SEL

Synchrophasor Applications

ERCOT STF Meeting, Feb 5, 2014

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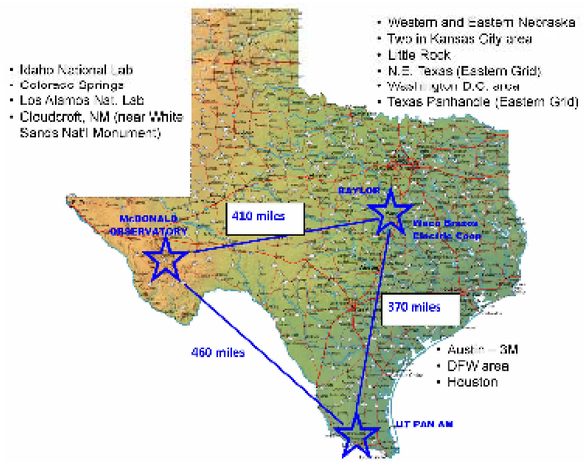
http://web.ecs.baylor.edu/faculty/grady/Texas_Synchrophasor_Network.html

The Texas Synchrophasor Network

Supported by Schweitzer Engineering Labs, EPRI, Southwest Power Pool, Brazos Electric Power Cooperative



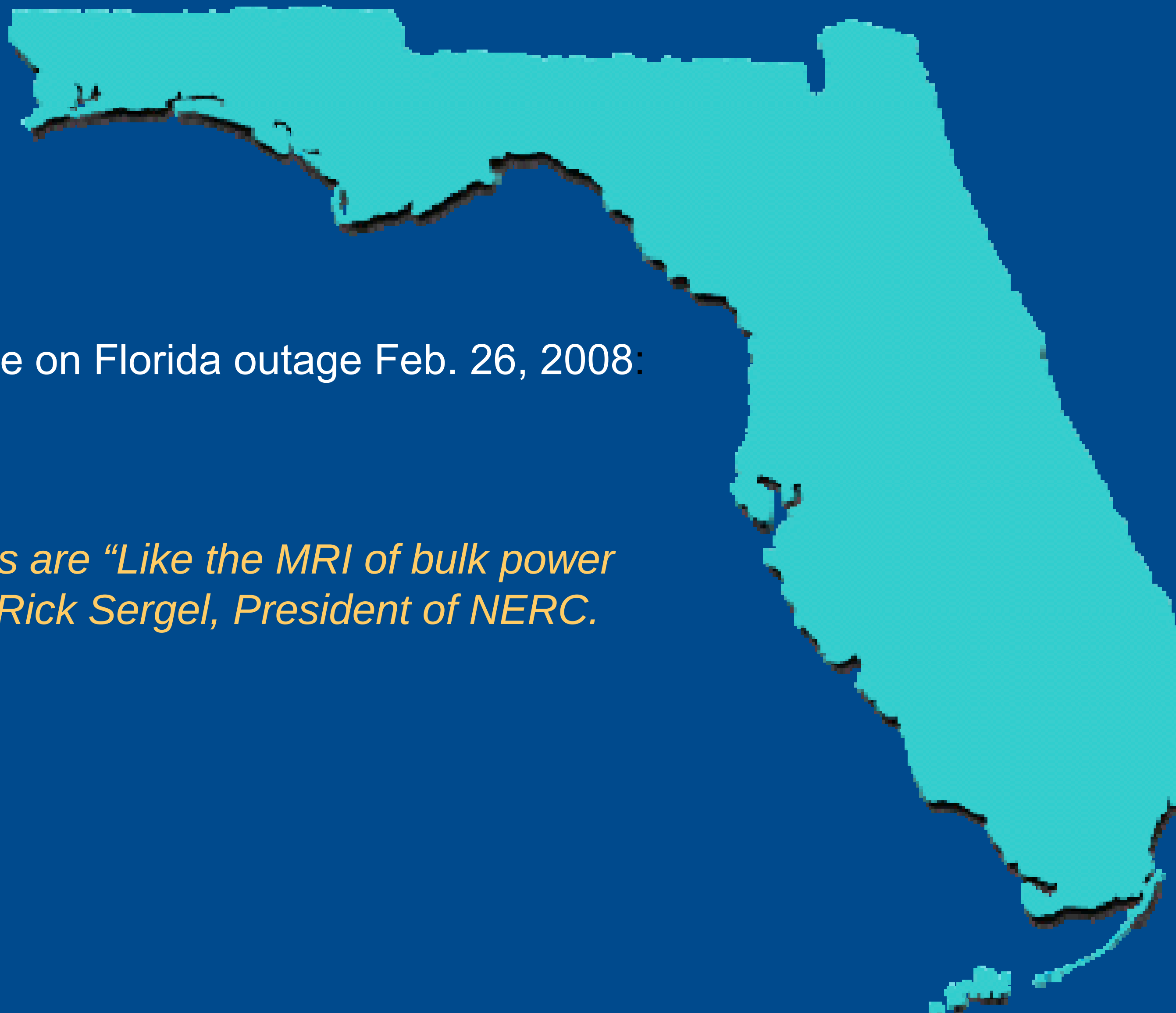
Recent Presentation

Compendium of Reports from 2009 and 2010 (135 pages)
Compendium of Reports from 2011 and 2012 (38 pages)

Reports for 2013

_20130418_Texas_Synchrophasor_Network_West_Explosion.pdf
_20130428_Texas_Synchrophasor_Network_Week_of_April_28_2013.pdf
_20130502_Texas_Synchrophasor_Network_Special_May_02_2013.pdf
_20130505_Texas_Synchrophasor_Network_Week_of_May_05_2013.pdf
_20130512_Texas_Synchrophasor_Network_Week_of_May_12_2013.pdf
_20130513_Texas_Synchrophasor_Network_Fun_Final_Exam_May_13_2013.pdf
_20130519_Texas_Synchrophasor_Network_Week_of_May_19_2013.pdf

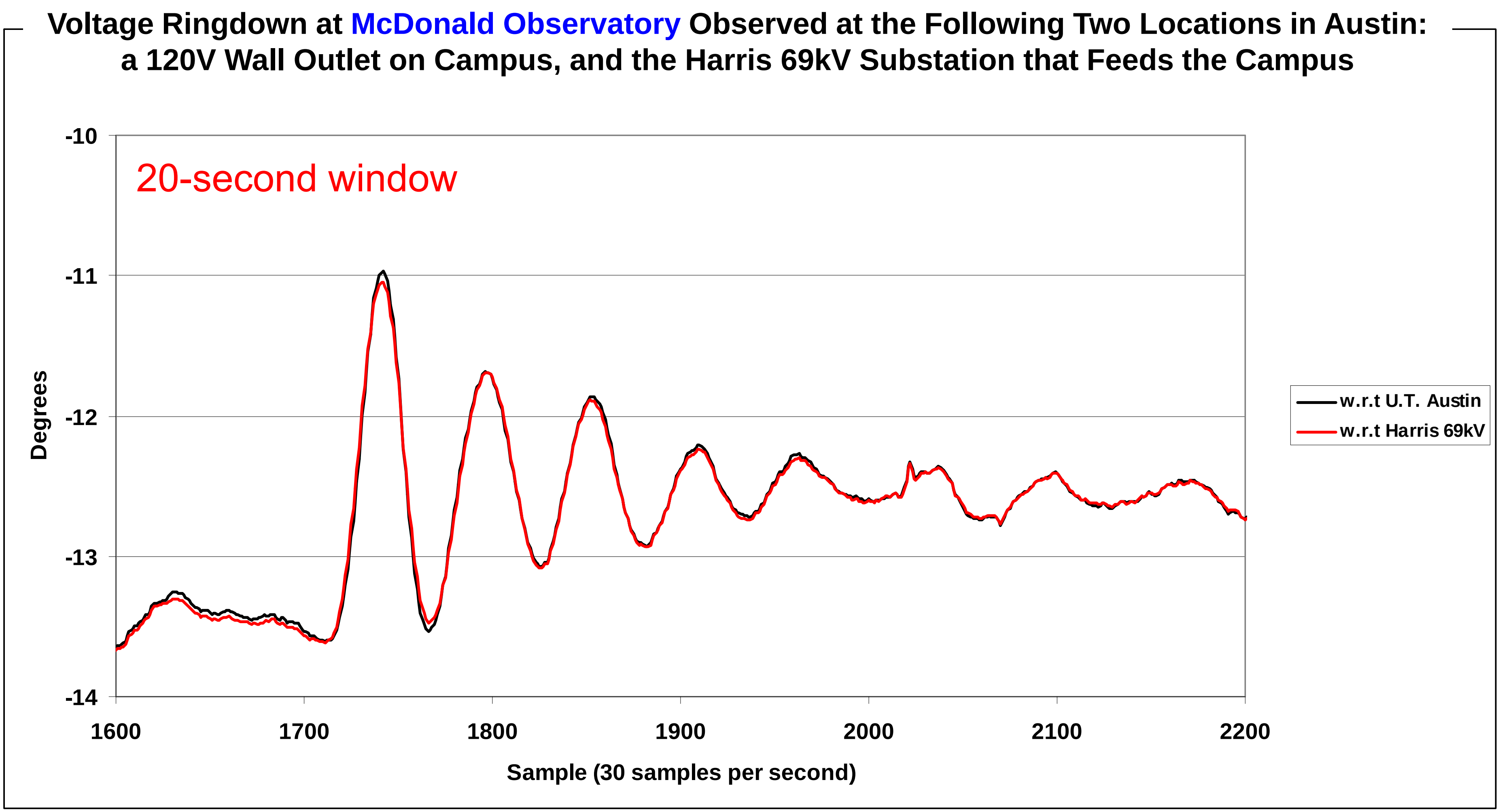
“The MRI of Power Systems”



NERC press release on Florida outage Feb. 26, 2008:

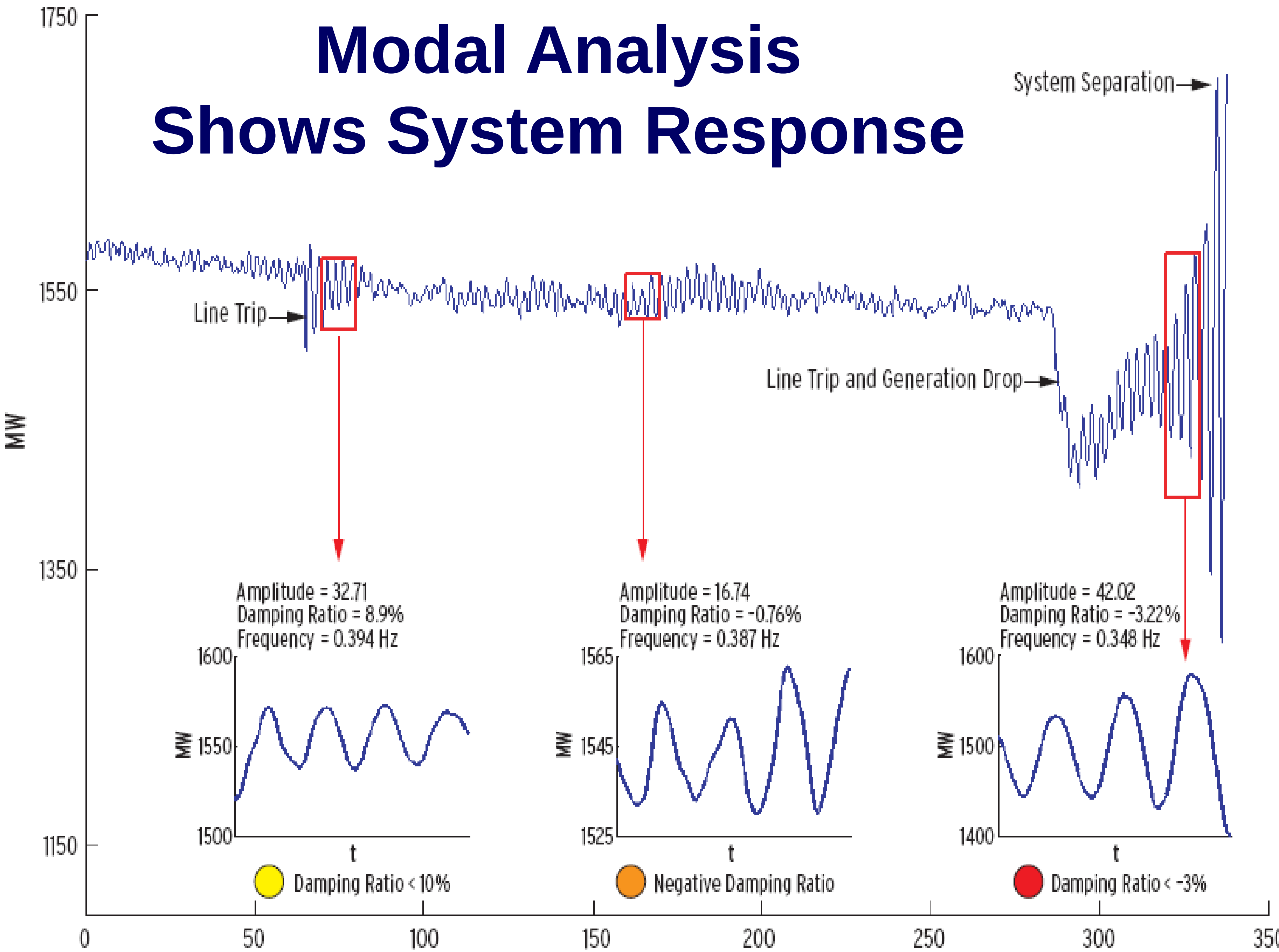
Synchrophasors are “Like the MRI of bulk power systems,” said Rick Sergel, President of NERC.

120V Wall Outlets Work for Synchrophasors (of course, we would prefer to have three-phase grid PMUs)

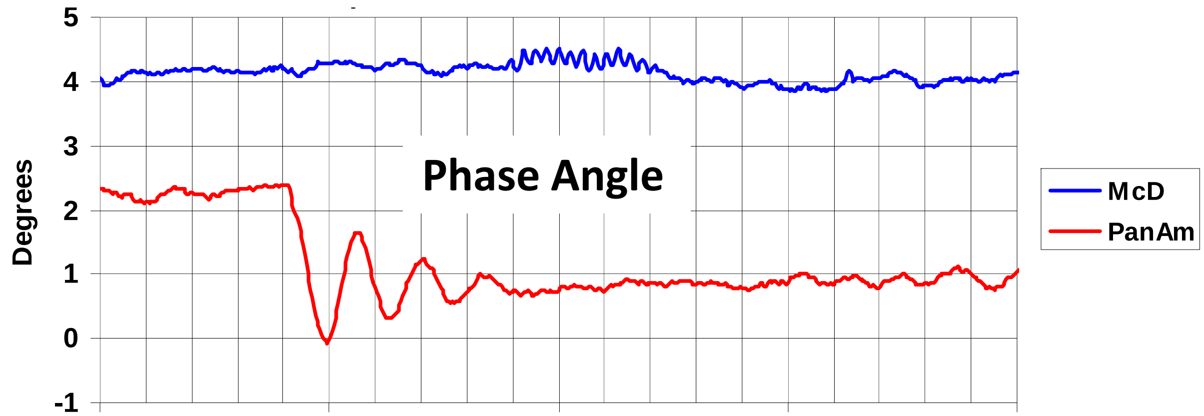


- The fixed net multiple of 30 degree phase shift between U.T. Austin 120V and Harris 69kV has been removed. The variable but steady power flow phase shift through the substation transformer has also been removed.

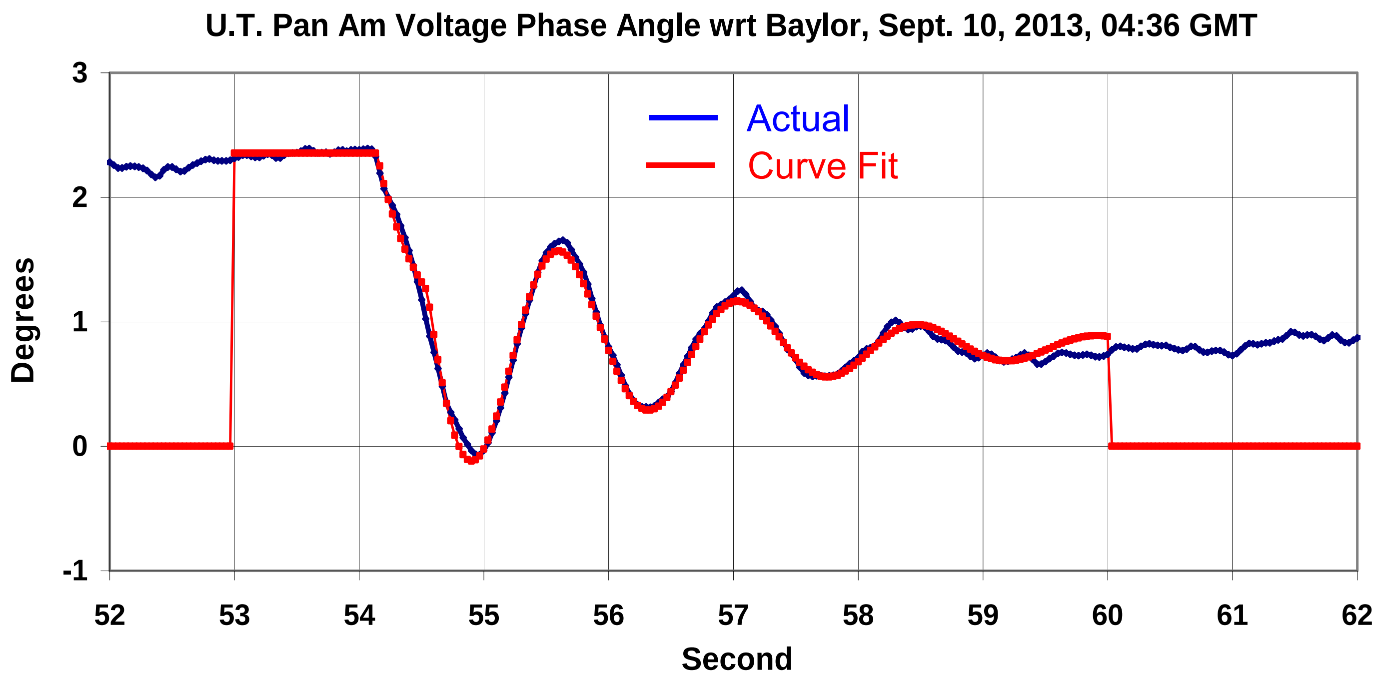
Modal Analysis Shows System Response



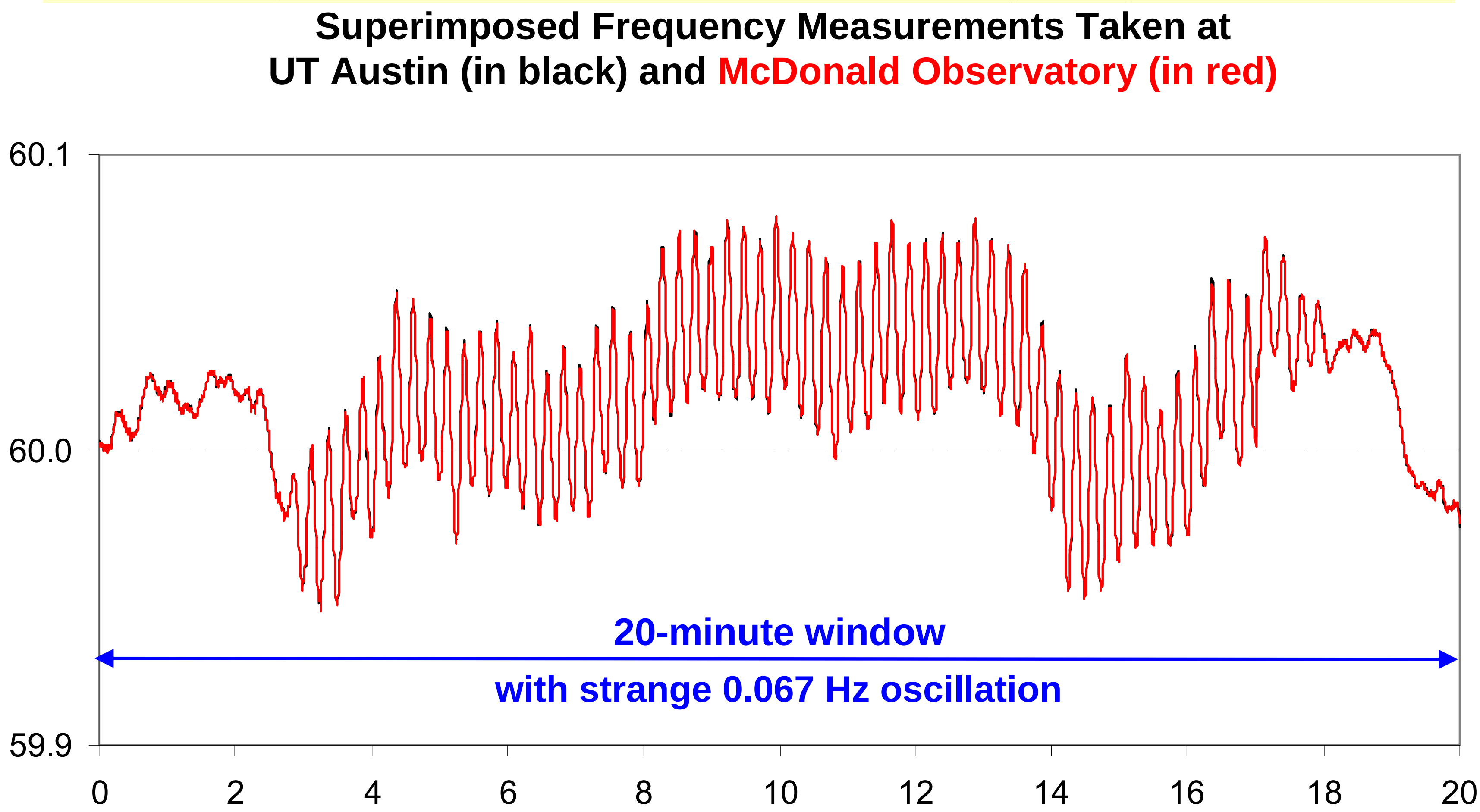
Grid response to unit trip gives a measure of stability via the normalized damping ratio, zeta



		Exponential Steady State Transition Curve				Damped Sinusoidal Term					
Start Sec	Stop Sec	A	B	T1	Tau1	C	T2	Tau2	Tdamp	Fdamp	Zeta
53	60	2.36	0.81	54.14	0.32	-1.29	54.55	1.96	1.44	0.696	0.116

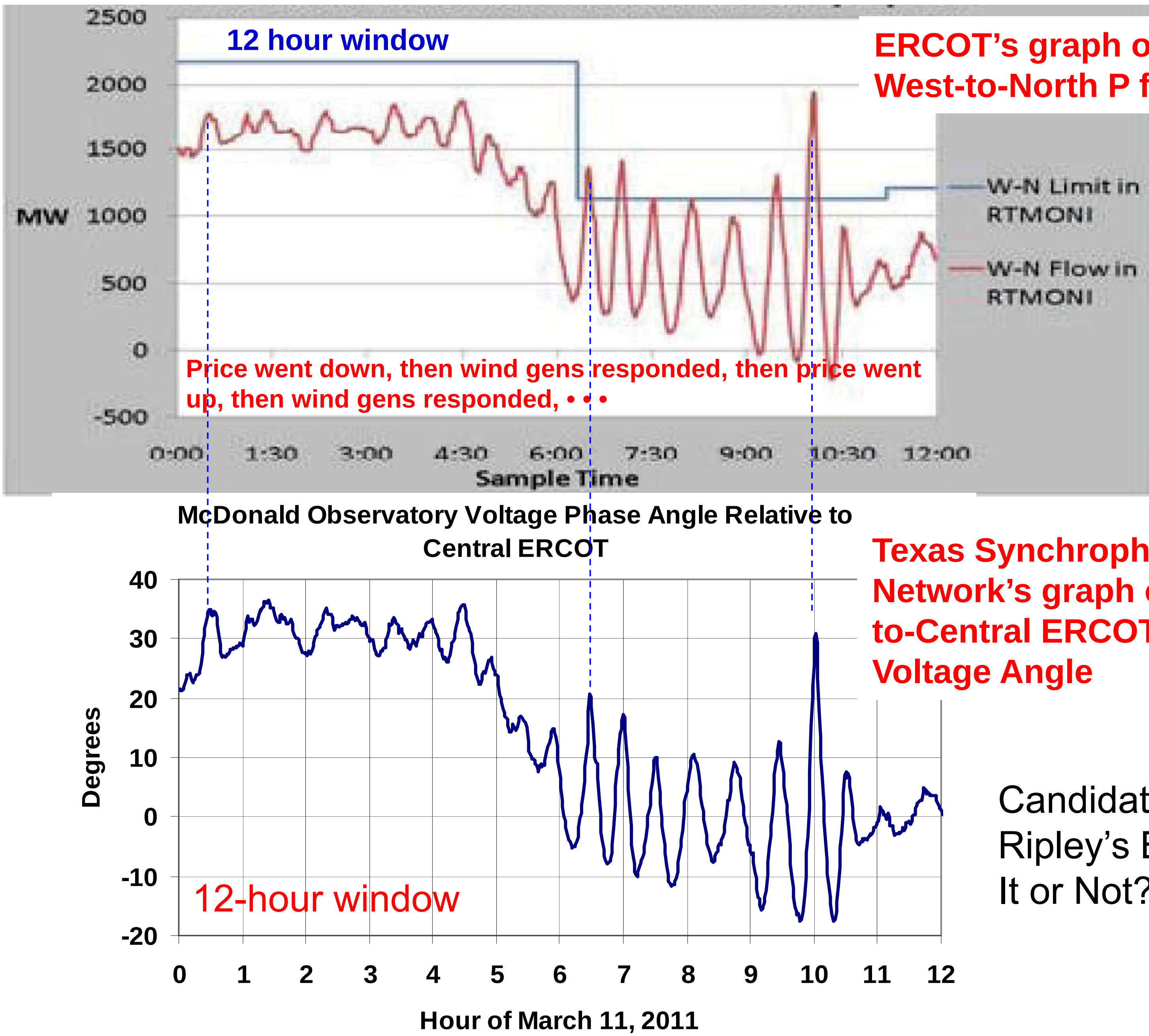


Surprises. Very Unusual Events Occur and Need Investigation



Cause - Throttle valving problem on generator under test. Slow frequency variation had gone unnoticed.

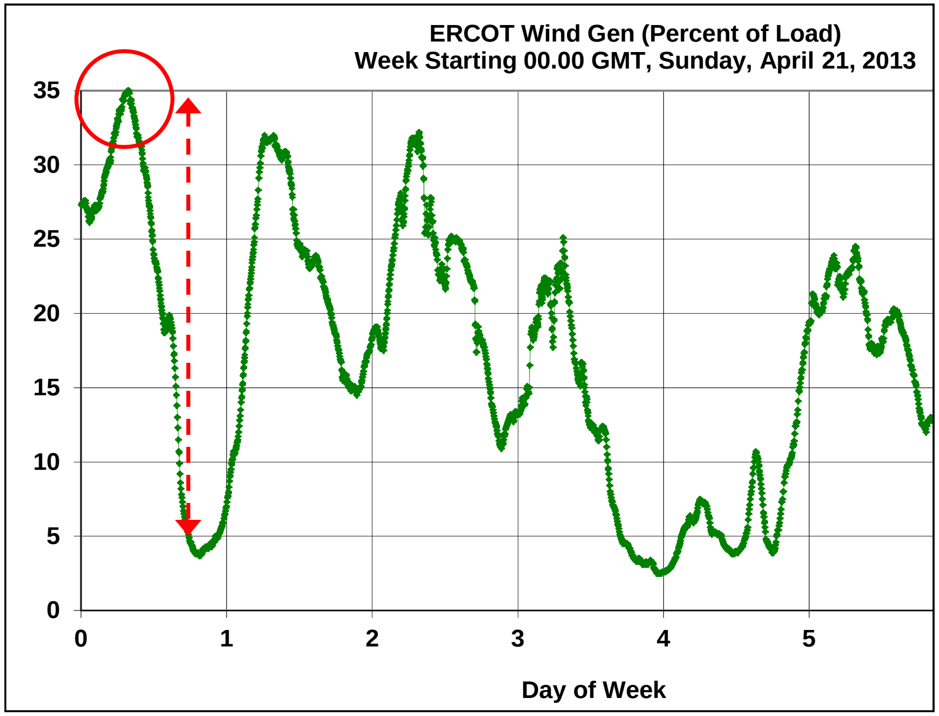
This is probably the world's first electricity market-induced grid oscillation!

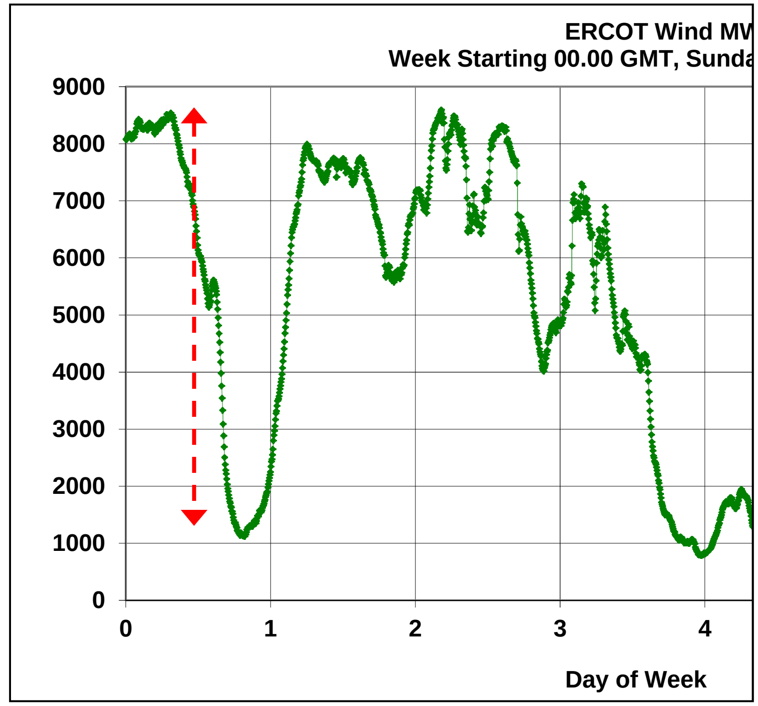


Texas Synchrophasor Network's graph of West-to-Central ERCOT Voltage Angle

Candidate for Ripley's Believe It or Not?

High Wind Generation Levels Present Challenges for Grids, but ERCOT is Handling Them Well

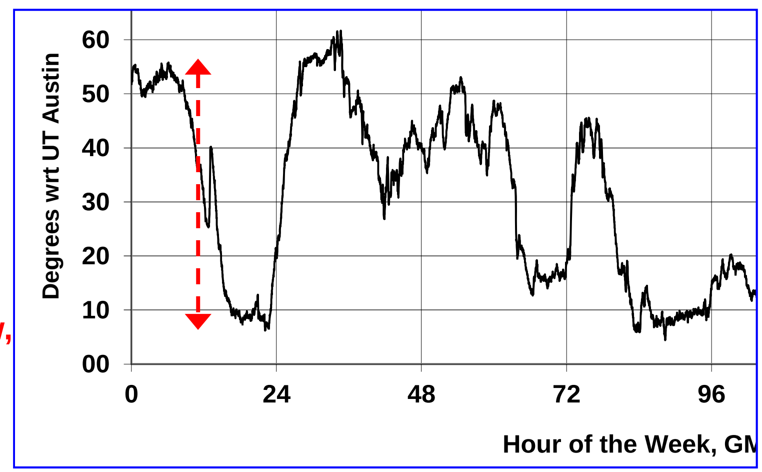




On April 21, 2013, wind generation dropped from

- 35% to 4% of total generation,
- 8500 MW to 1100 MW,

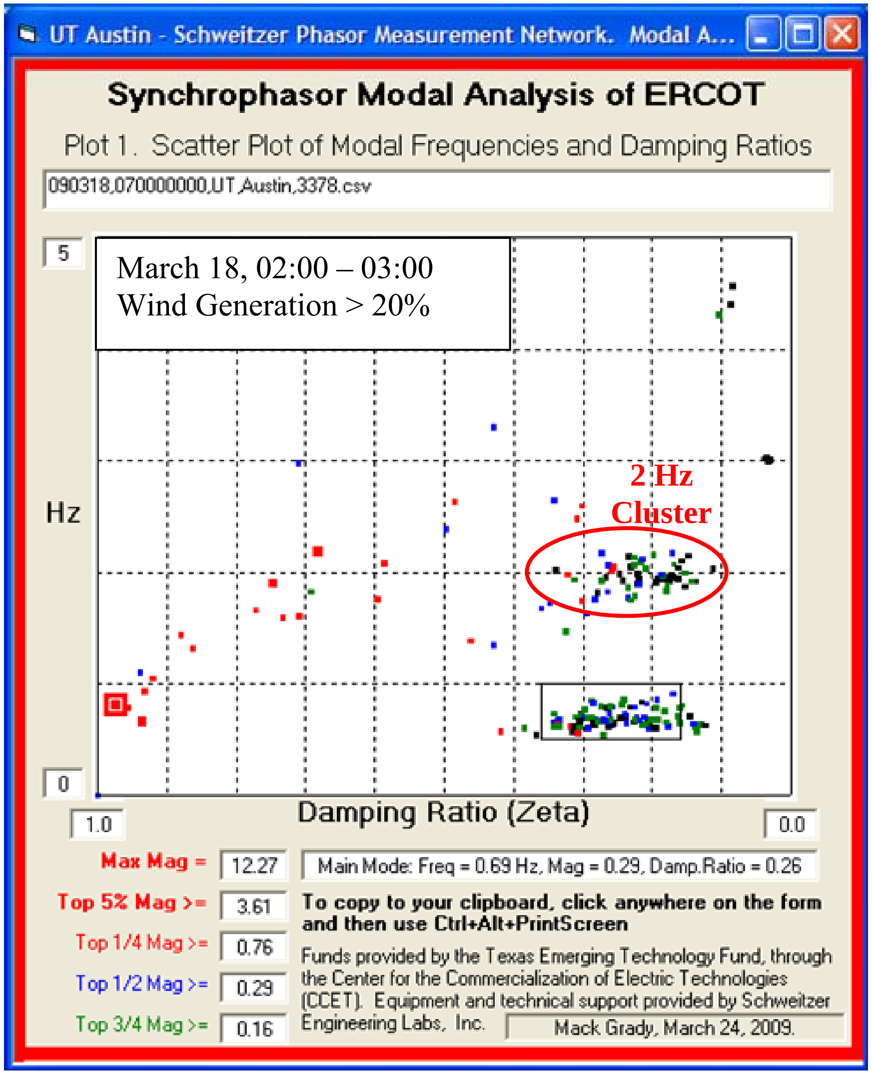
in 12 hours



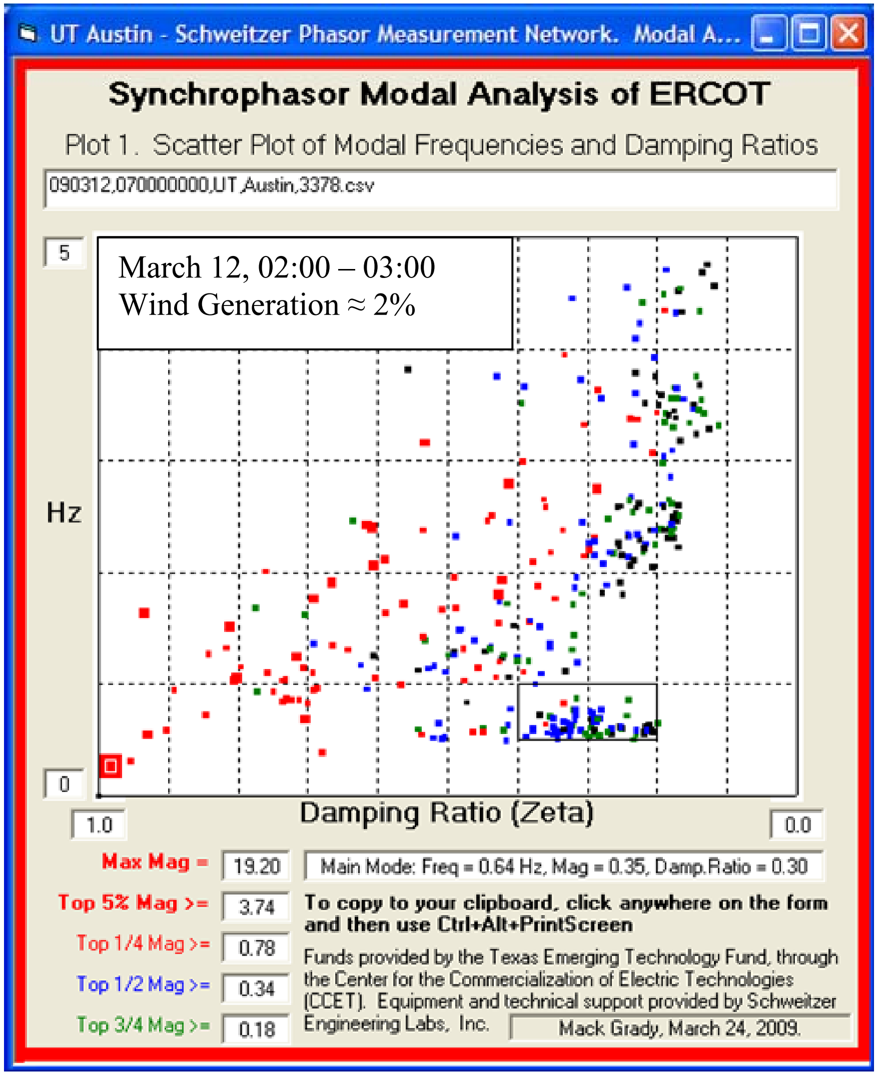
Voltage phase angle (loadflow, short circuit, stability, state estimator), dropped 40° and then rose 45°

Surprises. A 2 Hz Mode in Ambient Oscillation Sometimes Forms with High Wind Generation

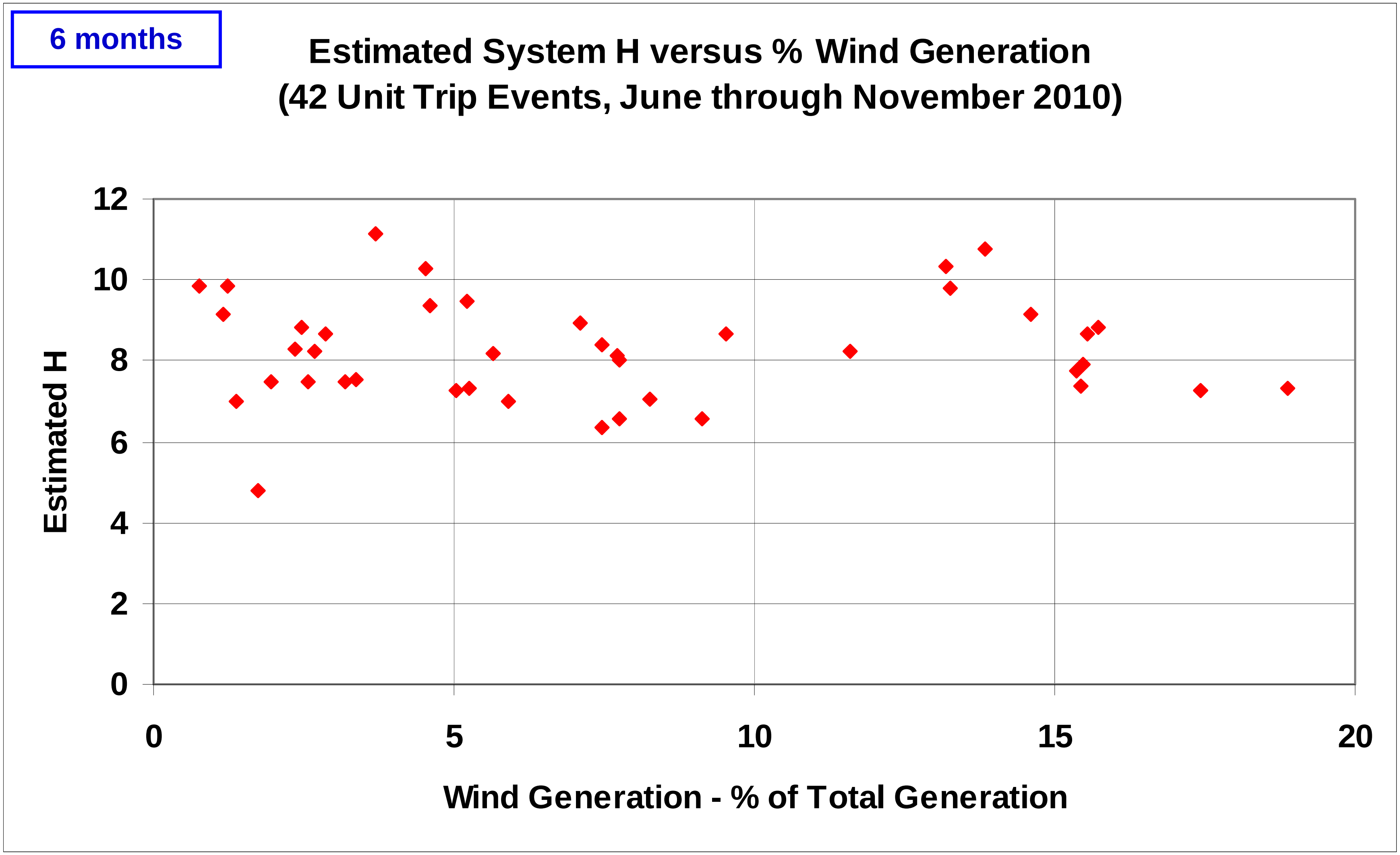
Big Wind (20%) with 2 Hz Cluster



Small Wind (2%) without 2 Hz Cluster



42 Major Unit Trips, 0.1 Hz or Greater. Conclusion - No Correlation Between Wind Generation and System Inertia



Does Wind Generation Impact Grid Inertia?

EPRI Study. Purpose – to compute ERCOT System Inertia Constant H From Frequency Response During 42 Unit Trips Having 0.1 Hz or Greater Freq. Drop.

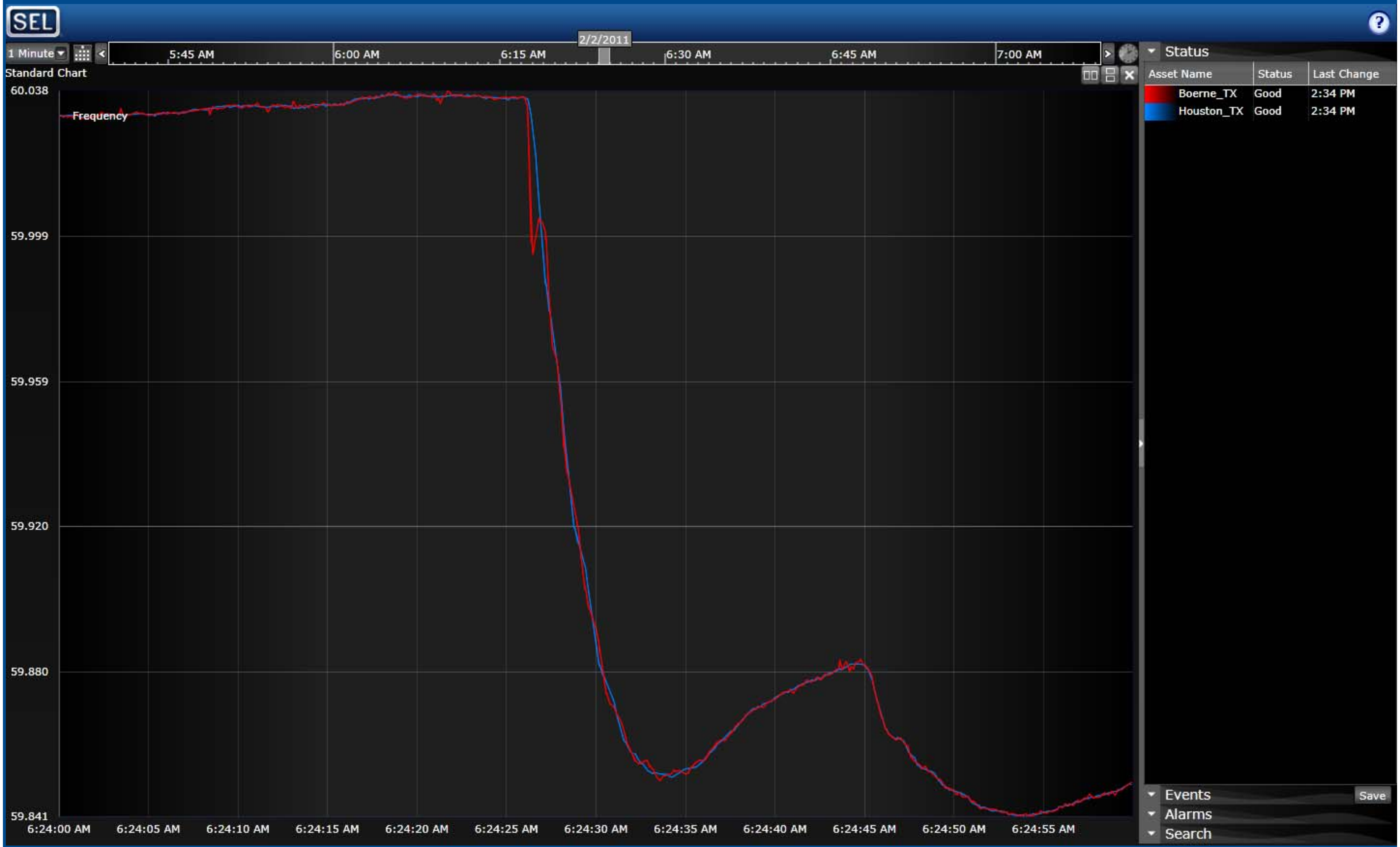
$$H \equiv \frac{\frac{1}{2} J\omega_s^2}{P_{rated}} = \frac{1}{2}\frac{(J\omega_s)\bullet\omega_s}{P_{rated}} = \frac{1}{2}\left[\frac{-\Delta P_m}{d\omega_s / dt}\right]\frac{\omega_s}{P_{rated}}$$

$$H = \frac{1}{2}\left[\frac{-\Delta P_m}{P_{rated}}\right]\frac{\omega_s}{(d\omega_s / dt)} = \frac{-\Delta P_m}{2P_{rated}}\frac{2\pi f_s}{2\pi(df_s / dt)} = \boxed{\frac{-\Delta P_m f_s}{2P_{rated}(df_s / dt)}}$$

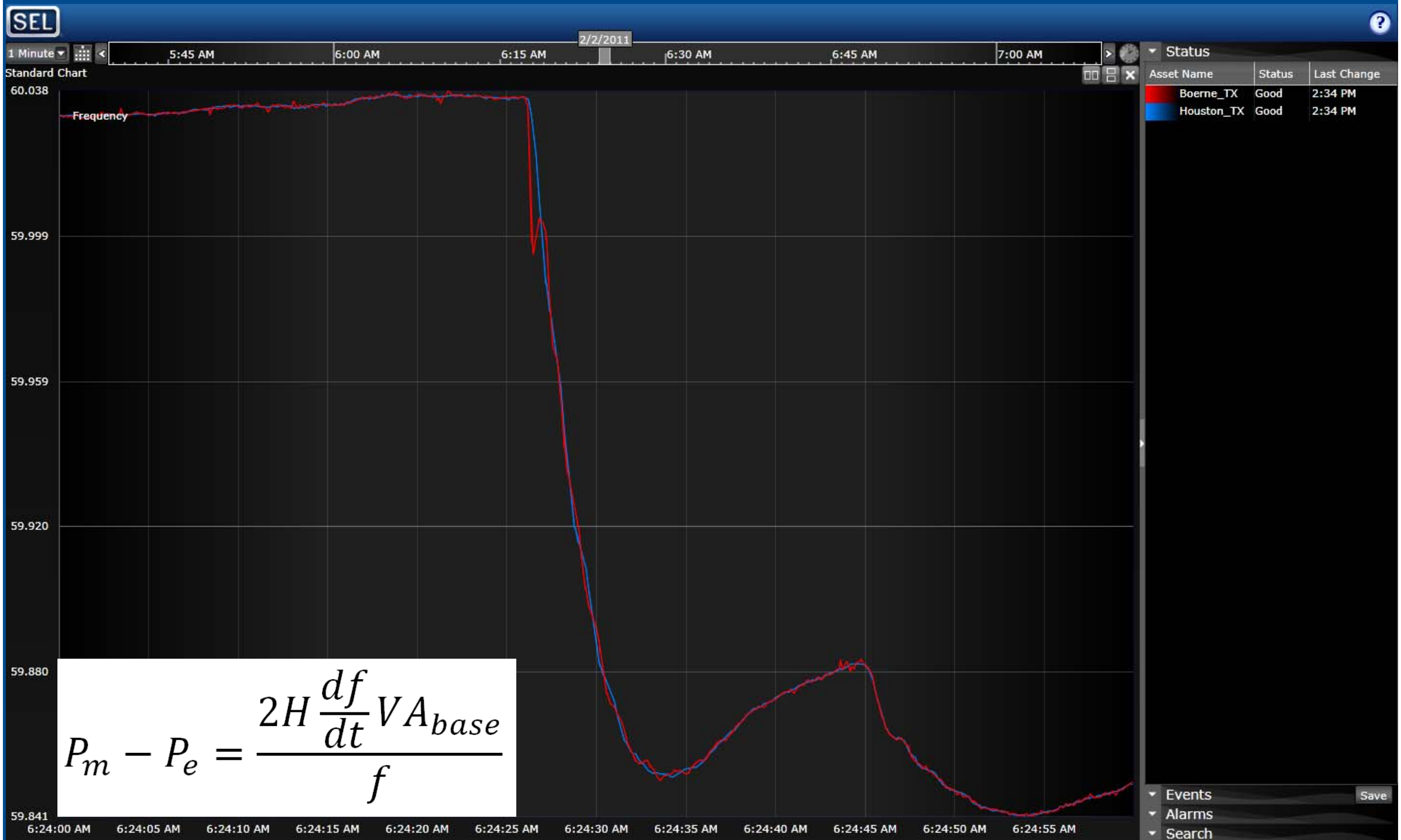
H has the units of seconds. The correct interpretation is that the kinetic energy in the equivalent system machine corresponds to H seconds of rated power. Thus, the machine could provide rated power for H seconds, at which time it would have spun down to zero RPM.

Select A Disturbance

776 MW Generator Tripped*

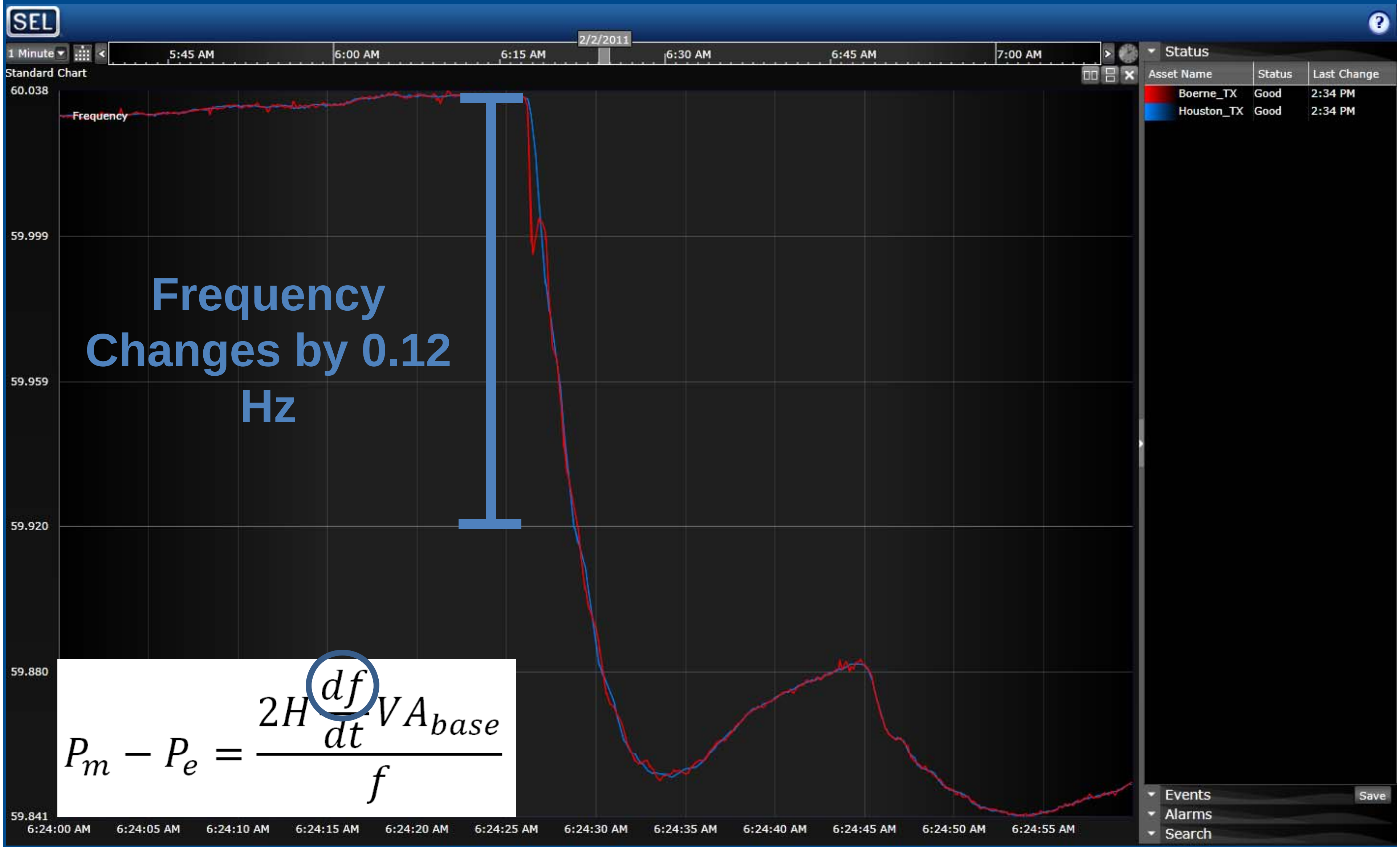


Real-Time $P_m - P_e$ Calculation



$$P_m - P_e = \frac{2H \frac{df}{dt} VA_{base}}{f}$$

Measure Frequency Change

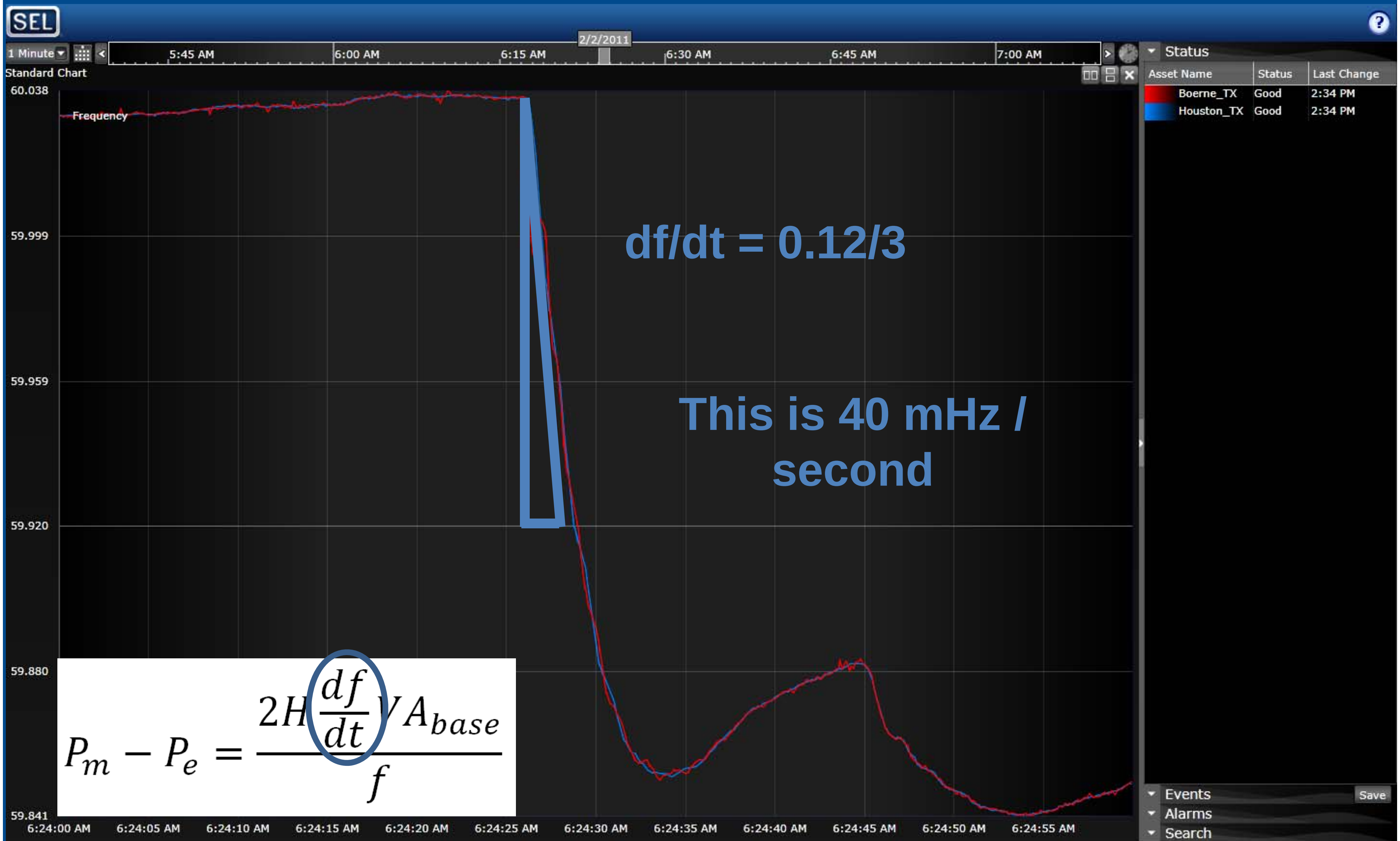


$$P_m - P_e = \frac{2H \frac{df}{dt} VA_{base}}{f}$$

Measure Time Change

$$P_m - P_e = \frac{2H\frac{df}{dt}VA_{base}}{f}$$

df/dt Calculation



df/dt = 0.12/3

This is 40 mHz / second

$$P_m - P_e = \frac{2H \frac{df}{dt} VA_{base}}{f}$$

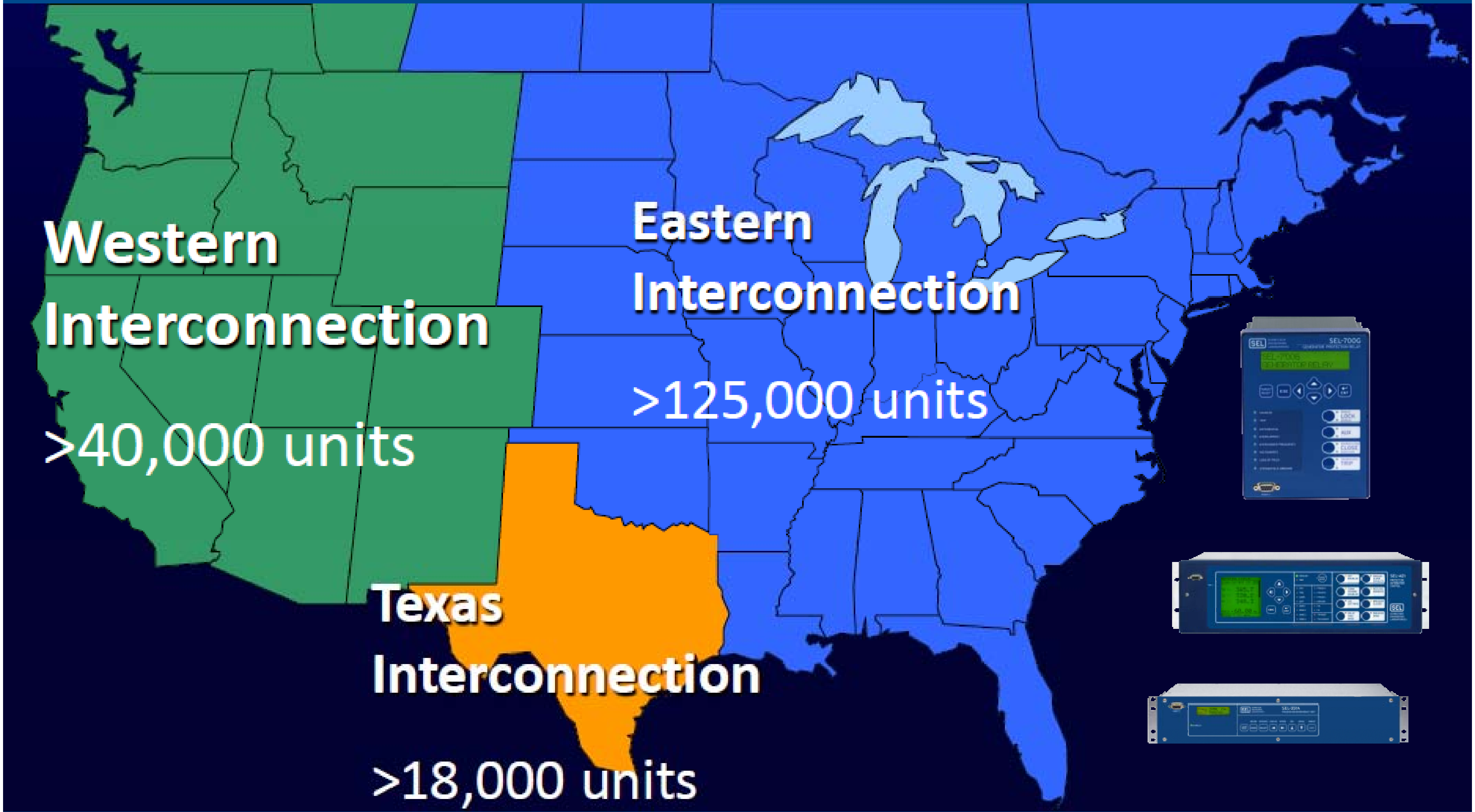
Estimated Generation Lost

- df/dt = -40 milliHz/second
- H = 9 seconds
- VA_{base} = 60 GW
- f_{nom} = 60 Hz

$$P_m - P_e = \frac{2 \cdot (9\ sec) \cdot (-0.04\ Hz/sec)\ \cdot 60GW}{60Hz}$$

- $P_m - P_e$ = 720 MW

Already Installed PMU-Capable SEL Devices in Each Grid

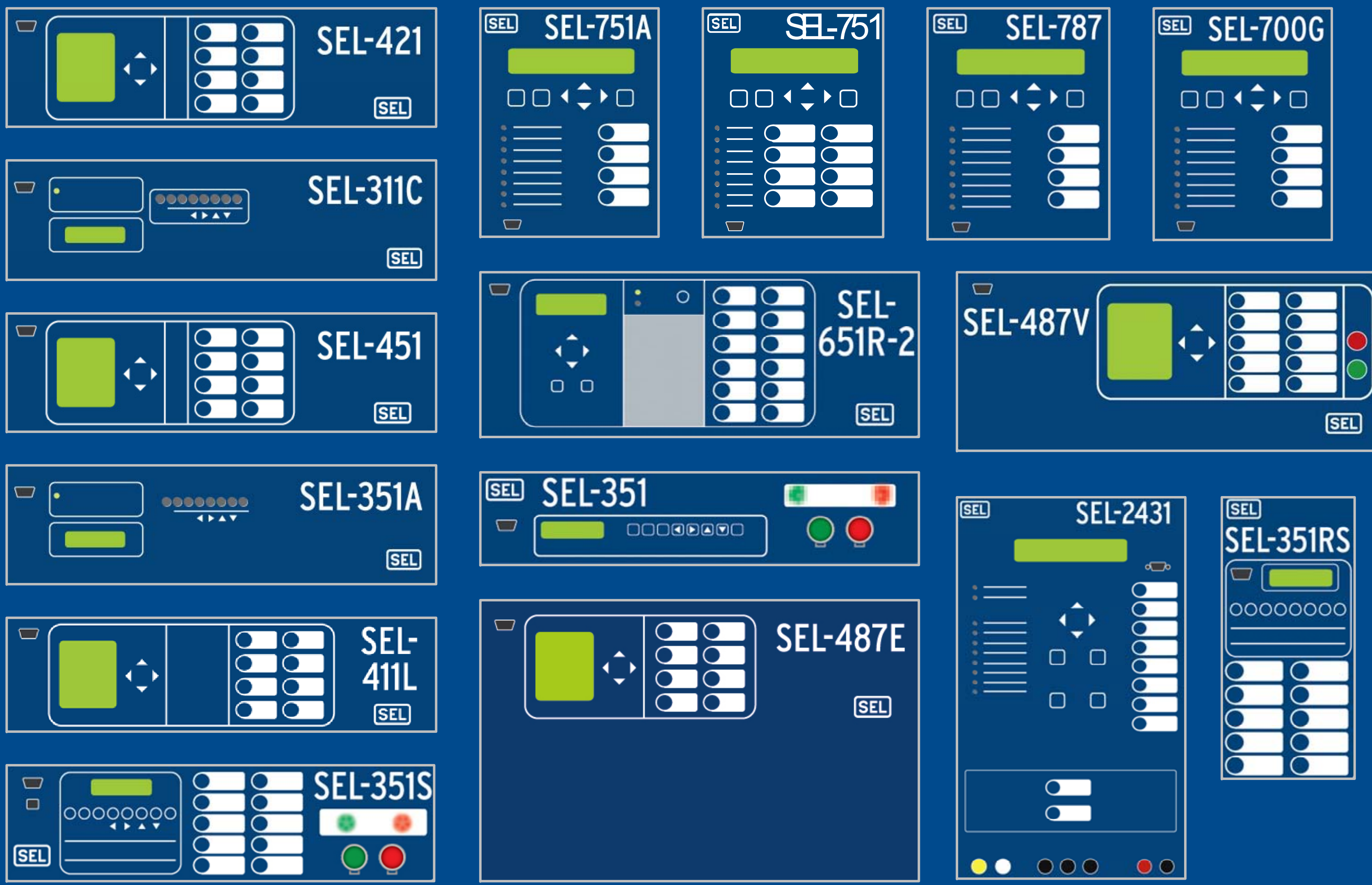


Developing Synchrophasor Solutions for Over a Decade

These solutions are in service today, worldwide

SEL Synchrophasor Building Blocks

Phasor Measurement Units

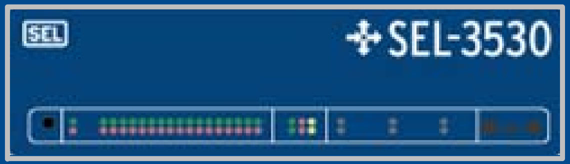


SEL Synchrophasor Building Blocks

Data Concentration

SYNCHROWAVE PDC

Control Solutions



Visualization and Analysis

SYNCHROWAVE Central

Secure Communications

Satellite Clocks

https://www.selinc.com/synchrophasors/

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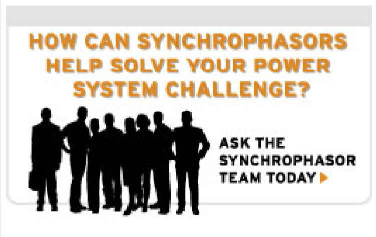
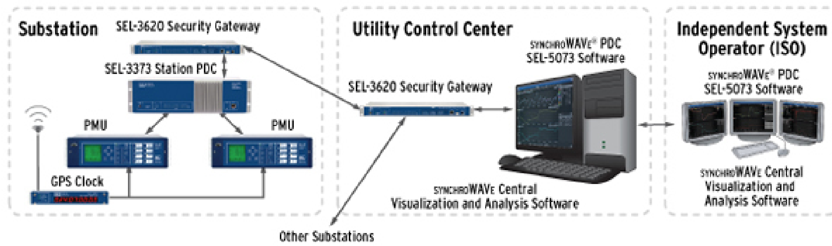


Synchrophasors Overview

Synchronized phasors (synchrophasors) provide a real-time measurement of electrical quantities from across the power system. Applications include wide-area control, system model validation, determining stability margins, maximizing stable system loading, islanding detection, system-wide disturbance recording, and visualization of dynamic system response. The basic system building blocks are GPS satellite-synchronized clocks, phasor measurement units (PMUs), a phasor data concentrator (PDC), communication equipment, and visualization software.

Typical Synchrophasor System Architecture



A complete system includes GPS clocks, PMUs, PDCs, secure communications, and visualization software.

Why choose SEL?

- SEL has a comprehensive portfolio of products to create a complete solution that meets your needs.
- SEL has experience implementing systems worldwide and guarantees all products with a ten-year warranty.
- SEL relays include PMU capability free of charge. This makes SEL systems economical and easy to implement.
- The SEL Engineering Services Division can design, install, and commission your system to meet your schedule and budget.

» New to SEL synchrophasors? Check out the FAQ.

Training

SEL University Training

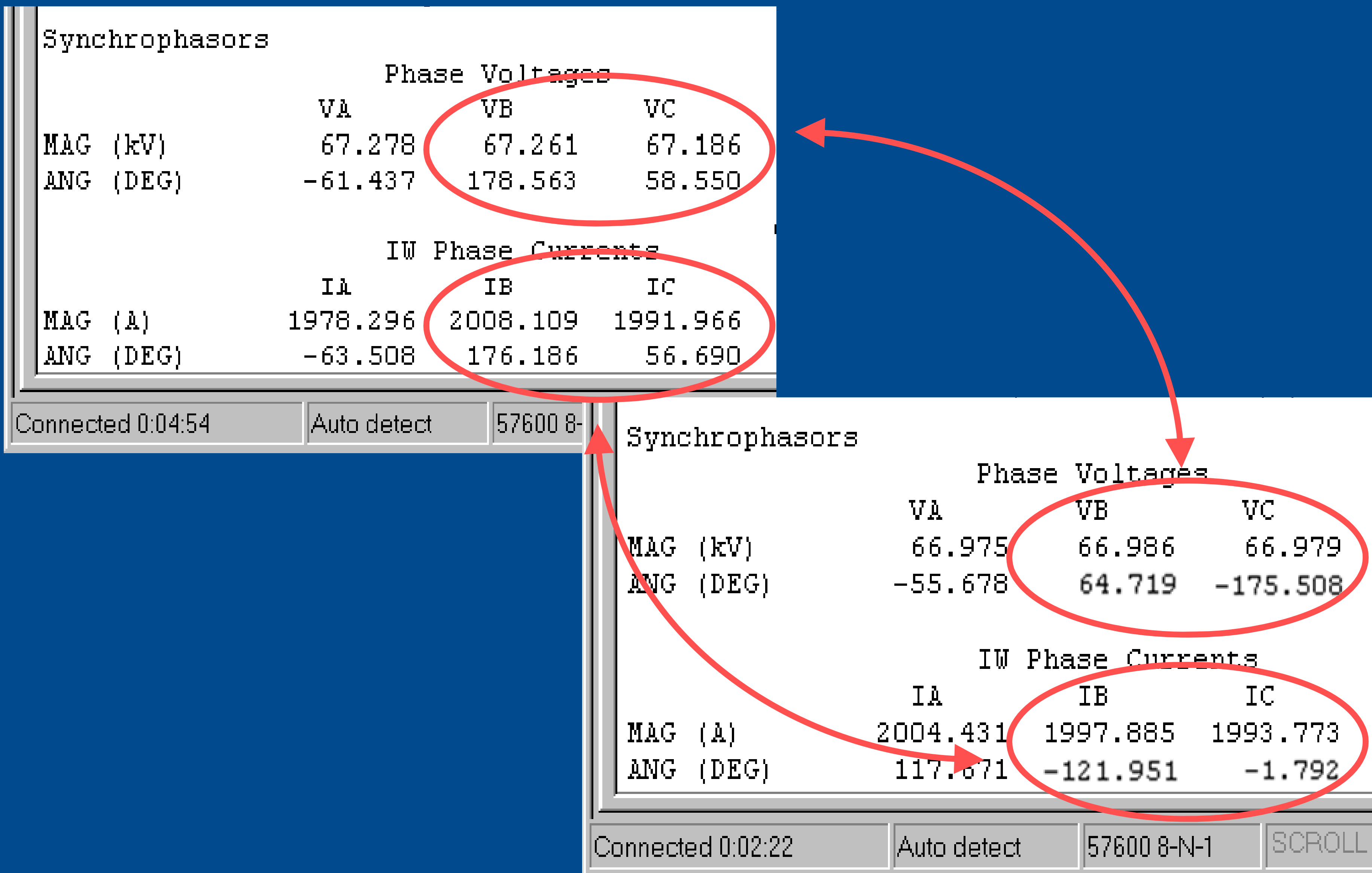
SYS 310—Modern Synchrophasor Visualization, Control, and Analysis

In this two-day, hands-on systems course, you will learn, step-by-step, how to configure a modern synchrophasor protection and control system and how to identify specific system instability conditions.

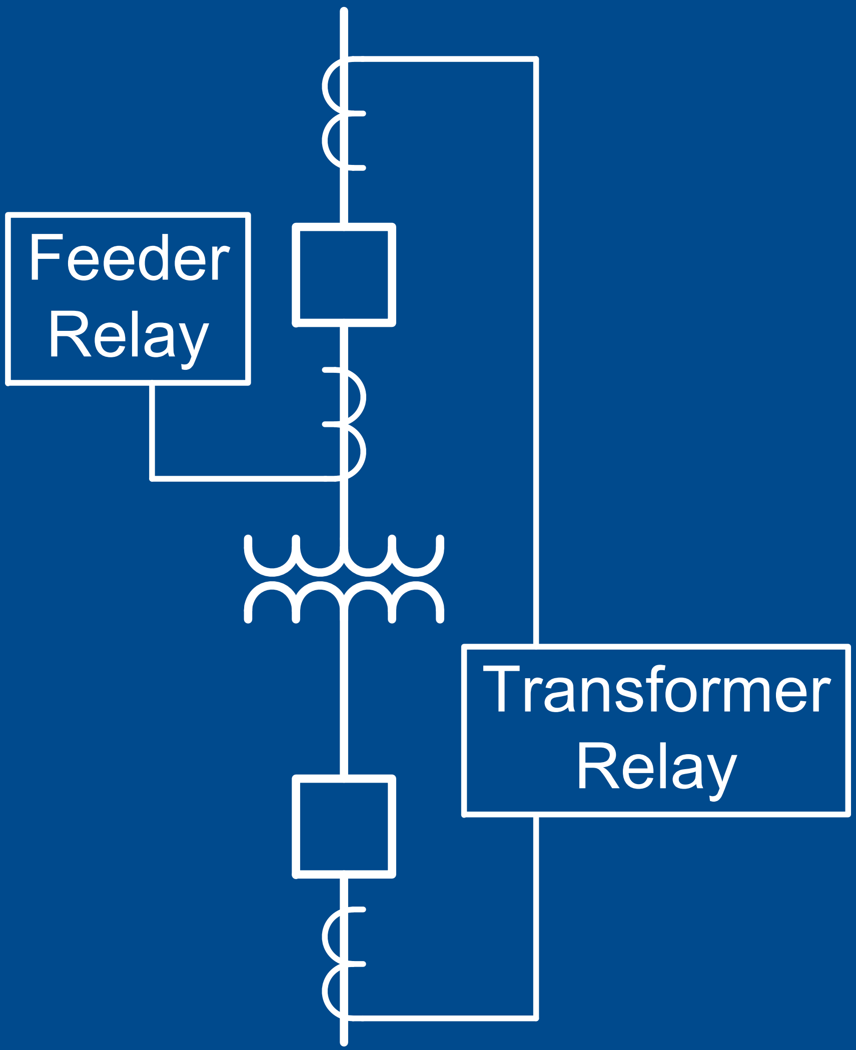
PMU Snapshots

```
Relay 1                                                  Date: 02/26/2013   Time: 14:54:14.000
Station A                                                Serial Number: 2004342280

Time Quality   Maximum time synchronization error:     0.000 (ms)  TSOK = 1

Synchrophasors
                      Phase Voltages                    Pos. Sequence Voltage
                  VA         VB         VC                      V1
MAG (kV)         0.741      0.789      0.855                   0.035
ANG (DEG)       91.797     92.717     93.027                 -44.573

                      IW Phase Currents                 IW Pos. Sequence Current
                  IA         IB         IC                      I1W
MAG (A)        278.365     62.777     52.277                  74.480
ANG (DEG)       65.338     92.177     91.954                  60.756

                      IX Phase Currents                 IX Pos. Sequence Current
                  IA         IB         IC                      I1X
MAG (A)         42.862     37.681     36.293                   2.178
ANG (DEG)       92.177     90.608     91.135                 110.375

                      IS Phase Currents                 IS Pos. Sequence Current
                  IA         IB         IC                      I1S
MAG (A)        317.201    100.449     88.568                  75.910
ANG (DEG)       68.835     91.588     91.619                  62.009

FREQ (Hz) 60.000
Rate-of-change of FREQ (Hz/s)    0.00
```

Easily Identify Errors

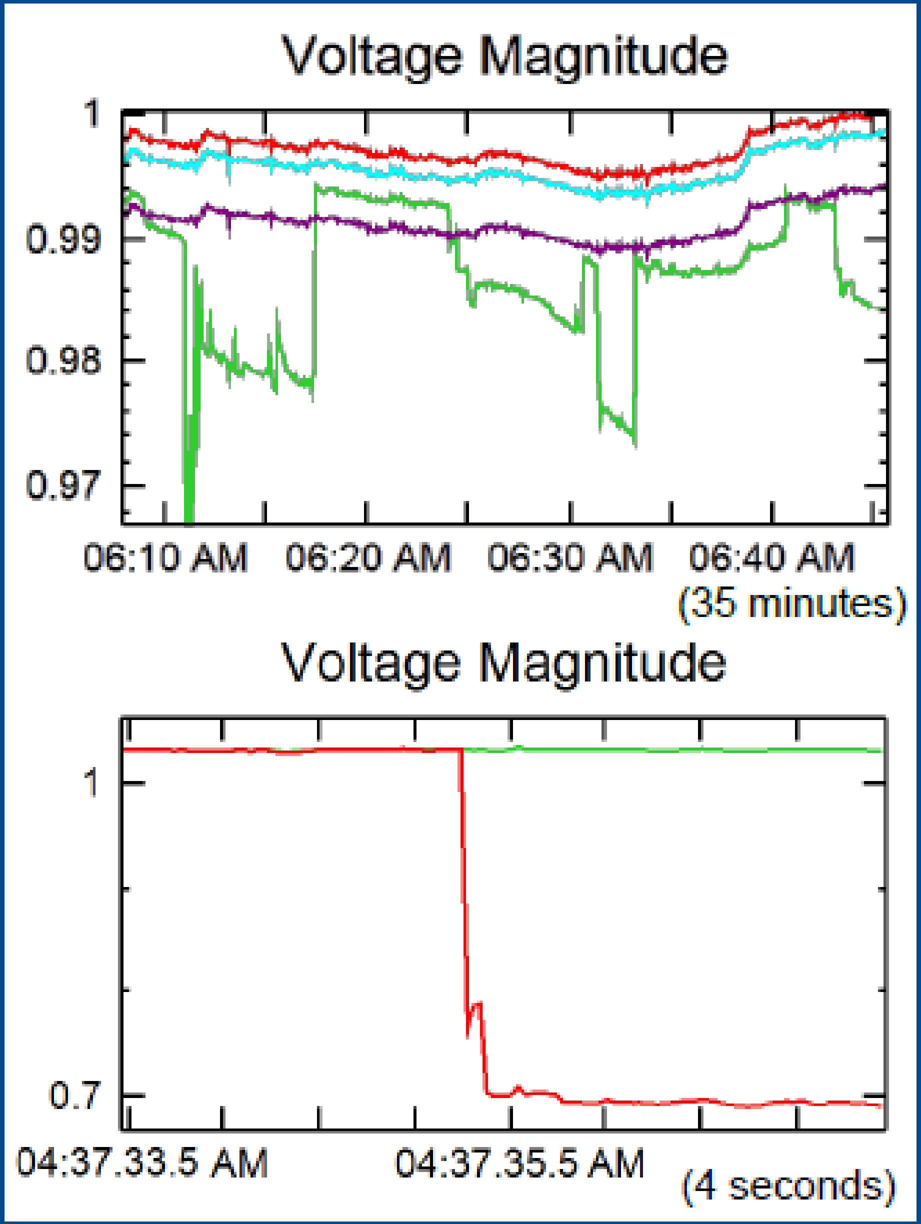


Check CT Polarities, Phasing, and Ratio

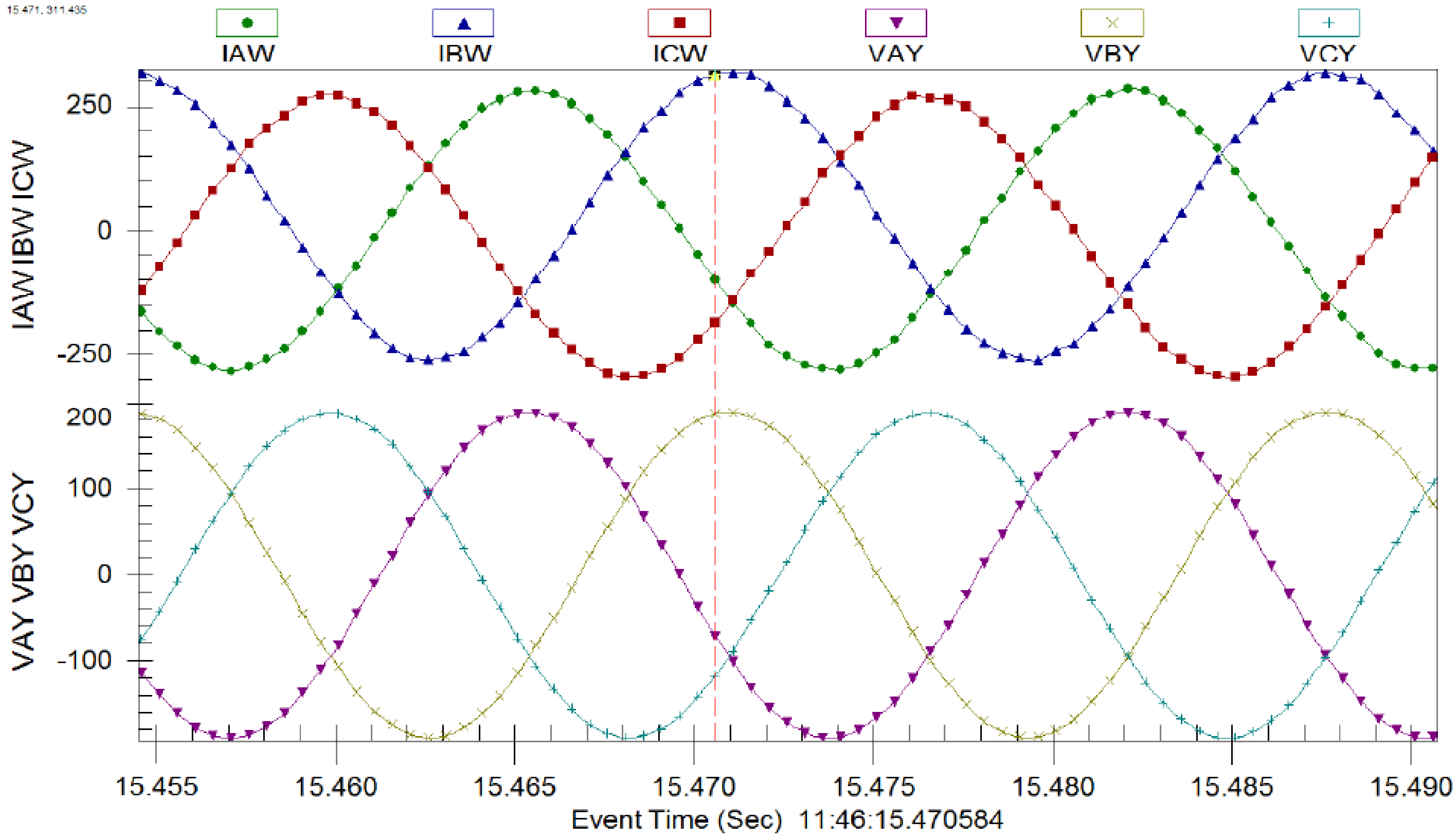


Find Problems With PTs, CVTs and CTs

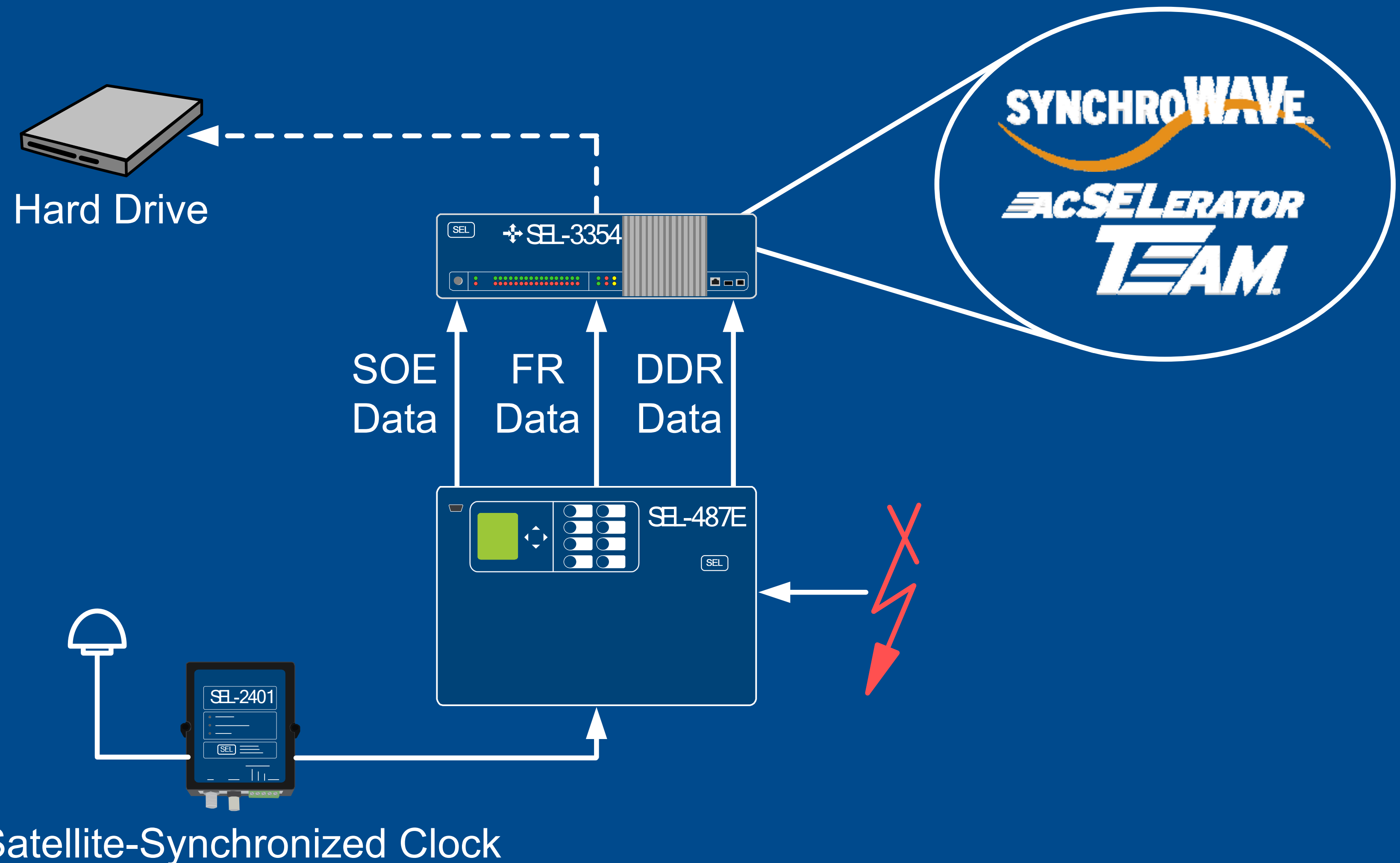
- Discover loose connections in potential circuits
- Detect CVT drift and future failure
- Prevent future outages and misoperations



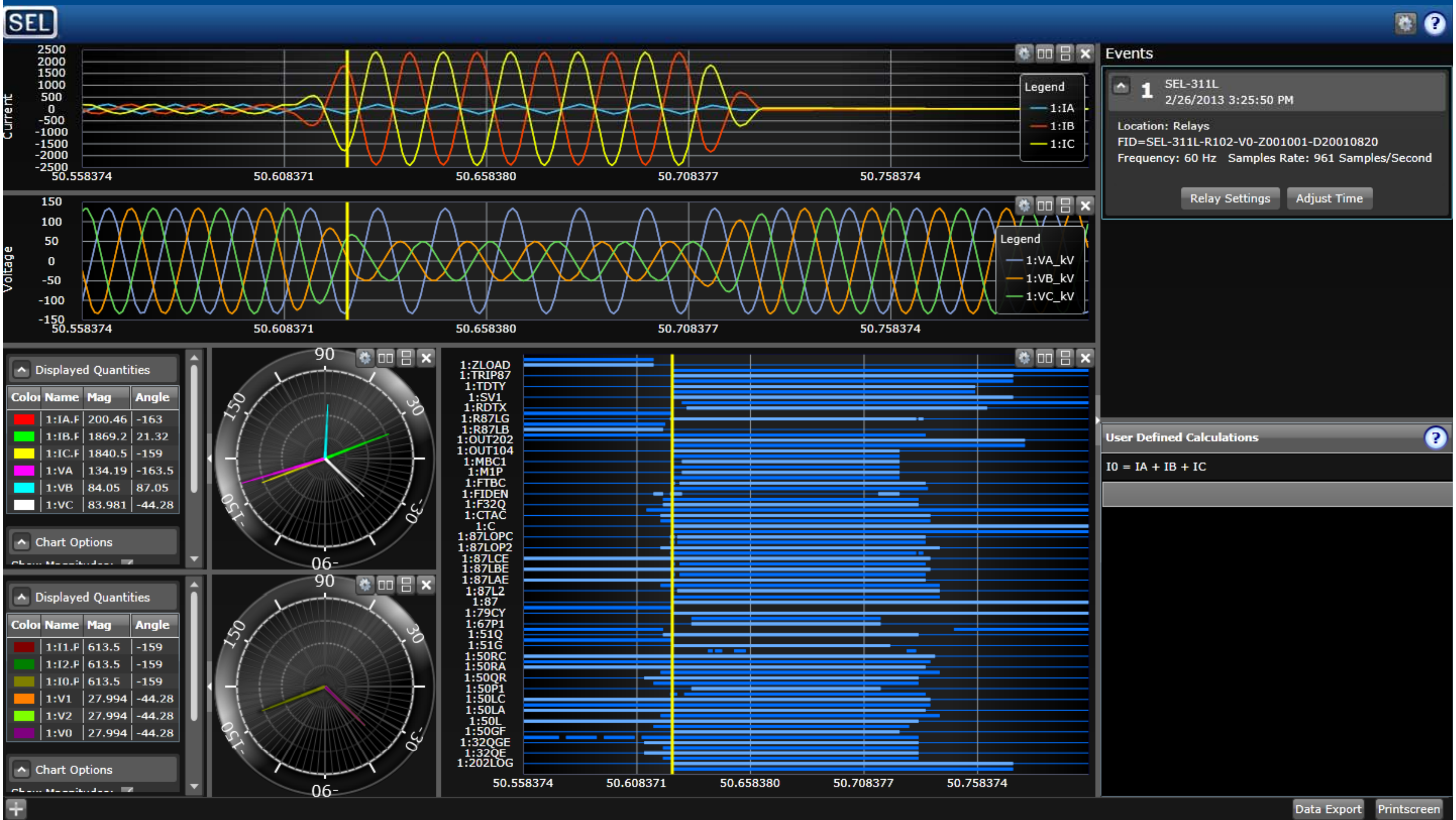
Samples Time Stamped +/- 5 microsec



NERC PRC-002-2
Disturbance Recording



Advanced Event Analysis



Improve Understanding of Events

Example – 10:23 p.m. July 14, 2012

Improper relaying on Grizzly-Ponderosa 500 kV

Eastern Interconnection Transient

3:06:48 a.m. July 21, 2012

Generator Trip

9:21:00 a.m. May 14, 2012

500 kV DC Line Trip

April 20, 2012

750 MW Generation Trip

July 8, 2012

Wide-Area Visualization

Get Instant Feedback After System Changes

Distribution Planning and Improvement

Example

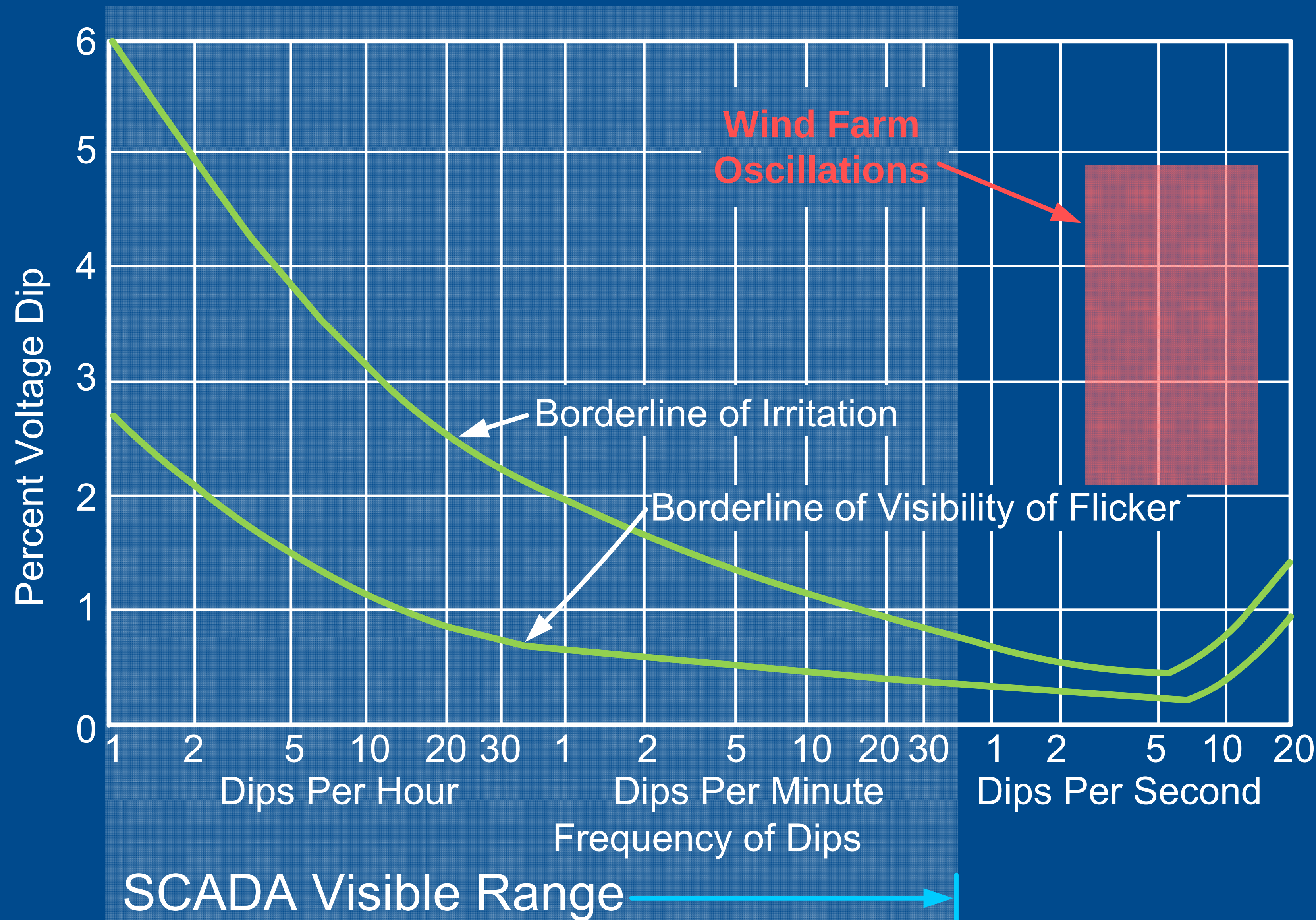
Detection of loose fuse caps,
loose connections at safety switch or terminal cabinets, and animal damage to wiring

Study the Impact of Renewables

Example – 7:13 a.m. January 7, 2012

Sudden high frequency oscillation – cause under investigation (an inverter?)

See Information That SCADA Misses

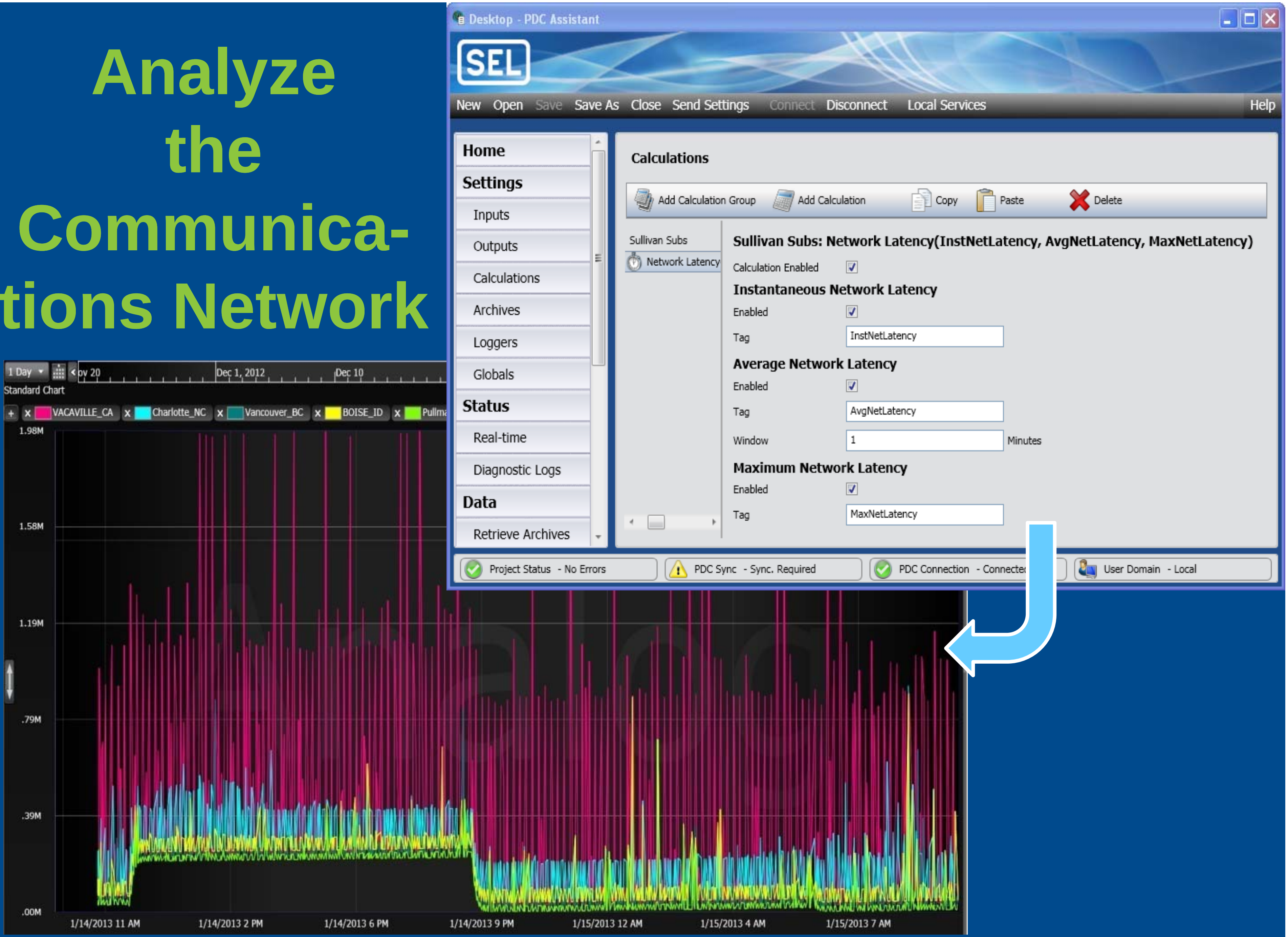


System Reconnection and Restoration

Example

Frequencies of three islanded systems

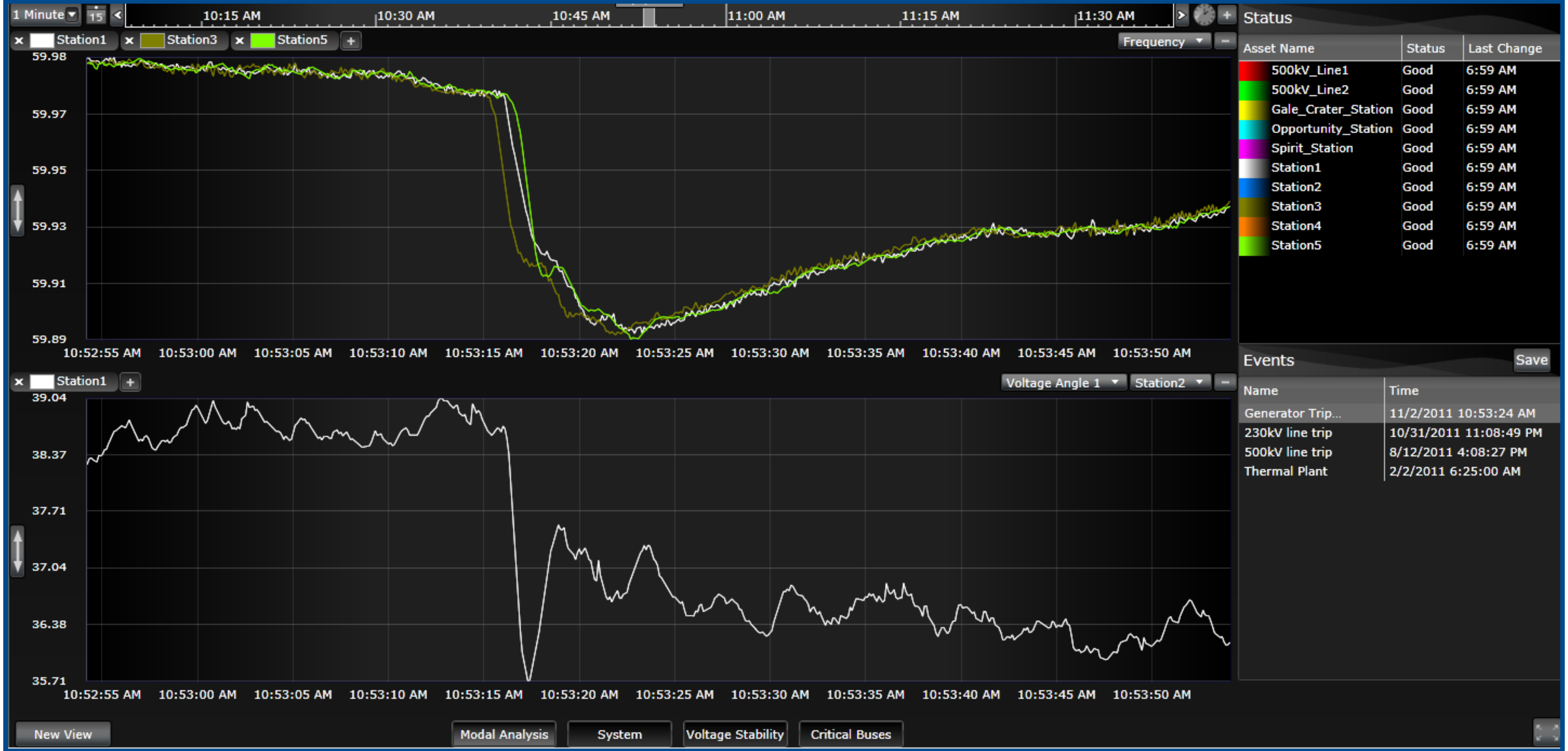
Analyze the Communica-tions Network



Model Verification

Example

Observe inertia (H) from generation rejection event



System Settings

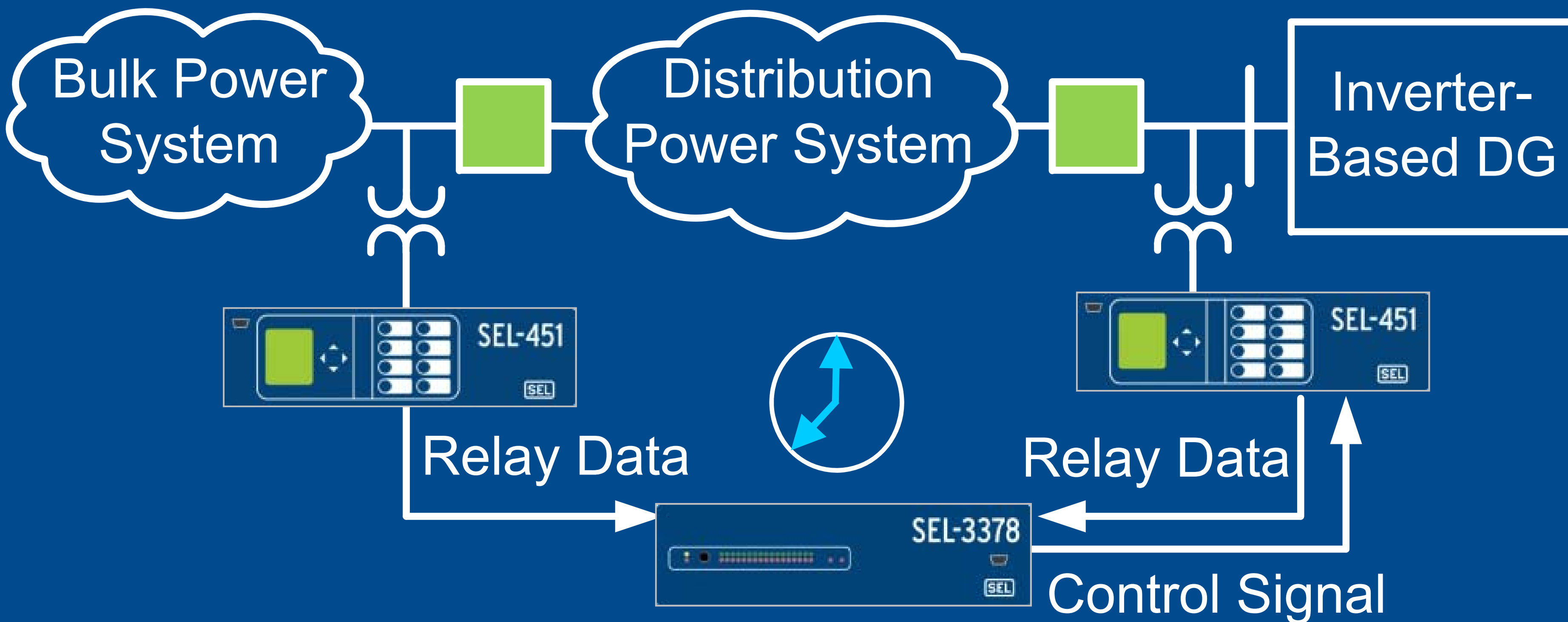
Example – January 18, 2012

Modal analysis shows marginal damping prior to unusual system events, led to power system stabilizer settings changes

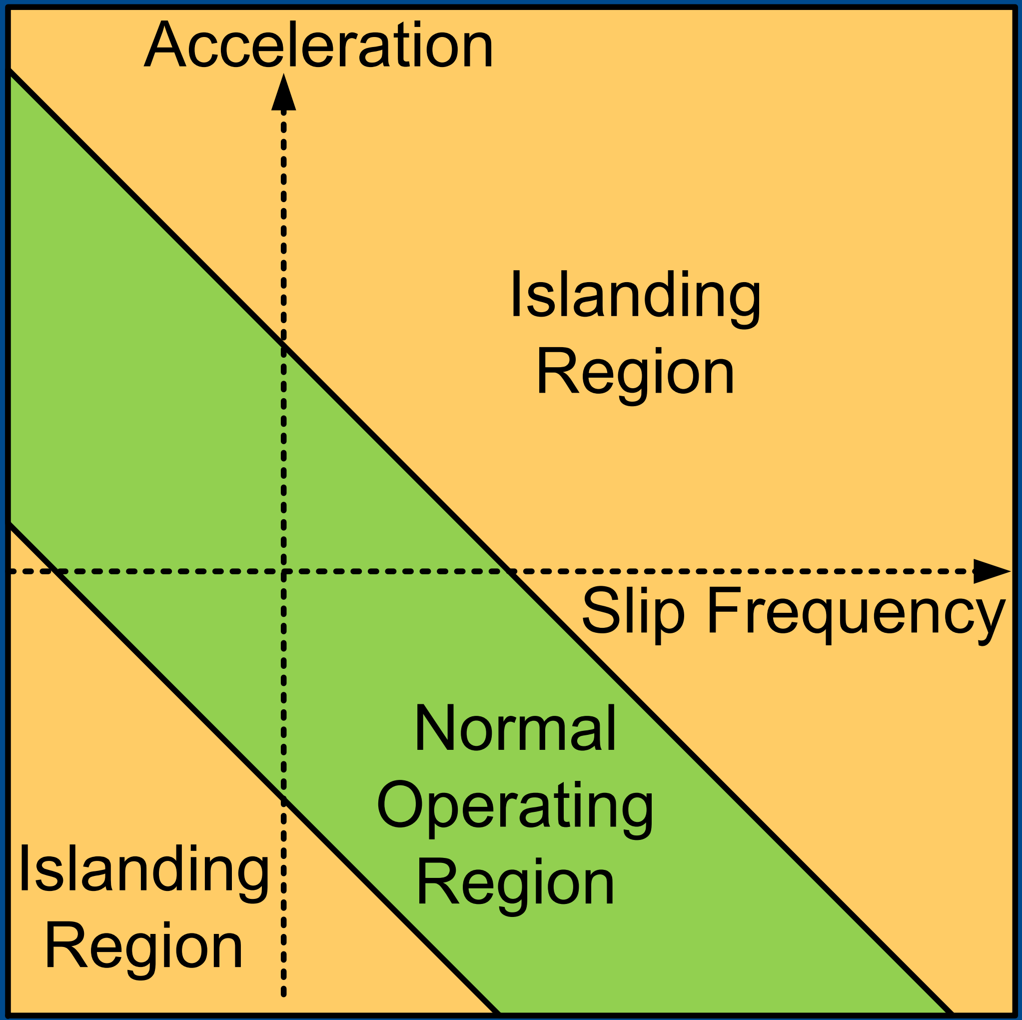
Anti-Islanding Example

- Implemented with Florida Power & Light
- Required for IEEE 1547
- Must disconnect DG within 2 seconds
- Options include
  - Transfer trip
  - Vector shift
  - Injected signal

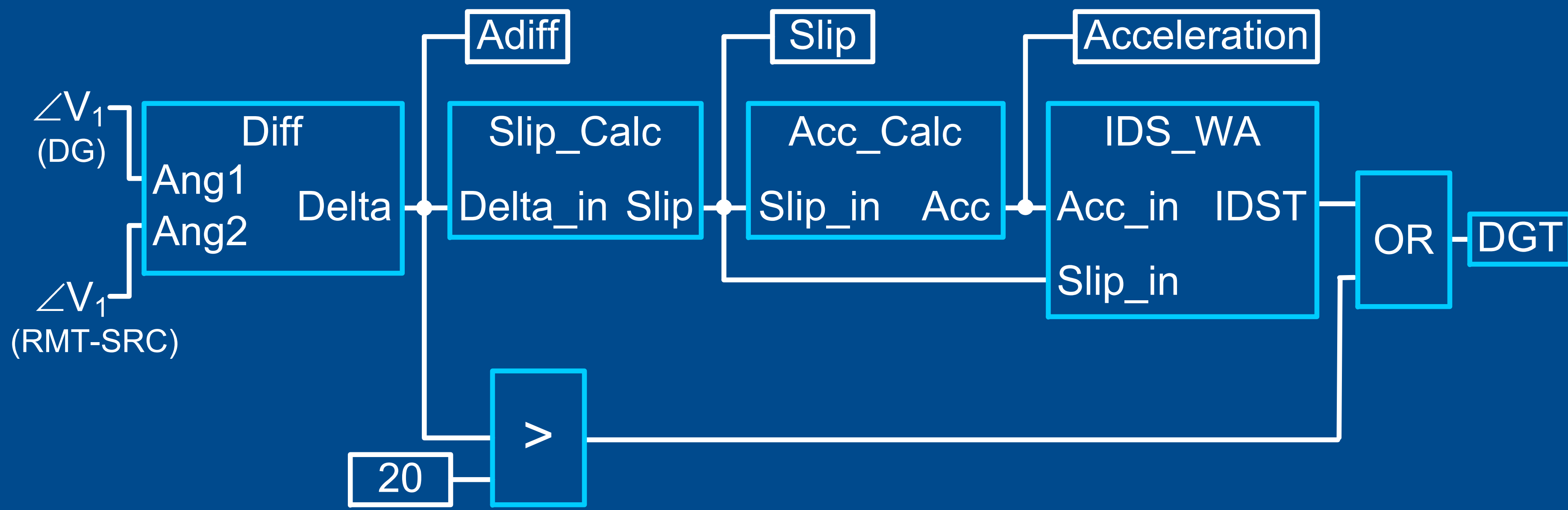
Architecture With Synchrophasors



Wide-Area IDS Uses Slip and Acceleration for Islanding Detection

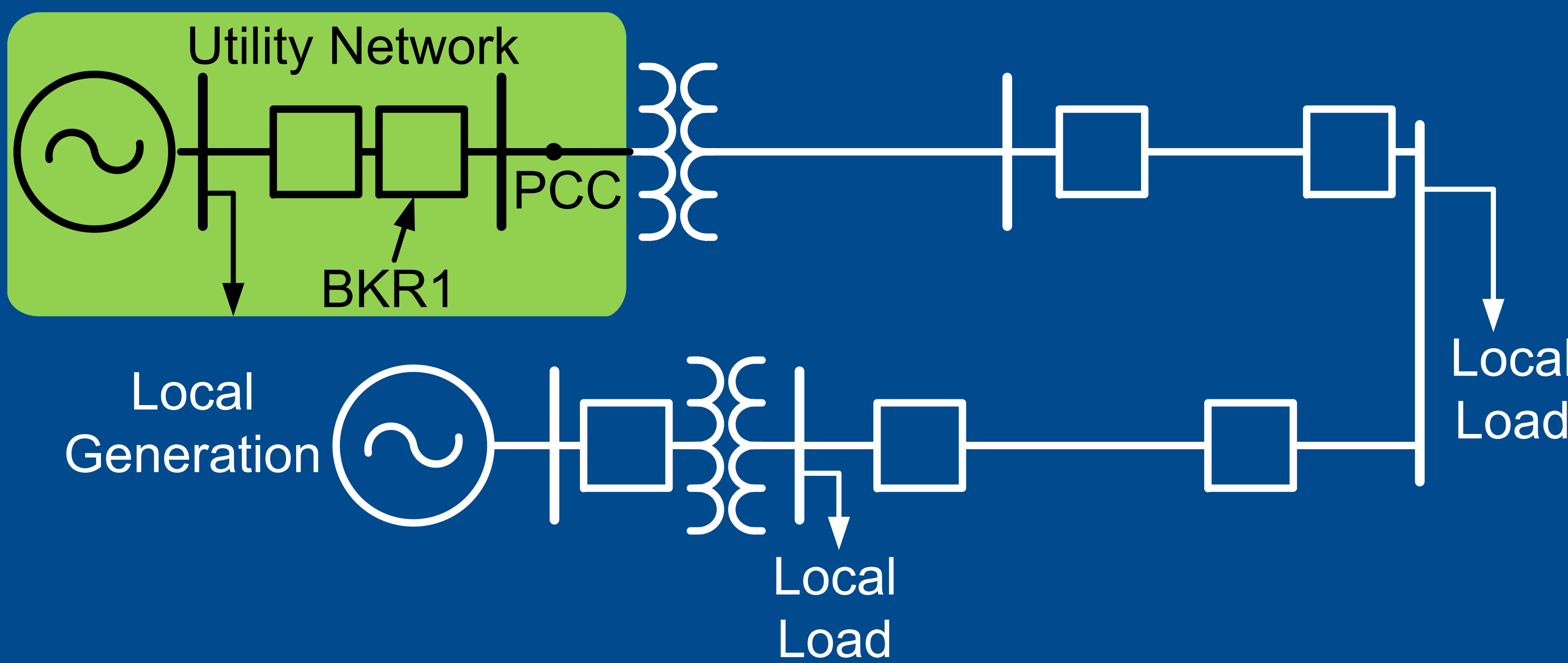


Wide-Area IDS Detects Islanding During Minimal Power Exchange Conditions

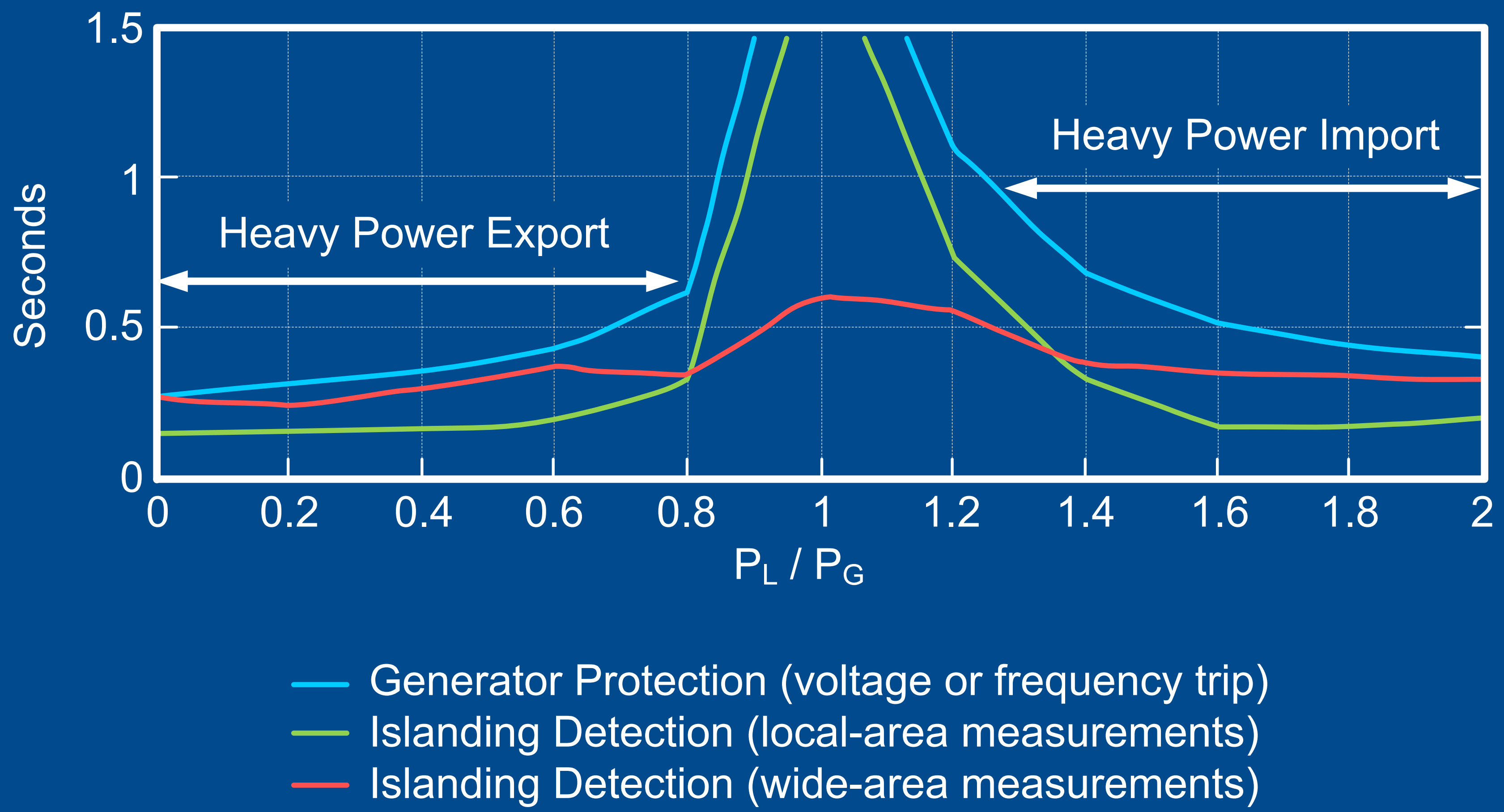


- Synchrophasor data are sent from the DG and remote source
- SVP time-aligns and makes coherent data available to logic

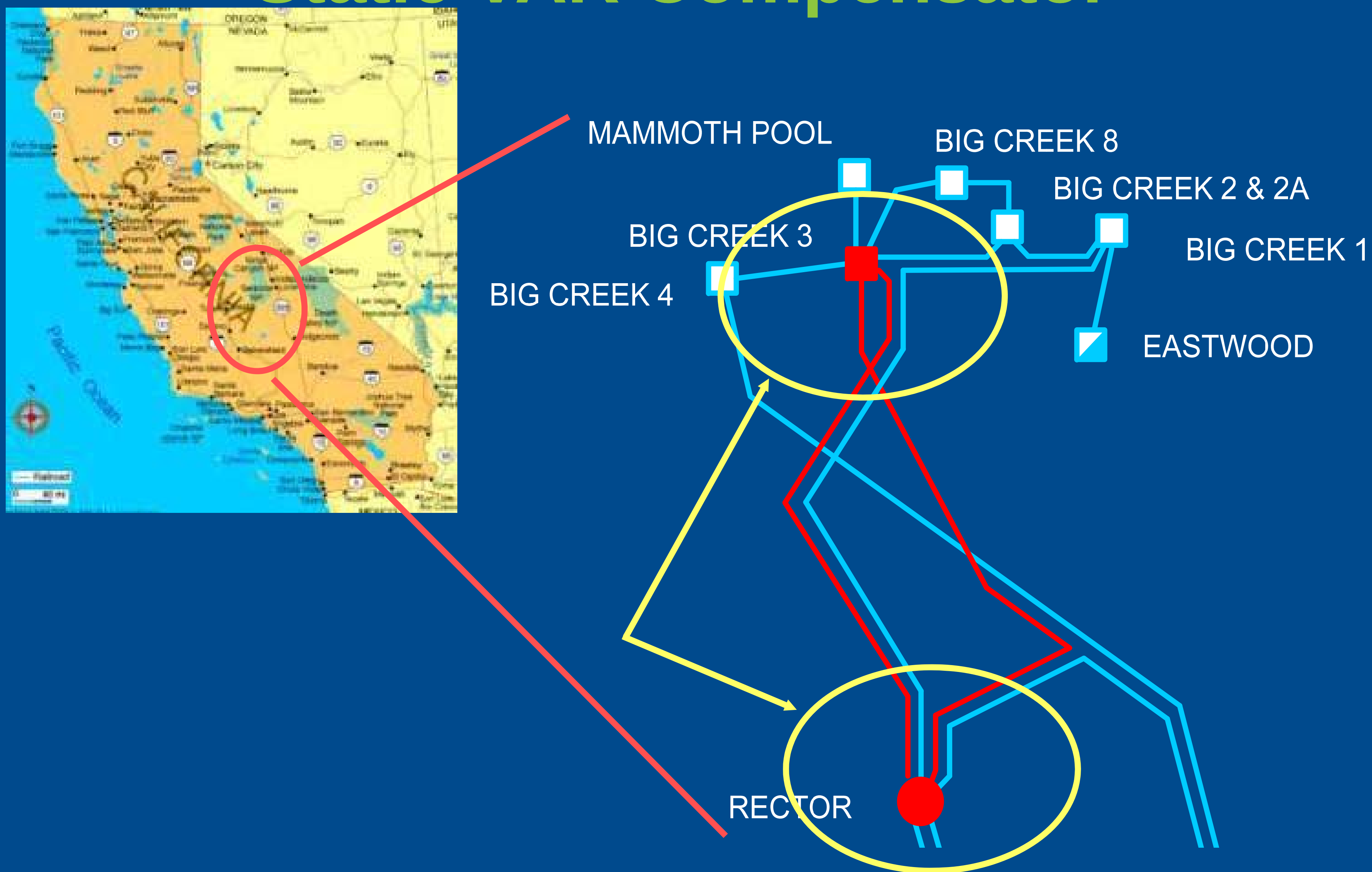
Responsive to All Conditions



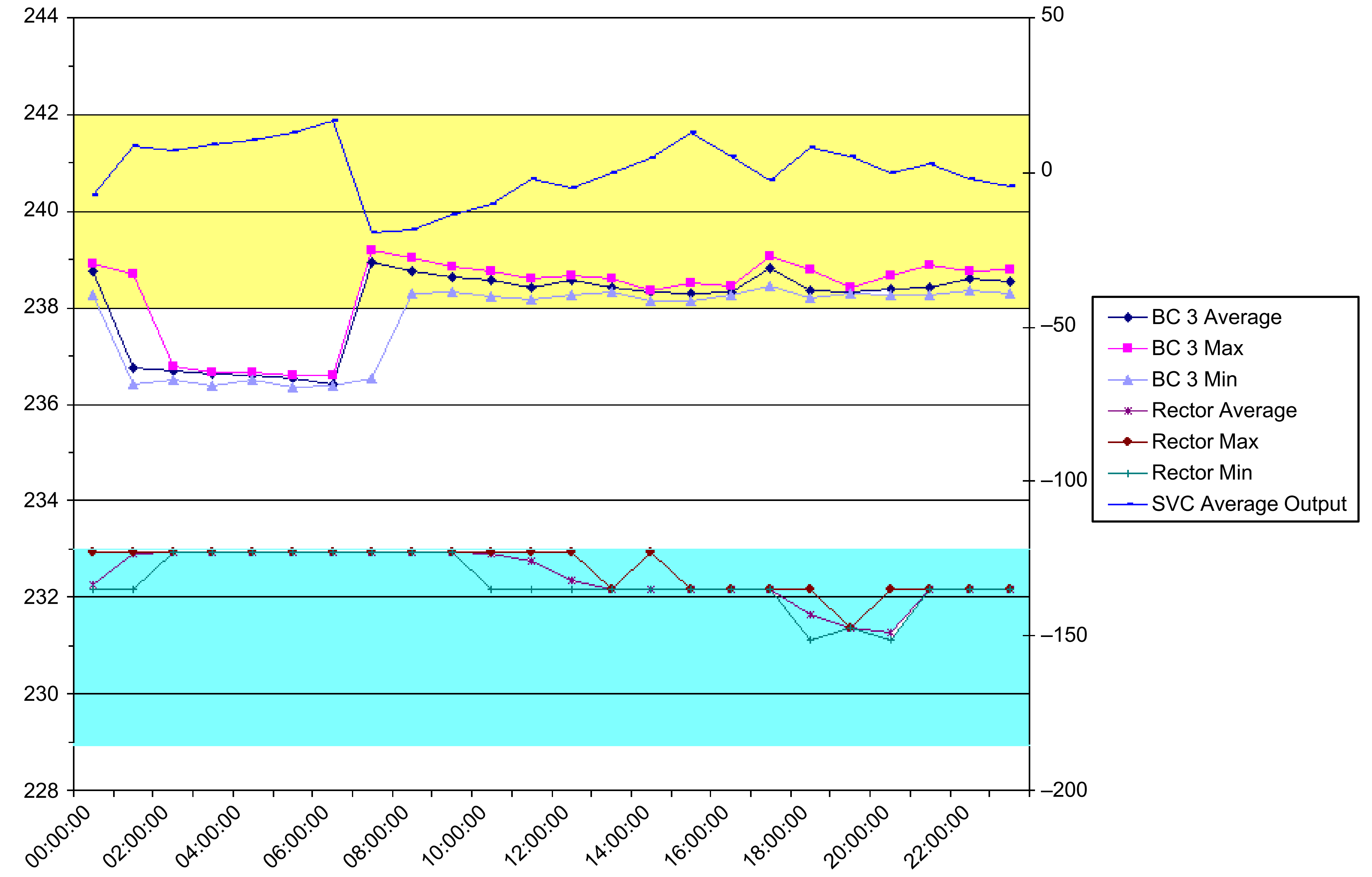
Responsive to All Conditions



Big Creek Controls Rector Static VAR Compensator



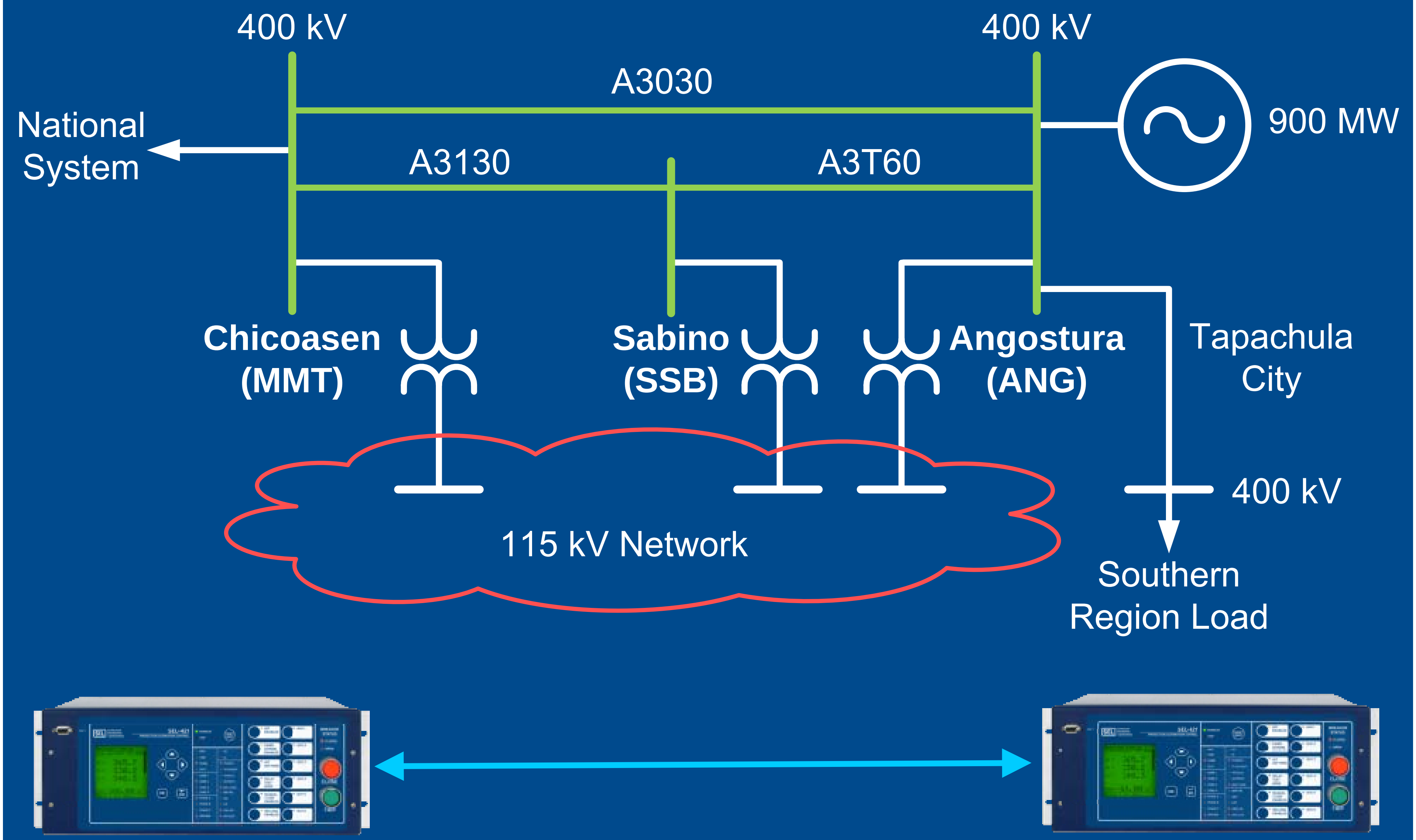
Closed-Loop Control at Big Creek Stabilizes Voltage



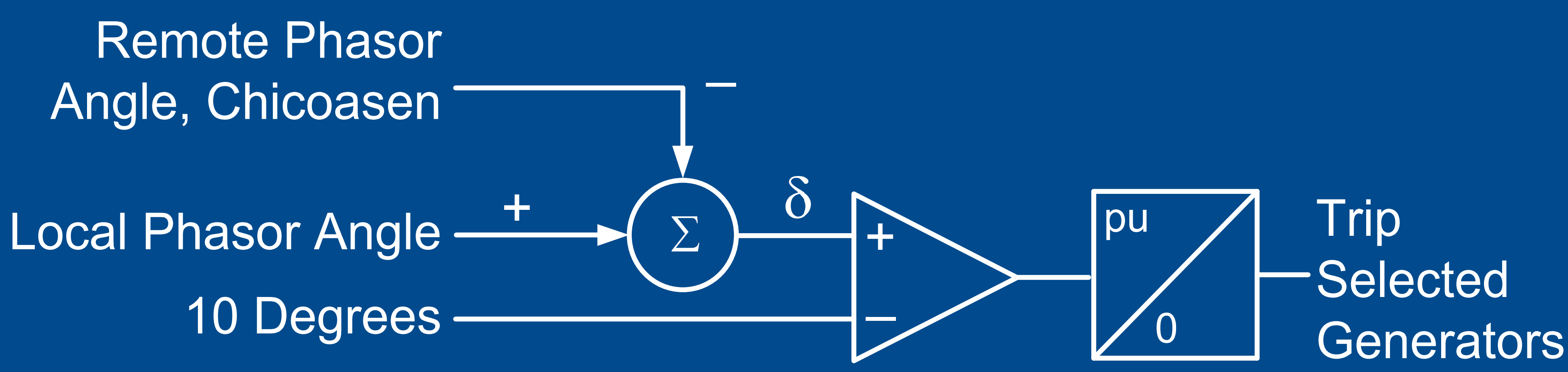
Transient Stability Control

CFE Mexico

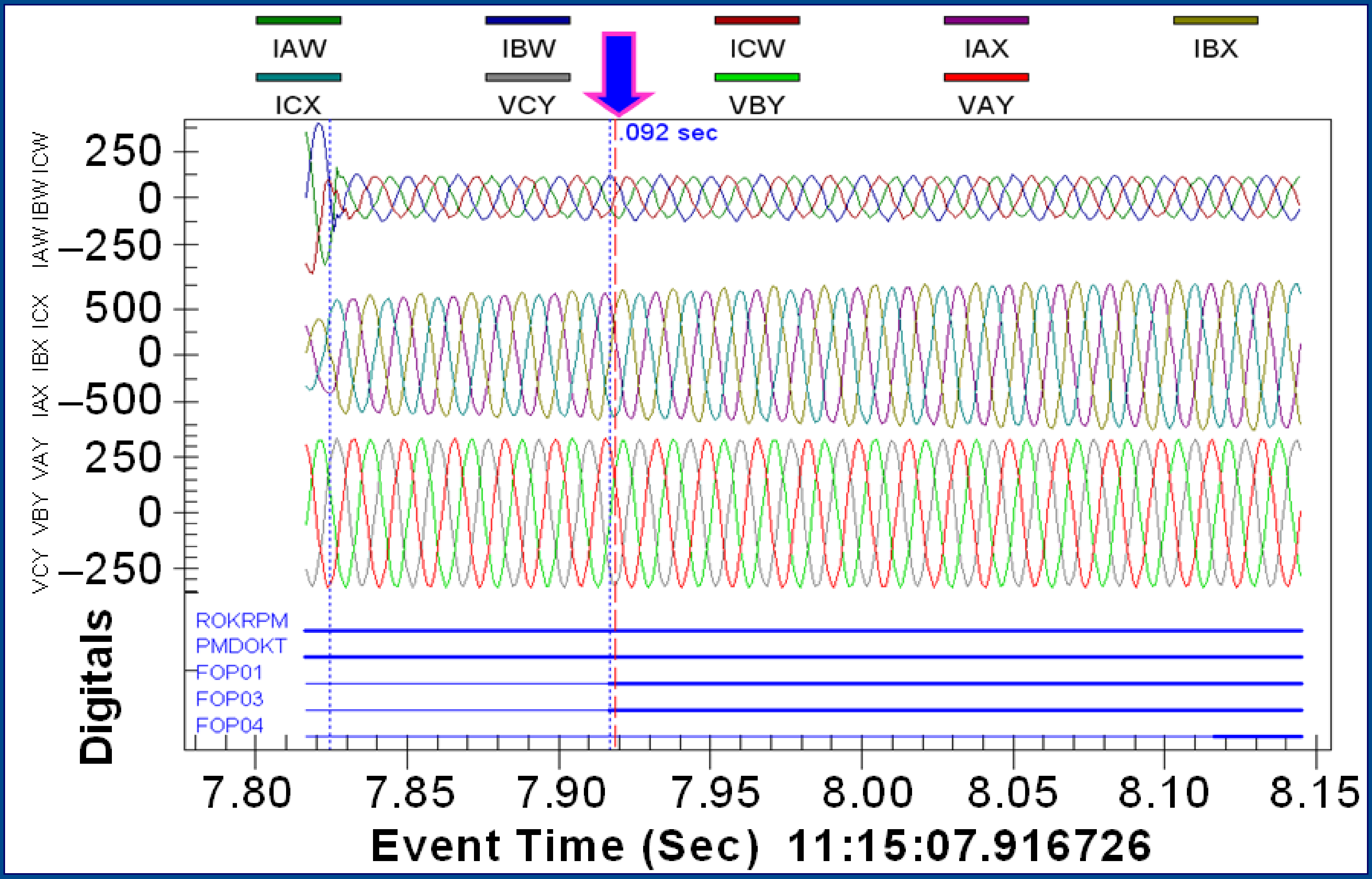
CFE AGSS System



Simple Synchrophasor Generator-Shedding Logic



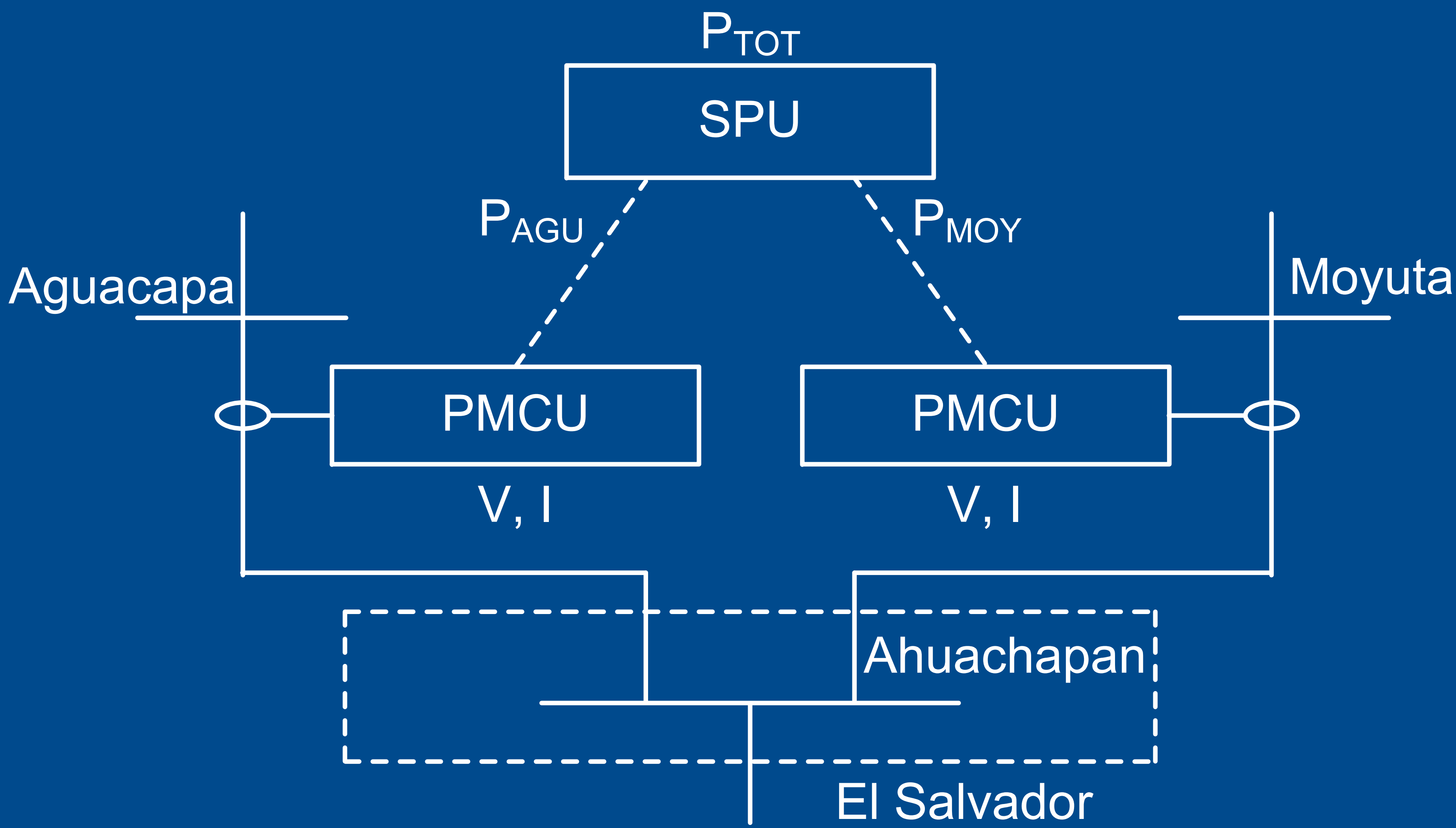
Wide-Area Protection at Relay Speeds



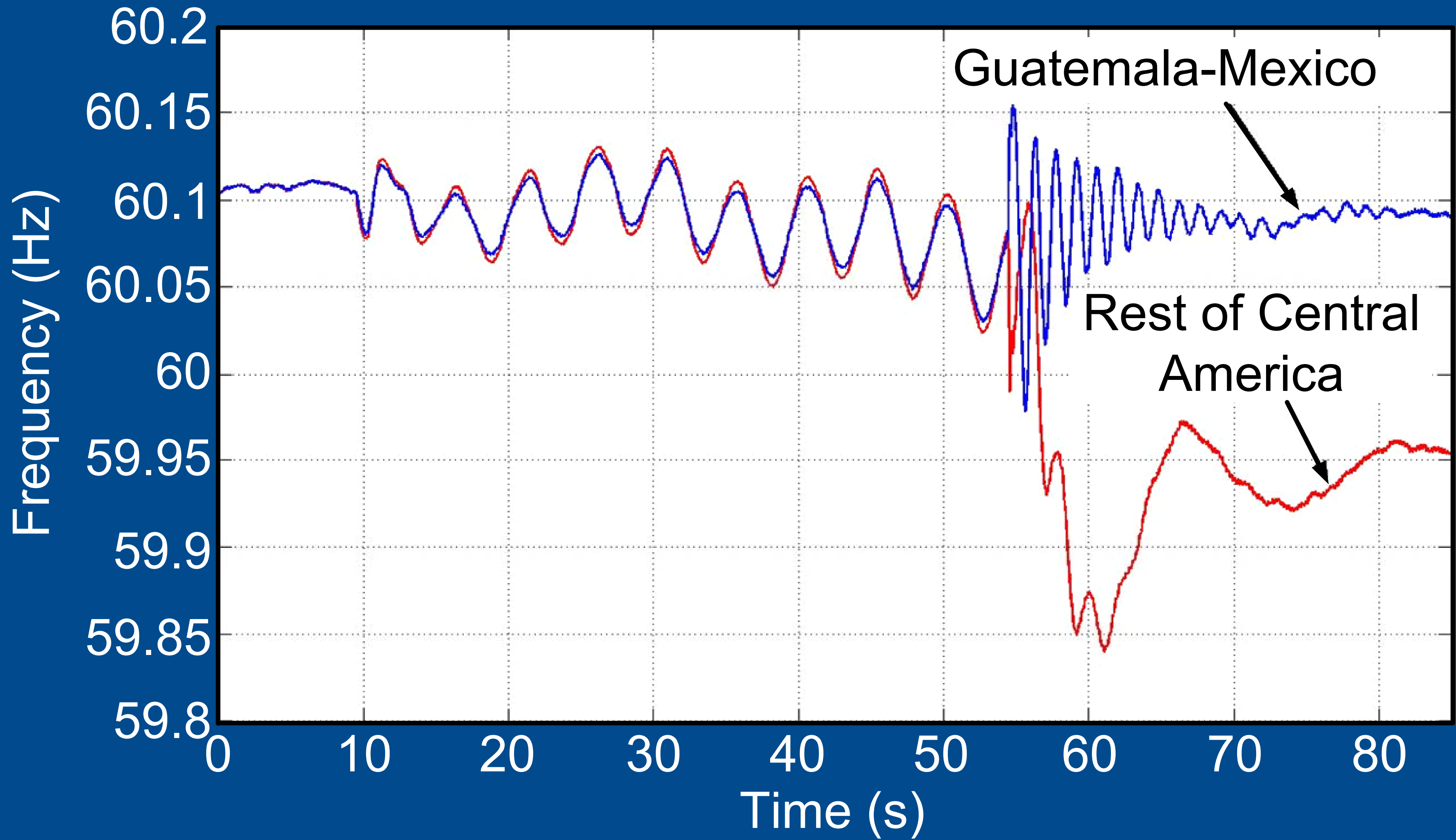
230 kV Backbone Connects Countries From Guatemala to Panama

Guatemala Wheels Power From Mexico to Central America

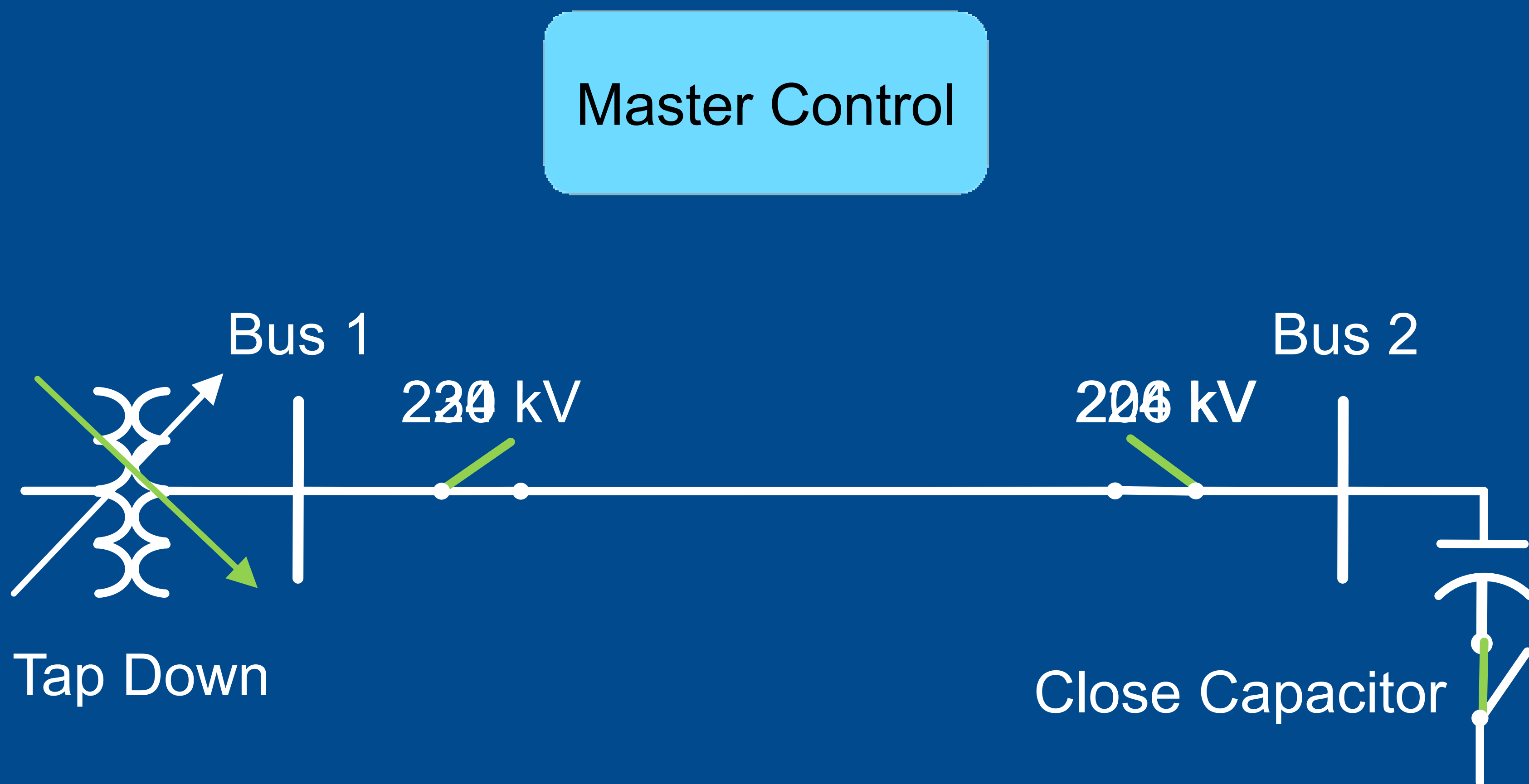
Supplementary Control Scheme (SCS) Trips Interconnection to El Salvador



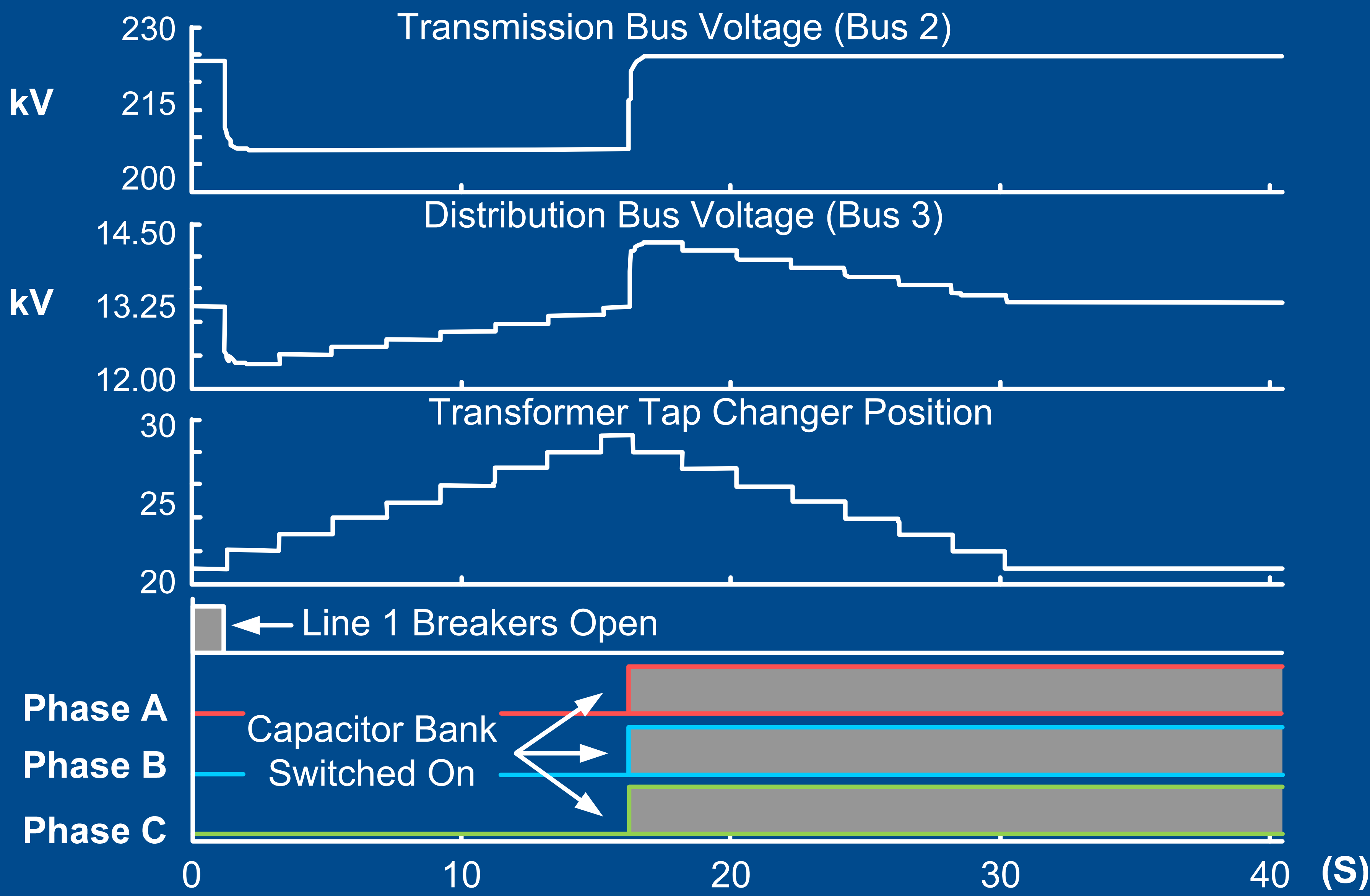
Oscillation Stability Assessment With Resulting Control Action Displayed



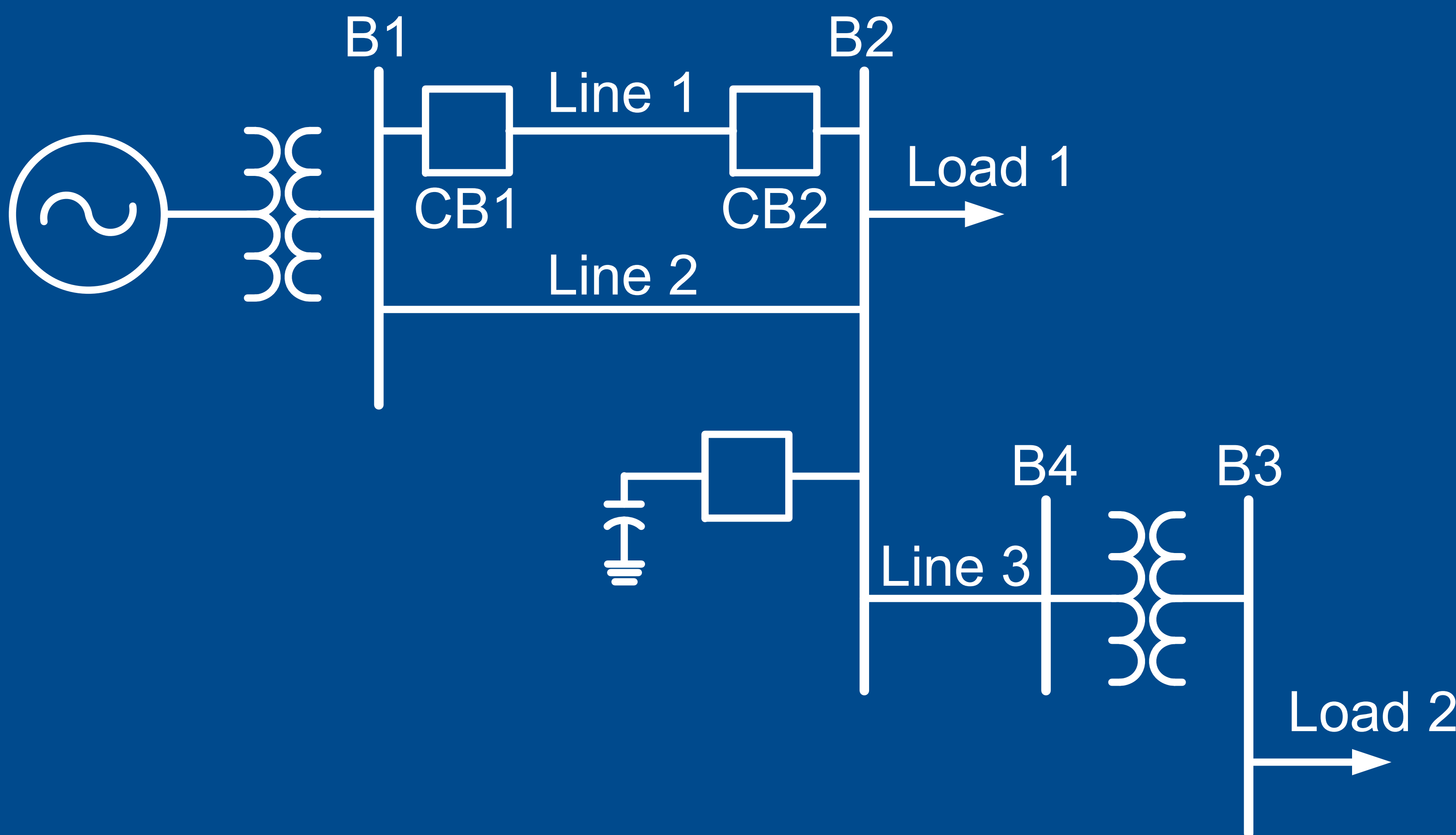
Traditional Control to Isolate Line



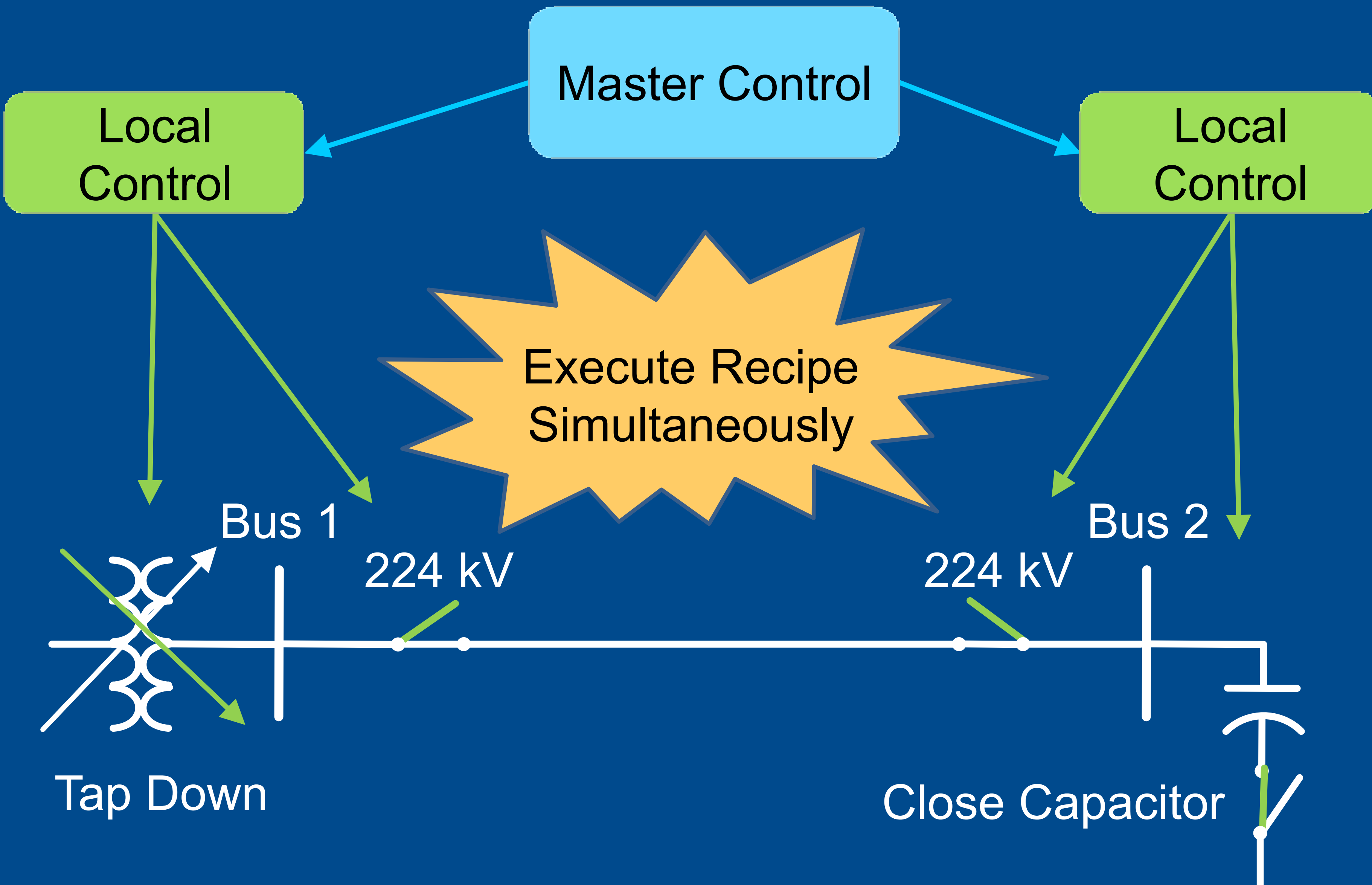
Traditional Method Causes Disturbances



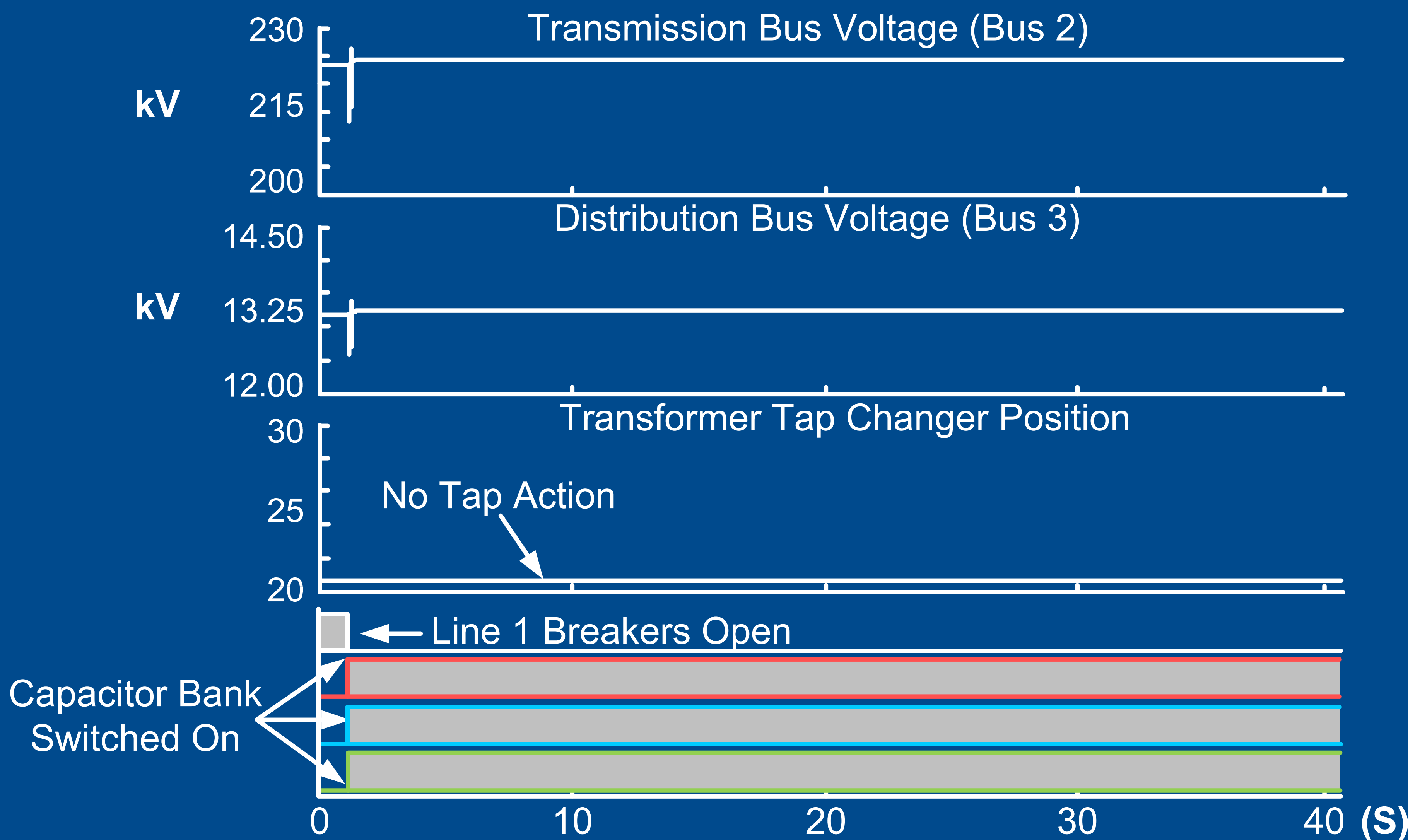
Time-Synchronized Control in Action



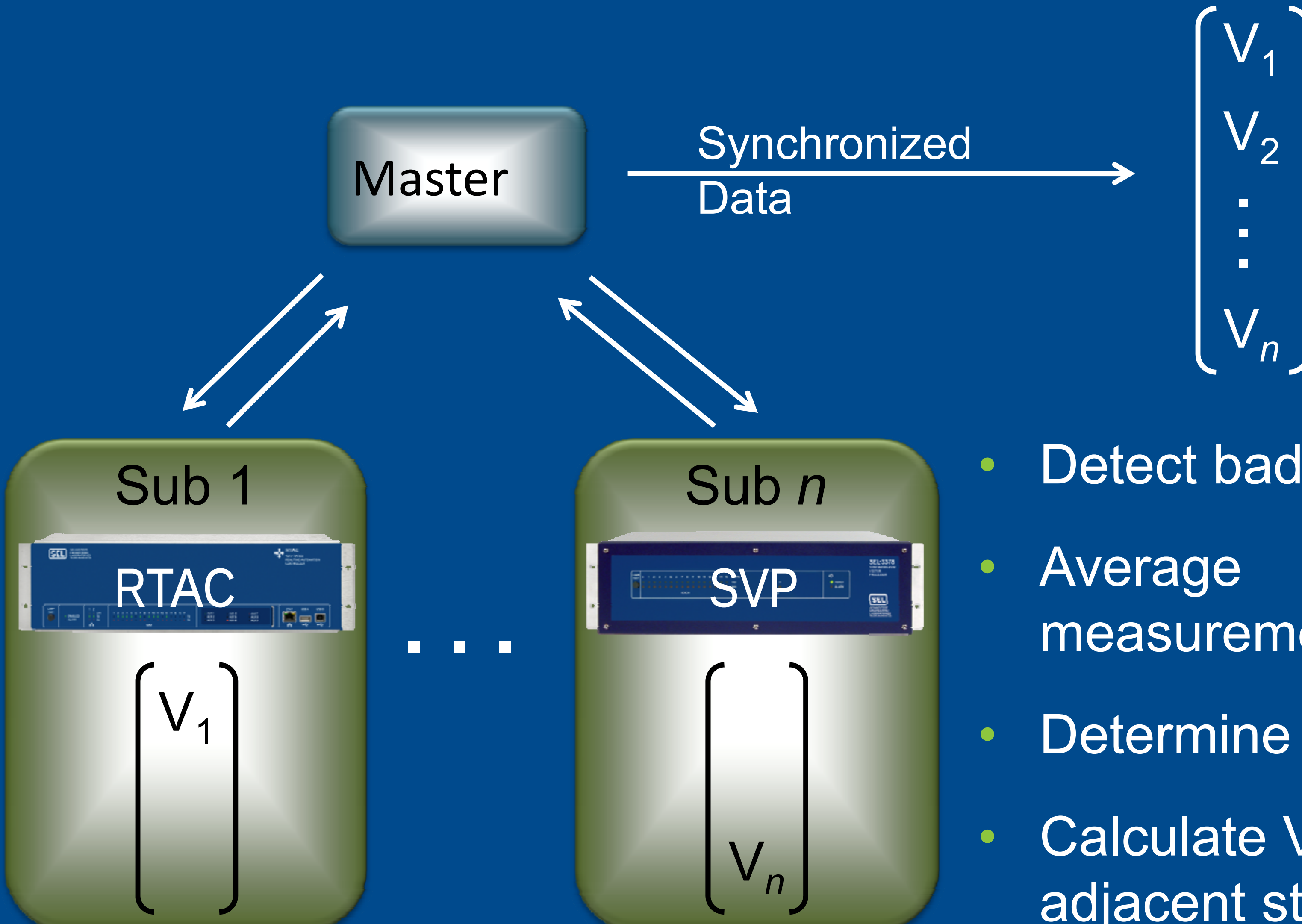
Synchronous Control to Isolate Line



Recipe Method Minimizes Impact

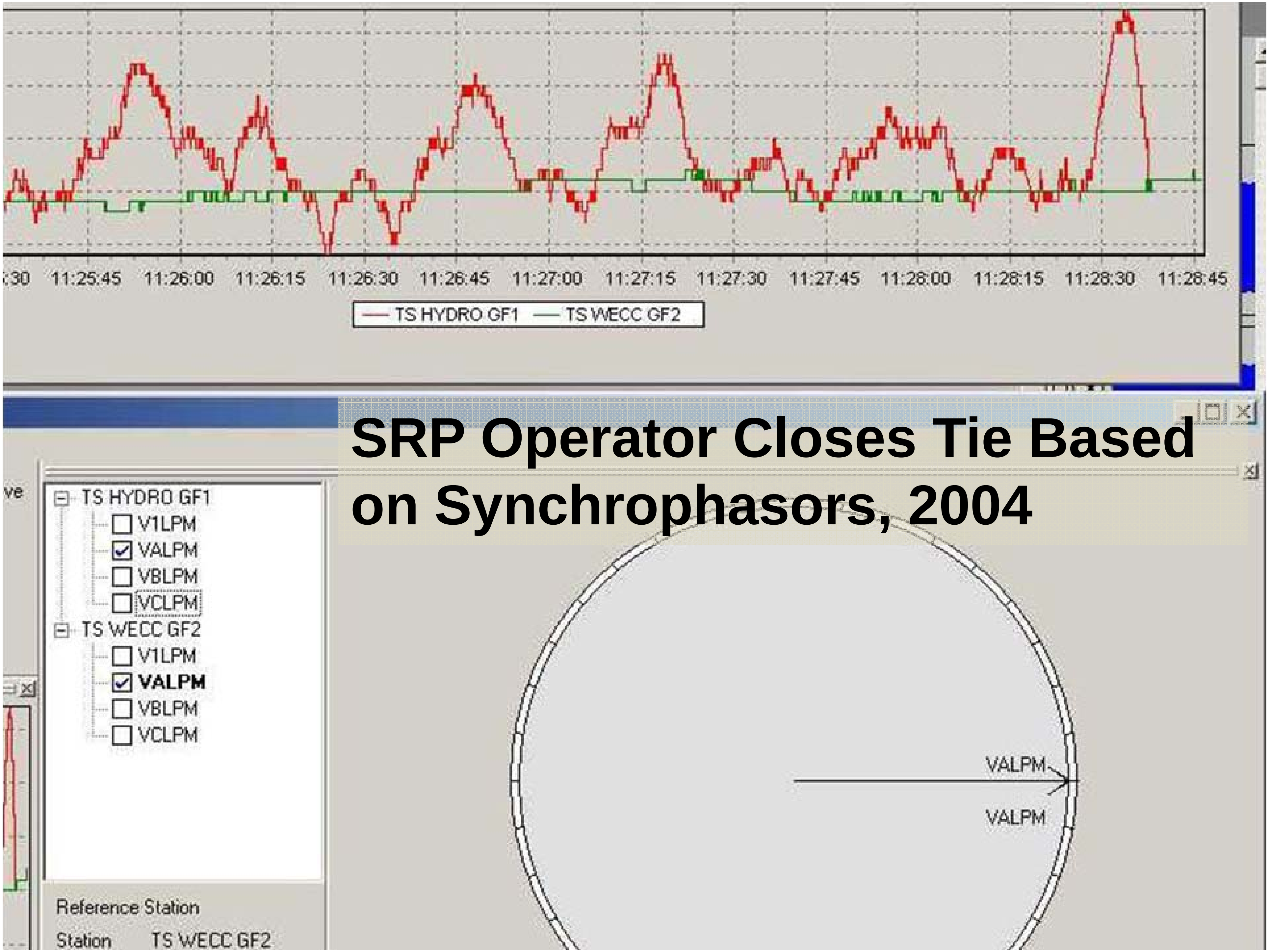


Directly Measure the State

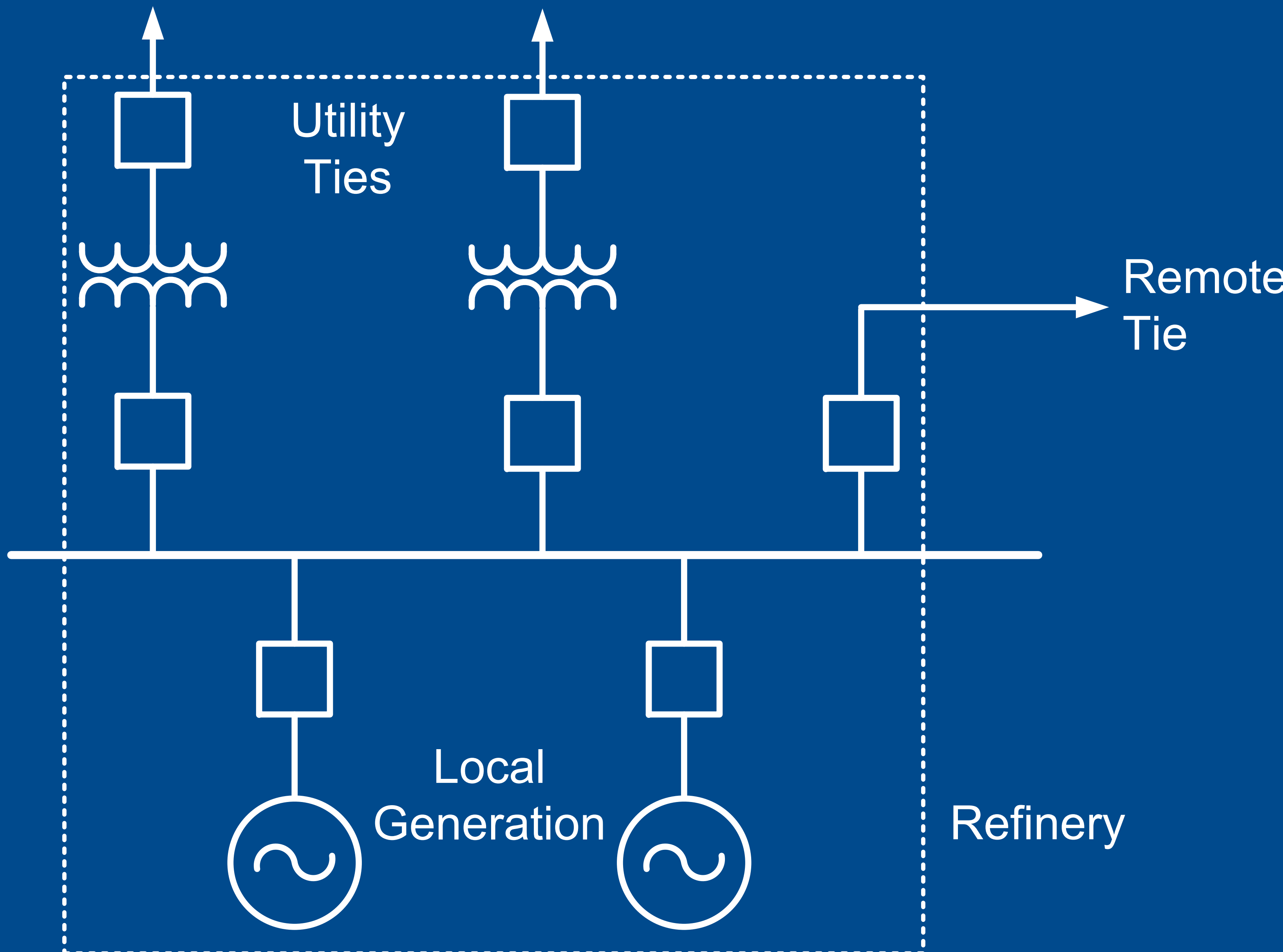


- Detect bad data
- Average measurements
- Determine topology
- Calculate V at adjacent stations:
  $V' = V + ZI$

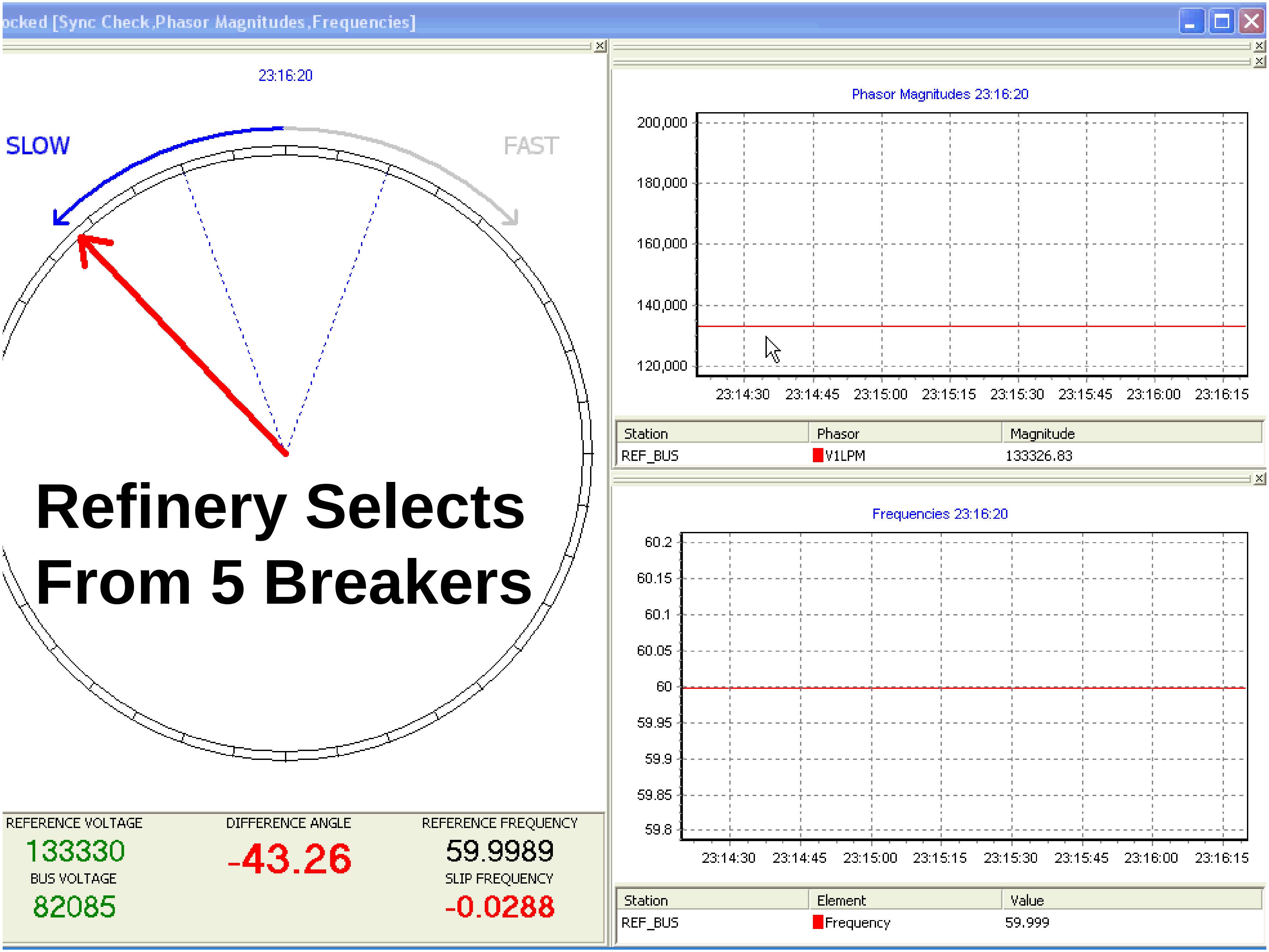
SRP Operator Closes Tie Based on Synchrophasors, 2004



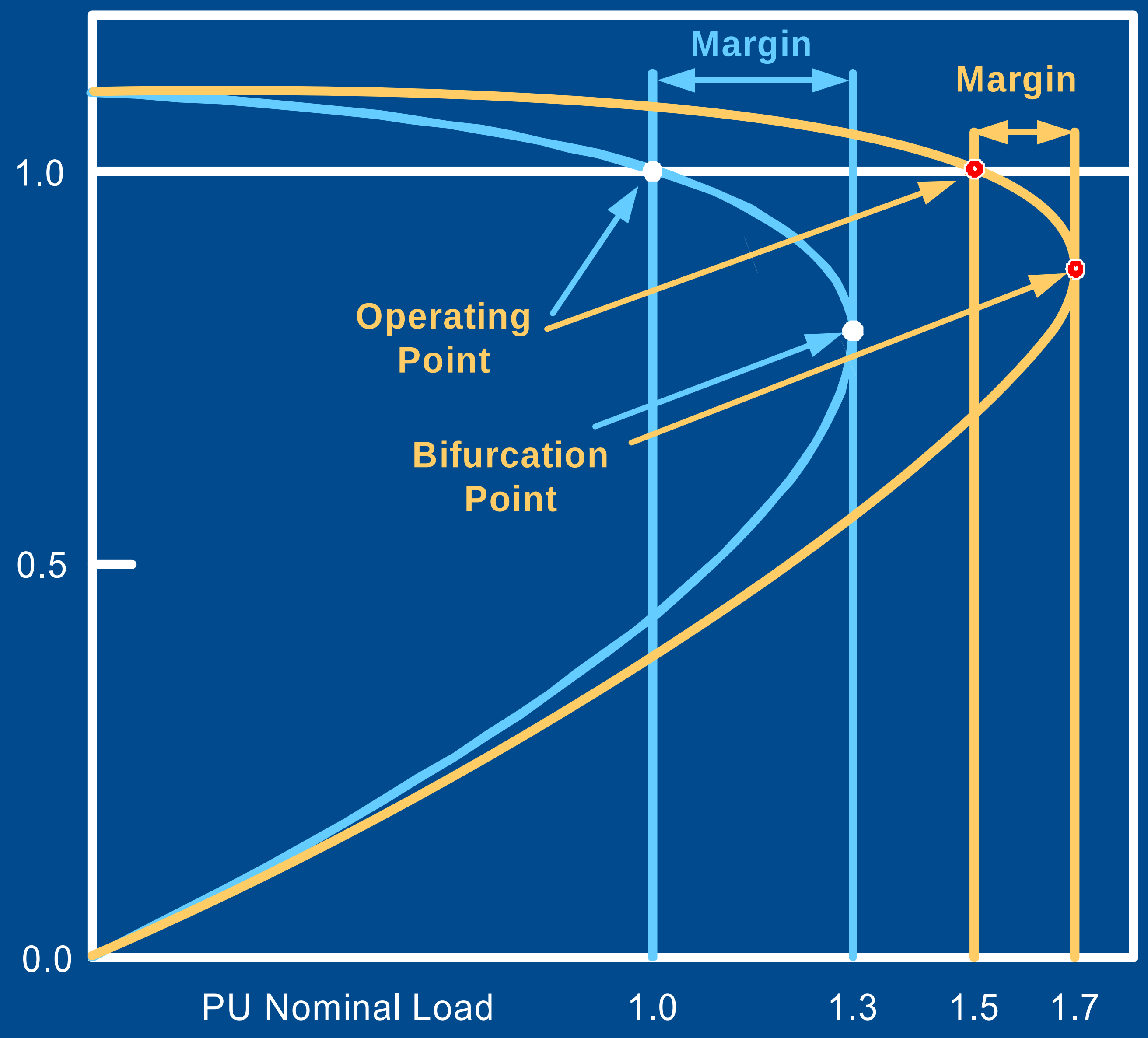
What if I Have Multiple Tie Points?



Refinery Selects From 5 Breakers



Utilities Are Operating Closer to the Edge



Long Island: Monitor Angles Between Transmission Distribution Buses to Detect & Prevent Voltage Collapse

$$S_{max} = \frac{(1 - \sin(\theta))\, V_s^{\,2}}{2 \cos(\theta)^2 X}$$

MAKING ELECTRIC POWER SAFE, RELIABLE, AND ECONOMICAL FOR 30 YEARS