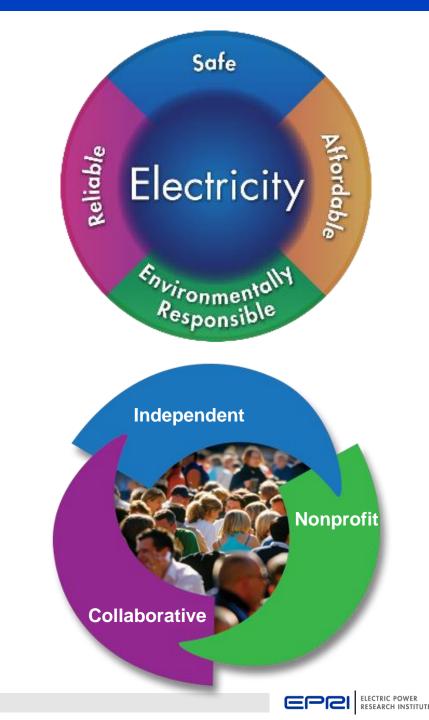
Objective, scientifically based results address reliability, efficiency, affordability, health, safety and the environment

Nonprofit

Chartered to serve the public benefit

Collaborative

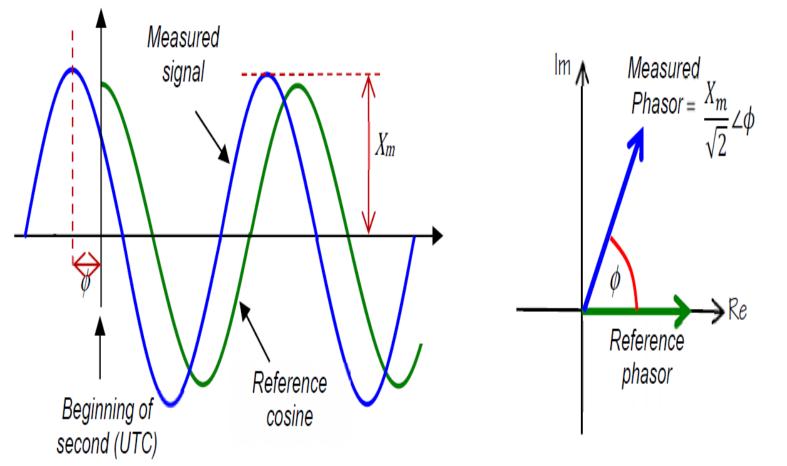
Bring together scientists, engineers, academic researchers, industry experts



Disclaimer

- The information in the next slides is from publicly available material
- EPRI is technology and vendor agnostic and does not recommend particular vendors or technologies over others
- The vendors are listed randomly. The list of vendors and tools is not exhaustive and it is based on the knowledge and experience of the presenter
- The example applications by utilities/ISOs are only representative and do not cover all the use cases presently in the industry

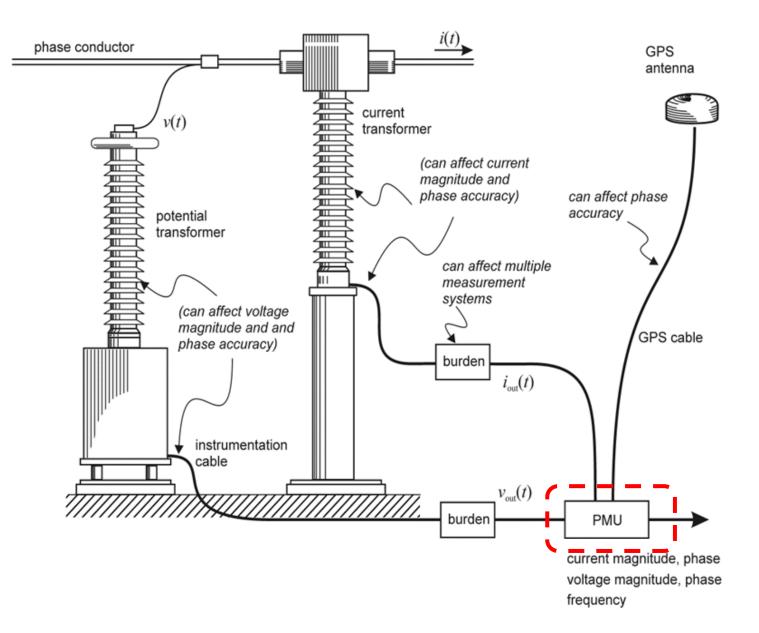
Synchrophasor Definition



- Phasor is defined as a complex number which represents a sine (or cosine) wave's amplitude and phase angle
- Synchrophasor represents a phasor of which the phase angle is expressed relative to a reference phasor which is synchronized to the coordinated universal time (UTC)
- Typically Global Positioning System (GPS) is used for time synchronization



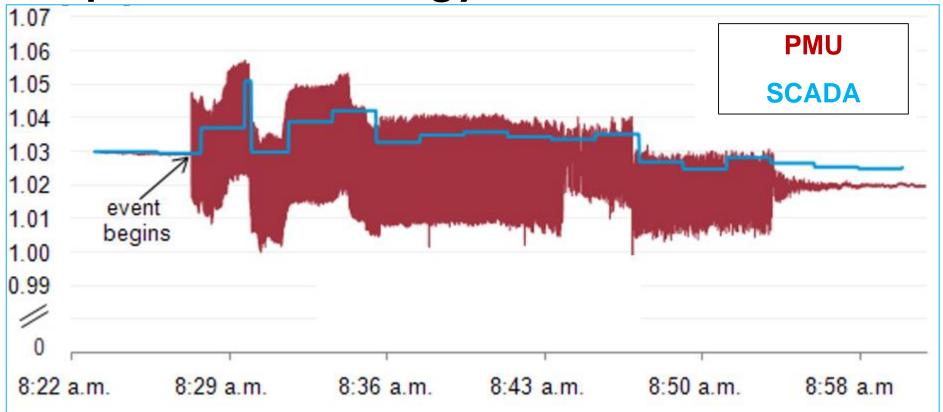
Phasor Measurement Unit (PMU)



- PMU is a device which measures synchrophasors
- A PMU can measure voltage and current synchrophasors, frequency and ROCOF
- A PMU can be a stand-alone device or a functional unit within another physical unit
- Input voltage and current signals are from PTs and CTs



Synchrophasor Technology vs SCADA

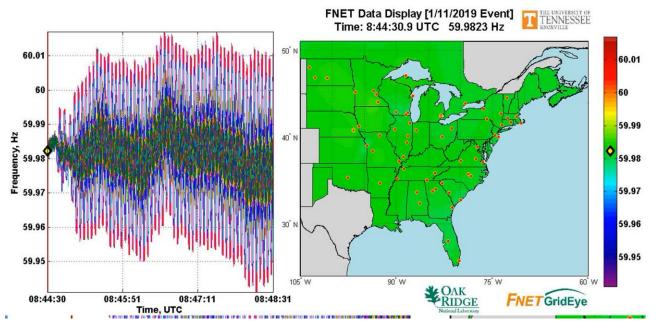


- Synchrophasor data comprises current and voltage phasors, frequency and rate of change of frequency (ROCOF), whereas SCADA data is analog measurements of RMS voltages and currents, and real and reactive power.
- Synchrophasor data have high resolution, typically reported at 10 to 60 records per second, compared to 2 to 4 seconds per record in the case of SCADA data.
- Synchrophasor data have time synchronization and are time stamped using precise, standard specified times.



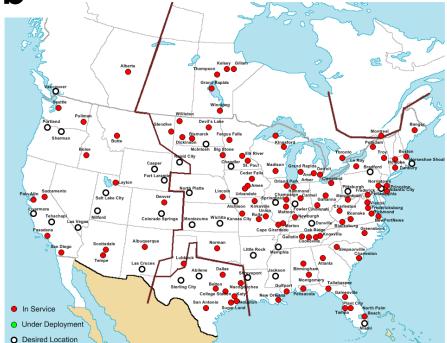
FNET/GridEye - UTK/Oak Ridge National Lab







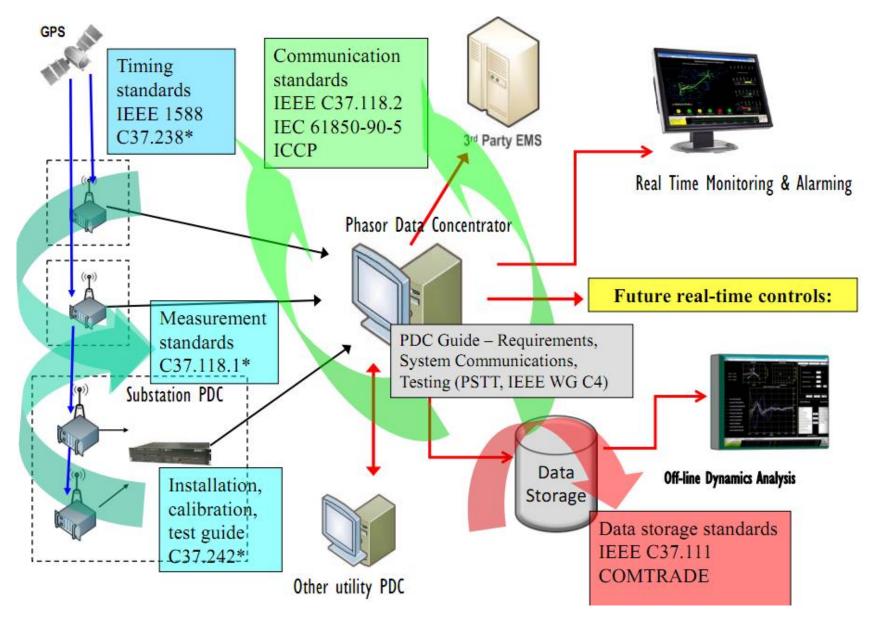
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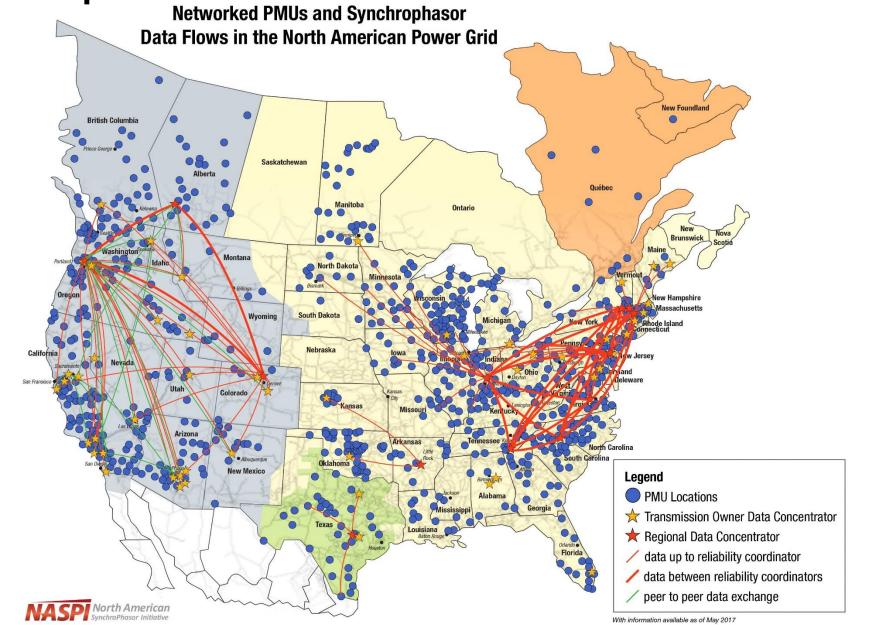


Synchrophasor Data Communication Protocol & Standards





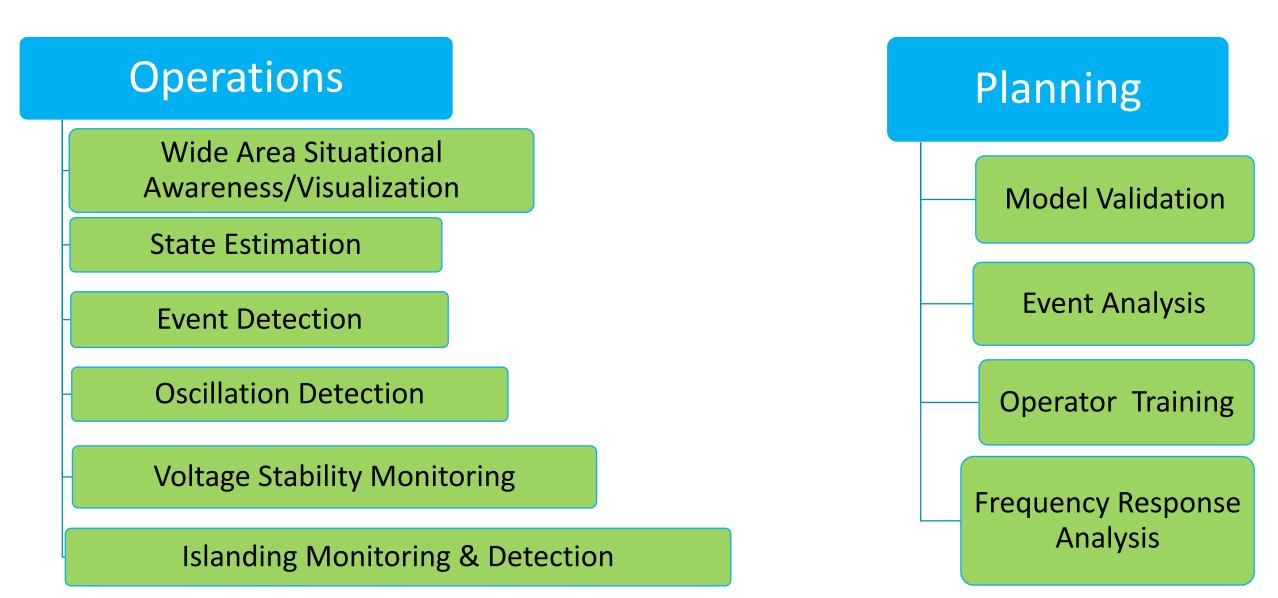
NASPI PMU Map



Synchrophasor Applications & Use Cases



Synchrophasor Applications

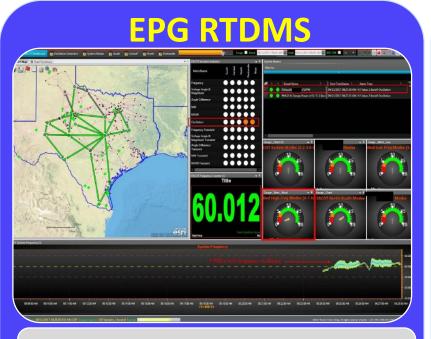




Wide Area Situational Awareness/Visualization



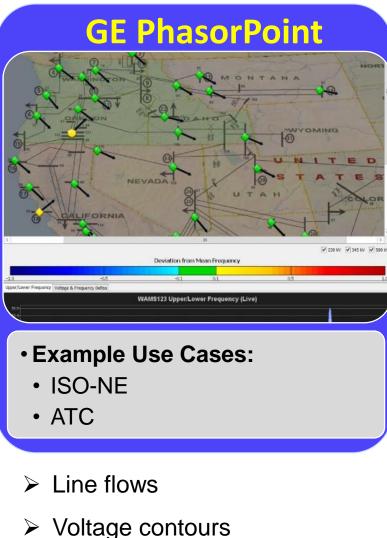
Wide Area Situational Awareness/Visualization – Vendor Tools & **Use Cases**



• Example Use Cases:

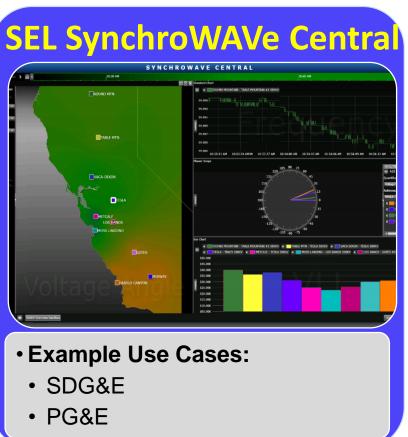
- ERCOT
- NYISO
- Geospatial displays
- > Chart trends
- Phasor diagrams

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Phase angle differences

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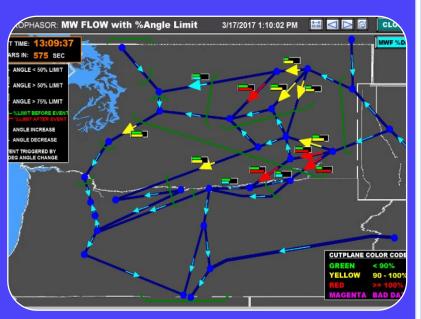


- Alerts/Alarms
- > Color codes
- > Arrows



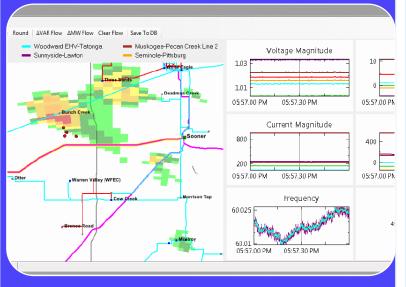
Wide Area Situational Awareness/Visualization – In-House Tools

BPA



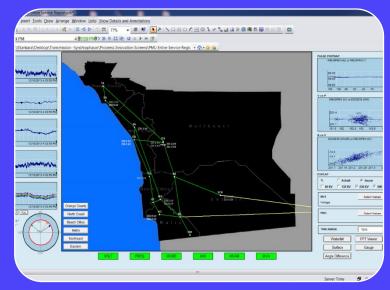
- Visualization displays using PI ProcessBook
- Over 18,000 synchrophasor measurements/second processed
- MW flows with % angle limit
- Phase angle monitoring
- Different colors and arrow sizes

OG&E



- PhasorView: In-house tool based on a Microsoft SQL database
- Synchrophasor data from 356 PMUs

SDG&E



Based on PI ProcessBook

- Empowers users to graphically create displays and enrich them with layers of dynamic data.
- Helps users instantly access and visualize PI Server data through interactive, graphical displays



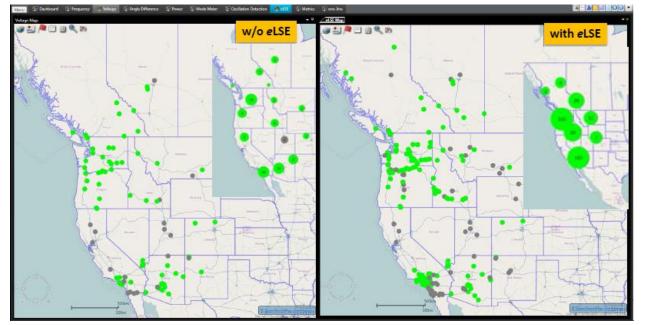


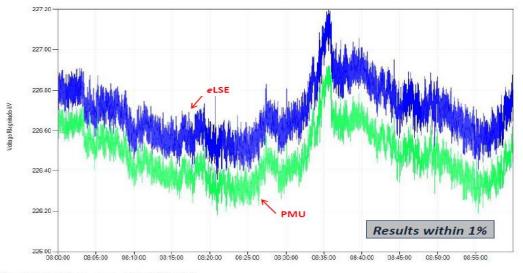
State Estimation





State Estimation – Linear State Estimation (LSE)





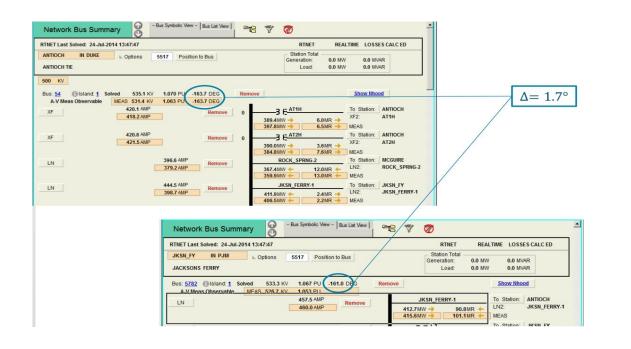
Start Time: 2017-01-04 08:00:00.000 End Time: 2017-01-04 08:59:59.965

- Synchrophasor measurement only based state estimator
- Complementary to SCADA SE or backup
- Example Use Cases
 - DVP: In-house three-phase LSE for 500kV system
 - PJM in-house
 - BPA & SCE EPG's eLSE
 - Peak RC V&R LSE



State Estimation – Hybrid State Estimation

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G_COULEE	BUS	230_MAIN_SEC_1	KVA	Good	/ Available	28.37 / 2		•	•	0.305	0.630				vs SE	: Esti	mate	ed Bus	s Vol	tage	Ang	gle	
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JOHN DAY	BUS	500_EAST	KVA	Good	/ Available	8.56 / 8				0.098	0.620		Row										
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EELER	BUS	203	KVA	Good	/ Available	-2.19 / -2			õ		Lir	e MALN_R	IDM 25	00						_			
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- Incorporation of synchrophasor data into EMS State Estimator
 - Duke Energy Alstom/GE
 EMS
 - Peak RC Alstom/GE EMS
 - NYISO ABB EMS
 - XM (Colombia)



Oscillation Detection & Monitoring



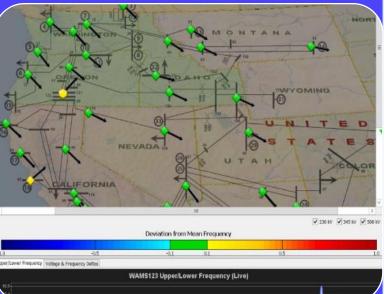
Oscillation Detection – Vendor Tools & Use Cases

EPG RTDMS - ERCOT



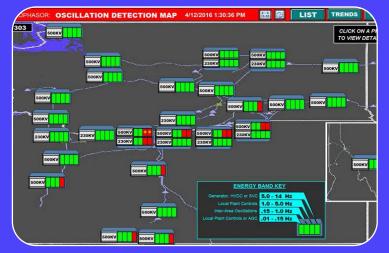
- 3 years of PMU data analyzed to identify ERCOT system modes
- Modes were analyzed to identify mode frequency, damping percentage, and energy level
- Mode meters in RTDMS were configured to track identified modes with the most common occurrence

GE PhasorPoint – ISONE



- Detection
- Characterization (Frequency, Damping, Mode shape)
- Alarming and Alerting
- Results are updated every 5
 seconds

BPA - ODM



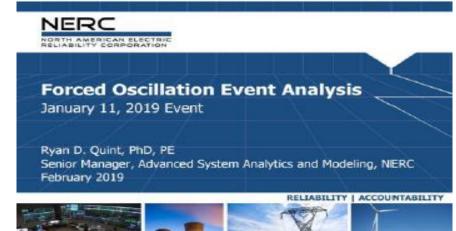
- Monitors oscillations using 150 measurements from 68 PMUs
- 4 frequency bands
- 0.01-0.15 Hz
- 0.15-1.0 Hz
- 1.0-5.0 Hz
- 5.0-14.0 Hz
- Tool is operational since 2016 and provides alarms to the operators



Forced Oscillations

- Typically due to equipment failure/malfunction
- January 2019 event
 - 0.25 Hz oscillations propagated through entire Eastern Interconnection and lasted for 17 mins
 - Resonance with 0.25 Hz inter-area mode caused the propagation
 - Up to 200 MW peak-to-peak magnitude
 - The source of oscillations was a Florida generator

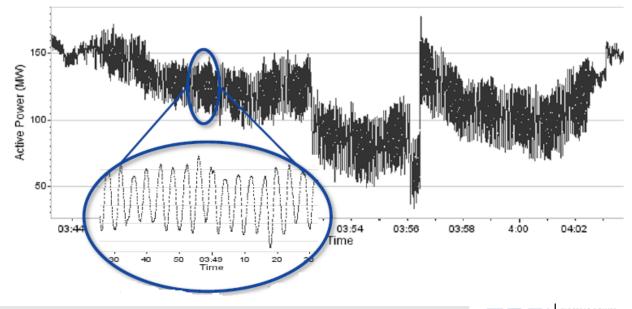




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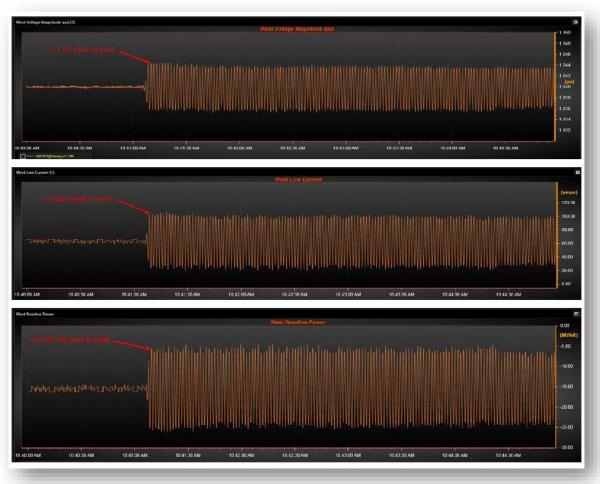
RESEARCH INSTITUT

MW flow in 345 KV tie-line between NYISO and ISO-NE





Wind/Solar Inverter Caused Oscillations



 Without use of synchrophasor data these oscillations cannot be observed

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 Wind/solar plant inverter controls might create oscillations due to control interactions with neighboring equipment or due to resonance with the network





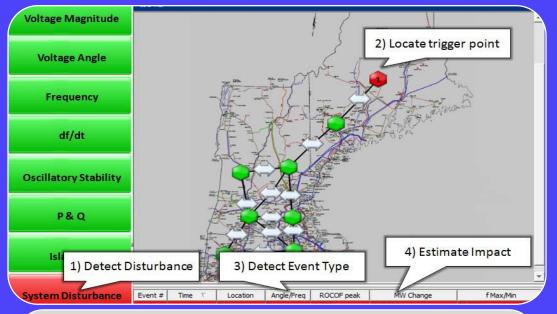
Event Detection





Event Detection – Vendor Tools & Use Cases

GE PhasorPoint – ISONE



• Event identification based on the rate of change of time-aligned voltage angle and frequency measurements

- Provides with
- disturbance alarm
- location
- event type
- estimated impact

BPA -	FDIM	

W17/2017 14:49:45 .0405 SRP 47 Alarm V17/2017 10:28:27 .0461 TSGT 47 Alarm V14/2017 10:425 .1342 47 Alarm V14/2017 10:52:39 .0591 SRP 48 Alarm V14/2017 11:55:09 .0591 SRP 48 Alarm V14/2017 11:25:20 .0735 SRP 48 Alarm V109/2017 20:45:56 .1107 48 Alarm V09/2017 20:45:56 .1107 48 Alarm V09/2017 14:27:22 .0124 33 14 V02/2017 15:42:06 .0465 AESO 48 Alarm V02/2017 16:33:47 .0308 39 17 V21/2017 23:41:26 .0442 48 Alarm V20/2017 .042 48 Alarm	9/17/2017 14:49:45 0.405 SRP 47 Alarm 9/17/2017 06:28:27 .0.461 TSGT 47 Alarm 9/17/2017 06:28:27 .0.461 TSGT 47 Alarm 9/17/2017 06:28:27 .0.461 TSGT 47 Alarm 9/14/2017 14:55:09 .0591 SRP 48 Alarm 9/14/2017 14:55:09 .0591 SRP 48 Alarm 9/14/2017 17:23:52 .0735 SRP 48 Alarm 9/09/2017 17:23:52 .0735 SRP 48 Alarm 9/09/2017 16:3:2:06 .0465 AESO 48 Alarm 9/09/2017 16:3:2:06 .0465 AESO 48 Alarm 9/02/2017 14:17:22 .0124 .33 14 9/02/2017 15:3:3:47 .0308 .39 17 8/21/2017 23:41:26 .0442 48 Alarm 8/20/2017 16:05:43 .0863 .48 Alarm 8/20/2017 16:05:43 .0863 .48 Alarm	Event Start_Time	Magnitude <u>(Hz)</u>	Rank1_PMU	PMU Count	Alarm Event	SRM Out-of-Plane Count
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/15/2017 12:27:28 .0432 TSGT 44 Alarm		8/15/2017 12:27:28	.0432	TSGT	44	Alarm	

- Monitors 52 PMUs
- For an alarm to trigger:
- •10 or more PMUs detect an event
- there is an at least 0.04 Hz frequency drop
- the 0.04 Hz deviation lasts for at least 10 secs

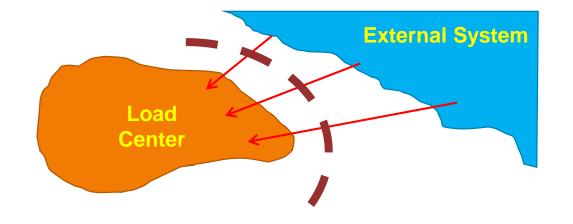


Voltage Stability

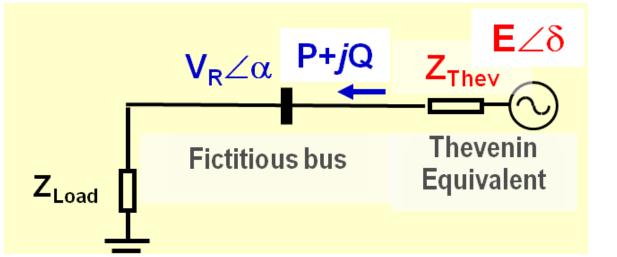




Voltage Stability Monitoring – Measurement Based Approach



- Voltage stability analysis based on Thevenin Equivalent
- Disadvantage: Cannot predict N-x stability margins

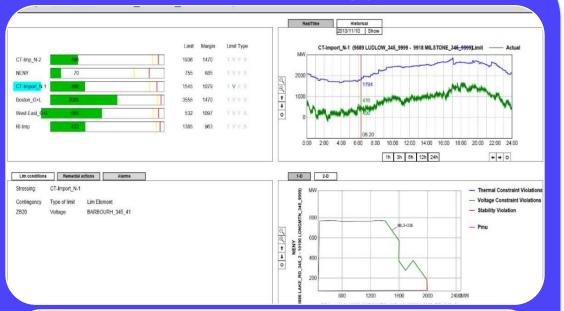


Tool Name	Developed by	Applied By
Measurement-Based	EPRI	Entergy
Voltage Stability		
Assessment (MBVSA)		
Real Time Voltage	Quanta Technology	PG&E, SCE
Instability Indicator (RTVII)		
Measurement-Based	In-house	BPA
Voltage Stability		

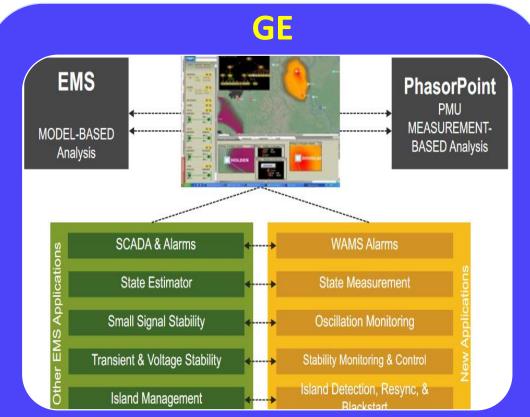


Voltage Stability Monitoring – Hybrid Approach

V&R Energy



 ROSE uses a "hybrid" approach in which SE model is used to compute voltage stability limits and synchrophasor data is used to determine where the current operation point is



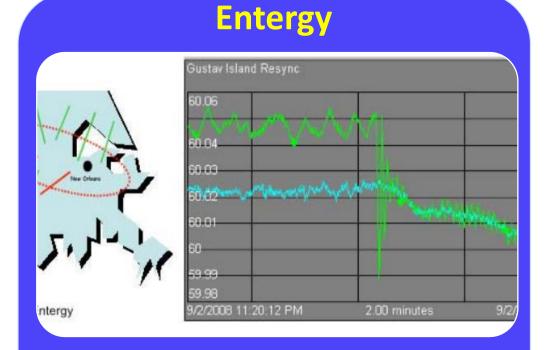
- Integration of WAMS with EMS
- EMS: Model Based Analysis
- WAMS: PMU Measurement Based
 Analysis



Islanding Detection & Restoration

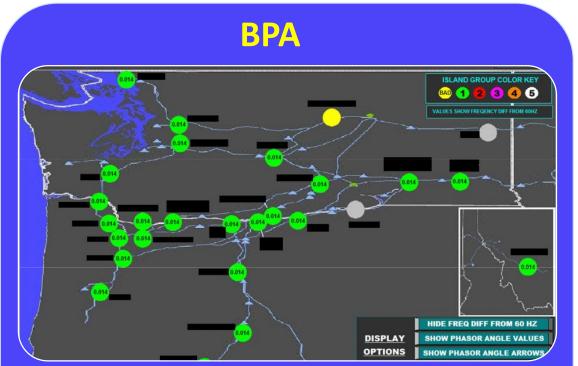


Islanding Monitoring Detection and Restoration



- In 2008 the Gustav hurricane created an island and frequency separation was detected by PMU measurements
- Synchrophasor measurements in Entergy's system significantly increased the situational awareness of grid operators during the hurricane Gustav and its aftermath in 2008

www.epri.com



• Tool provides information on power system islands, their boundaries, frequency, and angular separation, information which dispatchers and technical operations staff can use during the system restoration process

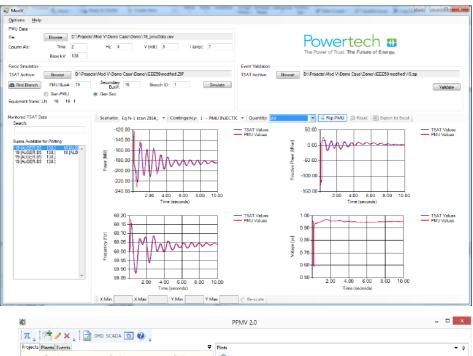


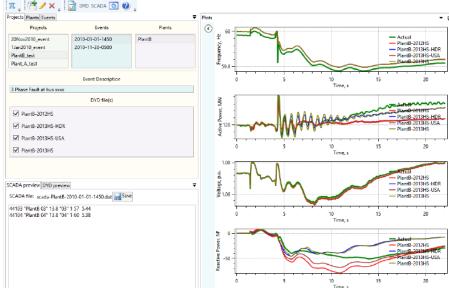
Model Validation





Model Validation Tools



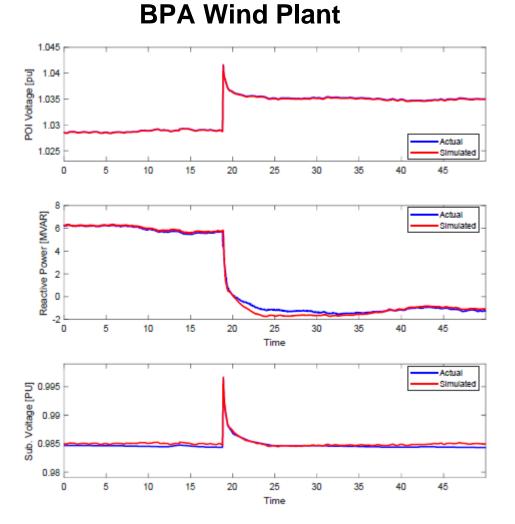


www.epri.com

- Tools with playback feature
 - GE PSLF
 - Siemens PTI PSS/E
 - Powertech Labs TSAT & ModV
 - Powerworld
- Tools for automated model validation
 - PNNL-BPA Power Plant Model Validation (PPMV)
 - EPG's Generator Parameter Validation (GPV)
- Tools for model calibration (perform optimization to estimate model parameters)
 - EPRI PPPD (can be used to verify the models of shunt FACTS devices, wind and PV power plants, and synchronous generator based conventional power plants)
 - Matlab Simulink



Synchrophasor Applications for Renewable Energy - Model Validation for Wind Farms and Solar Plants



- Use of generic wind/solar plant dynamic models
- Several utilities have installed PMUs at wind/solar power plants
- Recorded synchrophasor data can be used to perform model validation and controller tuning of wind/solar plants



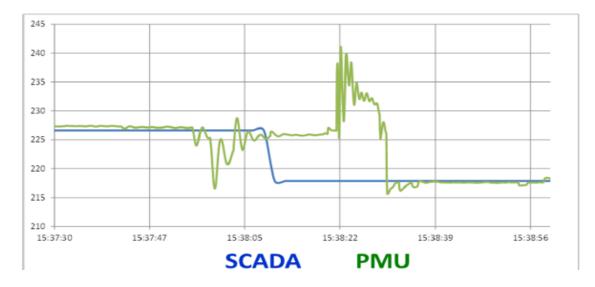
Event Analysis

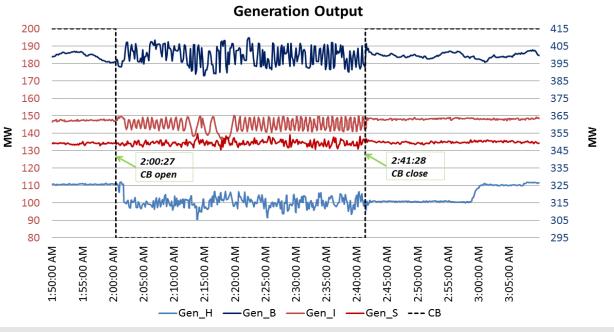


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Event Analysis Using Synchrophasor Data





Benefits of Synchrophasor Data Based Event Analysis

- High resolution, time-tagged synchrophasor data
- Reduced time for system events reporting and analysis
- Faster and easier communication with TO and ISO personnel on details of events
- In-depth system event analysis using specialized software features

Statement from BPA: "With SCADA, months would have been needed to analyze the event"

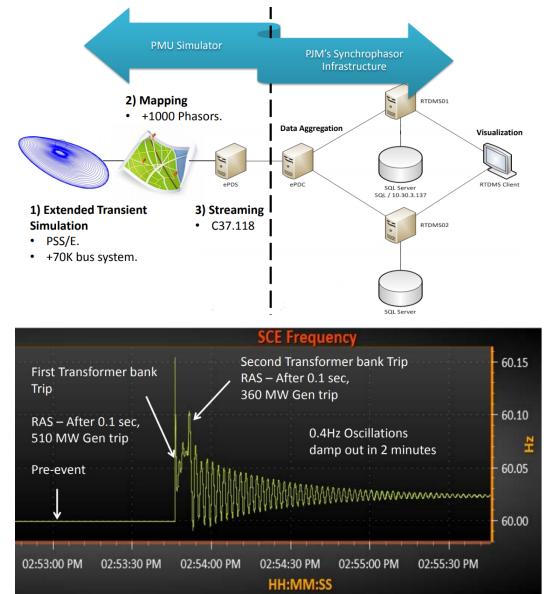


Operator Training





Operator Training on the Use of Synchrophasor Technology



- Grid operators should respond effectively to an alert and/or an event in real time operations
- Train operators to:
 - use advanced synchrophasor technology metrics such as phase angles, sensitivities and oscillations/damping to monitor, diagnose, and take timely corrective actions in real-time
 - understand the early warning indicators and event pre-cursors for events over a wide-area such as the entire interconnection that have the potential to cascade, e.g., wide-area phase angle differences
 - manage what-if scenarios
 - test alternate corrective actions and observe consequences in a training environment

Synchrophasor Data Quality

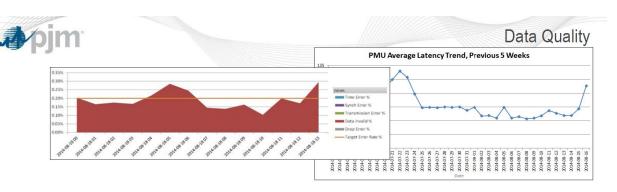


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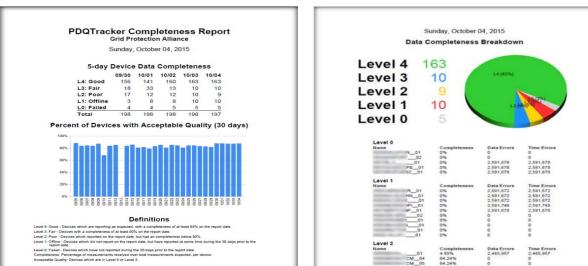
Synchrophasor Data Quality

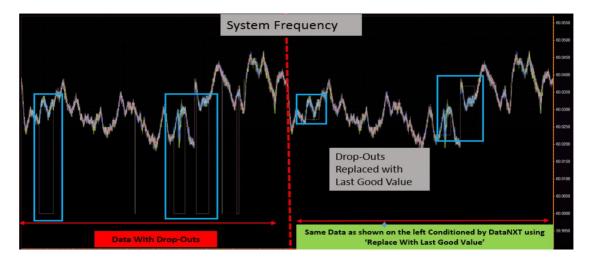
то	Total Error %	Drop Error %	Data Invalid %	Transmission Error %	Synch Error %	Time Error %	Average Latency	Min Latency	Max Latency
Apple	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	67	0	3861
Tomato	0.032%	0.001%	0.015%	0.000%	0.016%	0.000%	169	72	4065
Bean	0.046%	0.003%	0.044%	0.000%	0.000%	0.000%	210	99	4015
Garlic	0.214%	0.001%	0.177%	0.000%	0.035%	0.000%	149	121	4093
Brussel	0.415%	0.029%	0.385%	0.000%	0.001%	0.000%	210	59	2111
Pepper	0.505%	0.000%	0.000%	0.505%	0.000%	0.000%	141	75	3627
Lettuce	1.569%	1.512%	0.000%	0.000%	0.057%	0.000%	1243	682	4047
Parsley	1.731%	1.606%	0.000%	0.125%	0.000%	0.000%	1088	1045	4124
Daisy	6.323%	0.466%	5.837%	0.000%	0.018%	0.001%	1168	223	4125
Potato	9.364%	0.000%	9.363%	0.000%	0.000%	0.000%	310	137	4062
Basil	22.281%	0.000%	22.245%	0.000%	0.036%	0.000%	30	10	3981
Berry	33.338%	0.002%	33.335%	0.000%	0.000%	0.000%	3184	3013	4098
PJM Total	2.455%	0.757%	1.642%	0.033%	0.023%	0.000%	745	466	3750



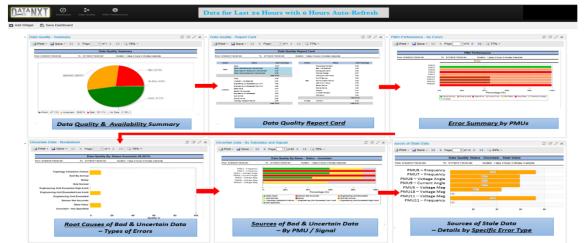
- Data quality is a major factor for successful integration of synchrophasor technology in utility/ISO operations
- Data quality requirements depend on the application
- Data Availability Missing Data
 - Data loss
 - Delivery delays
 - PMU hardware failure etc.
- Data Accuracy
 - Time accuracy (GPS)
 - Installation/Calibration (Instrumentation, CTs, PTs)
- Some ISOs are generating synchrophasor data quality reports
- Some ISOs are setting data quality targets with TOs

Synchrophasor Data Quality Tools





- GPA's Phasor Data Quality Tracker (PDQTracker)
 - Open source
- EPG's DataNXT
 - Data corruption checks
 - Time related validations
 - Validations using data characteristics
 - Validations using LSE (model based)
- GE PhasorPoint
 - PDC level data handling
 - Application level handling

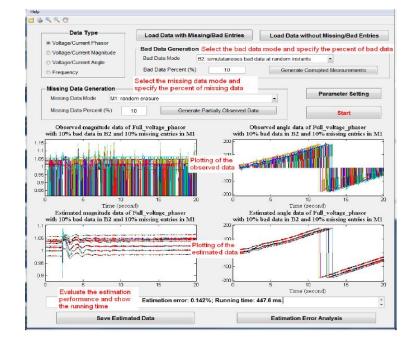


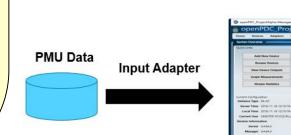


EPRI - Data Quality Conditioning of Streaming Synchrophasor Data

- Goal: 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 parameters
- Computationally efficient for real-time implementation
- Algorithms tested with recorded synchrophasor data provided by EPRI members
- Streaming Synchrophasor Data Quality (SSDQ) software offline & online versions
- Ongoing: Demos with streaming synchrophasor data hosted by utilities/ISOs
- Next: Collaboration with vendors for implementation in commercial platforms

Offline SSDQ Tool





Online SSDQ Tool

Average 5 / CP Tilologies / se Operations / s Total Manifies Zystem Threads fortave in Fool Active in Fool Mailing Thread Manifies / ser Hepsbyres Action Adapter SSDQ Algorithm

In collaboration

with **RPI**





r Applications Database	•		Search Clear			Description: e-terraphasorpoint is an advanced, fully integrated, smart grid ready suite of grid. Transmission operators must maintain stable operation of the power sy assets, while aging infrastructure and a changing generation profile introduced e-terraphasorpoint can bring great insight, reducing costs through more effec capacity, safeguarding its stability. This flexible, scalable and extensible phasor-based Wide Area Management with the e-terra solutions for Energy Management Systems (EMS), in order • Transform phasor data into actionable information to improve system secur • Coordinate WAMS and EMS to produce a unified view of the power system analyst decision-maining.	tem and increase the use of new challenges. tive use of power system System (WAMS) is integrated by and capacity. , enhancing operator and	Figure 1: Reference Angle Selection of Alstom/GE's e-terraphasorp
^	Search Results:					information sources. Key benefits include: • Mitigate risk of major disturbance. • Relieve transmission constraints. • Improve dynamic models.		
	Agency Name	Application Type	Vendor Name	Tool Name		Fulfil regulatory reporting requirements. Improve emergency response. Scalable – grow to the largest foreseeable systems.		
) (Canada)	ERCOT	Situational Awareness	EPG	RTDMS		Extensible – add new applications when required. Other details about the product are described in [1].		Devision from Nean Incourancy
(Austria)	ERCOT	Oscillation Detection	EPG	RTDMS		Built-In Data Quality Management:		Land Call Call Call Call Call Call Call Cal
	ERCOT	Event Analysis	EPG	PGDA		GE's built-in functionality for data quality management includes two aspects. PDC processing and synchrophasor applications (i.e.: oscillation detection, statement of the synchrophasor applications).	tate estimation) level data	Synchronous Area 1 UpperLower Frequency (Live)
ing Utility (Brazil)	ERCOT	Model Validation	Mathworks Powertech Labs, Inc.	MATLAB TSAT		handling. The e-terraphasorpoint PDC processing provides users both live str statistics. Live stream statistics include packet latency, percentage of time missing data frames and last valid data frame. Whereas, live PMU statistics	eam statistics and live PMU quality errors, percentage of include percentages of GPS	
d	ERCOT	Operator Training	EPG	PSOT		lock, valid data, data error and missing data. And the data handling of applicate heuristics. These heuristics are a) utilization of PMII data quality status information of the provided of the status of the stat	tion level is based on three mation from the field of PMU	· **
	ISO-NE	Voltage Stability	V&R Energy	ROSE		References:		าร์ต พริ. พริ. พริ. พริ. พริ. พริ. พริ. พริ.
Energy	ISO-NE	Event Detection	GE	PhasorPoint		[1], "e-terraphasorpoint", GE Software Solutions. [2], Alstom/GE, "Grid Software Solutions - Builtin Data Quality", presented at NAS	Pl. Mar. 2016.	Indexemble (Indexemble)
1	ISO-NE	Oscillation Detection	GE In-house	PhasorPoint OSL		· · · · · · · · · · · · · · · · · · ·		
y ID (Finland)	ISO-NE	Model Validation	Powertech Labs, Inc.	TSAT				
D (Finland)	ISO-NE	Data Quality Management	In-house	DQMS				
Québec (Canada)	NYISO	Situational Awareness	EPG	RTDMS				
	NYISO	Voltage Stability	ABB	Phasor Enhanced Voltage Stability N		Model Validation at NYPA		- 🗆 X
	NYISO	State Estimation	ABB	Phasor Enhanced State Estimator		Description:	Figure 1: SVC Model Validation Usin	ng SVSMO1 Model at NYPA.
Electric Power Grid (Chi	NYISO	Oscillation Detection	EPG	RTDMS	L 🛹 🕺	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	-2.2	Mensured
	NYISC	Fuent Application	506	PGDA		Var Systems models (also developed by EPRI) were used to parameterize [1], [2]. Figure 1 [2] shows representative results of the model validation.	0.24	Smulated
	NYPA	Model Validation	EPRI	SVSMV		- 2 1-1 takaoontana taoana ai ina maaa takaanan.		~ 11
ba Hydro (Canada)	Oute	Situational Awareness	In-house	PhasorView			-2.6	
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ELECTRIC POWER RESEARCH INSTITUT	E			Details		References:	activ	Man with the second second second
						[1]. EPRI and NYPA, "Model Validation of SVC and STATCOM Using PMU Data", presented at N-	S -3	

- 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

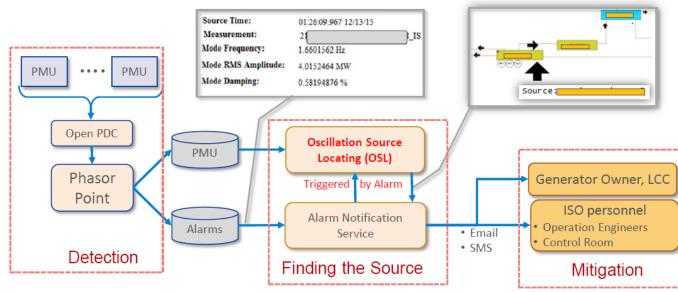


Trending PMU Applications

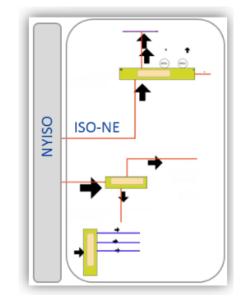


Oscillation Source Location

ISO-NE - **Dissipating Energy Flow**



Jan 2019 Event



IEEE PES PSDP TF: Oscillation Source Location

Cases #	Case name	Data of event	Power system - source of PMU	Type of oscillations	Frequency/Hz	Peak to peak magnitude	Source and location	Confidence level on the source location	Duration of sample set
1	ISO- <u>NE</u> case 1	Jun.17, 2016	ISO-NE	System-wide mode	0.27	Up to 27 MW	Generator outside of ISO-NE in Area 2.	100%	3 min
2	<u>ISO-</u> <u>NE</u> <u>case 2</u>	Oct.3, 2017	ISO-NE	Multi- frequency, wide-spread	Dominant modes: 0.08 0.15 0.31	- F	Generator outside of ISO-NE in Area 3.	100%	6 min
3	ISO- <u>NE</u> case 3	Ju1.20, 2017	ISO-NE	Regional	1.13	Up to 115 MW	Generator located East from Sub:2. Lines Ln:2 and Ln:4 lead to the area, where the source generator resides.	100%	3 min



Artificial Intelligence (AI)/Machine Learning Using Synchrophasor Data

DOE FOA 1861

FINANCIAL ASSISTANCE FUNDING OPPORTUNITY ANNOUNCEMENT



Department of Energy (DOE) Office of Electricity (OE)

BIG DATA ANALYSIS OF SYNCHROPHASOR DATA Funding Opportunity Announcement (FOA) Number: DE-FOA-0001861 FOA Type: Initial CFDA Number: 81.122, Electricity Delivery and Energy Reliability, Research, Development and Analysis

NASPI EATT

NASPI WHITE PAPER

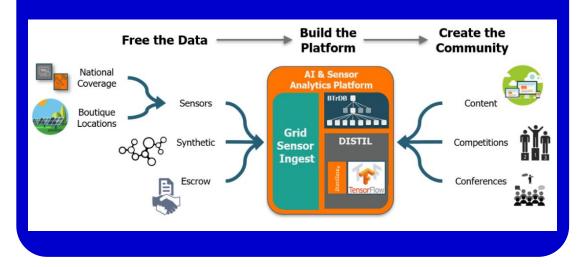
Data Mining Techniques and Tools for Synchrophasor Data



Prepared by NASPI Engineering Analysis Task Team (EATT)

January 2019

ARPA-E PingThings

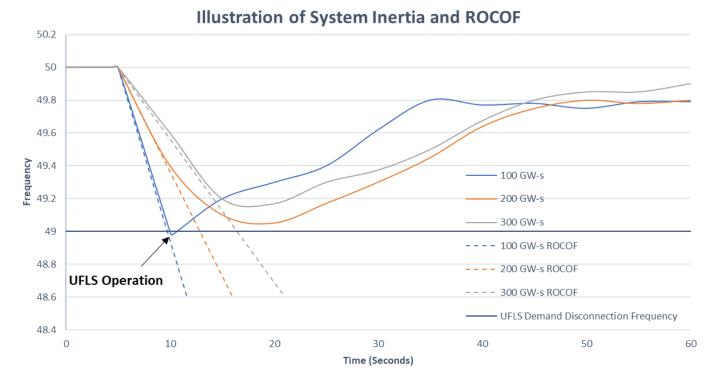




PMU Based Inertia Monitoring

- With increasing levels of IBR, system inertia is decreasing
- RoCoF increase, less time for PFR to respond
- Growing interest and need for online inertia monitoring inertia floor
- EPRI white paper "Online Inertia Estimation & Monitoring - Industry Practices & Research Activities"
 - 1. Present Industry Practices
 - 2. Research Activities and Proposed Technologies

- Reactive Technologies
- -GE
- EPG
- UTK



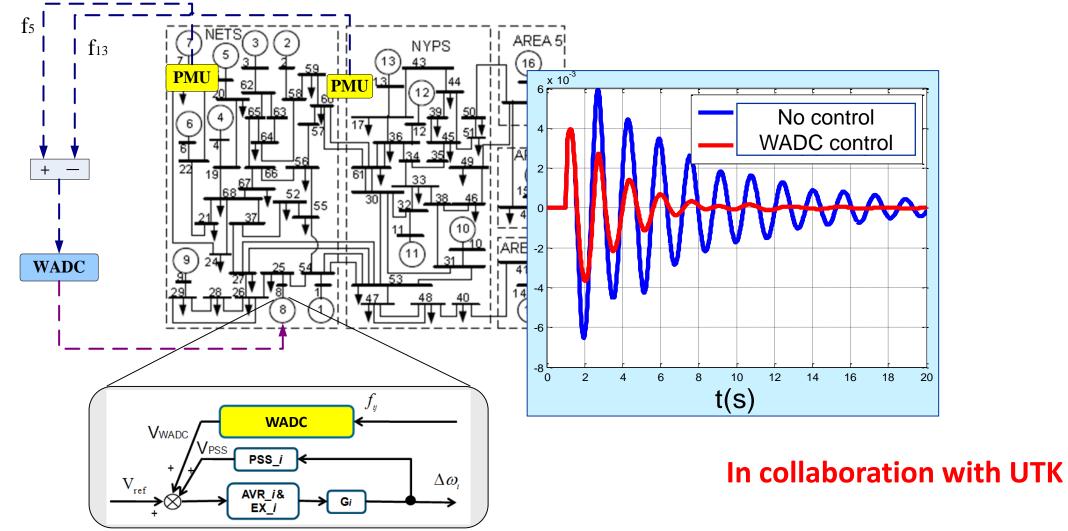


PMU Control Applications





EPRI-Synchrophasor-Based Wide Area Oscillations Damping Controller

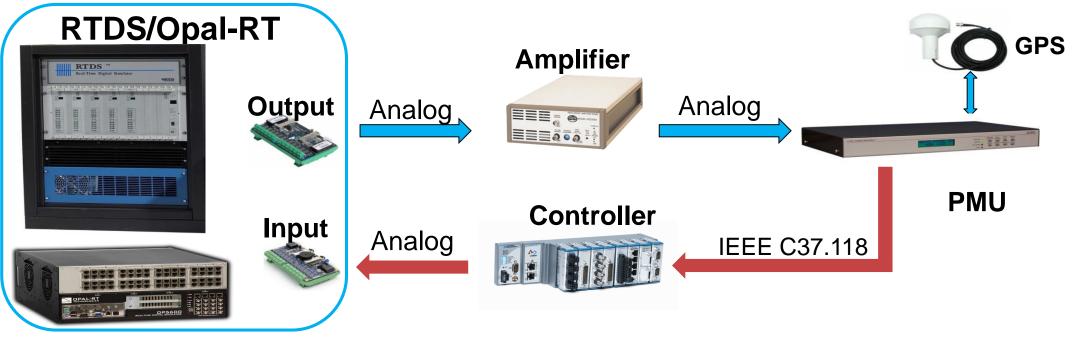


- Improved Damping of Target Inter-area/Local Oscillations Mode
- Application of Synchrophasor Technology in Closed Loop Wide Area Control



Synchrophasor-Based Closed-Loop Control Performance Requirements

- Performance of synchrophasor-based control applications with respect to PMU filtering
- Functional and performance requirements for control applications
- Verification through Hardware-In-the-Loop experiments
- High-resolution sampled value synchronized measurements versus synchrophasors



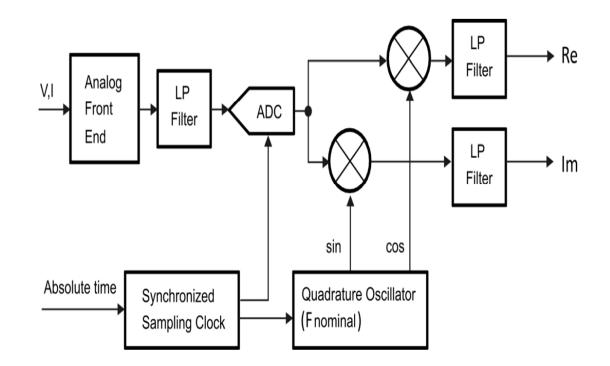


Towards Synchronized Sampled Value Measurements



Impact of PMU Signal Processing on Synchrophasor Measurements, Monitoring and Control Applications

- Growing penetration of Inverter Based
 Resources (IBRs) → grid dynamics not common in the past
- Need for accurate and high-resolution monitoring of these dynamics/transients
- Emerging synchrophasor-based closed-loop control applications – Use of fast actuators (e.g. IBRs)
- Signal processing within a PMU might compromise the accuracy of the monitoring as well as the control action and effect



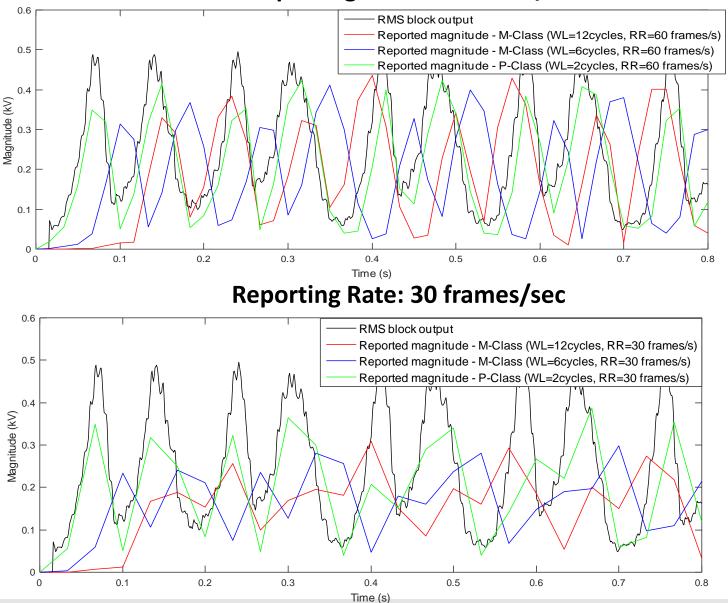
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Inverter PLL Instability Example

www.epri.com

Reporting Rate: 60 frames/sec



- Original signal contains a wide range of frequency components
- Reported voltage magnitude different than true RMS due to attenuation of all frequency components above the Nyquist frequency as well as their overlapping and aliasing
- P-Class PMU report closer to true RMS compared to M-Class
- Filter window length affects the output delay → phase-shift



References

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- PJM, "PJM Synchrophasor Data Quality", NASPI Synchrophasor Data Quality Management and Improvement Workshop, Atlanta, GA, Mar. 21, 2016
- GPA, "PDQ Tracker Phasor Data Quality Alarming & Reporting", presented at NASPI, Mar, 2016.
- EPG, "DataNXT Data Validation, Data Quality Reporting, and Data Conditioning", presented at NASPI, Mar, 2016
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- PingThings ARPA-E "A National Infrastructure for Artificial Intelligence on the Grid"



Together...Shaping the Future of Electricity

