Overview of synchrophasor technology and uses

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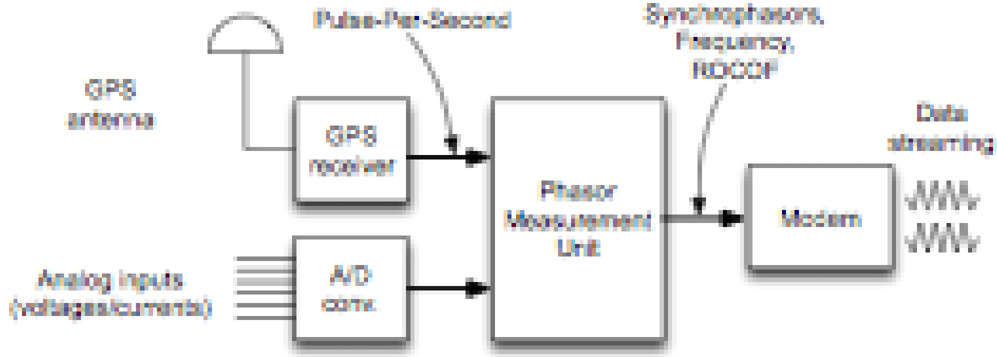
What's a PMU?

PMU = a device that produces synchronized measurements of phasor (its amplitude and phase), frequency and ROCOF from voltage and/or current signals based on a common time source (often UTC-GPS).

- Signal input -- 3 input channels per phasor; multiple PMUs/substation
- Timing input – from GPS, IRIG-B, etc.
- Signal processing -- measurement and phasor calculation algorithms
- Data output per IEE/IEC standards
- Data storage
- Data output to high-speed communications network



Mario Paolone, IEEE-PES Tutorial, 7/13

Typical PMU rack installation

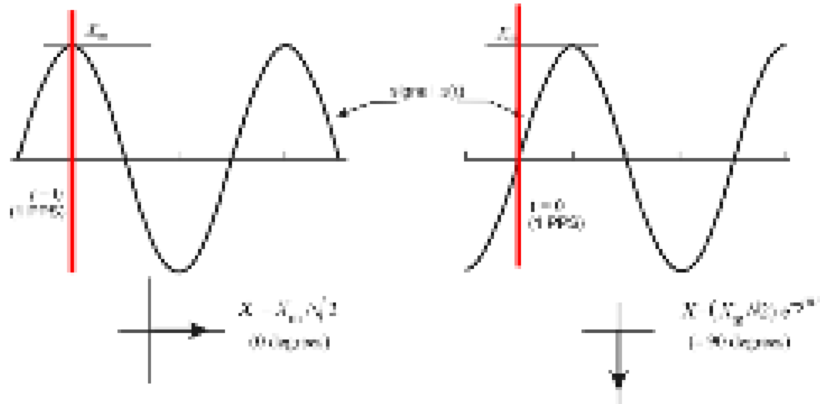
Front Rear

Ken Martin, IEEE-PES Tutorial, 7/13

What’s a synchrophasor?

IEEE Std. C37.118-2011 definition:

$$x(t) = X_m \cos\left(2\pi f_0 t + \varphi\right) \Leftrightarrow X = \left(X_m / \sqrt{2}\right)e^{j\varphi}$$



- A phasor is a complex number that represents both the magnitude and phase angle of the sine waves found in electricity. Phasor measurements that occur at the same time (time-synchronized) are called synchrophasors.
- PMUs measure voltages and currents at dispersed locations on the grid to produce (calculate) time-stamped voltage and current phasors and determine the phase angles between points on the grid; phase angle are good indicators of stress on the grid.
- PMU functionality exists in several devices including DFRs and high-speed relays.

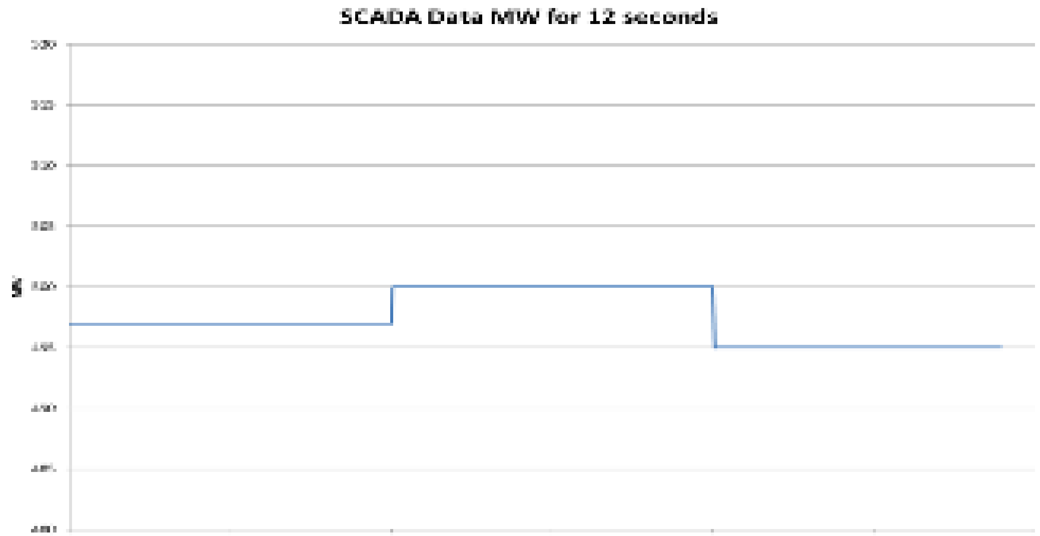
Why PMUs?

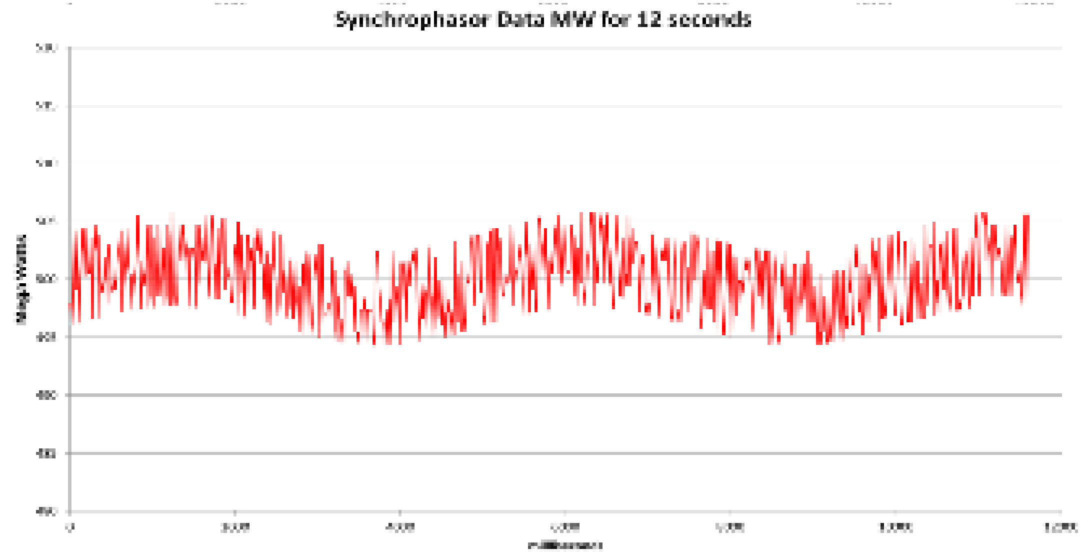
SCADA

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

PMU

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



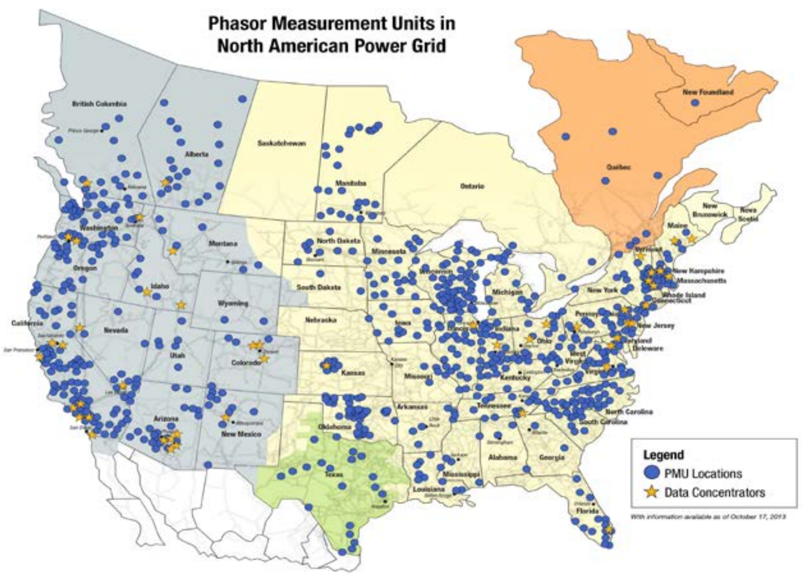


What's in a synchrophasor system?

- PMUs (or upgraded relays, DFRs, etc.)
- Data alignment and archive/historian phasor data concentrators
- 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; state estimation; 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; frequency response tracking and management

Got PMUs?

Over 1,000 PMUs, most networked, most funded by federal ARRA + matching funds



Major North America synchrophasor projects & PMUs

ATC	92
CCET (ERCOT)	41
Duke Carolinas	98
Entergy	49
FPL	45
ISO-NE	77
MISO	148
NYISO	40
PJM	56
WECC	481
Total North America	1,127 +

So how are others using PMUs?

Here are a few examples

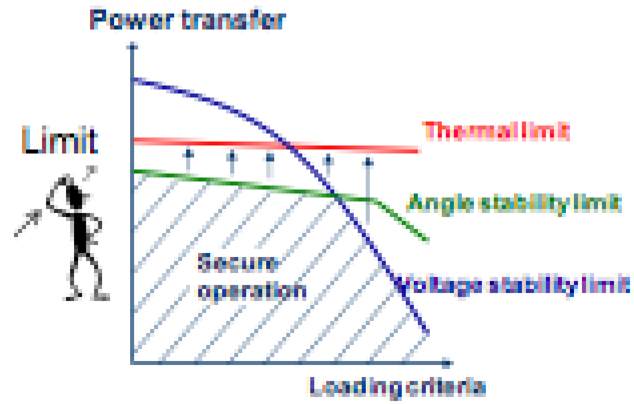
Wide area situational awareness and more -- WECC, with 481 PMUs

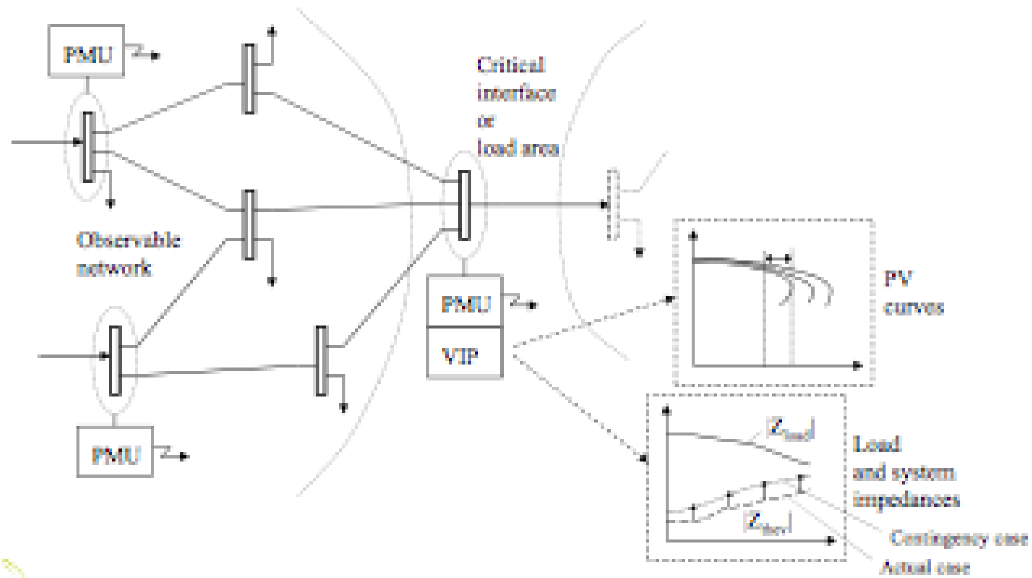
- Real-time wide-area situational awareness into every TO control room
- Use grid condition info at key locations across the interconnection for:
  - Dynamic voltage stability
  - Frequency monitoring
  - Oscillation detection
  - Mode meter
  - Islanding detection
  - Model validation
  - Post-event analysis
  - Baselining studies about prevailing grid conditions (esp phase angles) and determine threshold settings for alerts and alarms

Transmission operations

Calculate real-time ATC and transmission limits to maintain system security

- Real-time state estimation
- On-line voltage stability monitoring
- Angle stability monitoring
- Frequency rate of change monitoring

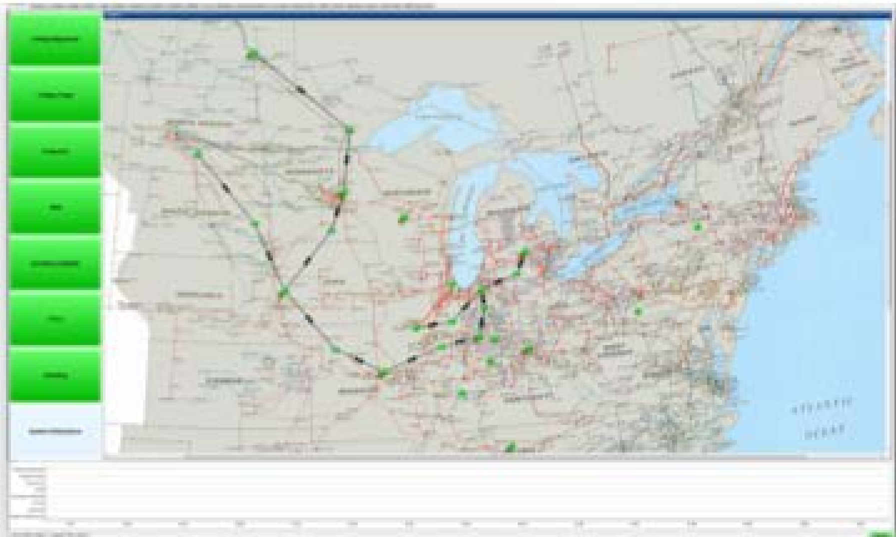


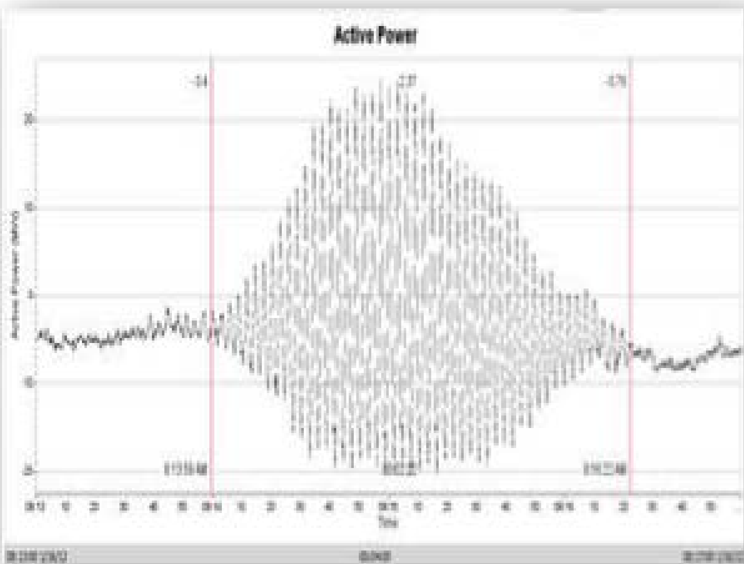


Kjetil Uhlen, NTNU, IEEE-PES GM Tutorial 2013

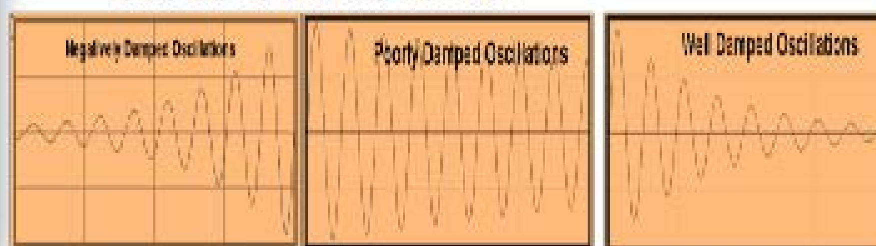
MISO – wide-area monitoring & visualization

- Uses PhasorPoint software
- Helps verify Phase Angles are within thresholds
- Helps alert operators when oscillations not being damped



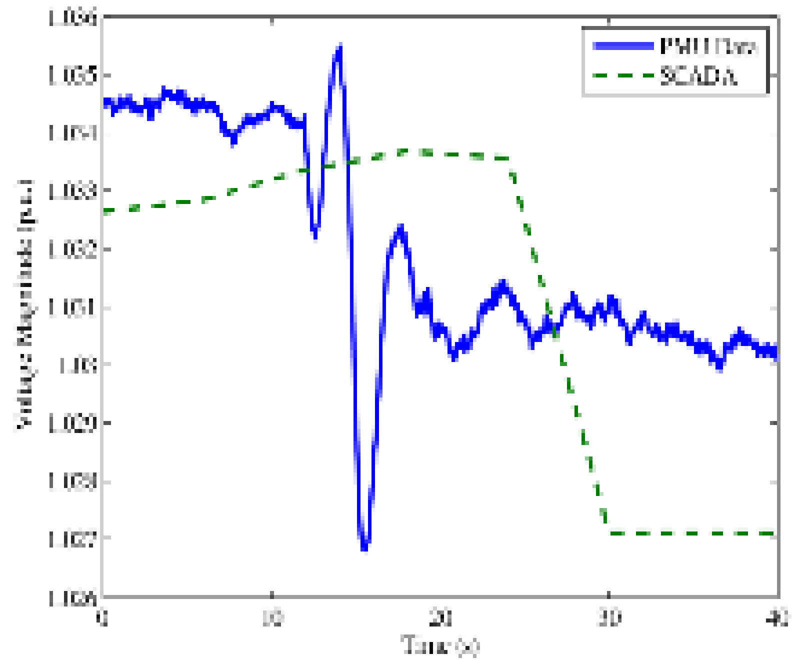


- PowerTech Voltage Stability Assessment Tool (VSAT) and Transient Stability Assessment Tool (TSAT) monitor the dynamic state of the Grid



Dynamic visibility

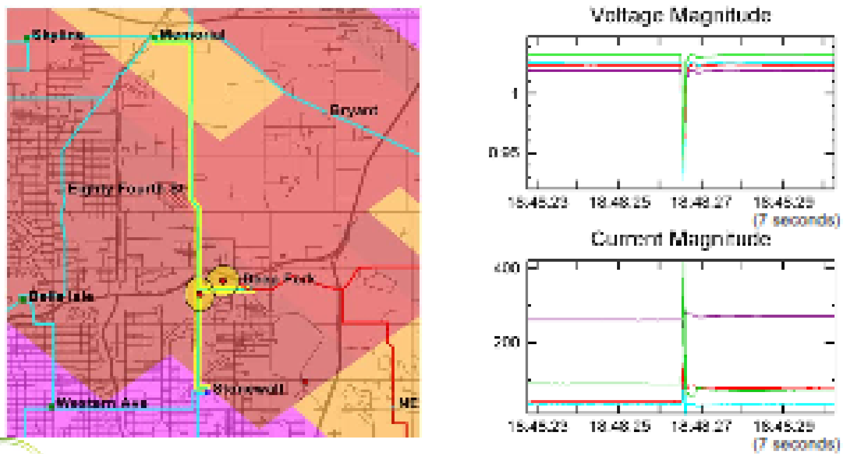
- Better understand frequency response and system dynamic performance
- Particularly valuable for integrating renewable generation, e.g. voltage oscillations caused by wind plants
- Use phasor data to improve accuracy of generator models and system models



Comparison of SCADA vs. PMU data for a loss-of-generation event

More transmission operational uses – OG&E

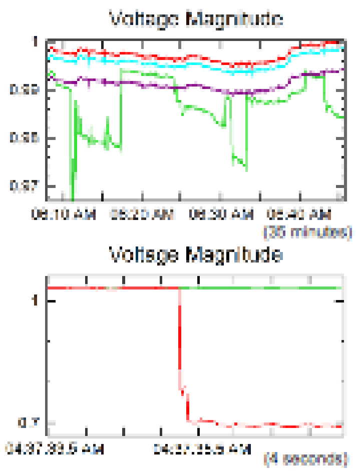
Disturbance/Misoperation Analysis



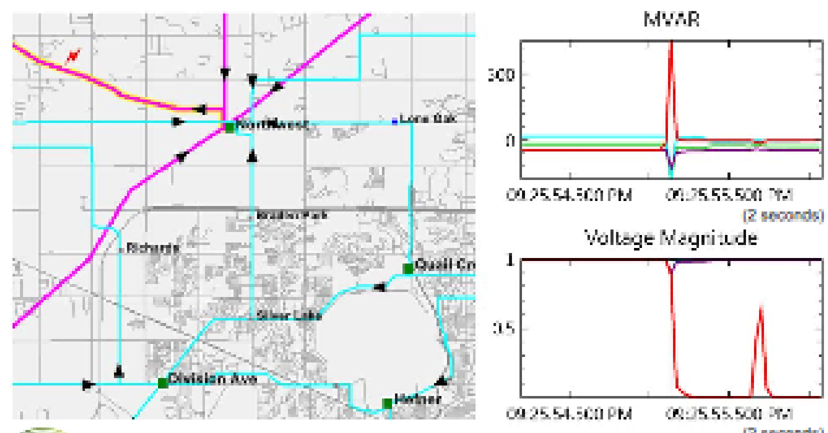
Fast diagnosis of real-time operational events to answer customer questions

Problem #3 – Failing Equipment

- Discovered many loose connections in the potential circuits at fuses or terminal blocks
- This has caused misoperations in the past (relays get confused)
- Proactively finding these helps prevent future outages and misoperations



Fault Location Using VAR Flows

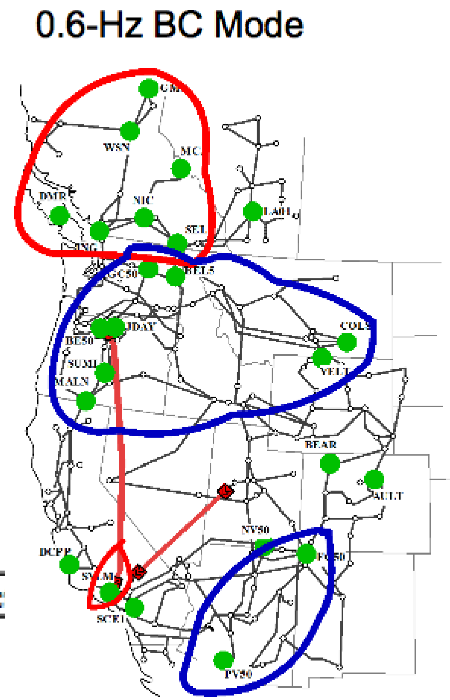


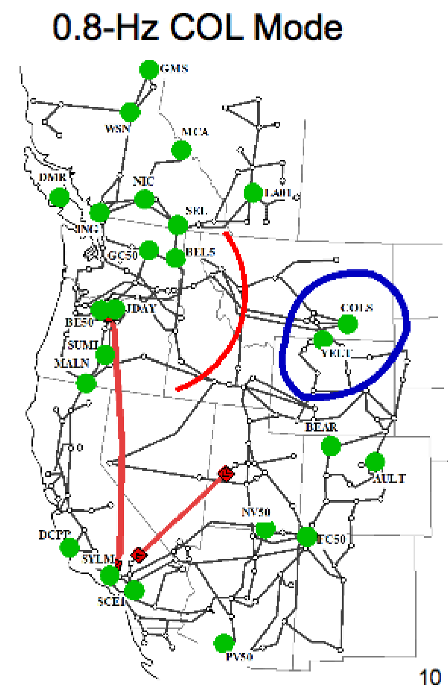
Examples from OG&E presentation to NERC OC, 2012

Analyze oscillatory modes and events

Recent WECC discoveries about interconnection-wide modes

[JSIS meeting 10/13]





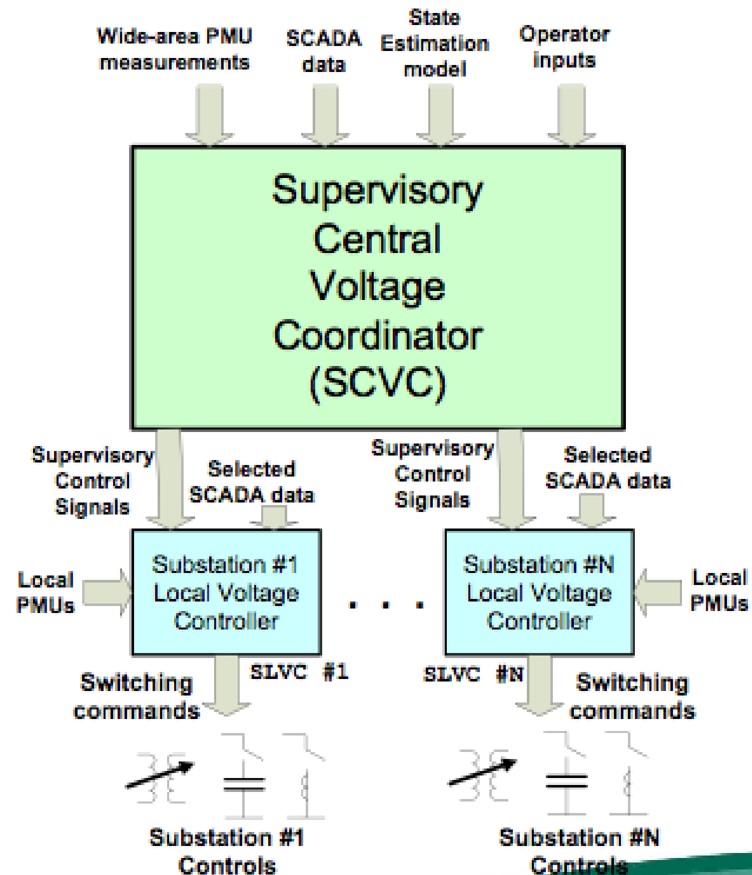
Mode	Freq. (Hz)	Shape	Interac			
NS A	0.25	Alberta vs System. BC and PNW swing with Alberta	Alberta Interconnect. COI. Cust.	Alberta	A	to combine into one NS mode with reduced damping. Need to understand damping better.
NS B	0.38	Alberta vs (BC + N. US) vs (S. US).	Alberta Interconnect. COI. Cust. Boundary.	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.

SCE -- Automated voltage control

- 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 also being done in Europe at primary (generators, SVC), secondary (regional) and tertiary (system-wide voltage optimization).

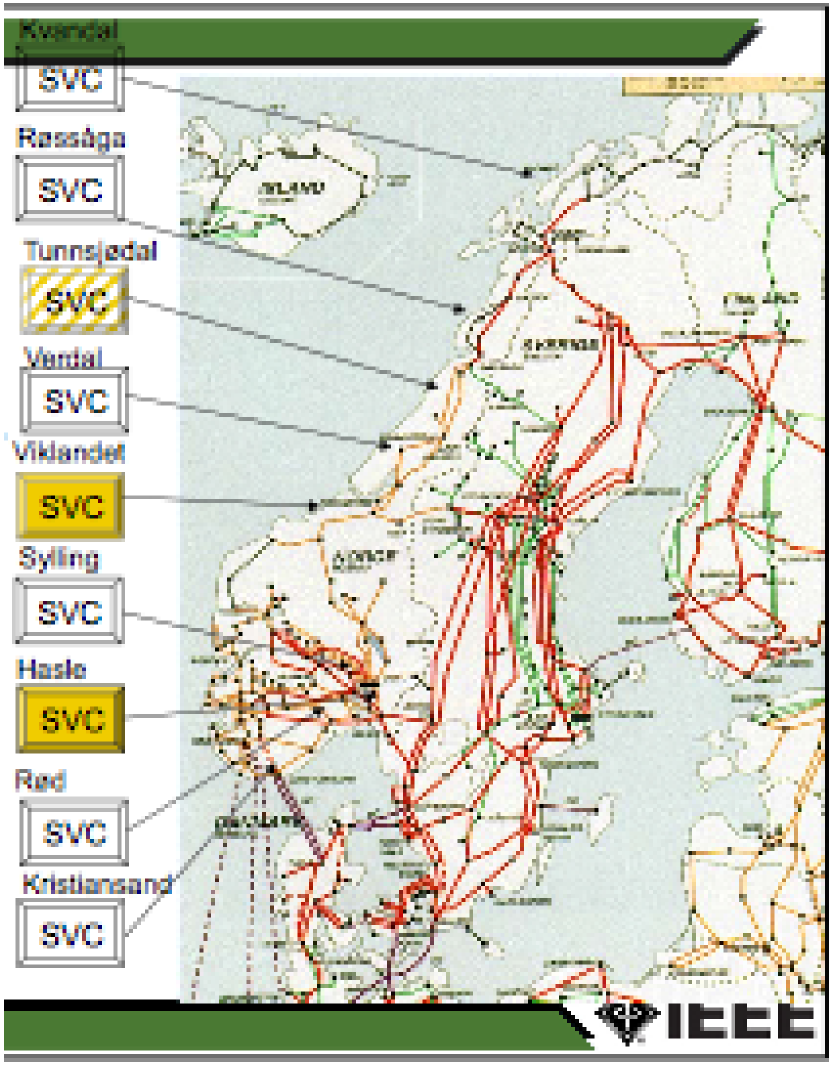
Block Diagram of Wide-Area Voltage Control in SCE Transmission Network



SCE – Wide-area voltage and VAR control of SCE transmission network, JSIS 10/15/13

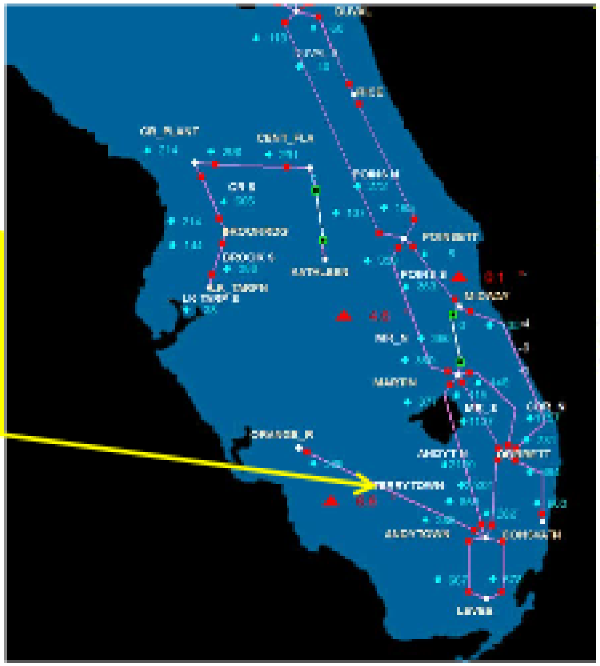
Power oscillation damping

Norway – Stattnet using PMUs to trigger automated, coordinated use of SVCs to dampen low-frequency inter-area oscillatory modes

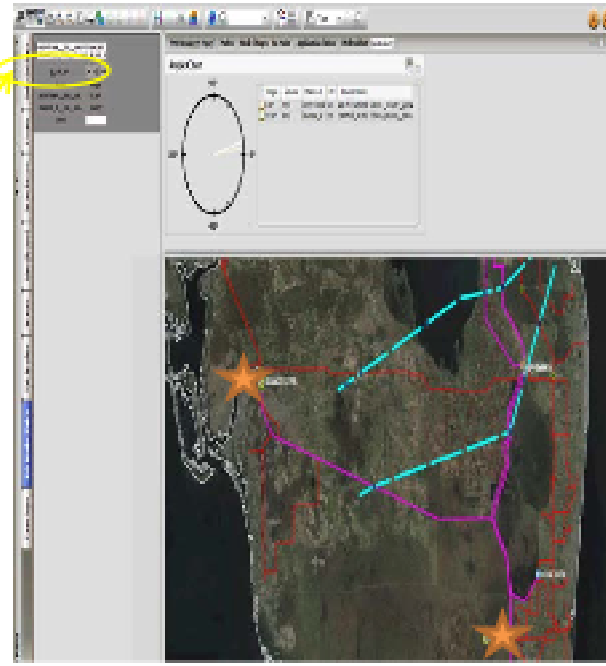


FPL – state estimator validation

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

FPL presentation at NASPI, 10/13

FPL – phase angle reclosing monitoring

Before

Phase angles are estimated using the State Estimator application. Large power transfers will results in larger angle differences.

- 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

FPL presentation at NASPI, 10/13

For more information

- North American Synchrophasor Initiative – www.naspi.org -- 8 years of Work Group meeting presentations from specific utilities and evolving uses and successes
- NASPI technical workshops and tutorials -- https://www.naspi.org/techworkshops
- Some basic synchrophasor reference papers -- https://www.naspi.org/documents