SCHWEITZER ENGINEERING LABORATORIES

Synchrophasor-Based Monitoring, Analysis, and Control

Roy Moxley

Schweitzer Engineering Laboratories, Inc.

Making Electric Power Safer, More Reliable, and More Economical®

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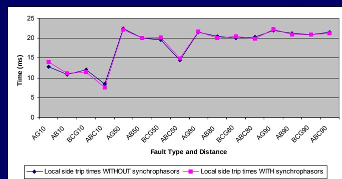
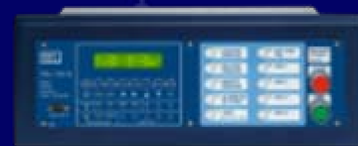
The Power System Is Changing

Photo Courtesy of Shawn Jacobs, OG&E

SEL Synchrophasor Vision





- '02 — Synchrophasors in a Relay
- '03 — Synchrophasors in a Meter
- 8/03 — Synchrophasors on the Web
- '05 — IEEE Protocol in a Relay
- SYNCHROWAVE
- '06 — Retrofit Synchrophasors In a Relay
- Utility Grade PDC
- '06 — **Real-Time Control in a Relay (Mexico)**
- '07 — **SCADA Synchrophasors**
- '07+ — **Real-Time Vector Processor**

Synchrophasors Are Standard

SEL-421 IEEE C37.118

SEL-451

SEL-487E **NEW!**

SEL-787

SEL-734 SEL Fast Message

SEL-311A, B, C

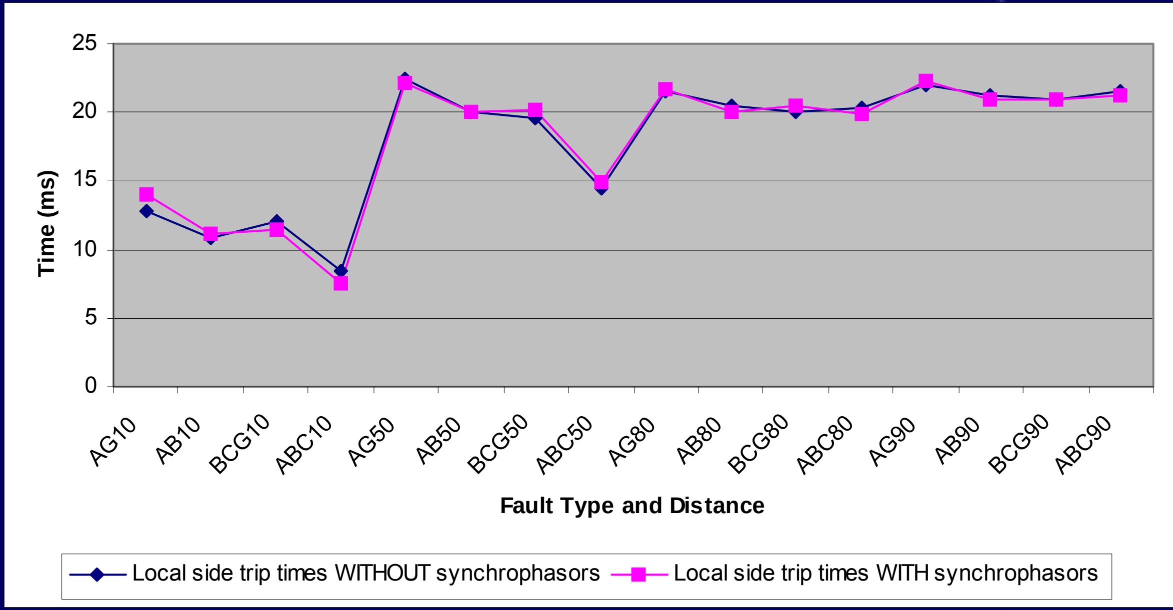
SEL-311L

SEL-351

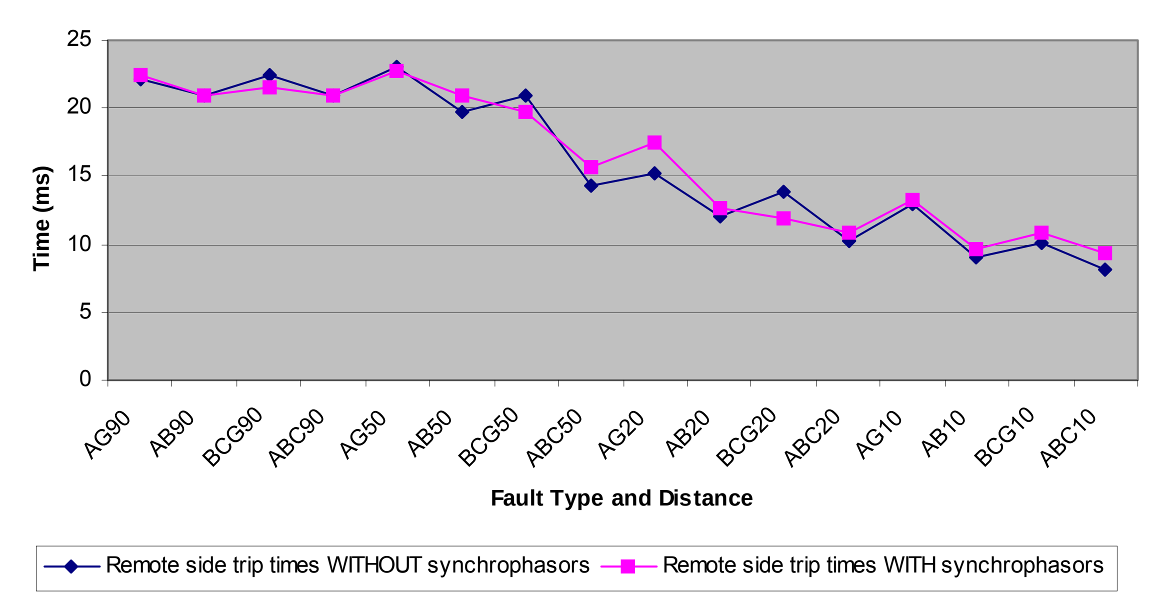
SEL-351S

SEL-351A

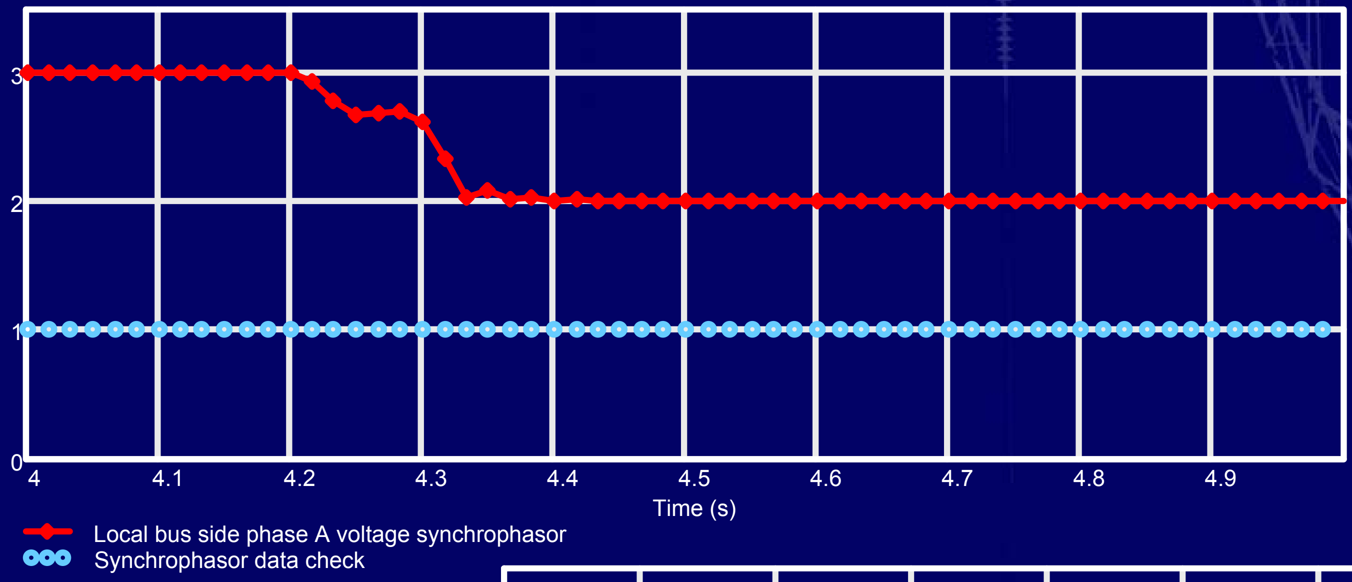
Protection AND Synchrophasors



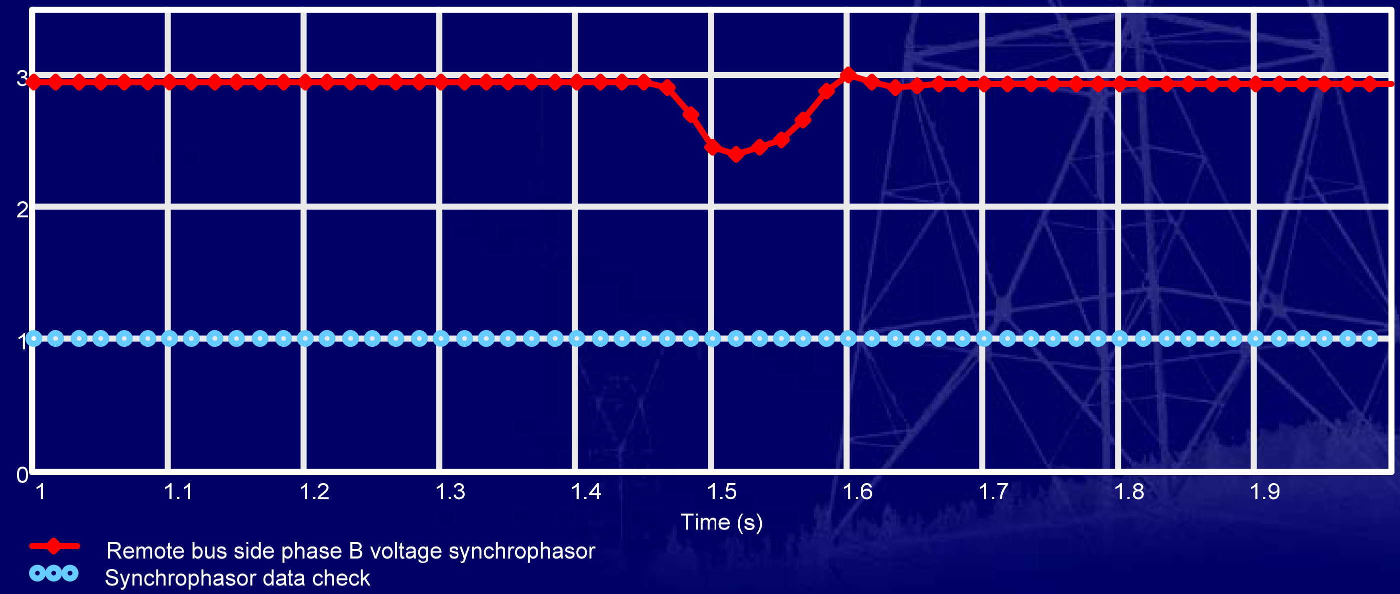
Synchrophasors do not hurt relay performance



Relaying Has No Impact on PMCU Function



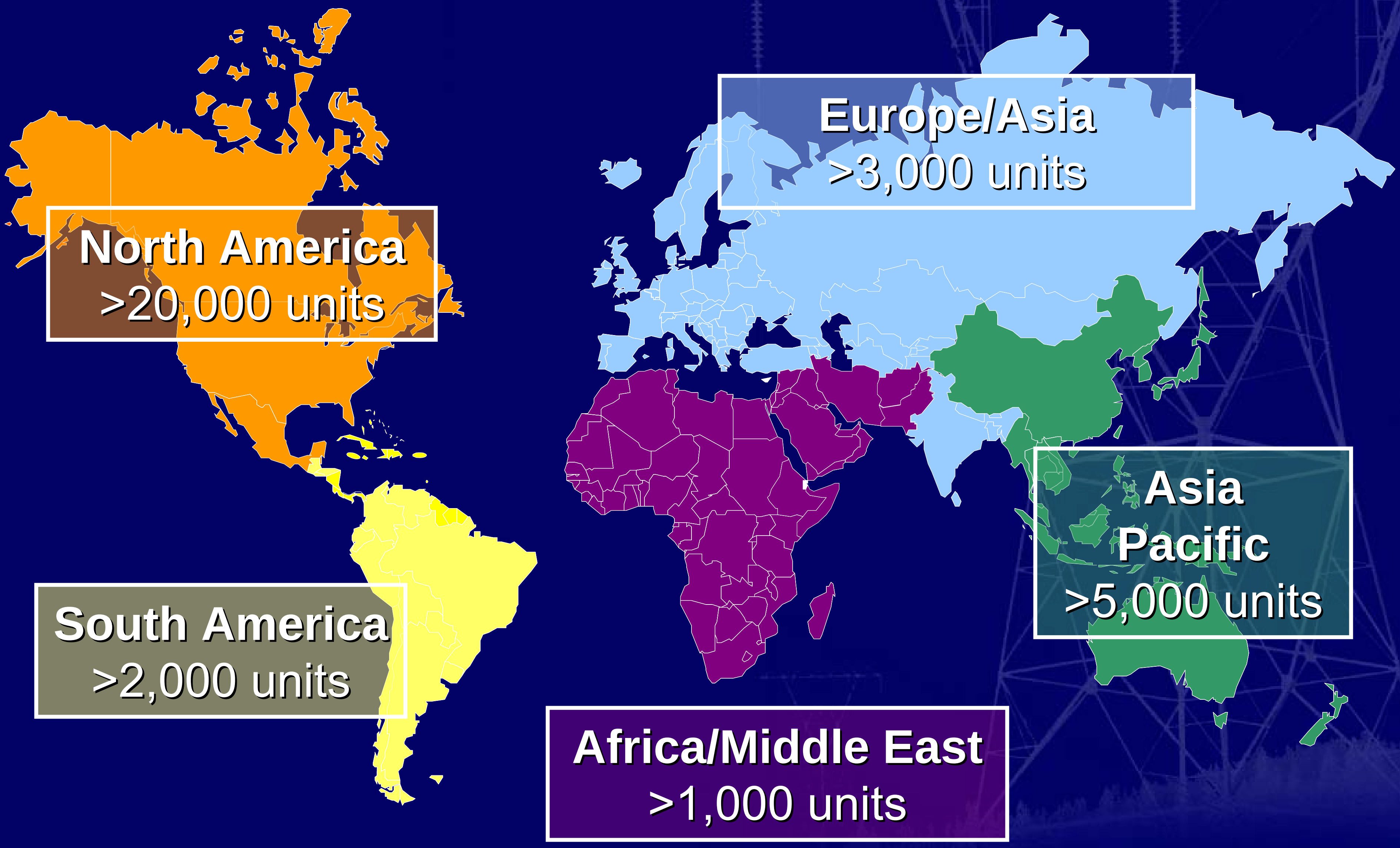
No lost data



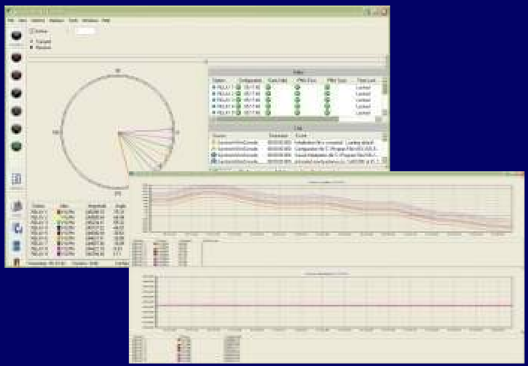
Relays Are Right for Synchrophasors

- Phasor measurement and control unit (PMCU) ≥ PMU
- Minimal incremental cost
- Reduced current and voltage connections
- High-accuracy measurements
- High reliability and availability
- Future control applications
- Relays are everywhere

SEL Synchrophasor Equipped Devices Worldwide !



Application Options – Not "One Size Fits All"



SEL-5078
Visualization

SEL-3306 Hardware PDC
SEL-5077 Software PDC
SEL-3378 Vector Processor

SEL-5077, SEL-5078 Archiving

System Operator,
Reliability Council

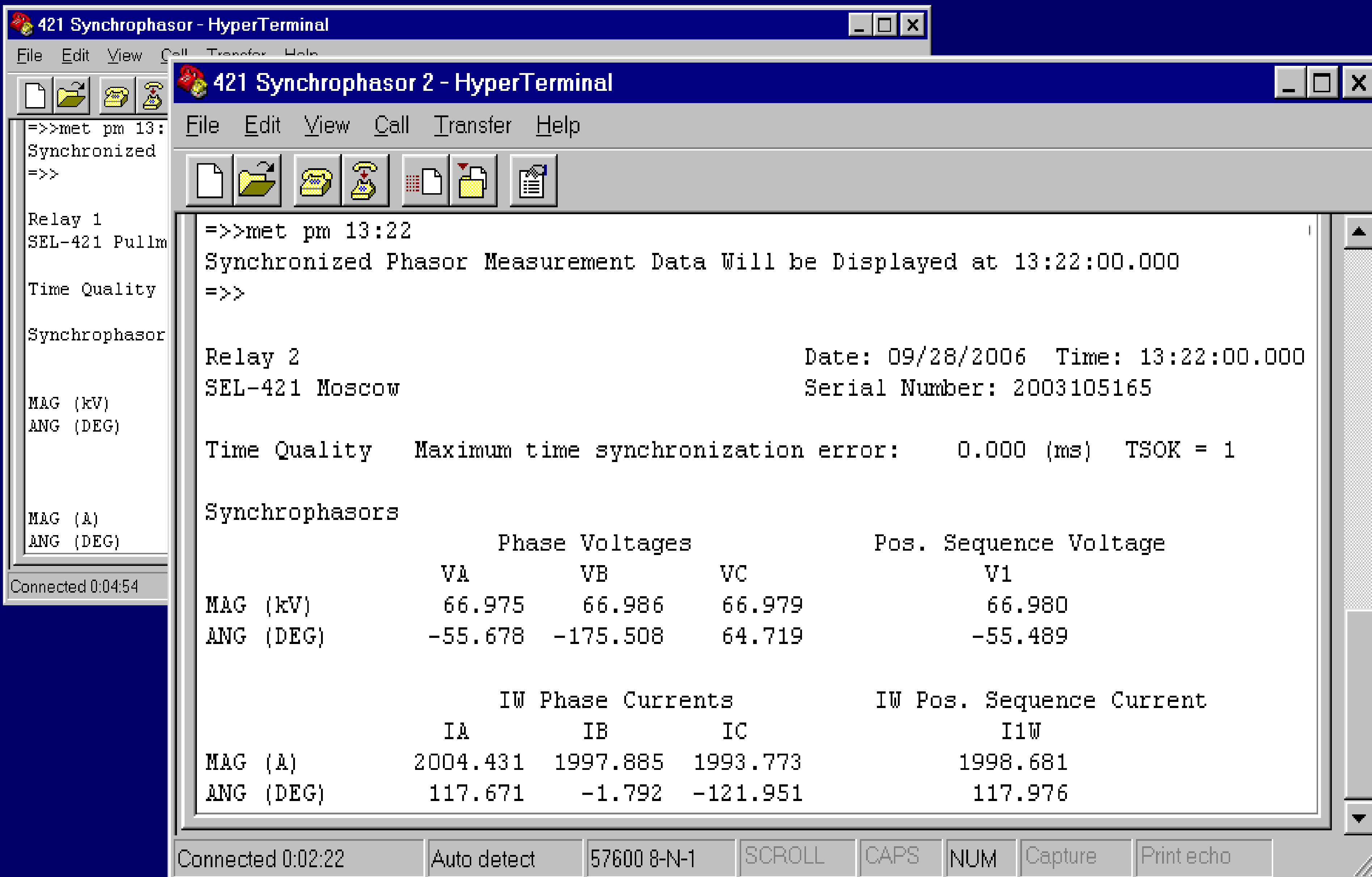
PMU's

Protection and Control Time Frame

~1.0 Second ~30 Seconds

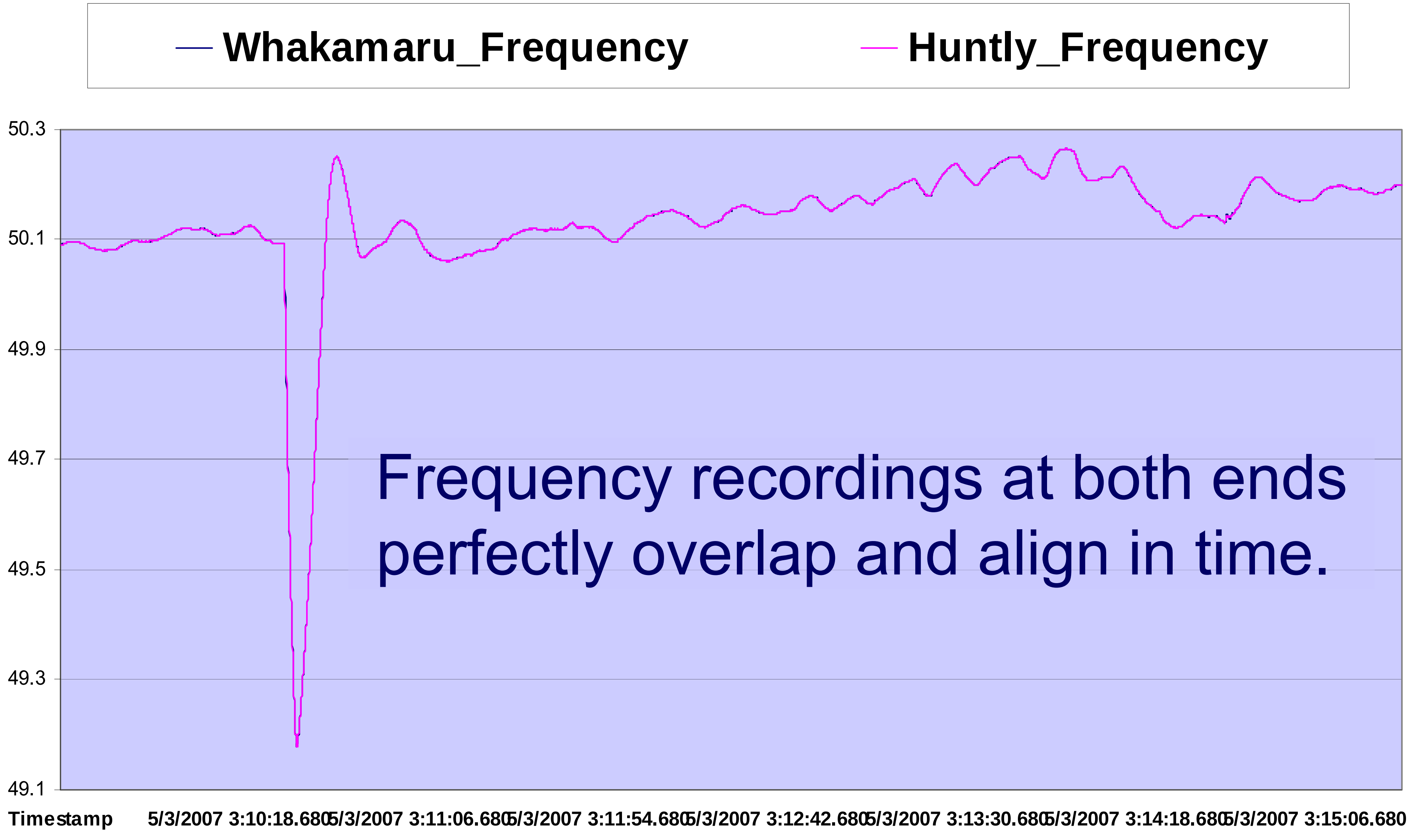
Relay Action | Control Action | Human Action

METER PM 13:22

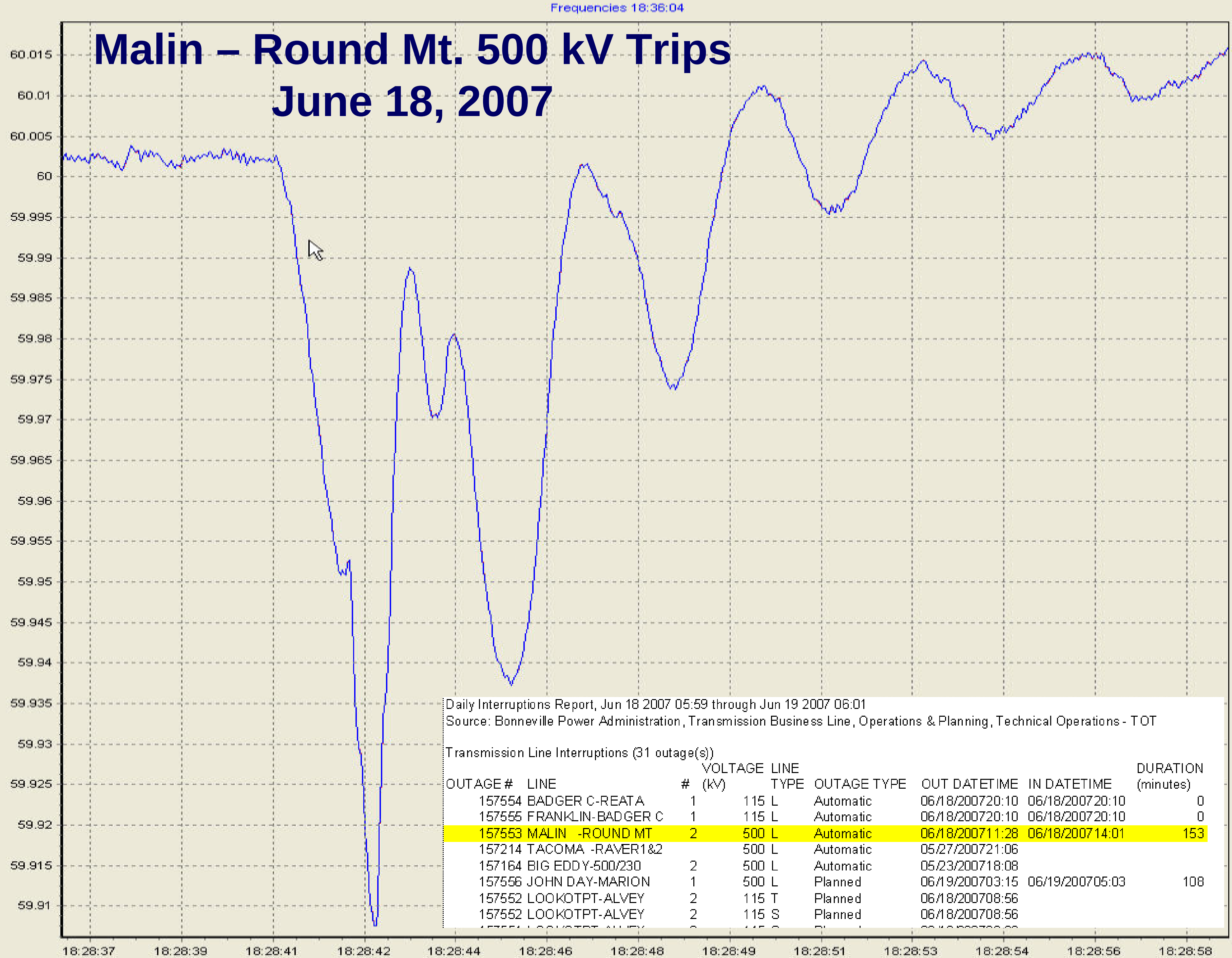


Monitor a Gen Drop Test (New Zealand)

Test Shows System Remains Stable When 400 MW Dropped



Malin – Round Mt. 500 kV Trips
June 18, 2007



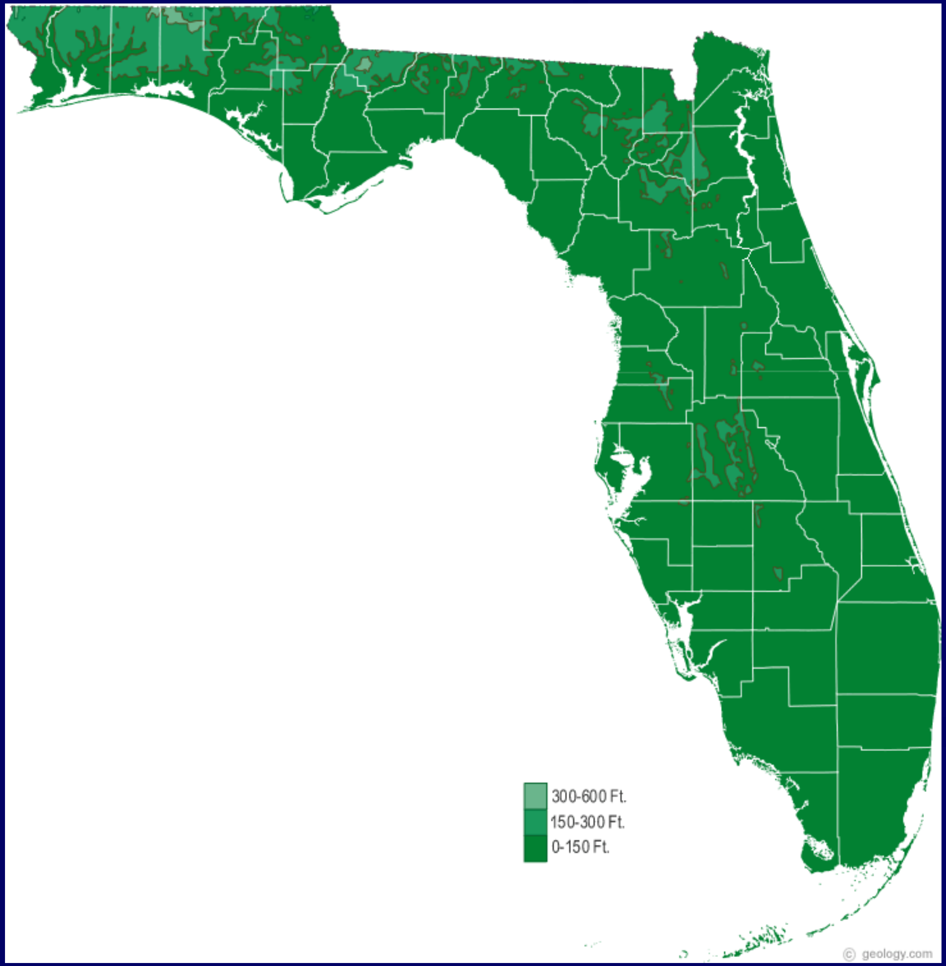
Daily Interruptions Report, Jun 18 2007 05:59 through Jun 19 2007 06:01

Source: Bonneville Power Administration, Transmission Business Line, Operations & Planning, Technical Operations - TOT

Transmission Line Interruptions (31 outage(s))

OUTAGE #	LINE	#	VOLTAGE (kV)	LINE TYPE	OUTAGE TYPE	OUT DATETIME	IN DATETIME	DURATION (minutes)
157554	BADGER C-REATA	1	115	L	Automatic	06/18/200720:10	06/18/200720:10	0
157555	FRANKLIN-BADGER C	1	115	L	Automatic	06/18/200720:10	06/18/200720:10	0
157553	MALIN -ROUND MT	2	500	L	Automatic	06/18/200711:28	06/18/200714:01	153
157214	TACOMA -RAVER1&2		500	L	Automatic	05/27/200721:06		
157164	BIG EDDY-500/230	2	500	L	Automatic	05/23/200718:08		
157556	JOHN DAY-MARION	1	500	L	Planned	06/19/200703:15	06/19/200705:03	108
157552	LOOKOTPT-ALVEY	2	115	T	Planned	06/18/200708:56		
157552	LOOKOTPT-ALVEY	2	115	S	Planned	06/18/200708:56		

"The MRI of Power Systems"

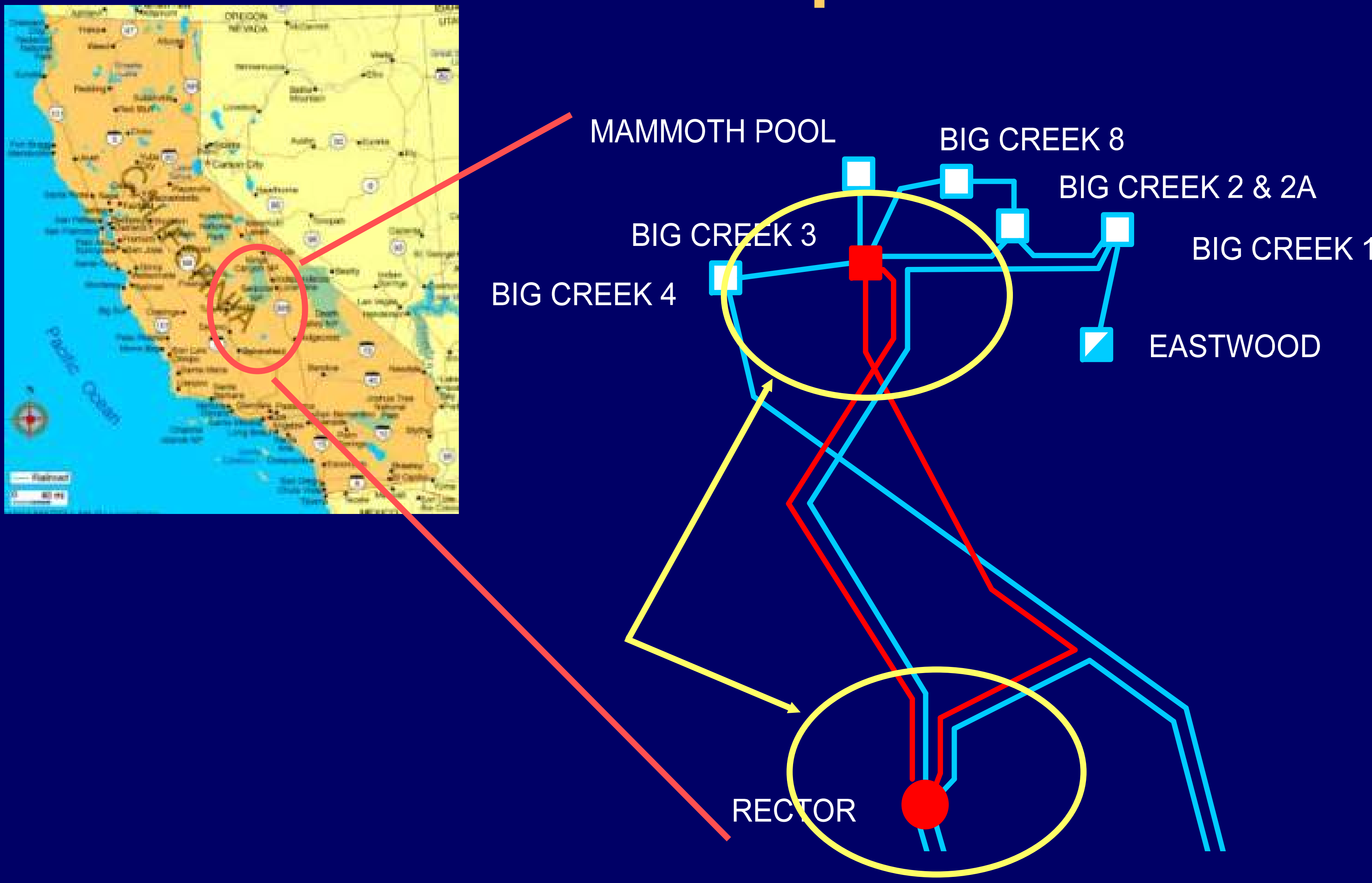


NERC press release on Florida outage Feb. 26, 2008:

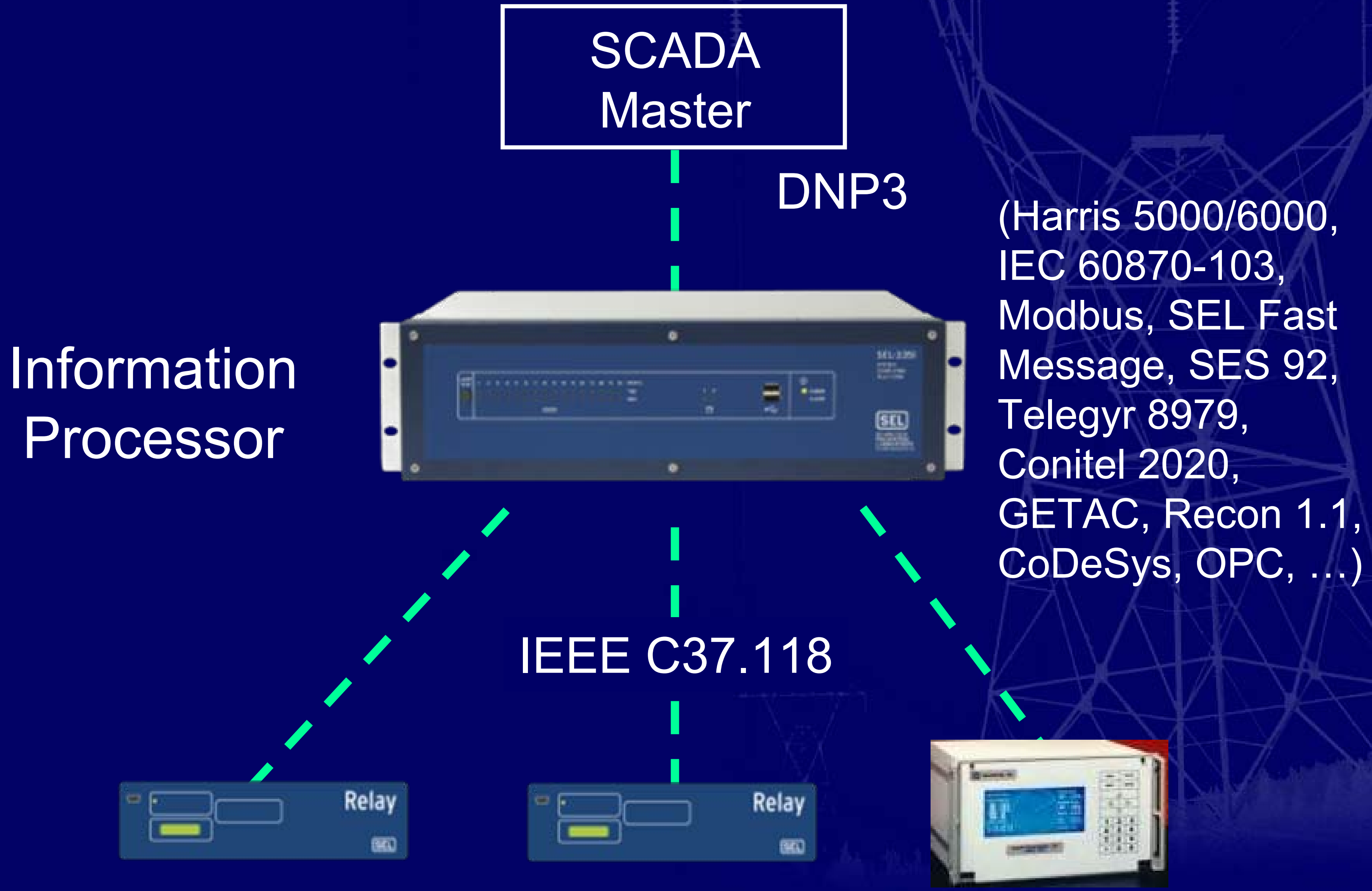
Synchrophasors are "Like the MRI of bulk power systems"

Synchrophasor-Based Control – Now a Reality

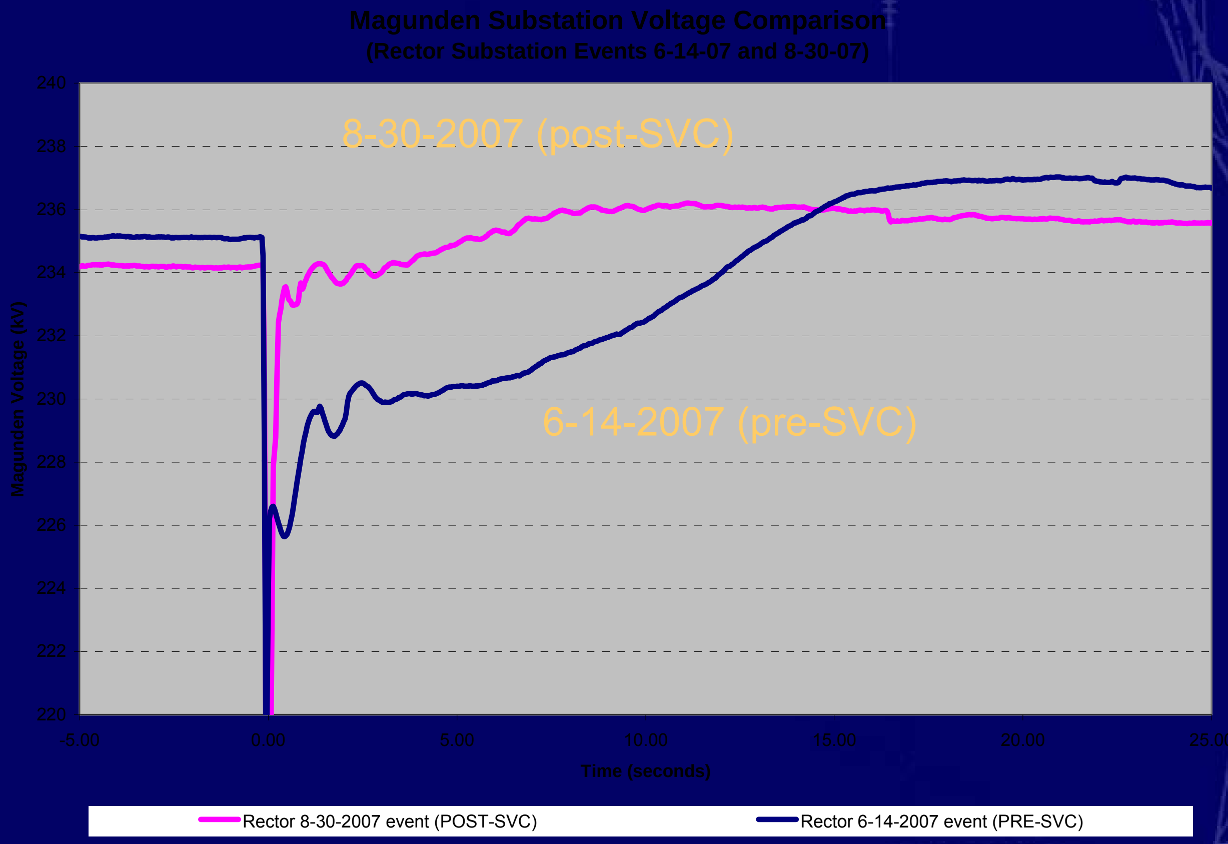
Big Creek Controls Rector Static VAR Compensator



SCE Uses C37.118 From Relays and PMU



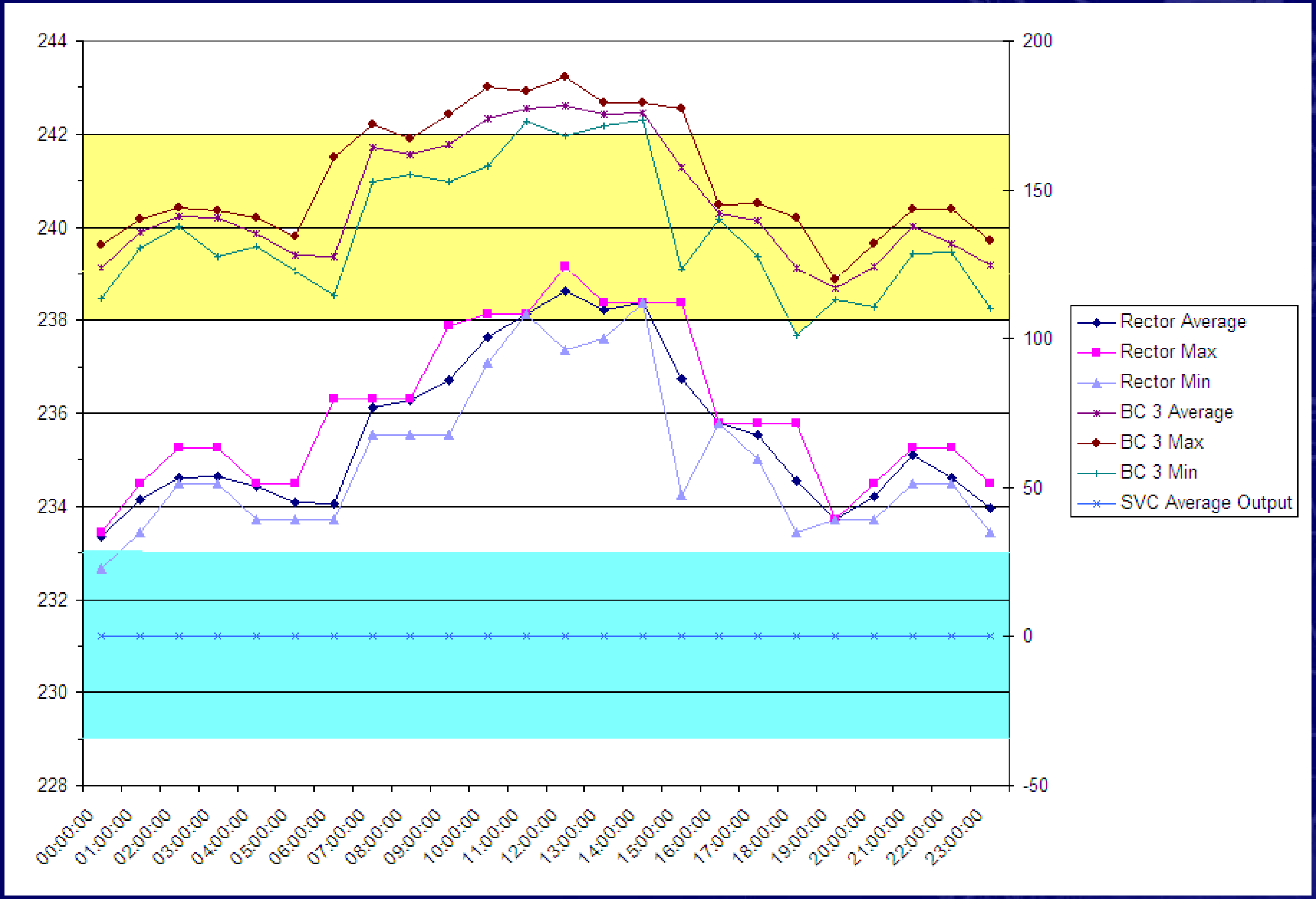
Impact of the Rector SVC: 6-14-07 (pre-SVC) vs. 8-30-07 (post-SVC)



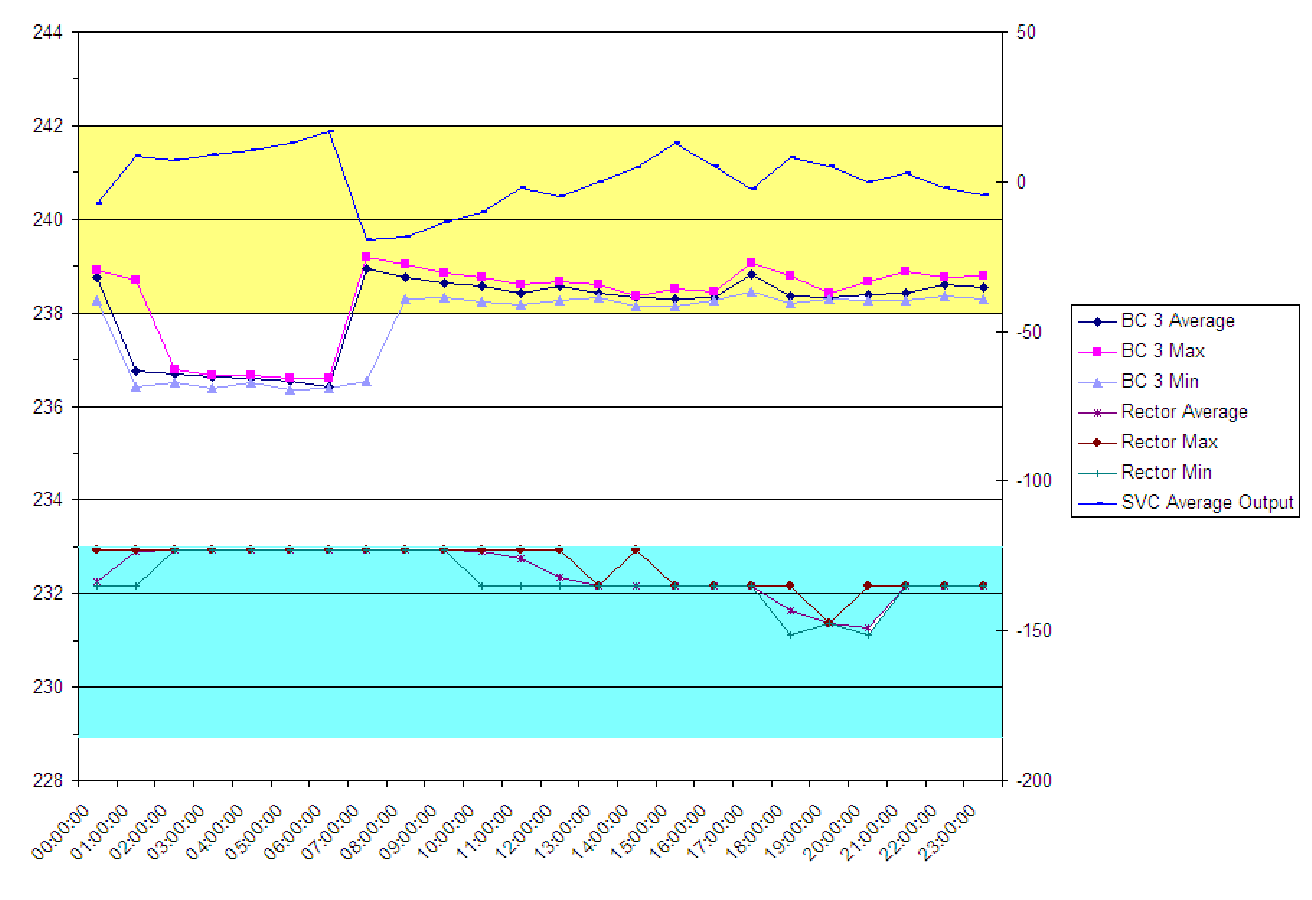
NOTE: Voltages shown were measured ~70 miles south of Rector Substation (actual low voltage event was of greater magnitude at Rector substation itself)

The Rector SVC had the apparent effect of reducing the magnitude & duration of the fault-induced slow voltage recovery…

Effect of SVC Operation on Big Creek Before -

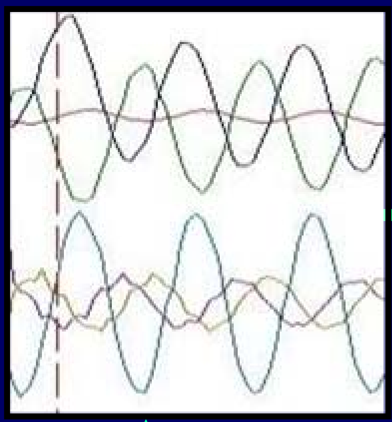


Effect of SVC Operation on Big Creek After -



Synchronous Vector Processing

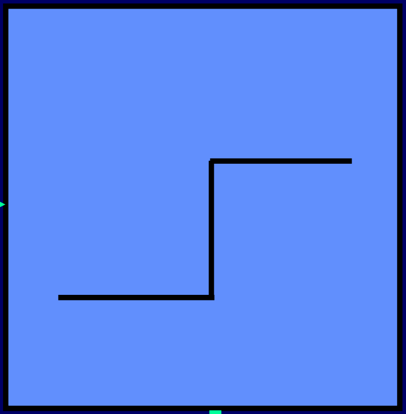
System Measurement



Function Calculation

f(x)

Output Designation



Send Control to System (Application)

Apply the SVP

- Collect synchronous phasor measurements
- Collect logical inputs
- Perform vector and scalar math
- Make decisions
- Produce outputs
- Report data

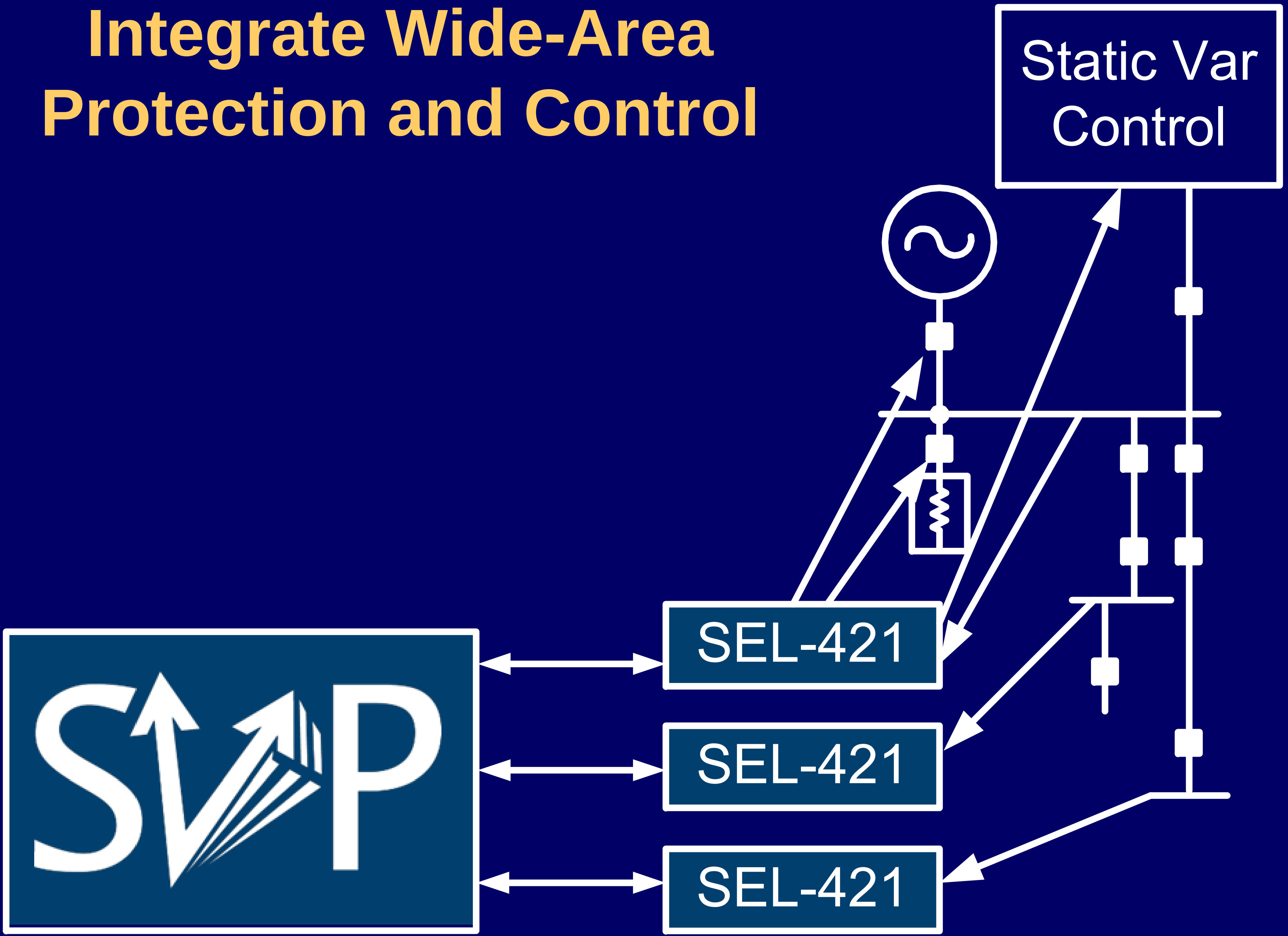
Select Quantities From Each PMU

PMU1
PMU2
PMU3

Analogs
- $|V_1|$
- $\angle V_1$
- $|I_1|$
- $\angle I_1$
- Freq
- PSV42
- TE (time error)

Binary data
- Status
- Triggers

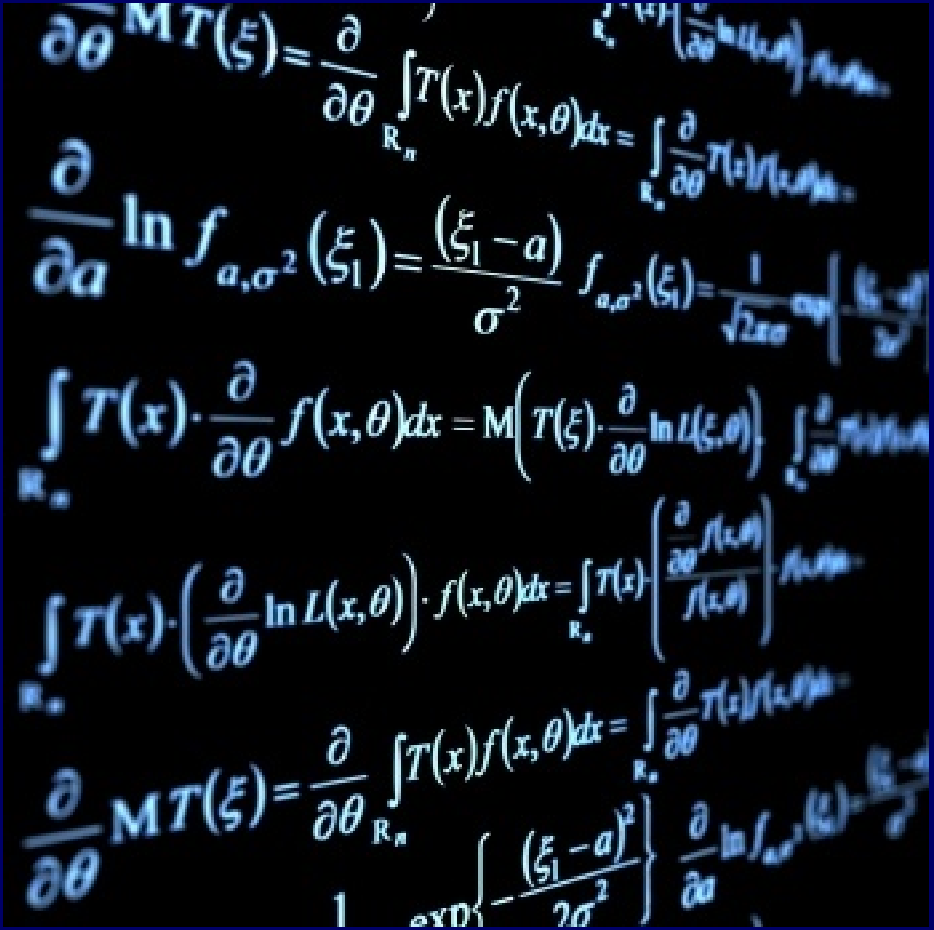
Integrate Wide-Area Protection and Control



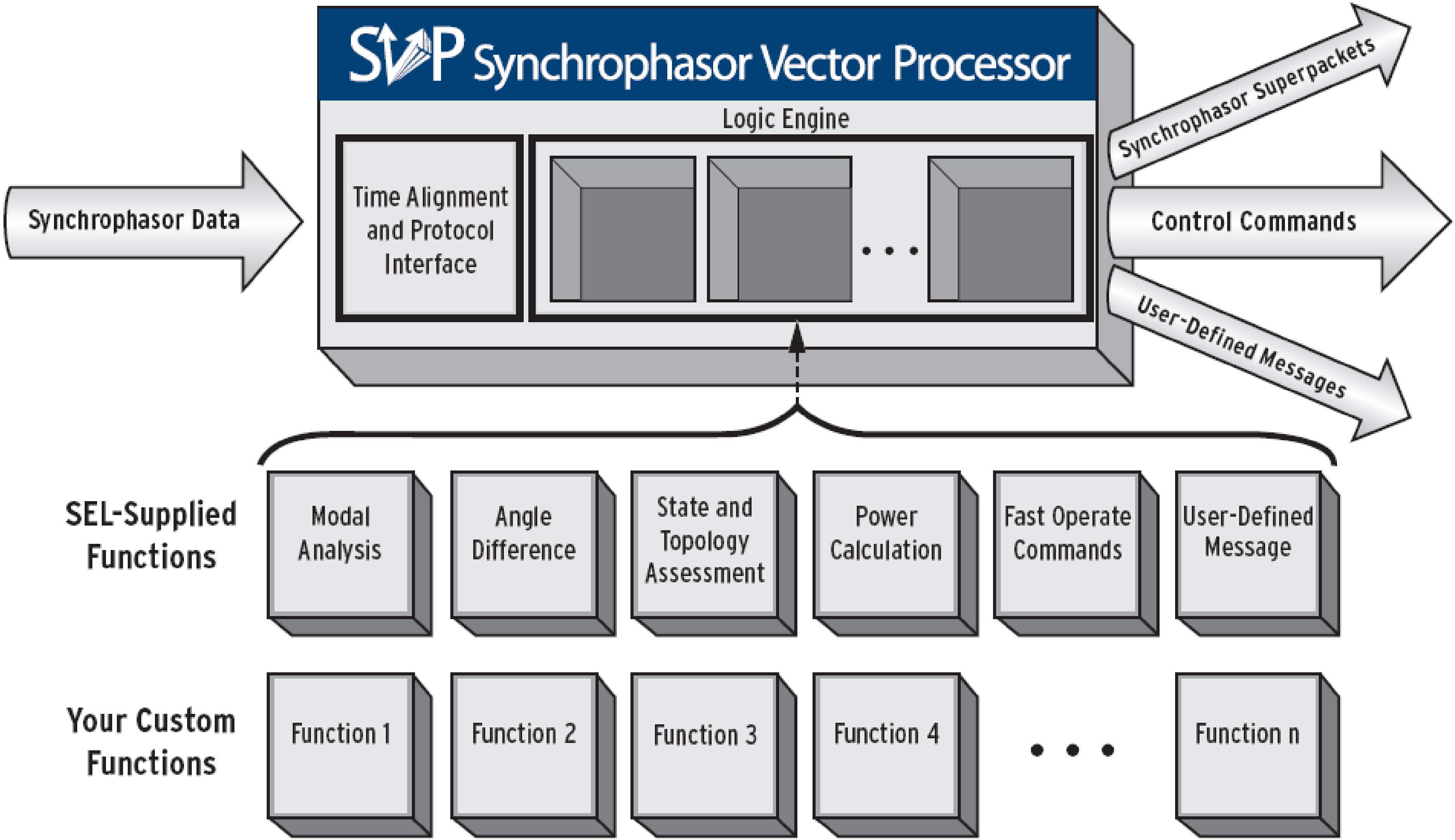
Apply Flexible Function Calculations

IEC 61131 engine
- Math
- Trig
- Differentials

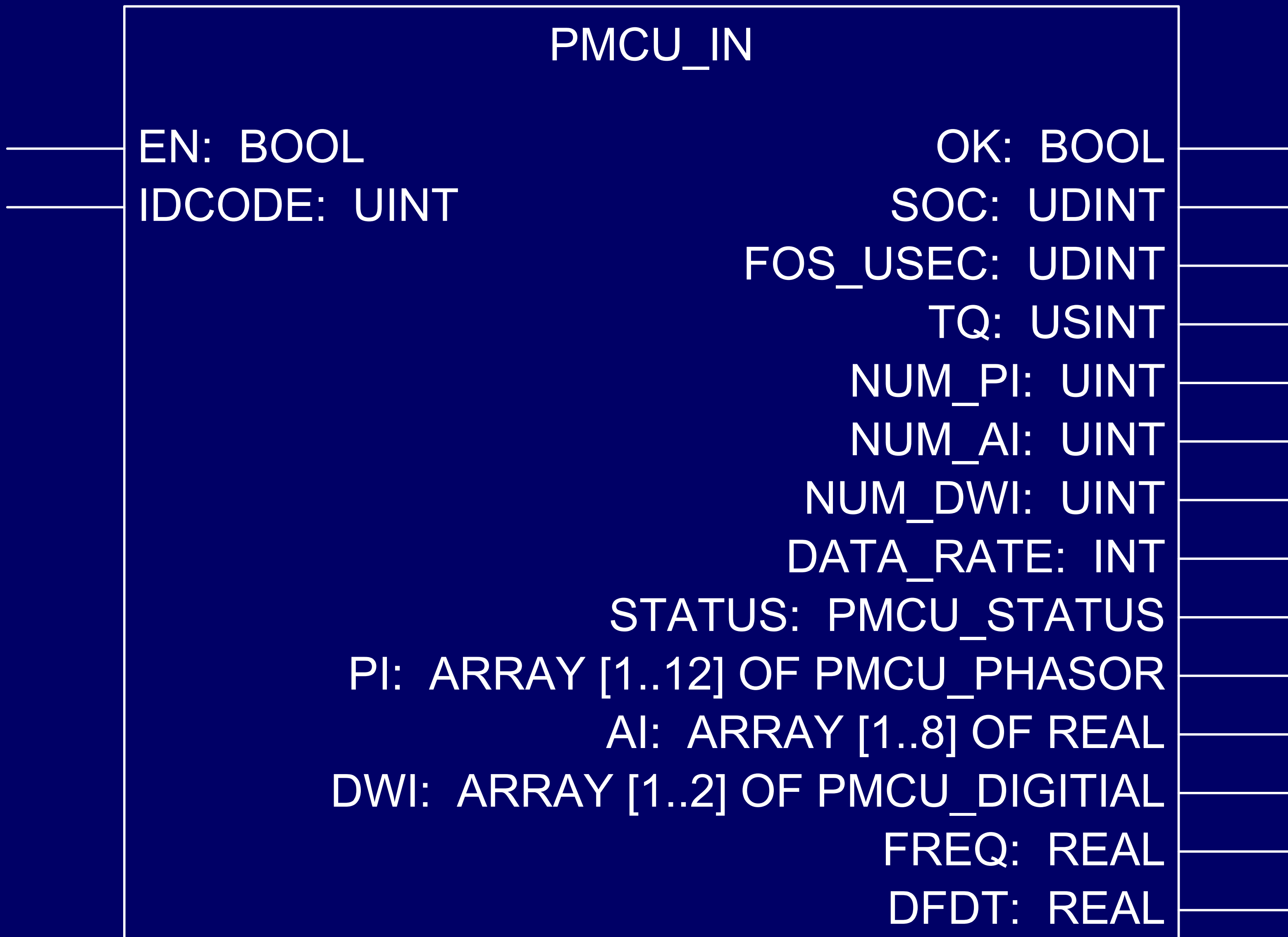
Preprogrammed blocks
- Power
- Angle difference
- Modal analysis
- Station topology check



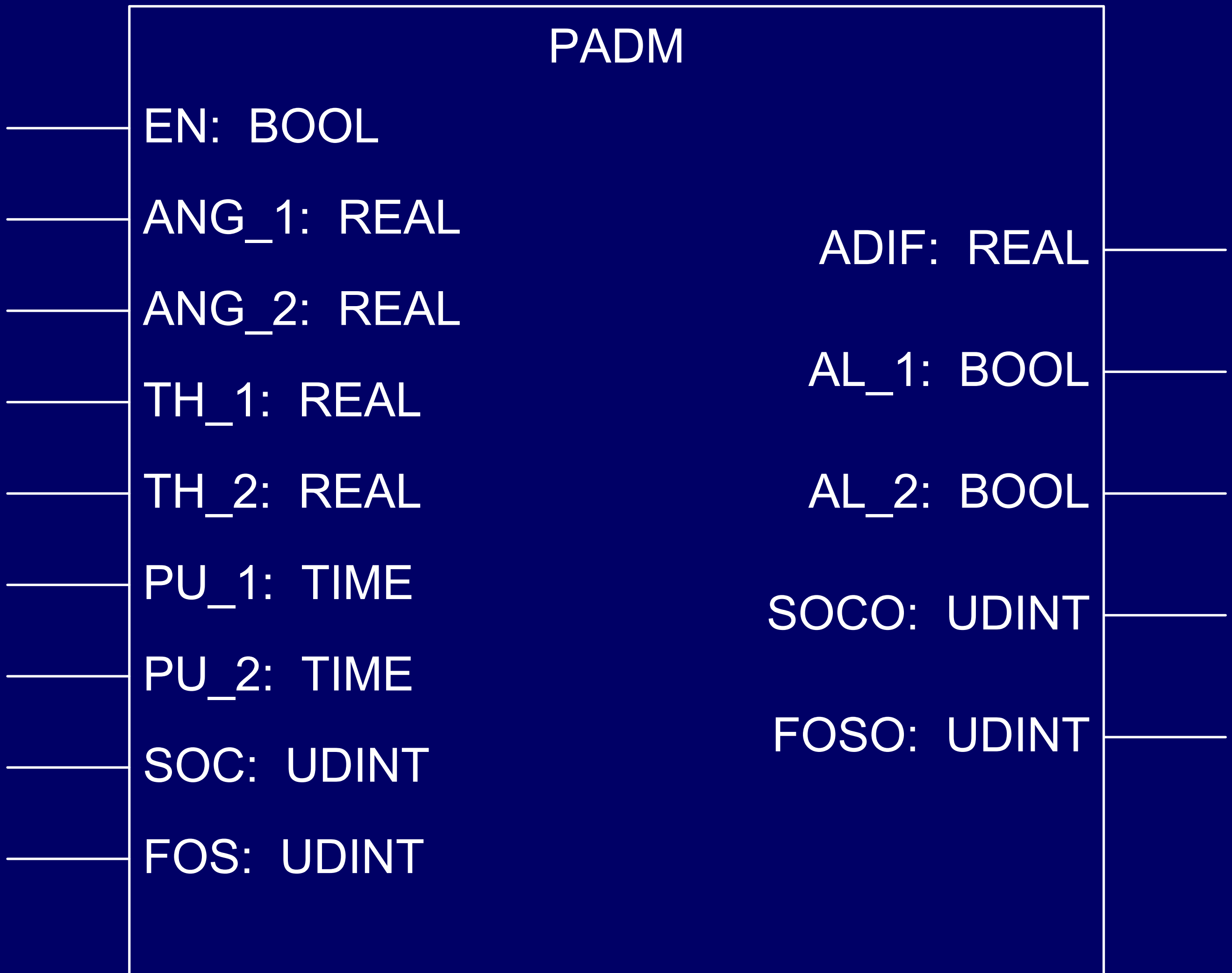
Combine Pre-Configured with Custom Functions

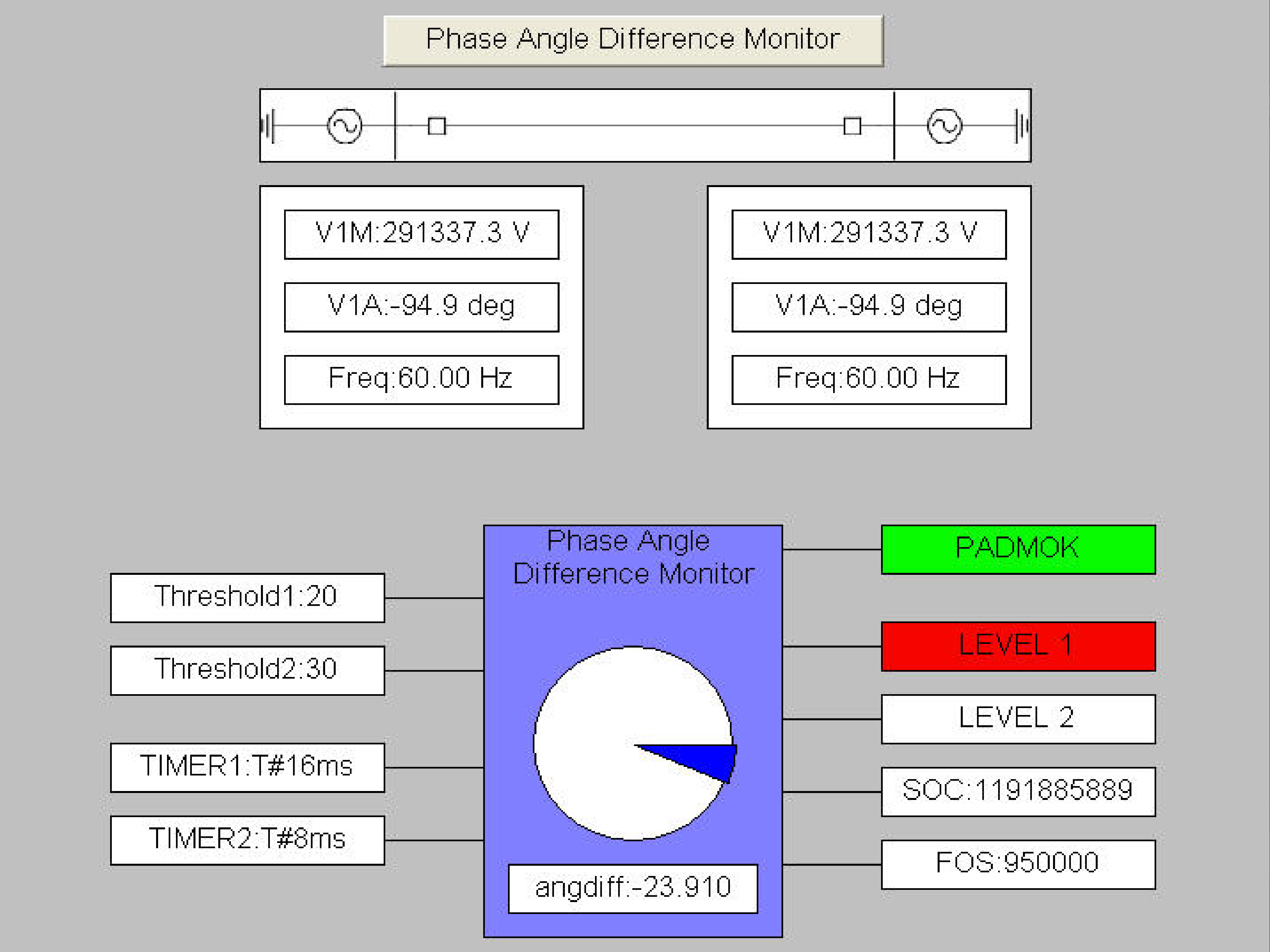


Provides Function Blocks

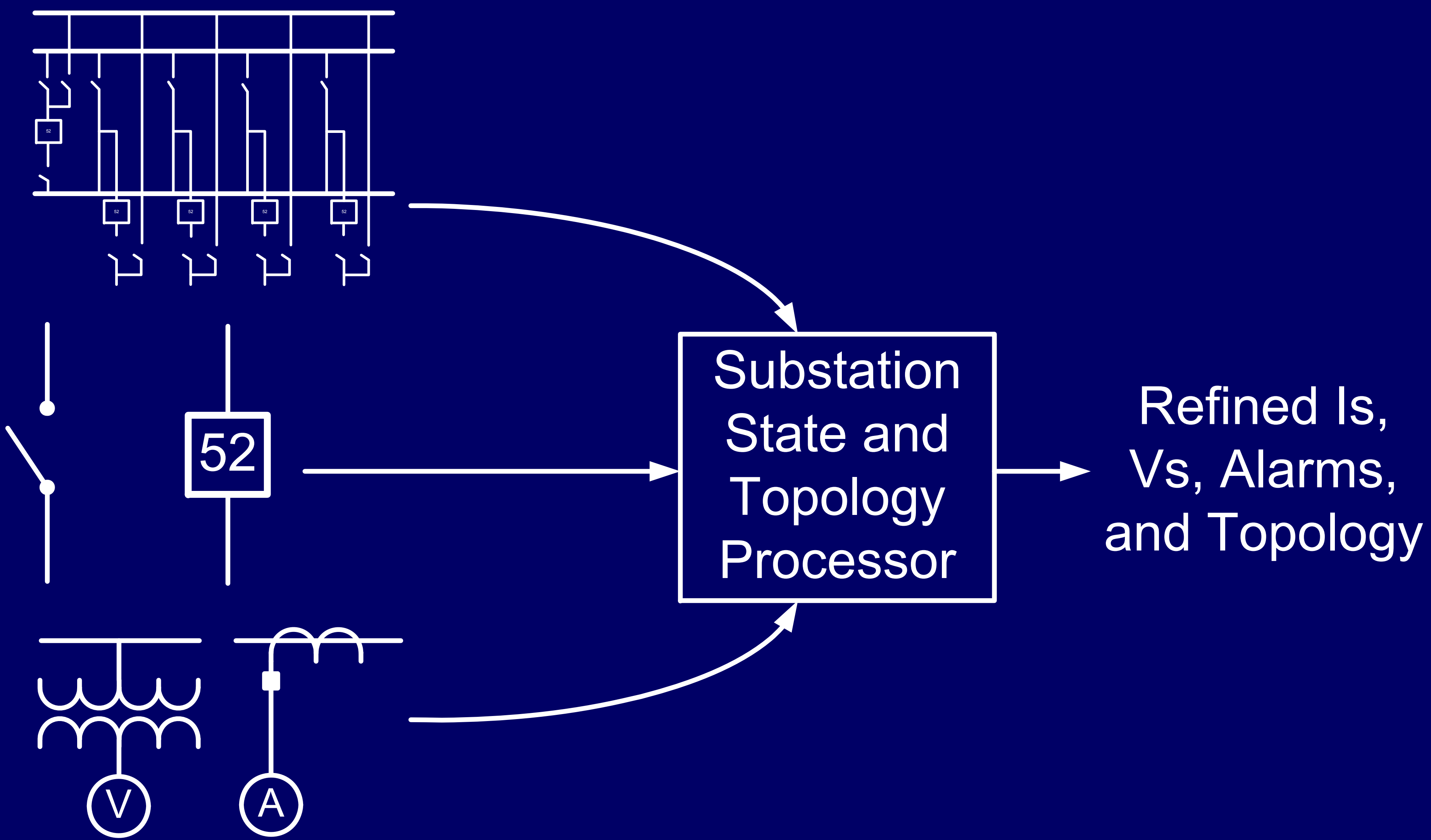


Map PMU Quantities to Phase Angle Difference Monitor

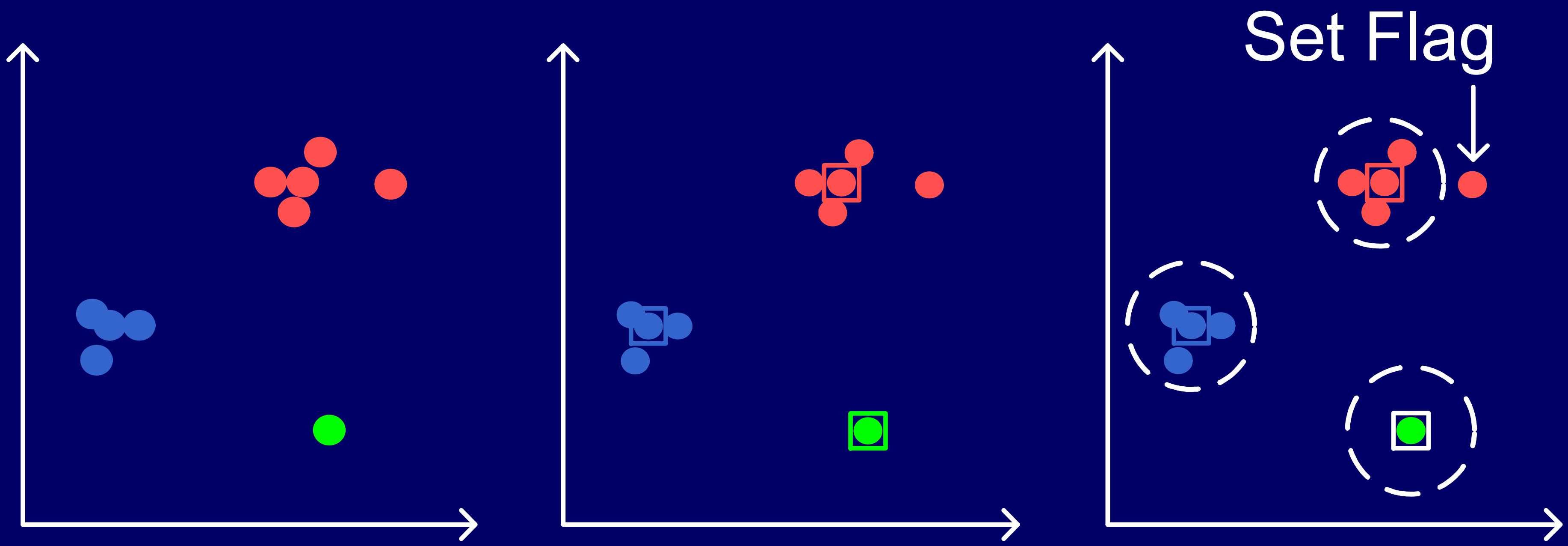



Phase Angle Difference Monitor
V1M:291337.3 V
V1A:-94.9 deg
Freq:60.00 Hz
V1M:291337.3 V
V1A:-94.9 deg
Freq:60.00 Hz
Threshold1:20
Threshold2:30
TIMER1:T#16ms
TIMER2:T#8ms
Phase Angle Difference Monitor
angdiff:-23.910
PADMOK
LEVEL 1
LEVEL 2
SOC:1191885889
FOS:950000

Improve Local Measurements



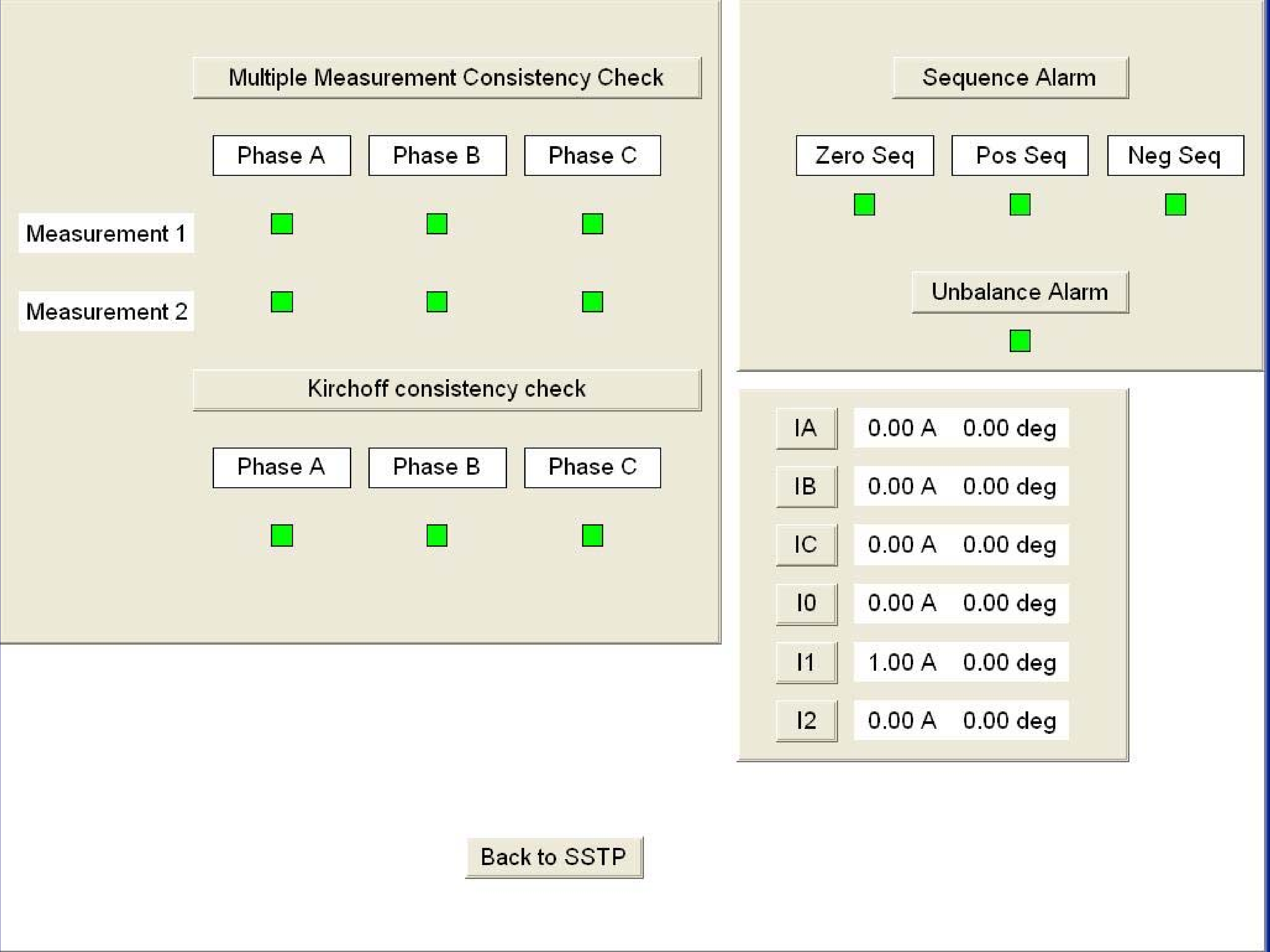
Identify and Quarantine Bad Data



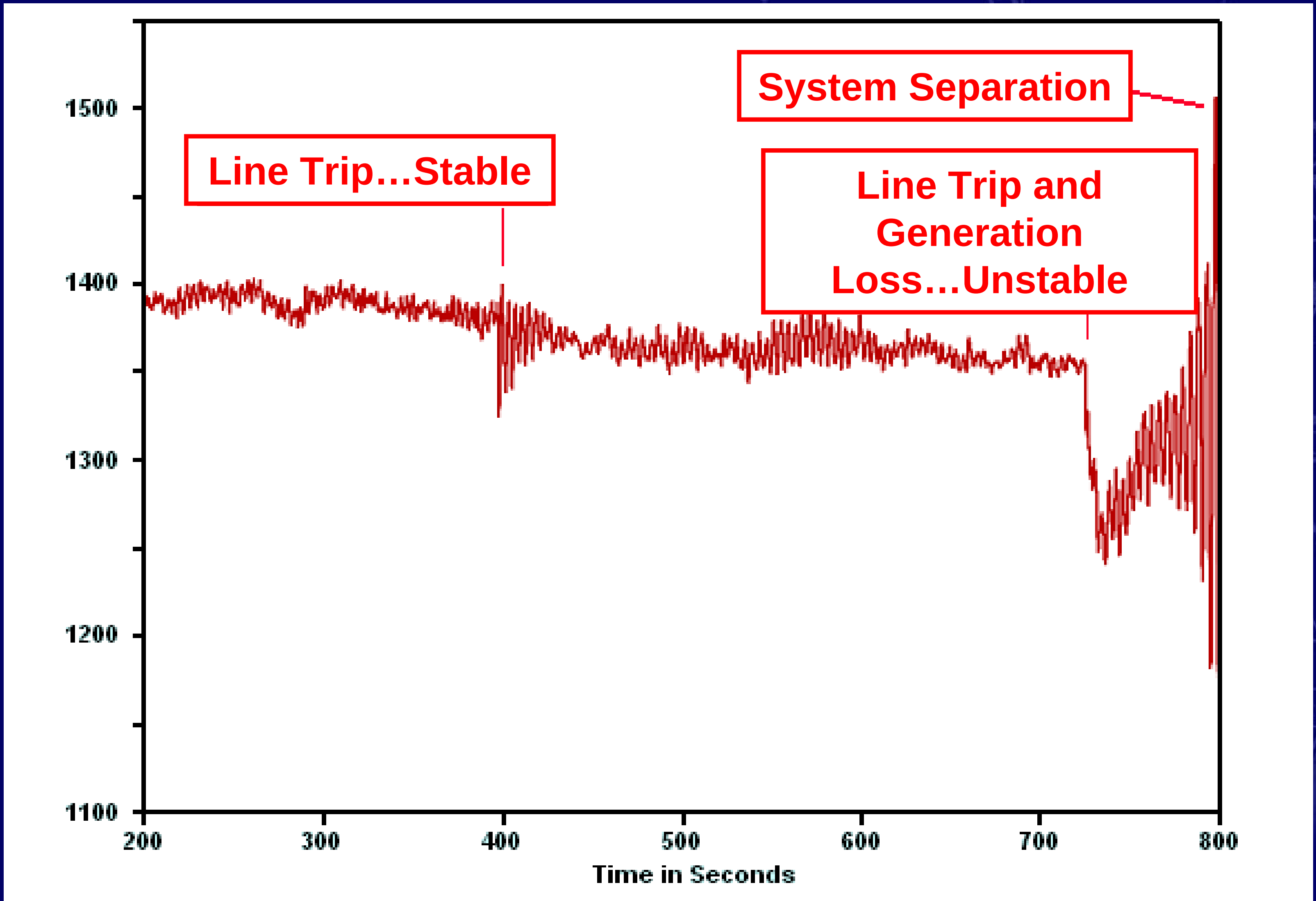
Measurements

Measurements
+
Calculate
Median

Measurements
+
Calculate Median
+
Flag and
Quarantine


Multiple Measurement Consistency Check
Phase A
Phase B
Phase C
Measurement 1
Measurement 2
Kirchoff consistency check
Phase A
Phase B
Phase C
Sequence Alarm
Zero Seq
Pos Seq
Neg Seq
Unbalance Alarm
IA 0.00 A 0.00 deg
IB 0.00 A 0.00 deg
IC 0.00 A 0.00 deg
I0 0.00 A 0.00 deg
I1 1.00 A 0.00 deg
I2 0.00 A 0.00 deg
Back to SSTP

Real-Time Modal Analysis Monitor Predicts System Disturbances



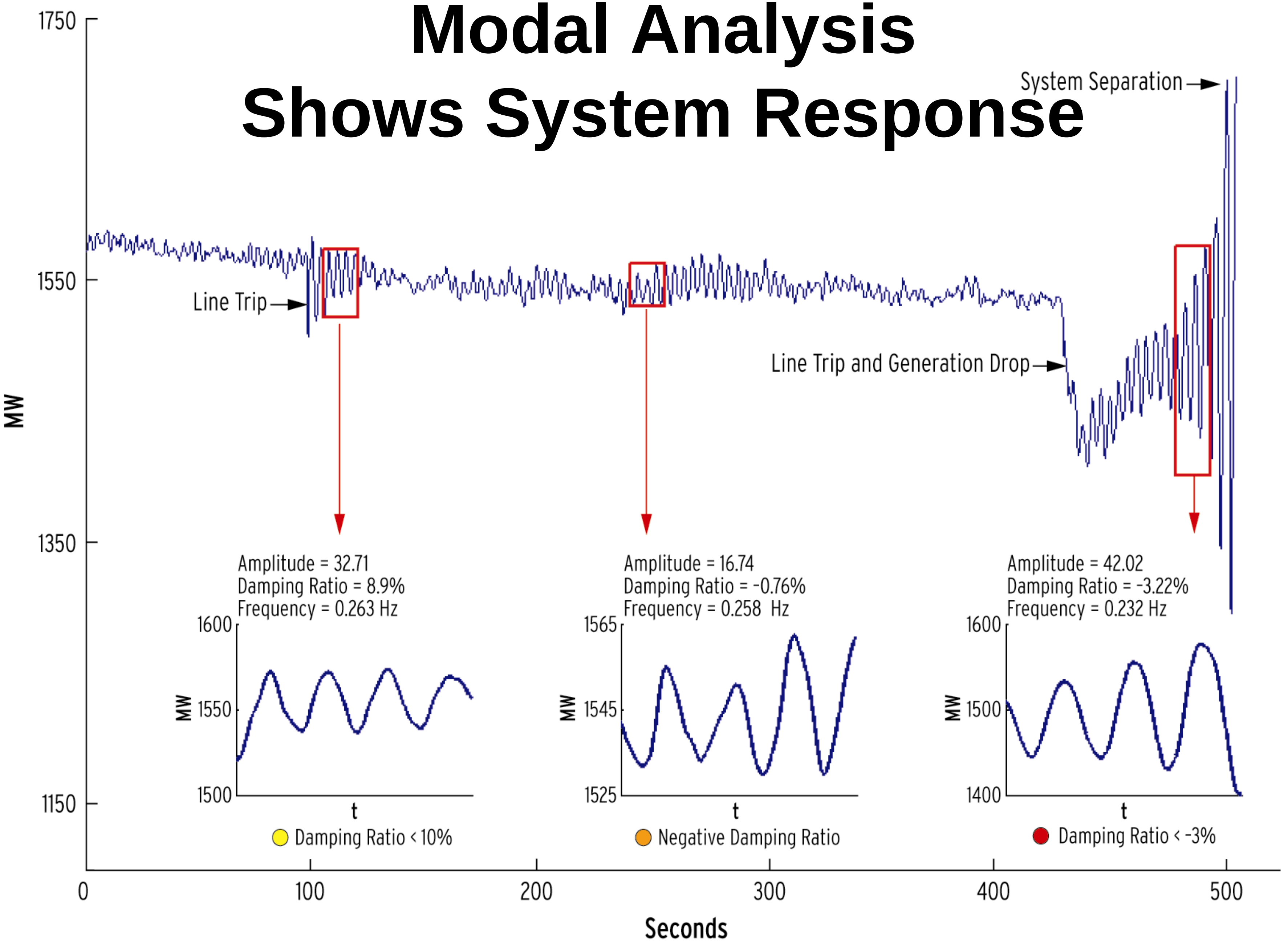
Use Oscillation Frequency and Damping Ratio

For the complex Eigen value pair: $\lambda = \sigma \pm j\omega_d$

Oscillation frequency is: $f_{osc} = \dfrac{\omega_d}{2\pi}$

Damping ratio is: $\varsigma = -\dfrac{\sigma_i}{\sqrt{\sigma^2 + \omega_d^2}}$

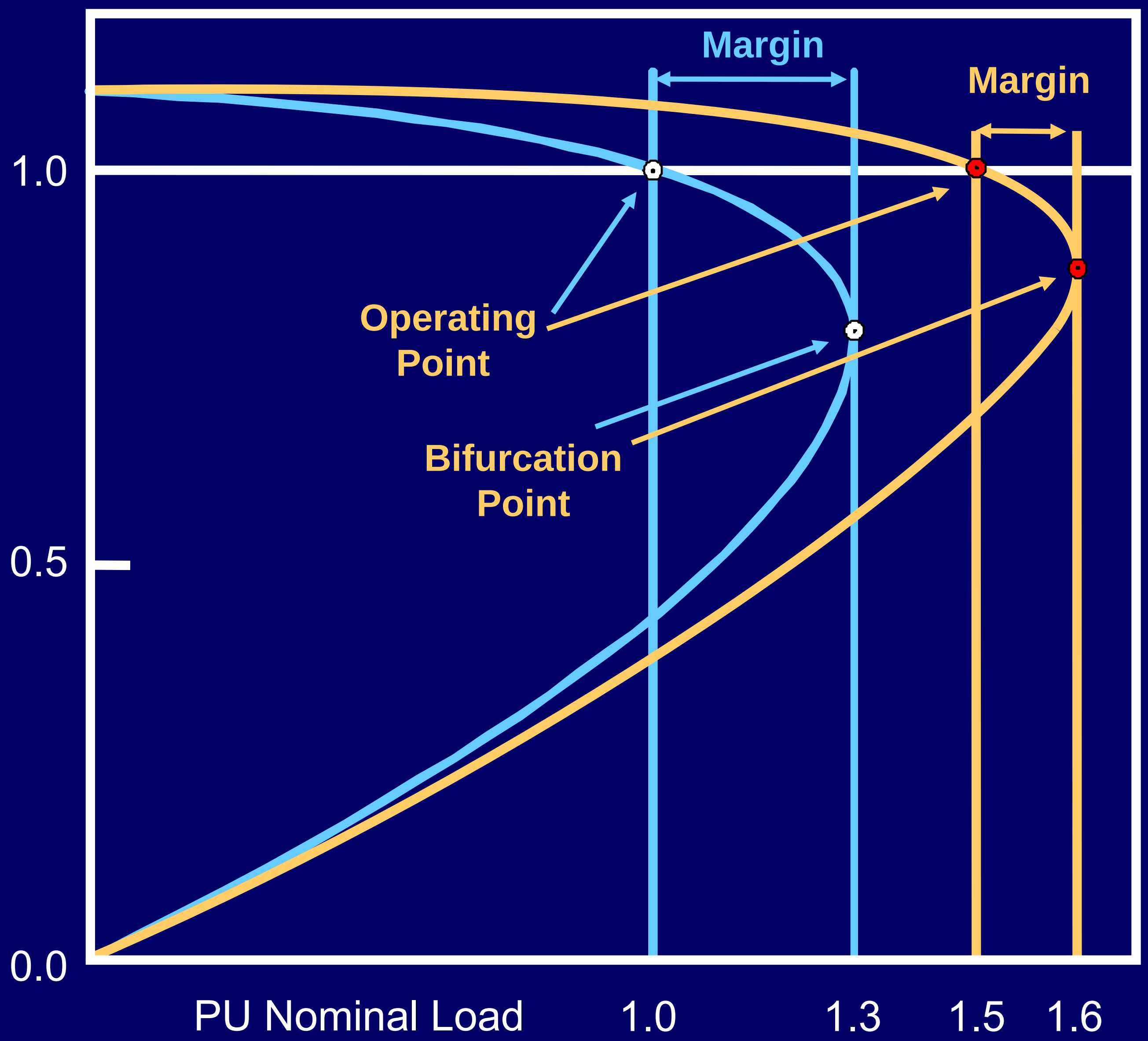
Modal Analysis Shows System Response



Develop Custom Applications

- Voltage Collapse Detection
- Instability of Distributed Generation
- Complex Power Swings
- Others ?

Utilities Are Operating Closer to the Edge



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

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

Calculate Voltage Stability Index (VSI)

- SVP calculates maxima: P, Q, and S
- Calculate margins:

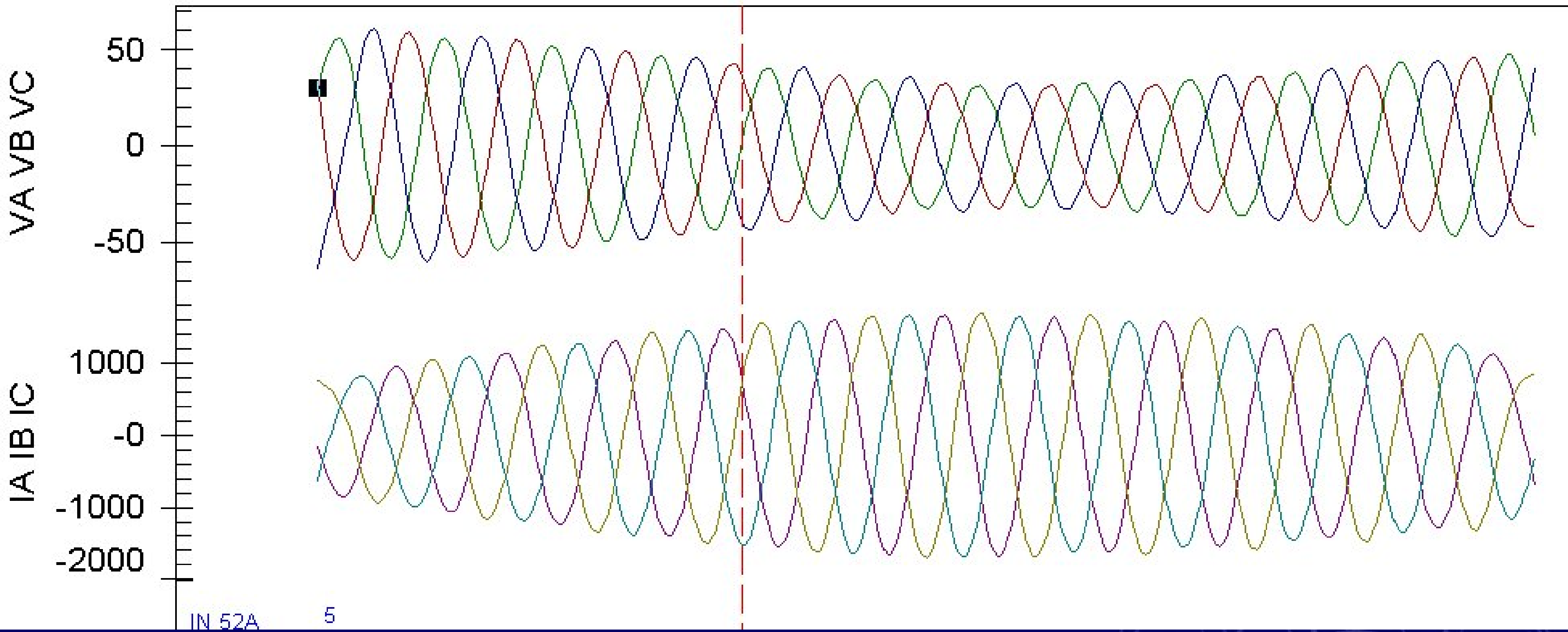
$$P_{margin} = P_{max} - P$$

$$Q_{margin} = Q_{max} - Q$$

$$S_{margin} = S_{max} - S$$

$$VSI = \min\left(\frac{P_{margin}}{P_{max}}, \frac{Q_{margin}}{Q_{max}}, \frac{S_{margin}}{S_{max}}\right)$$

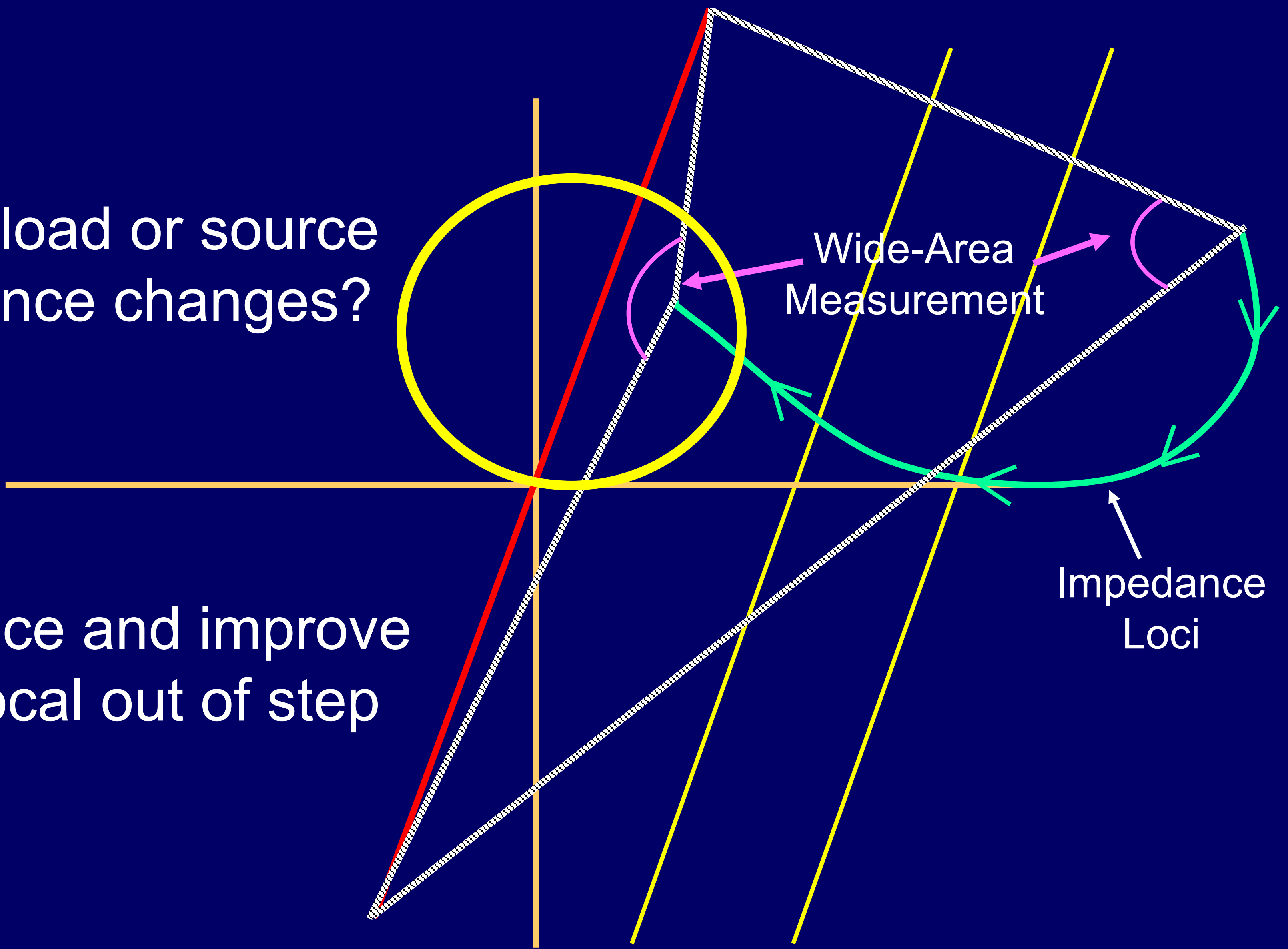
Improve Power Swing Detection



Actual Swing from 2003 Blackout

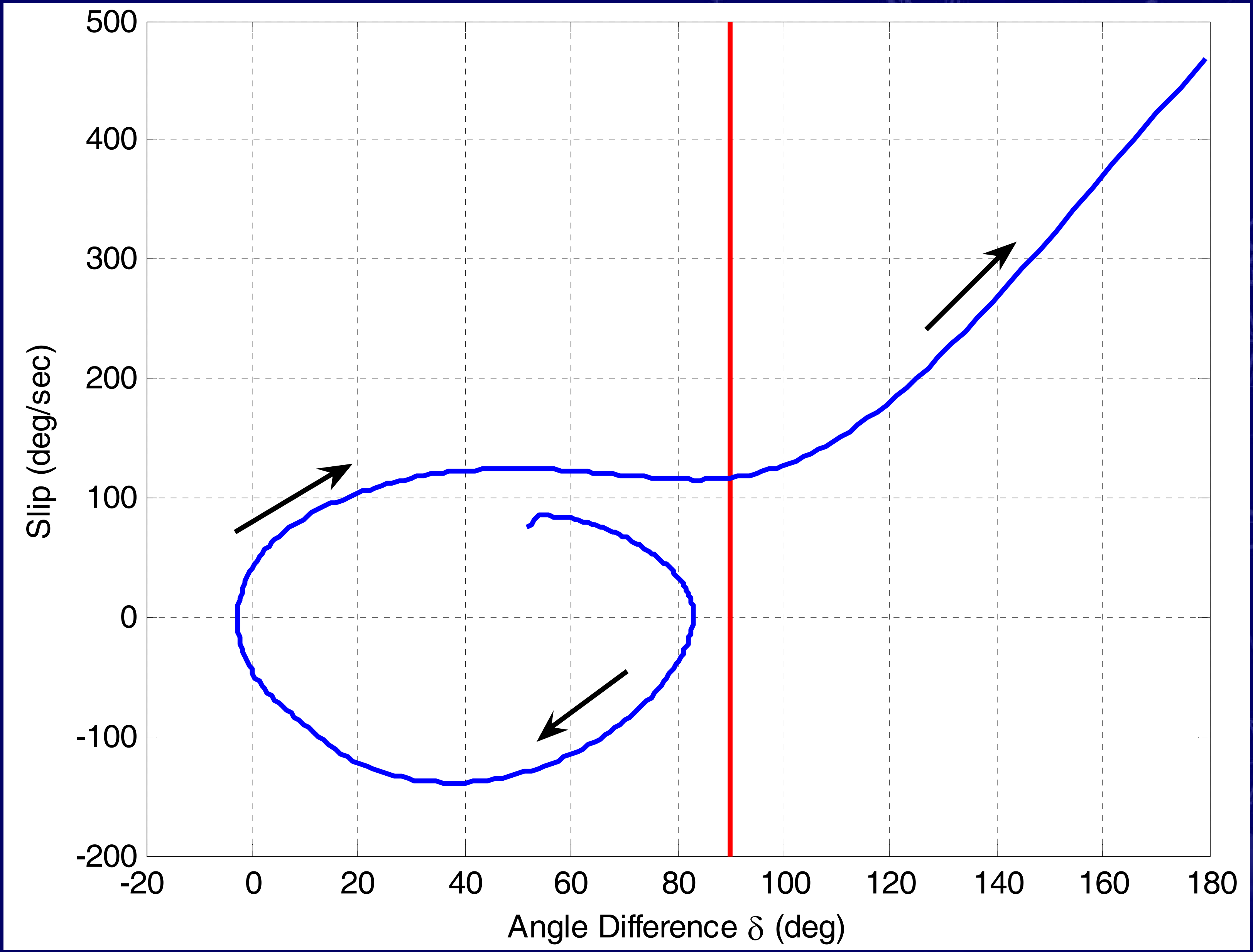
Wide-Area Measurement Is Better than Traditional "Blinder" Methods

What if load or source impedance changes?

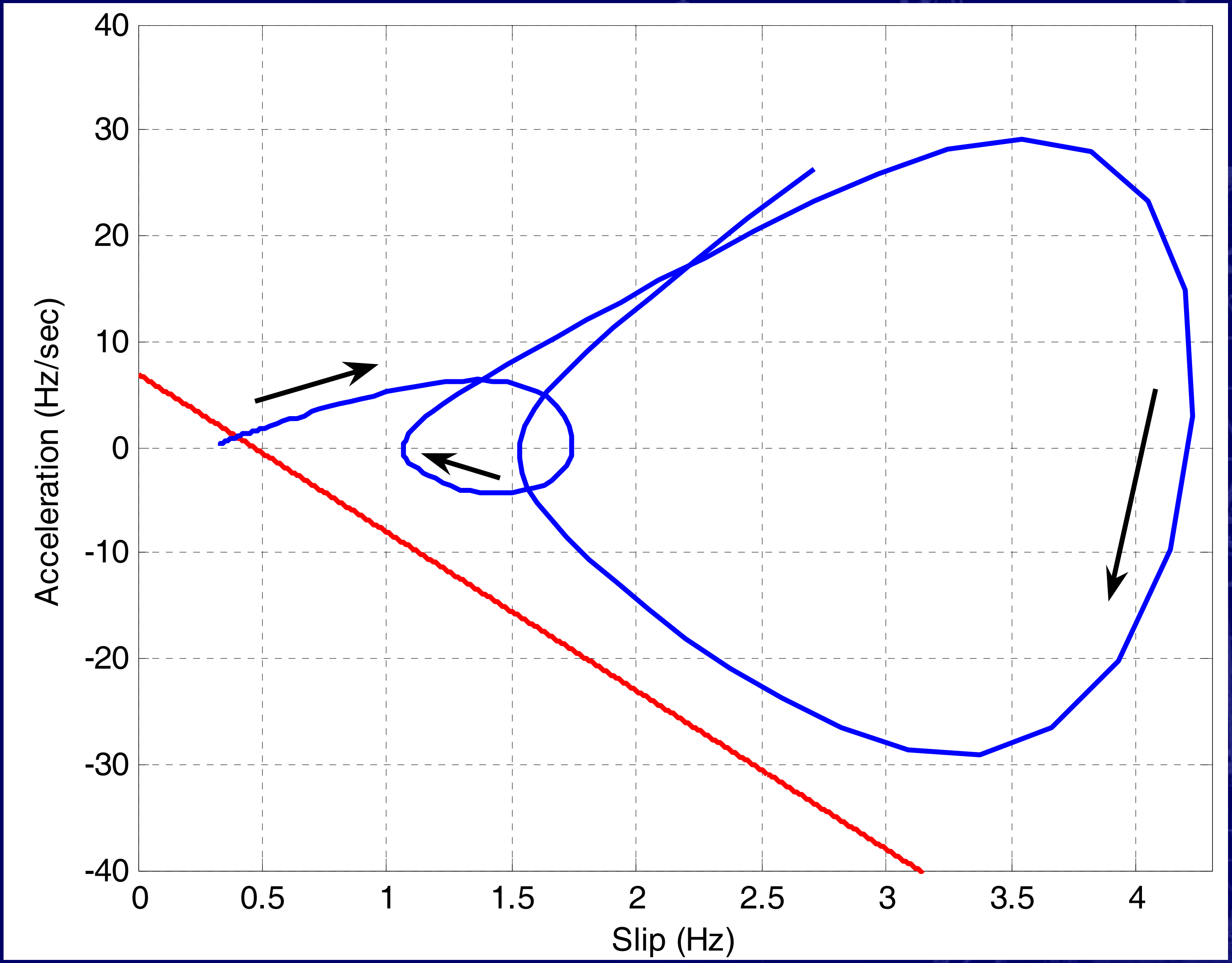


Replace and improve on local out of step

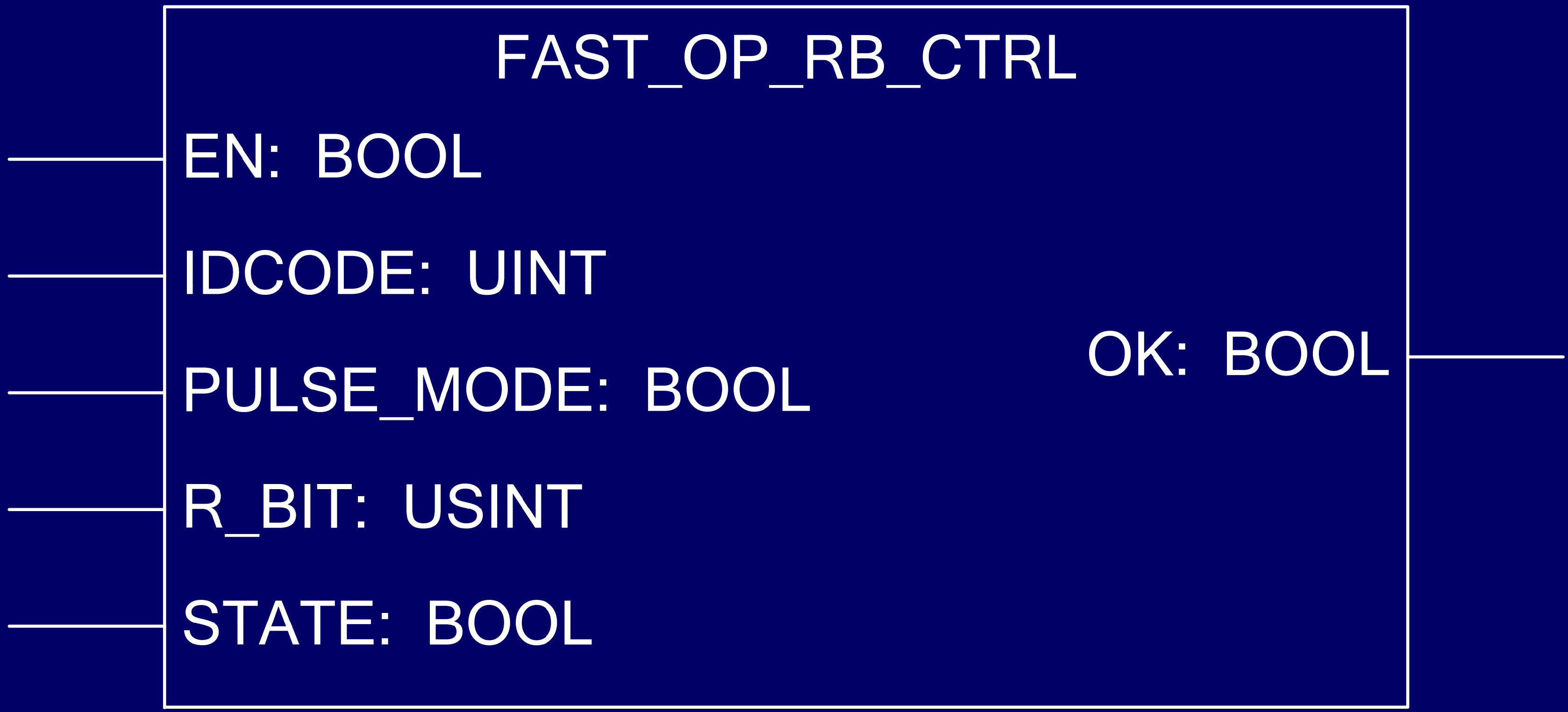
Delta/Delta-Dot Phase Plane Analysis



Delta-Dot Delta-Doubledot Phase Plane



Use Fast Operate Control Blocks for Closed-Loop Control



Synchrophasors Are Standard

SEL-421 IEEE C37.118

SEL-451

SEL-487E **NEW!**

SEL-787

SEL-734 SEL Fast Message

SEL-311A, B, C

SEL-311L

SEL-351

SEL-351S

SEL-351A

Synchrophasors Provide New and Improved Capabilities

- Angle measurement
- Disturbance analysis
- Modal analysis
- Out-of-step detection
- Real-time control

What Else Can They Do For You?

Thank You!