NASPI and Synchrophasor Technology Progress

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NERC OC-PC Meetings, December 2013

NASPI North American SynchroPhasor Initiative

Overview

- Intro – why synchrophasors?
- Signs of progress
- Examples of synchrophasor on-line uses
- Examples of synchrophasor off-line uses
- What's next for synchrophasor technology
- What's next for NASPI

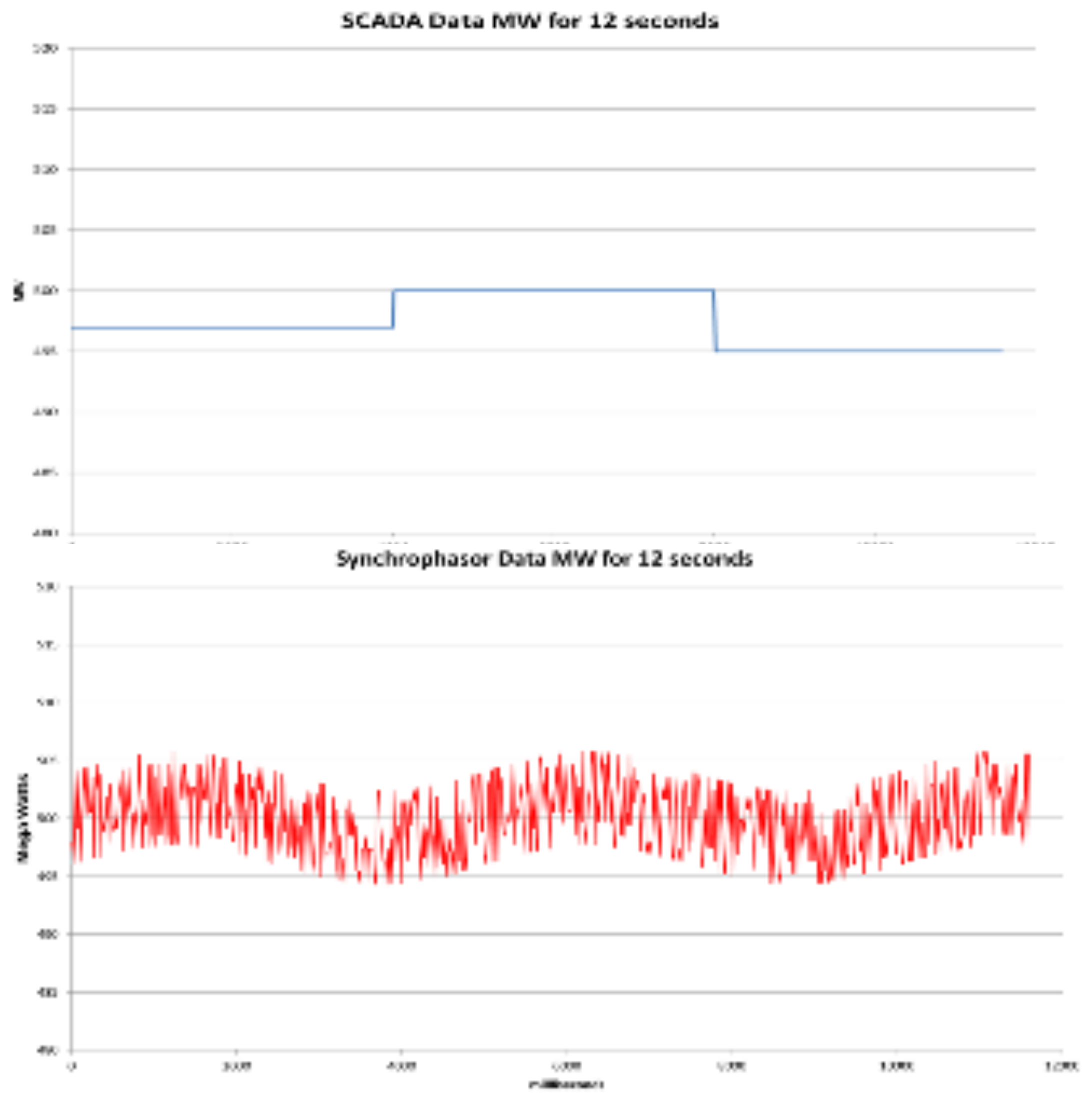
Why PMUs?

SCADA data

- 1 measurement every 2 to 10 seconds
- Time-stamped when the measurement arrives at EMS

Phasor measurement unit data

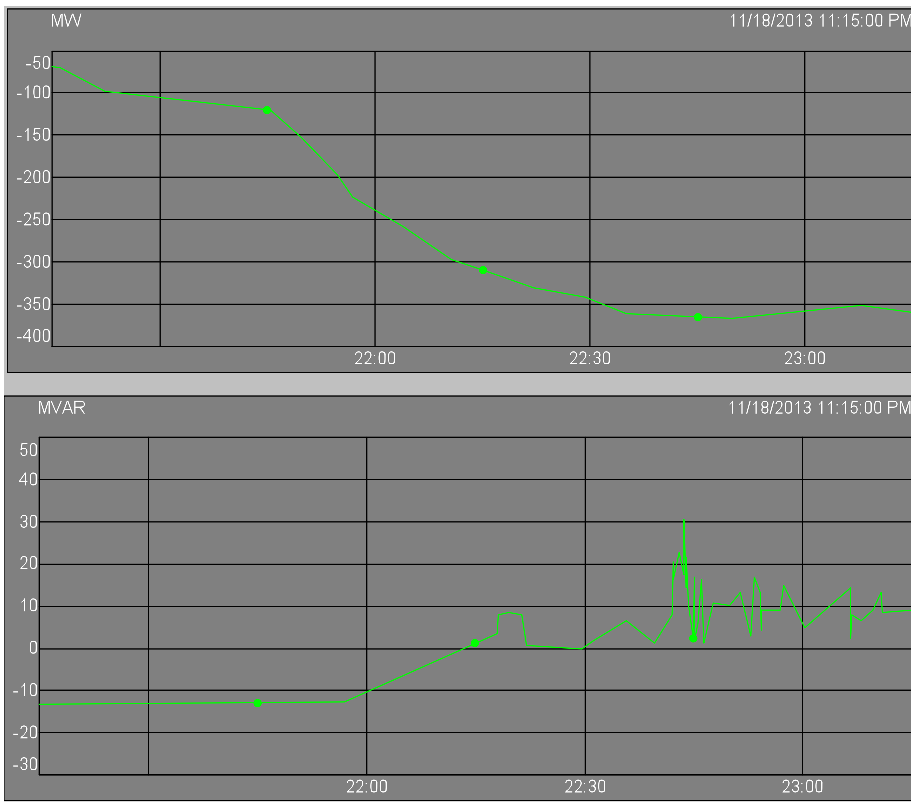
- Measures at 30 to 120 frames/second
- GPS time-stamped at measurement or calculation to one micro-second accuracy
- Time-aligned in phasor data concentrator
- Unprecedented visibility into system operations



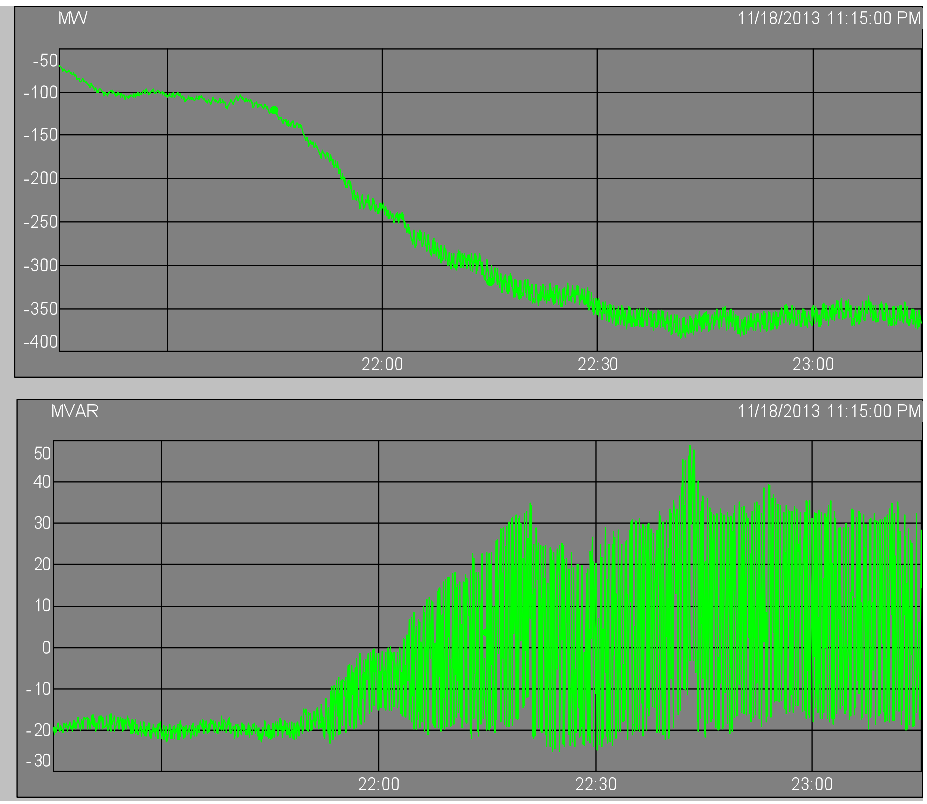
High time granularity improves visibility

Wind ramp in BPA area
11/18/2013 from 9:15 PM to 11:15 PM

SCADA Data



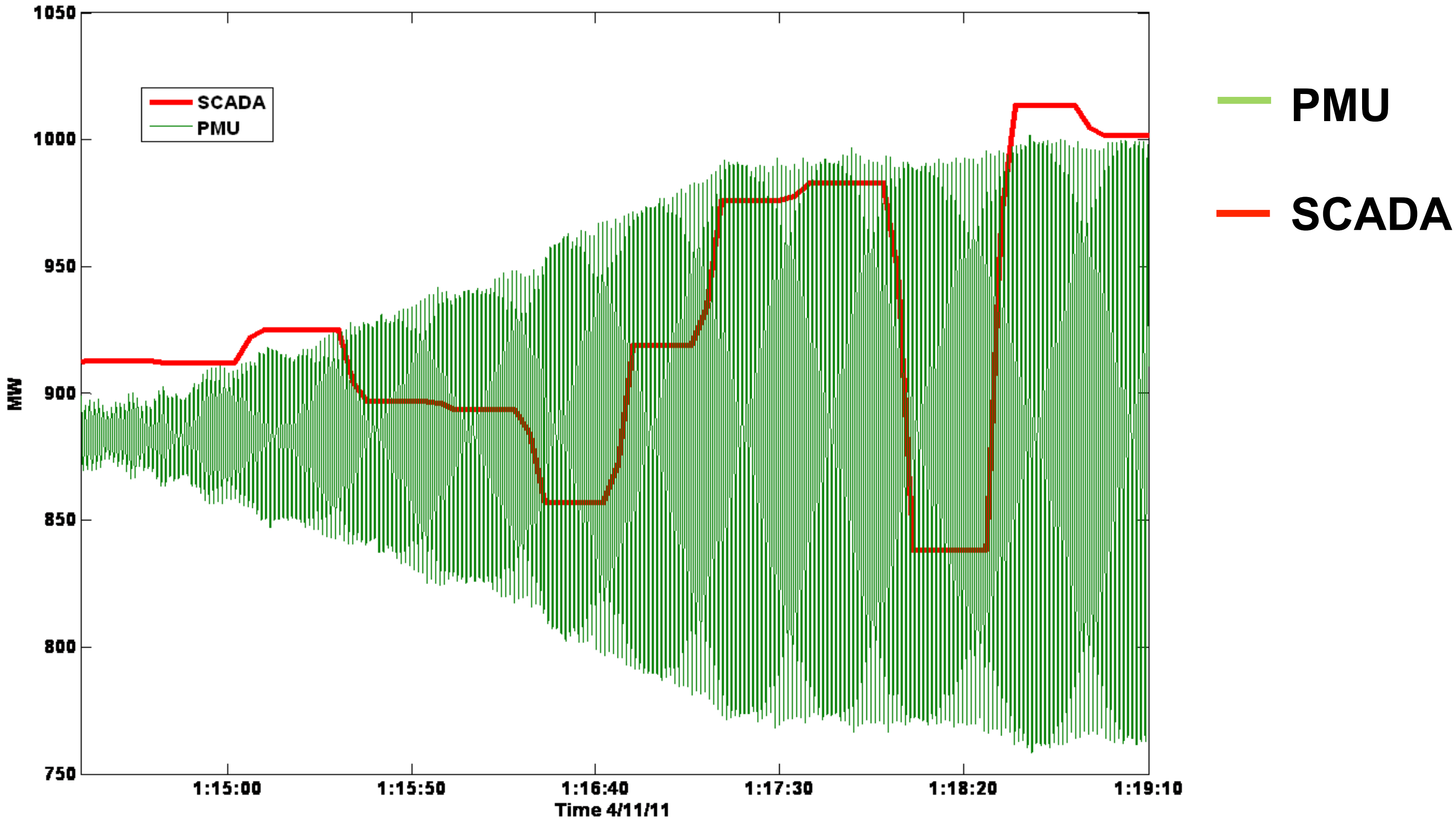
PMU Data



Source: BPA

Better visibility -- power station oscillation

Dominion system operators didn't see this un-damped oscillation (green = PMU) on SCADA (red) until they were notified by the power station operators.



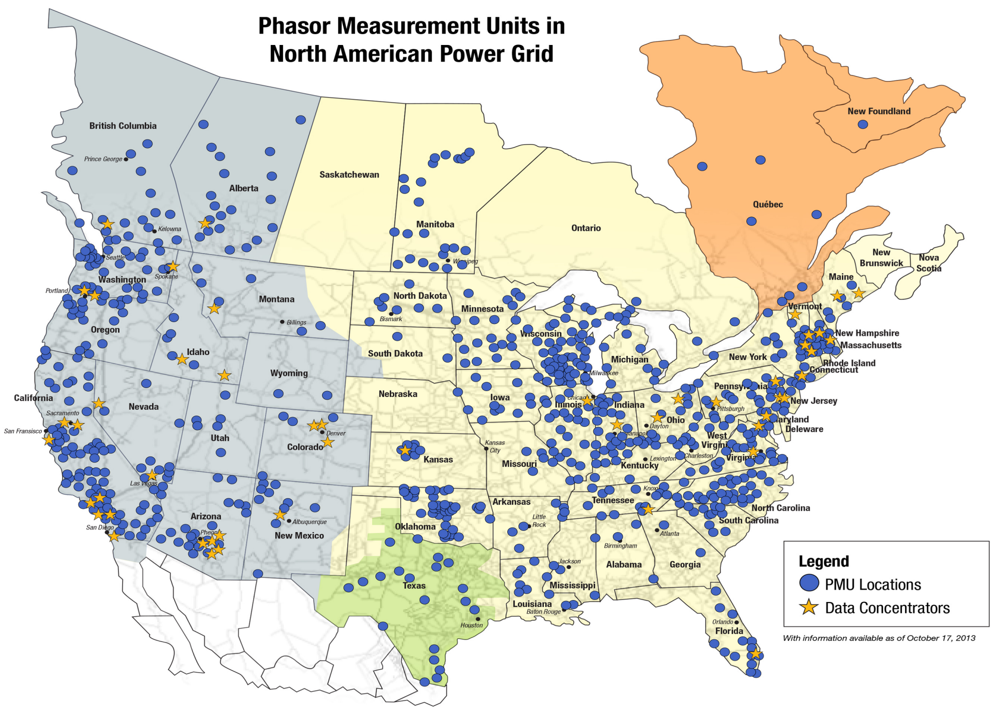
Source : Dominion Virginia Power

What's in a synchrophasor system?

- PMUs (can include upgraded relays, DFRs, etc.)
- Phasor data concentrators for data alignment and archive/historian function
- High-speed communications networks & secure IT infrastructure
- Applications
  - Real-time: wide-area visualization and situational awareness; frequency monitoring; voltage stability analysis; oscillation detection; mode monitoring; state estimation; islanding detection; automated controls; redundancy for SCADA/EMS
  - Off-line planning & analysis, model validation; automated event processing; event analysis; dynamic limits, alarms and alerts; operator training with event replays
  - Forensic event analysis

Got PMUs?

Almost 1,700 PMUs, most networked, most funded by $400+ million in federal ARRA Smart Grid grants and matching private sector funds

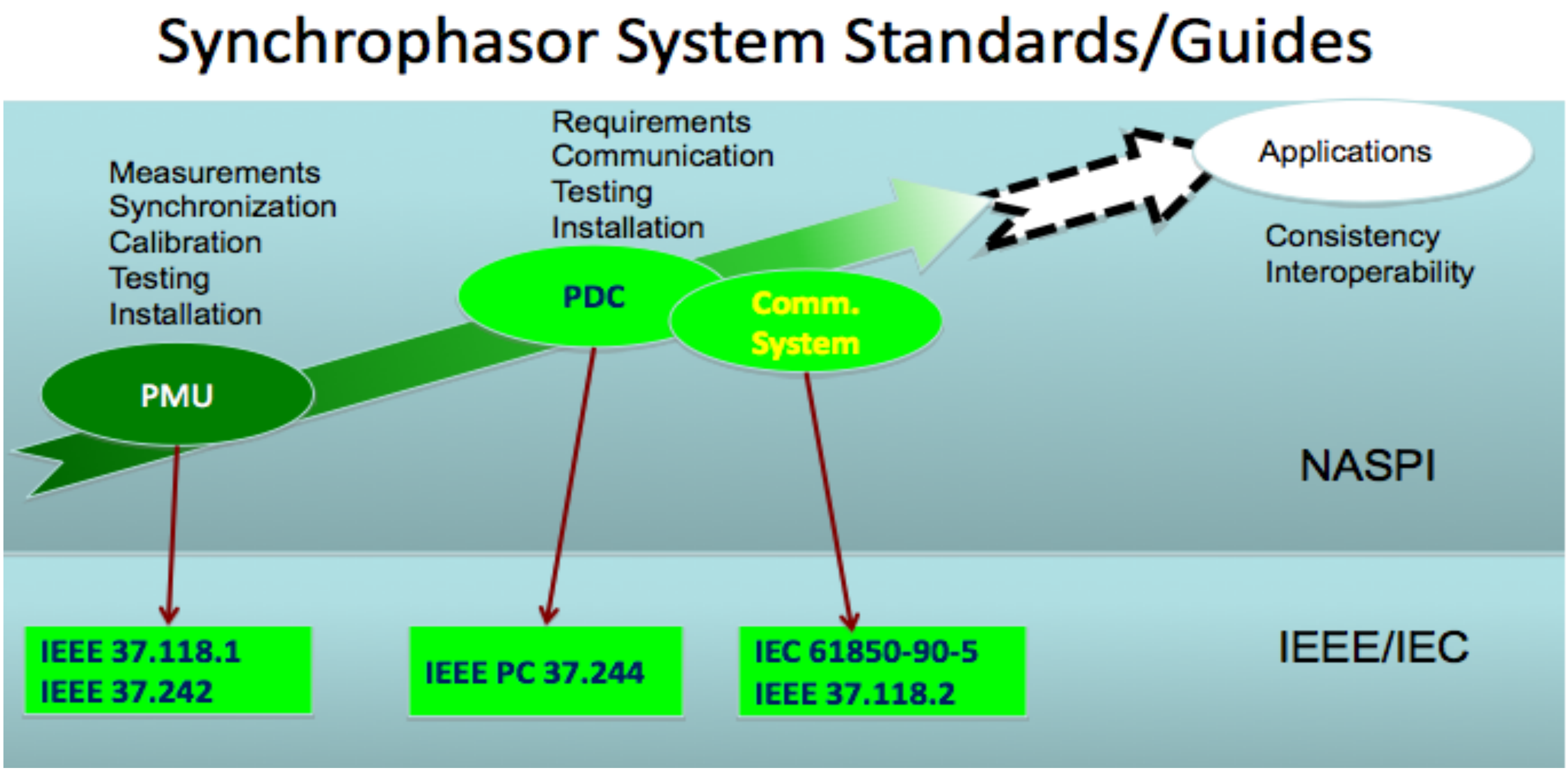


Major North America synchrophasor projects & PMUs

ATC	102
CCET (ERCOT)	45
Duke Carolinas	104
Entergy	49
FPL	45
ISO-NE	77
MISO	365
NYISO	48
PJM	314
WECC	522
Total North America	>1,671

Standards and the path to technology adoption

Technical standards are on the critical path for full technology adoption and maturity. There were no modern synchrophasor standards in 2006.



Key standards and guides
2007-2013, all initiated within NASPI

- IEC 61850-90-5
  - Addresses new communication requirements to take advantage of IEC 61850 environment
  - Joint efforts by IEC, IEEE, DOE, NIST, NASPI PSTT, users and vendors
  - Interoperability tests at proof-of-concept facilities have been essential
- IEEE C37.118.1 (from IEEE C37.118)
  - Measurement of and requirements for synchrophasors, frequency, & rate of change of frequency
  - IEC 60255-118-1 under TC 95: IEC synchrophasor measurement standard based on IEEE C37.118.1
- IEEE C37.118.2 (from IEEE C37.118)
  - Communication of phasor measurements, message format
- IEEE C37.238
  - The standard profile for use of Precision Time Protocol (IEEE 1588 Ver. 2) for transferring precise time over Ethernet for power system applications
- IEEE 27.242
  - Guide for synchronization, testing, calibration and installation of PMUs (balloted 3/12)
- IEEE C37.244
  - Guide for PDC requirements, communication needs & requirements, test techniques

NASPI evolution

2006 – NERC and US-DOE converted the Eastern Interconnection Phasor Project into the North American SynchroPhasor Initiative (NASPI) and NERC began funding NASPI and hosting meetings

– Less than 200 research-grade PMUs on the grid
– 175 members on listserv, 50 people at meetings

2014 – US-DOE begins funding NASPI, EPRI hosting meetings

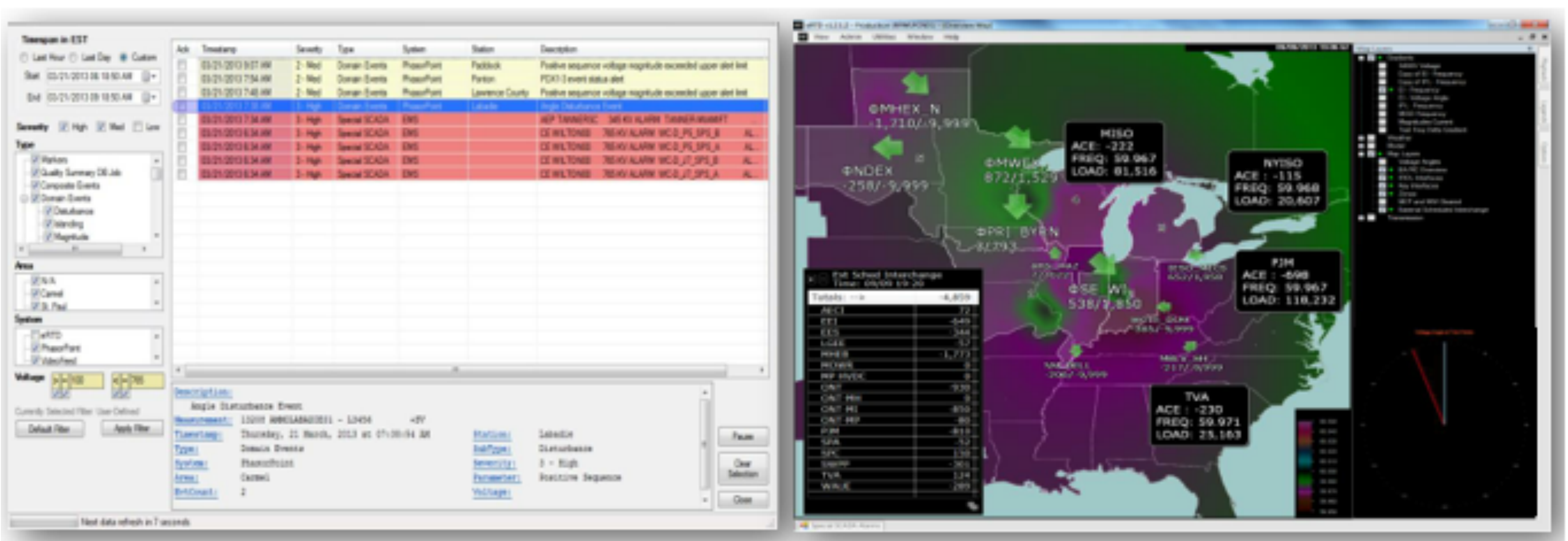
– Almost 1,700 production-grade, networked PMUs on the grid
– 850 members on listserv, 200+ people at meetings

Examples of synchrophasor on-line uses

- Wide-area visualization
- Oscillation detection
- Event detection, analysis and response; event replay
- Mode meter
- Angle difference monitoring
- Island detection
- Operator training
- State estimator improvements
- Fault location and analysis
- Back-up to EMS
- Back-up to AGC

Wide-area visualization and situational awareness

- Available now or coming soon to control rooms in and across NYISO, ISO-NE, WECC, BPA, ERCOT, MISO and PJM
- Combinations of
  – Wide-area view with dynamic and trending assessments
  – Operator dashboards with aggregated alerts into single display
  – Shared screens across multiple control rooms
  – PMU data may be integrated with EMS and other data sources

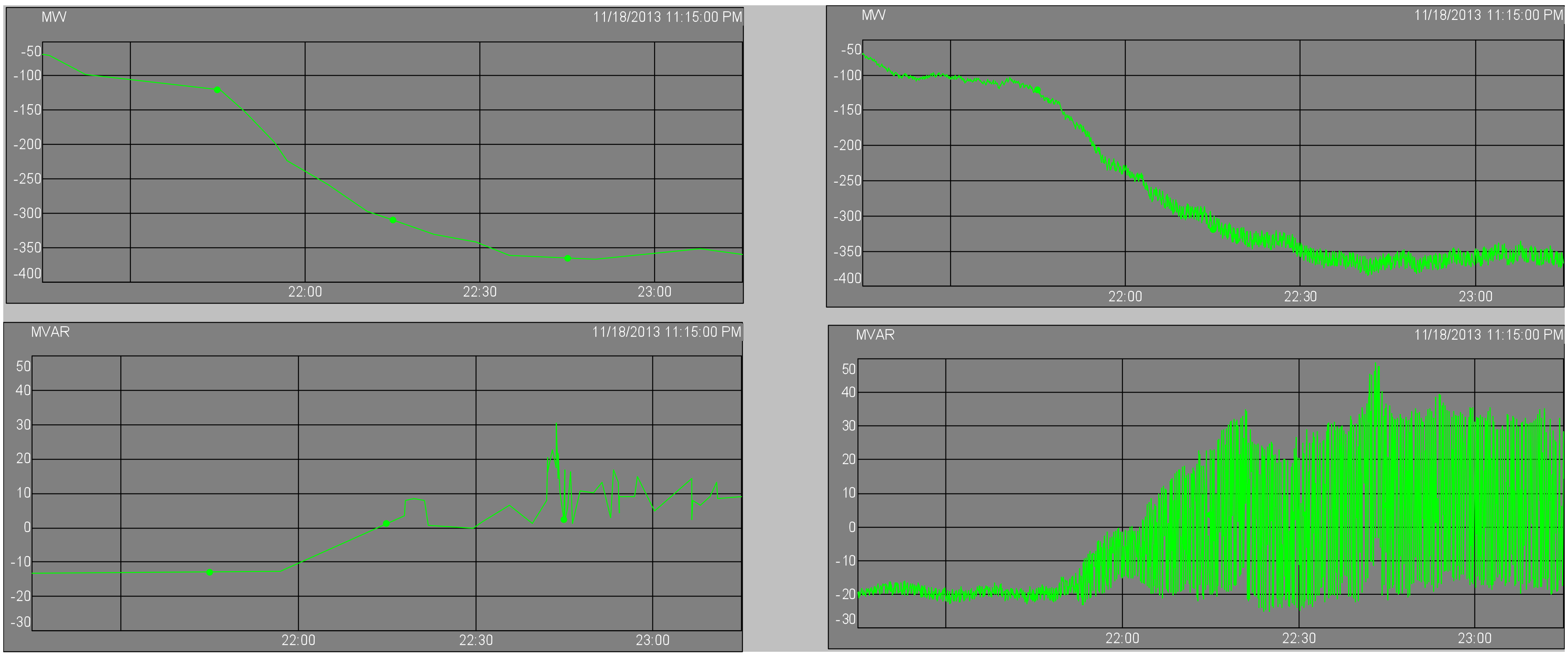


Source: MISO presentation at NASPI 10/13

Oscillation detection

“Oscillation detection and analysis is the premier application of PMU technology”
- Vickie Van Zandt

SCADA Data **PMU Data**



Source: BPA

Oscillation detection

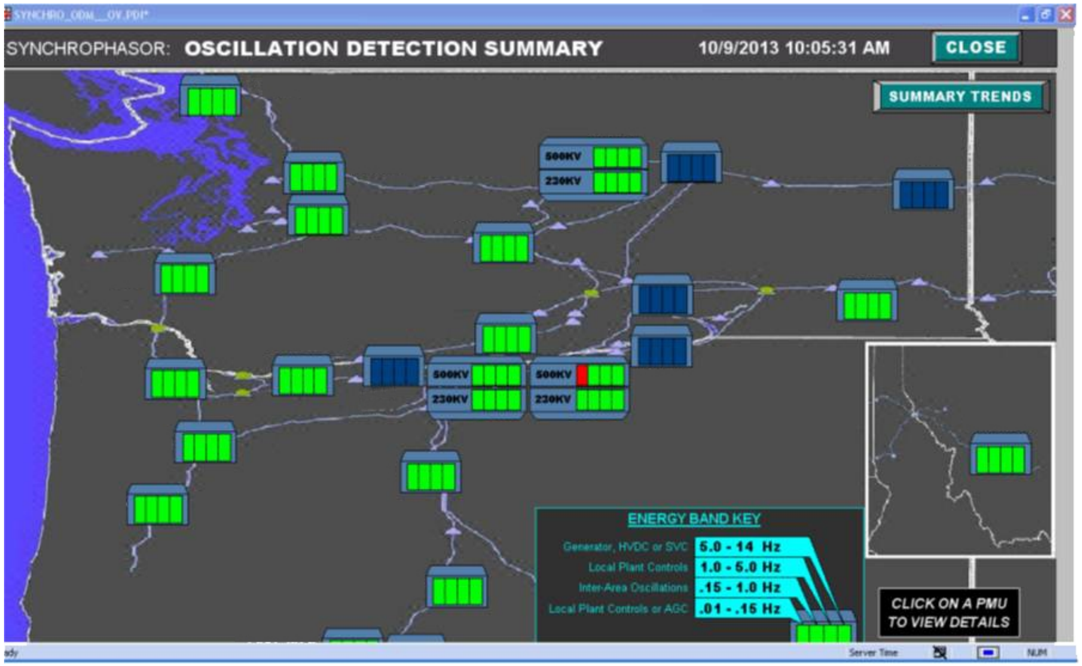
Operational in BPA control room starting October 1, 2013

- Scans voltages, power and frequency at interties, power plants, DC ties, wind hubs for sustained oscillations in four frequency bands

- Alarms when a sustained oscillation is detected

- Trend displays available for problem drill-down

- Engineering support applications for baselining and setting alarm thresholds

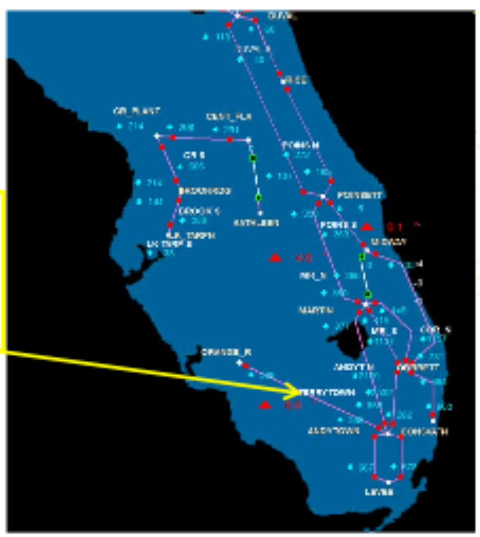


State estimation

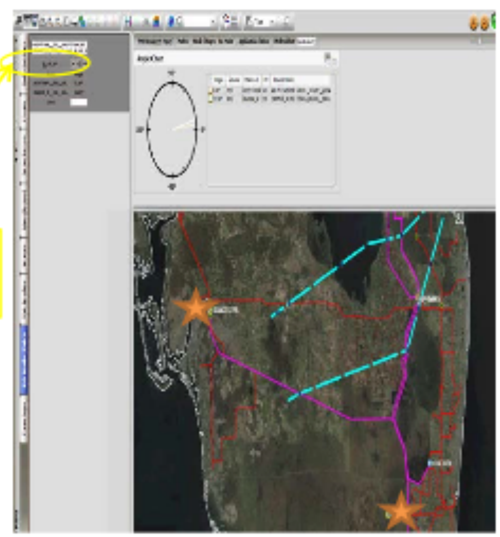
- Current or imminent use of synchrophasor data into state estimator at PJM, WECC, BPA, ISO-NE, Dominion, BPA, Duke Carolinas, NYISO
- Validation of state estimator at FPL, ATC, others
- Duke working on synchrophasor-only state estimation

FPL

Angle difference calculated by State Estimator (SE) is 6.6°



Real time PMU angle is 6.39°

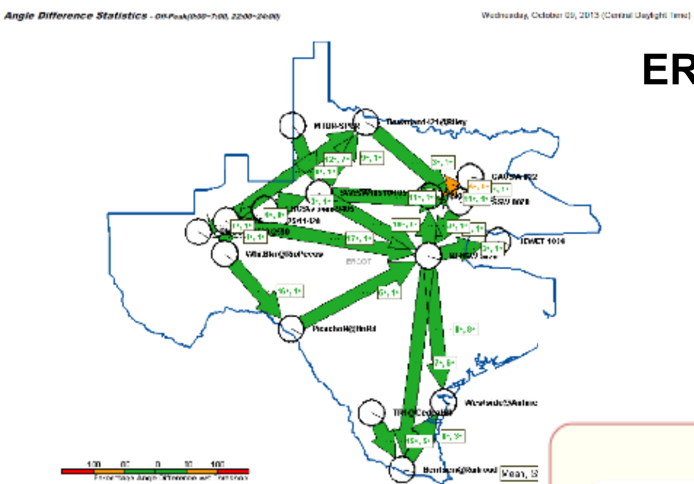


❖ Compared Key 500kV Stations PMU measured angle difference V.S. State Estimator estimated

Source: FPL presentation at NASPI, 10/13

Phase angle monitoring

Real-time phase angle monitoring and difference displays in use in WECC, PJM, CAISO, BPA, MISO, ERCOT (below left), FPL (below right)



ERCOT

FPL – monitor phase angle reclosing

Before

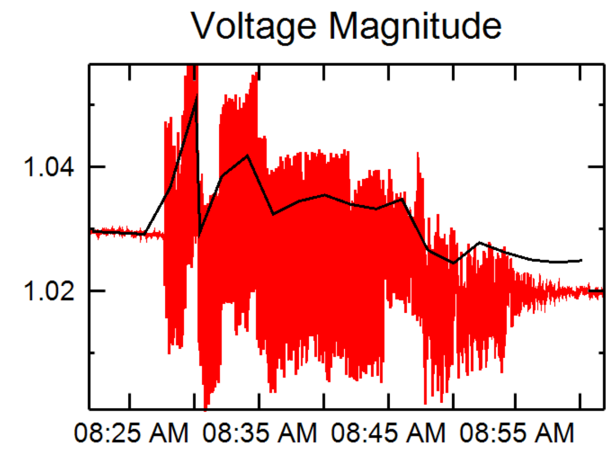
- Phase angles are **ESTIMATED** and dependent on accuracy of the State Estimator (SE) application within the Energy Management System (EMS)
- Phase angles are critical information for operators

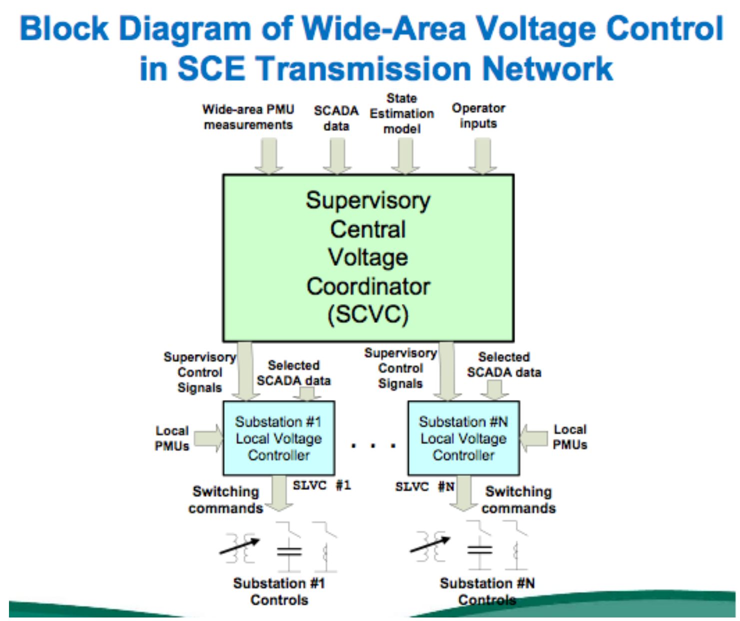
Current

- Phase angles are **MEASURED** directly by PMU's
- Operators have the ability to see the phase angle data via enhanced graphical and dynamic displays

Voltage stability monitoring and control

- Voltage stability monitoring now in use or imminent at ISO-NE, WECC, CAISO, MISO, NYISO, OG&E, others
- OG&E, BPA, ERCOT tracking wind plant-related voltage oscillations
- SCE using PMU data with automation to relieve operators from repetitive tasks and improve system quality and utilization. Local substation voltage control uses local PMU measurements.
- Multi-level hierarchical voltage control of transmission network coming soon to SCE; already in use in Europe.





Top -- OG&E, SCADA v. synchrophasors at windfarm, Disturbance analysis at OG&E, Georgia Tech 6-13
Bottom -- SCE – Wide-area voltage and VAR control of SCE transmission network, JSIS 10/15/13

Other operational uses of PMU data

- OG&E
  - Disturbance and equipment mis-operation analysis
  - Fault location using VAR flows
  - Failing equipment identification
- Duke
  - Identified oscillations affecting a nuclear unit as caused by a nearby hydro unit
  - Analyzed voltage dips created by generator AVR misbehavior, that couldn't be seen by SCADA
- ATC – determining causes of grid disturbances so operators can answer customer questions about faults and PQ
- ERCOT – uses PMU data to verify load response to DR calls
- WECC, California ISO and BPA – model validation studies of disturbance events

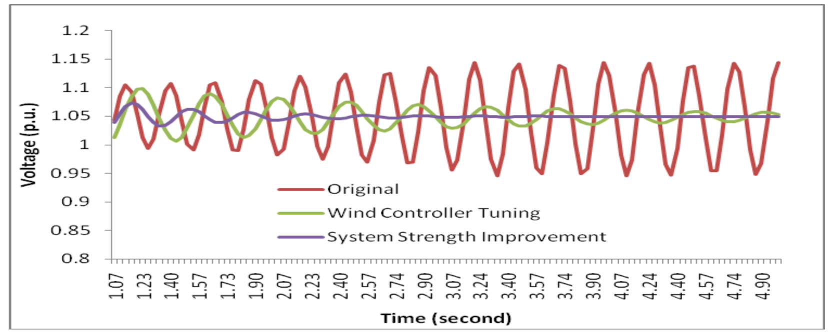
Examples of synchrophasor off-line uses

- Model validation
  - Power plant validation under MOD standards
  - Wind plant models
  - State estimator validation
- Oscillation detection
- Frequency analysis – BAL standards
- Manage transmission throughput and limits
- WECC event library of synchrophasor data
- Disturbance analysis
- Discovery of failing equipment and mis-operations
- Replay grid events for operator training

Model validation

Examples

- ERCOT – tune wind plant model
- NYPA
  - SVC unit
  - Marcy STATCOM



Source: ERCOT – Blevins at NASPI model validation workshop 10-13

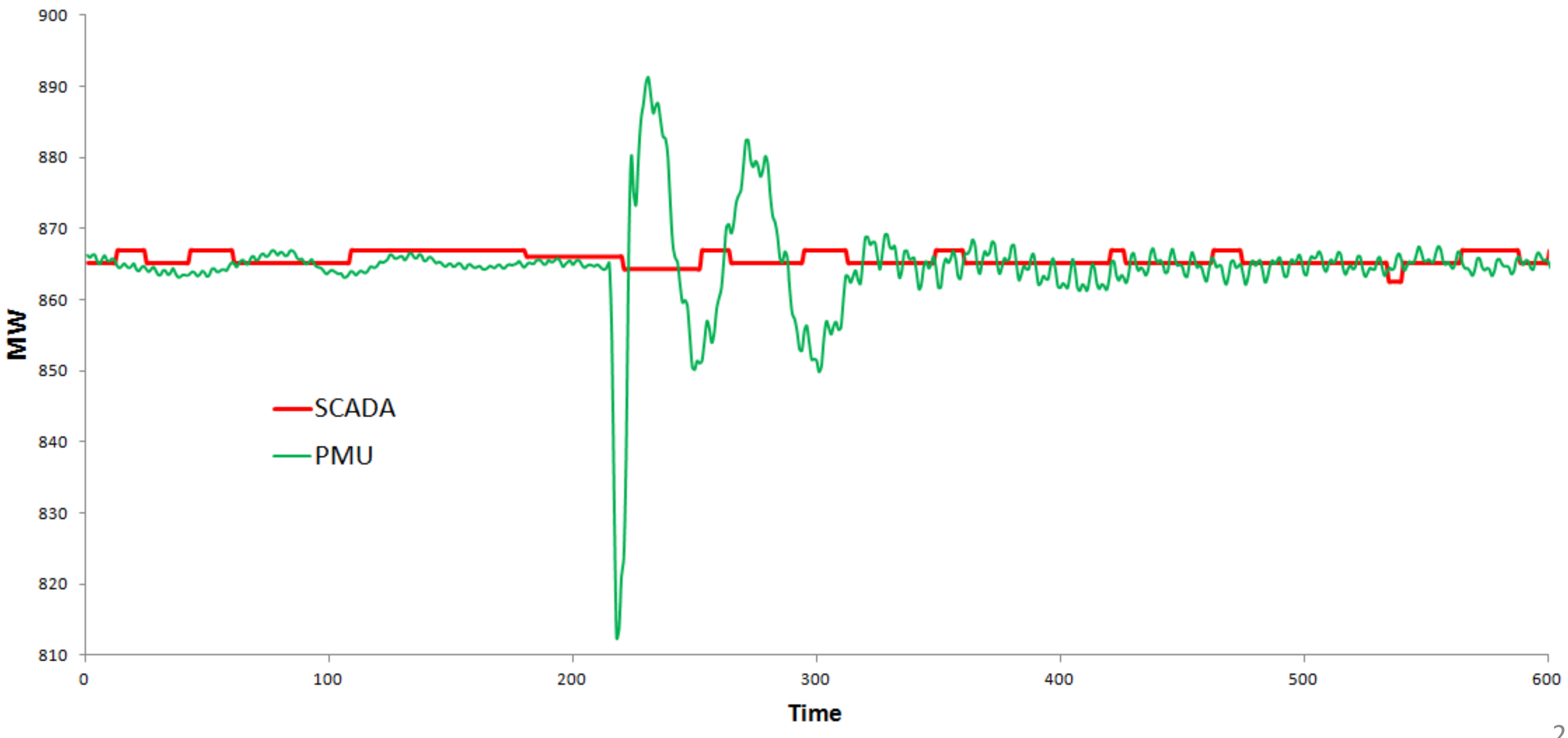
- BPA has 10+ years of using PMUs for generator model validation, covering 20+ GW of its generation capacity
- ISO-NE – HVDC unit and Millstone nuclear unit
- OG&E with NREL & UVIG – wind and PV plant models

BPA and PJM require all new generators to have a PMU at the point of interconnection with the BPS for this purpose.

Coming soon – use synchrophasor data for <u>system</u> model validation and load model improvements

Three-phase fault near power station

This three-phase fault on a 230 kV line close to a generator couldn't be seen in the SCADA trace (red), but the fault and unit response is clear in the PMU data (green). This lets engineers validate generator models, determine if generator controls are operating properly, and detect and respond to oscillations from the plant.



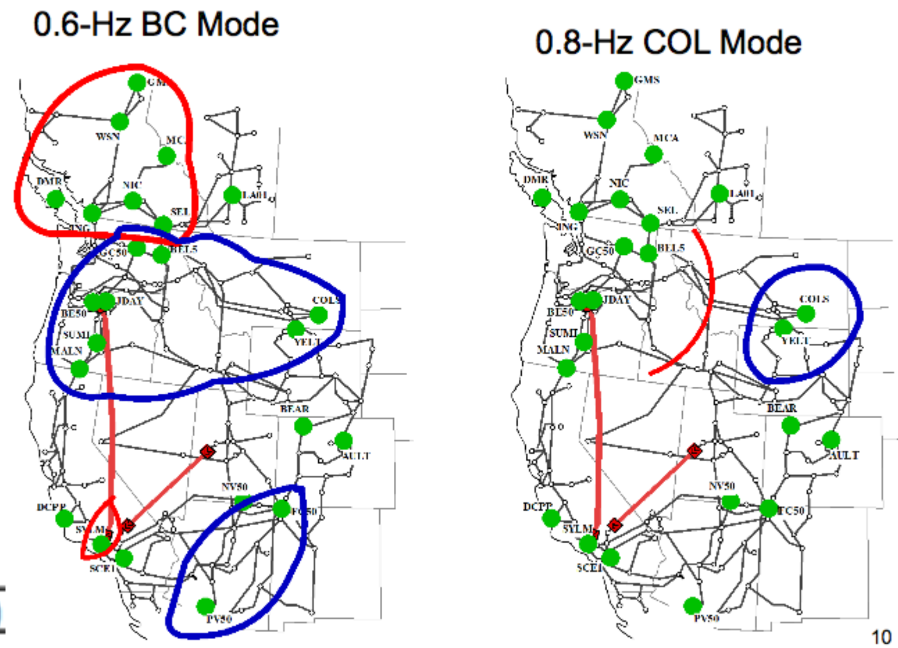
Source: Dominion Virginia Power

Analyze oscillatory modes and events

In use at WECC, BPA, ISO-NE, ERCOT, PJM, MISO, CAISO, Duke Carolinas, FPL, others

Recent WECC discoveries about interconnection-wide modes

[Source: JSIS meeting 10/13]



Mode	Freq. (Hz)	Shape	Interaction Path(s)			
NS A	0.25	Alberta vs System. BC and PNW swing with Alberta	Alberta Interconnect. COI. Cust.	Alberta	A	An Alberta trip causes NSA and NSB to combine into one NS mode with reduced damping. Need to understand damping better.
NS B	0.38	Alberta vs (BC + N. US) vs (S. US).	Alberta Interconnect. COI. Cust. Boundary.	Wide-spread. PDCI	A	This is the most wide spread mode in the system. Need to understand damping better.
EW A	0.5	(SW US) vs (Mid W. - CO)	Unkown	Unkown	C	Need PMUs in east part of loop.
MT	0.55 to 0.8, 0.8 typical	MT vs system.	Garrison.	Colstrip	B	Sometimes MT swings against BC.
BC	0.6	BC (Kemano) vs system. Ripples to S. Cal.	Cust. ?	Kemano?	B	Strong interactions with PDCI and PNW.
EW B	0.7	Unknown	Unkown	Unkown	F	

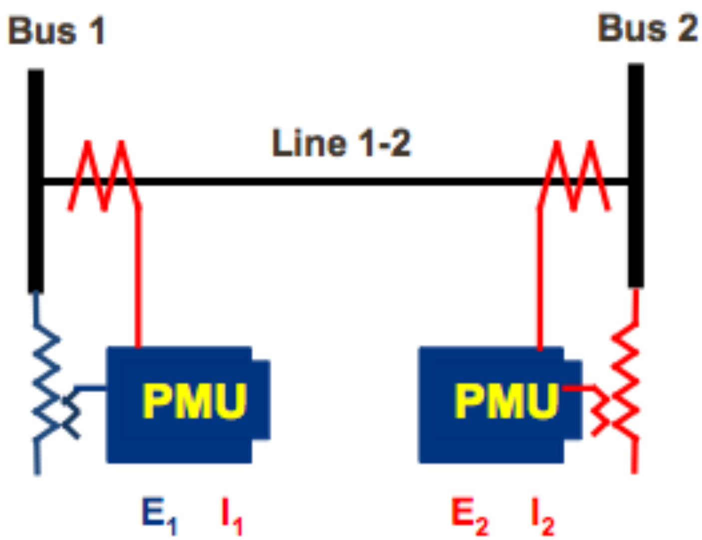
NOTE: "Grade" is a measure of how well we currently understand this mode.

Manage transmission throughput

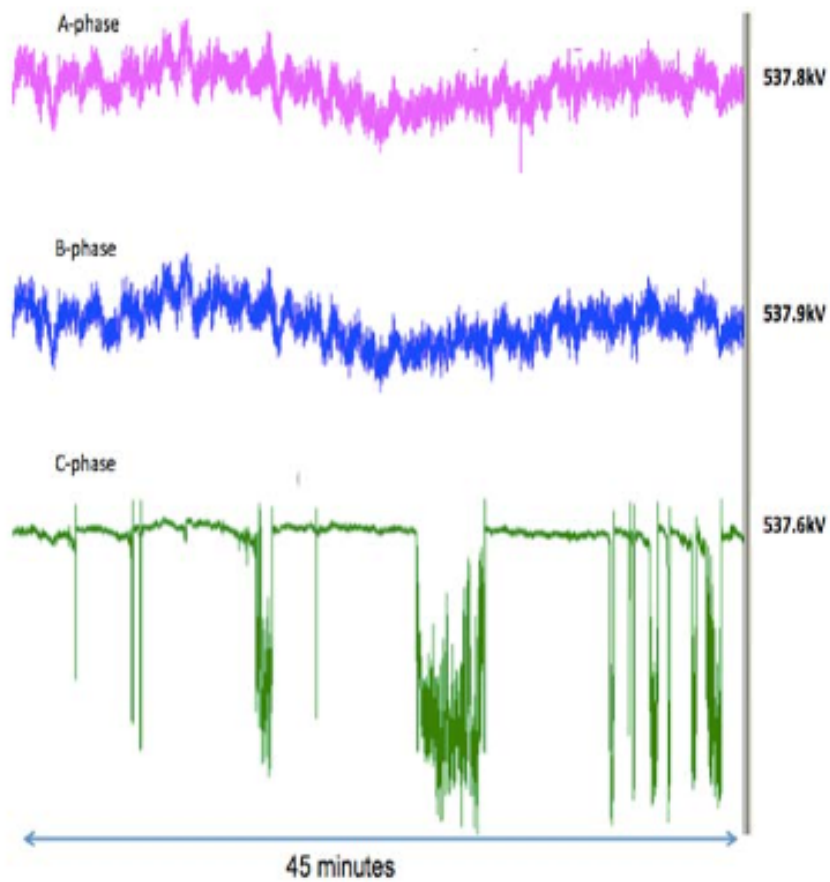
- Proposal pending in WECC to increase throughput on the California-Oregon Intertie by 100 MW, based on synchrophasor data-based recalculation of the COI voltage stability limit and synchrophasor data-driven reactive power management to stabilize the grid in case of disturbance. This re-rating could yield well over $35 million in benefit over decades of use – without new capital investment.
- Many other major transmission paths could benefit from similar synchrophasor-based re-rating analysis.
- Synchrophasor data and analytics can be used for real-time line ratings, congestion management, and to increase renewable generation throughput.

Calibrate instrument transformers

Dominion is using PMU data to calibrate current and voltage transformers to better determine network performance during normal and abnormal conditions – and spotted imminent equipment failure.



A field example of PMU records indicating imminent failure of the voltage transformer in phase-C four days before the failure alarm on the line relays were triggered.



Dominion presentation at NASPI, 10/13

What's ahead for synchrophasor technology?

APPLICATIONS

- Baselining and data mining
- Set alarms and alerts
- Calibrate state estimators and further integrate phasor data
- Congestion management
- Automated controls for stability management
- Phasor data-based GIC detection
- Operator training using synchrophasor data in simulators

INSTITUTIONAL

- Keep improving PMU data quality and delivery reliability
- Eastern Interconnection Data-Sharing Network to include synchrophasor data
- Improve PMU conformance to standards and interoperability
- More technical standards, protocols and guidelines (including PMU and PDC installation and configuration guidance)
- More open-source software and sharing
- PMUs that can detect GPS failure and use alternate time sources for extended time periods
- High-security infrastructure as phasor data applications are used for mission-critical purposes
- Consider the role of high-speed grid data and analysis in NERC reliability standards

What's next for NASPI?

- New roles for DOE, EPRI and NERC
- Updated mission and focus
  - Accelerate recognition of benefits and value from current synchrophasor system and technology investments, particularly control room solutions
  - Continue joint information-sharing and problem-solving efforts, including open-source software, data delivery and quality improvements
- Continued mainstreaming of synchrophasor technology, activity and expertise
  - NERC, NATF, NAGF, WECC-JSIS
  - Technical standard-setting bodies (IEEE, IEC)
  - Maybe testing and certification processes
- Same project manager…
- Reassess progress, value and funding in late 2015

Some useful resources

- NASPI at www.naspi.org
- NASPI Model Validation Technical Workshop
- NASPI Visualization Technical Workshop
- NASPI-NREL Renewables Integration Technical Workshop

  see https://www.naspi.org/techworkshops

- NASPI Work Group meeting presentations

  https://www.naspi.org/meetings

- WECC JSIS materials

  https://www.wecc.biz/committees/JSWG/default.aspx

Closing thoughts

We've come a long way since 2006 toward our goal of advancing synchrophasor technology development and deployment. NERC sponsorship was critical for that progress – thanks!

But there's still a lot left to do to realize full value out of the investments already made, and achieve technology maturity that enhances grid reliability and economics.

NASPI will continue to be a facilitating and accelerating force in this effort.

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