AREVA Activities related to SynchroPhasor Measurements

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Topics

- PMU impacts on EMS control centers
  - State Estimator with PMUs Joint-funding project
    - Online State Estimator using PMUs at TVA
  - New Paradigm of measurement-based analysis
  - Advanced Visualization Framework for PMUs
    - Overview & Demo of eterra-Vision
- AREVA PMU – Harmeet Kang
- PMU integration with PhasorPoint (Psymetrix)

The Control Center Landscape is Changing

- **The rapid growth of PMUs creates a new <u>evolutionary grid operations paradigm</u>**
- **The big question is:**
  - ***<u>How will this benefit power system operations?</u>***

Power System Operations…

- **Load and system conditions change continuously…**
  - **Quasi-steady state conditions for majority of the time**
  - **Occasionally goes into dynamically changing conditions**
- **Control center operators objective is:**
  "Ensure that the lights stay on all the time!"
  - **Prevent Blackouts!**
  - **Create defense plans to mitigate cascading**

EMS Benefits of "Phasor[1]" Data

Phasor data

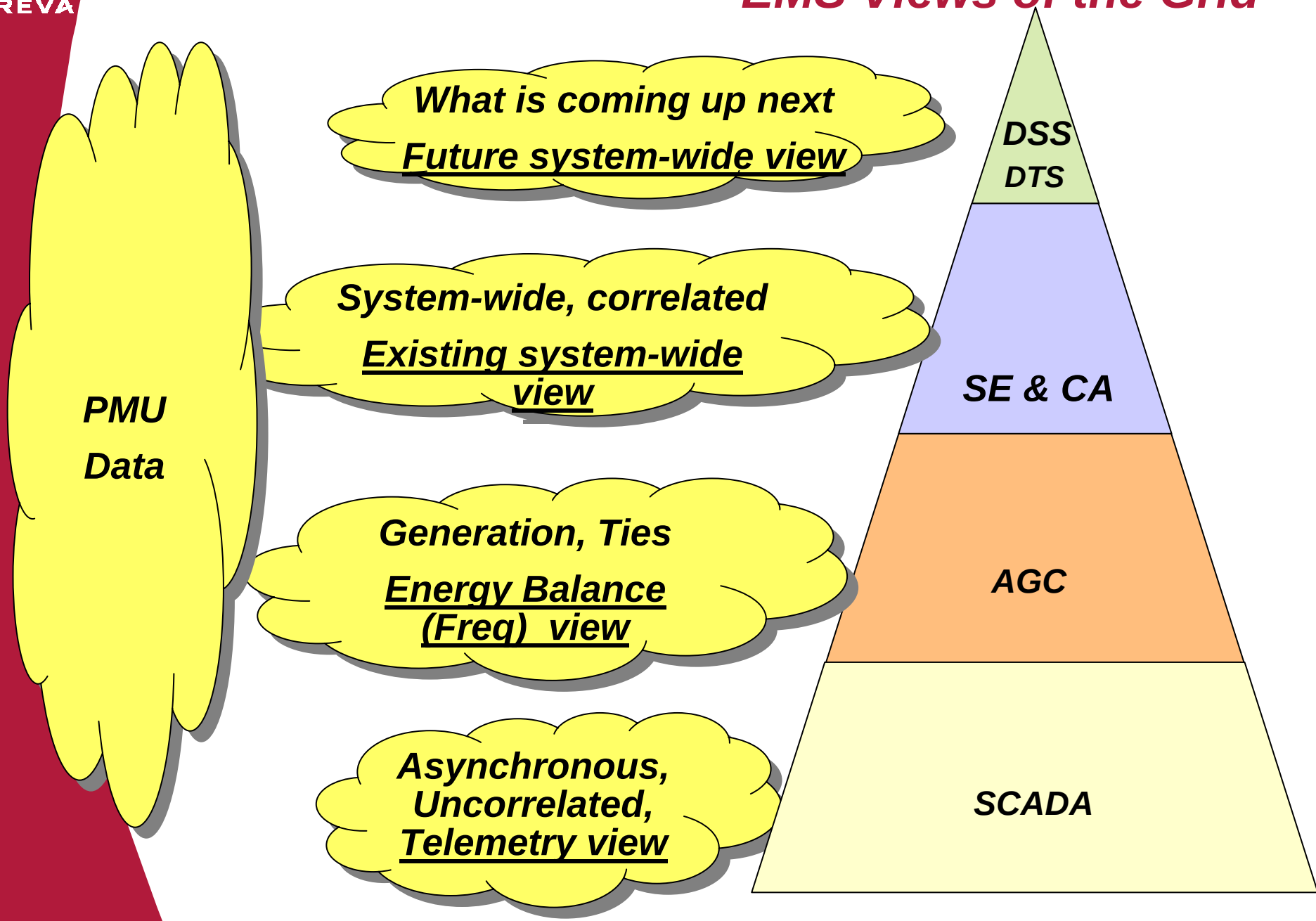
- Refresh rate 30 samples/sec
- Time tagged data
- Compatible with modern communication technology
- Responds to system dynamic behavior
- Angle-pair change means: MW change; 'electrical distance change'

EMS SCADA data

- Refresh rate 2-5 seconds
- Latency and skew
- Relies on legacy 'older' communication technology
- Responds to system static behavior
- Freq change means: Generation/Load imbalance

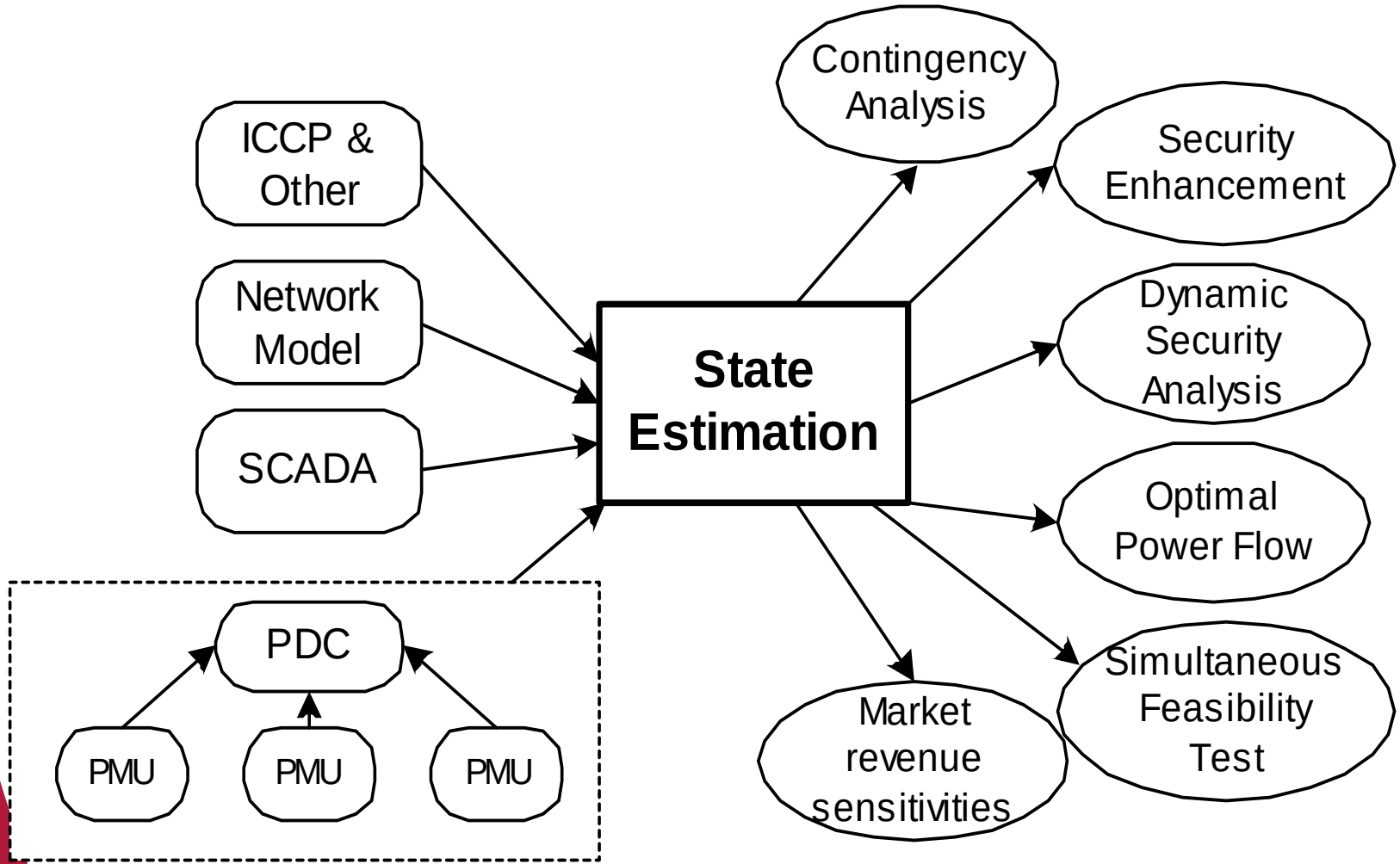
1"Phasor" is in quotes to suggest that we are not talking strictly about phasors, but about high speed, accurately time-tagged 'synchronous'data in general.

EMS Views of the Grid



SE's Role in Power System Operations

State Estimation has become a critical, 'must-run successfully' control center function.



Existing SE Software

- **PMU data is automatically used (whenever available) as input data for the SE solution algorithm:**
  - **Voltage phasor data**
  - **Current phasor data**

Early SE benefits realized

- SE quickly identified bad measurement data at the TVA PDC:
  - Some values were off by sq. root of 3, some scaling issues; some were off by 120 degrees…
- PMU data accuracy class was less than we had hoped.
- With just relatively few PMU data (compared to thousands of SCADA data), only local benefits were realized.
- Substation topology telemetry errors/anomalies were identified (big help for the SE analyst!)
- Emphasized the need for enhanced metrics to evaluate & monitor SE solution performance

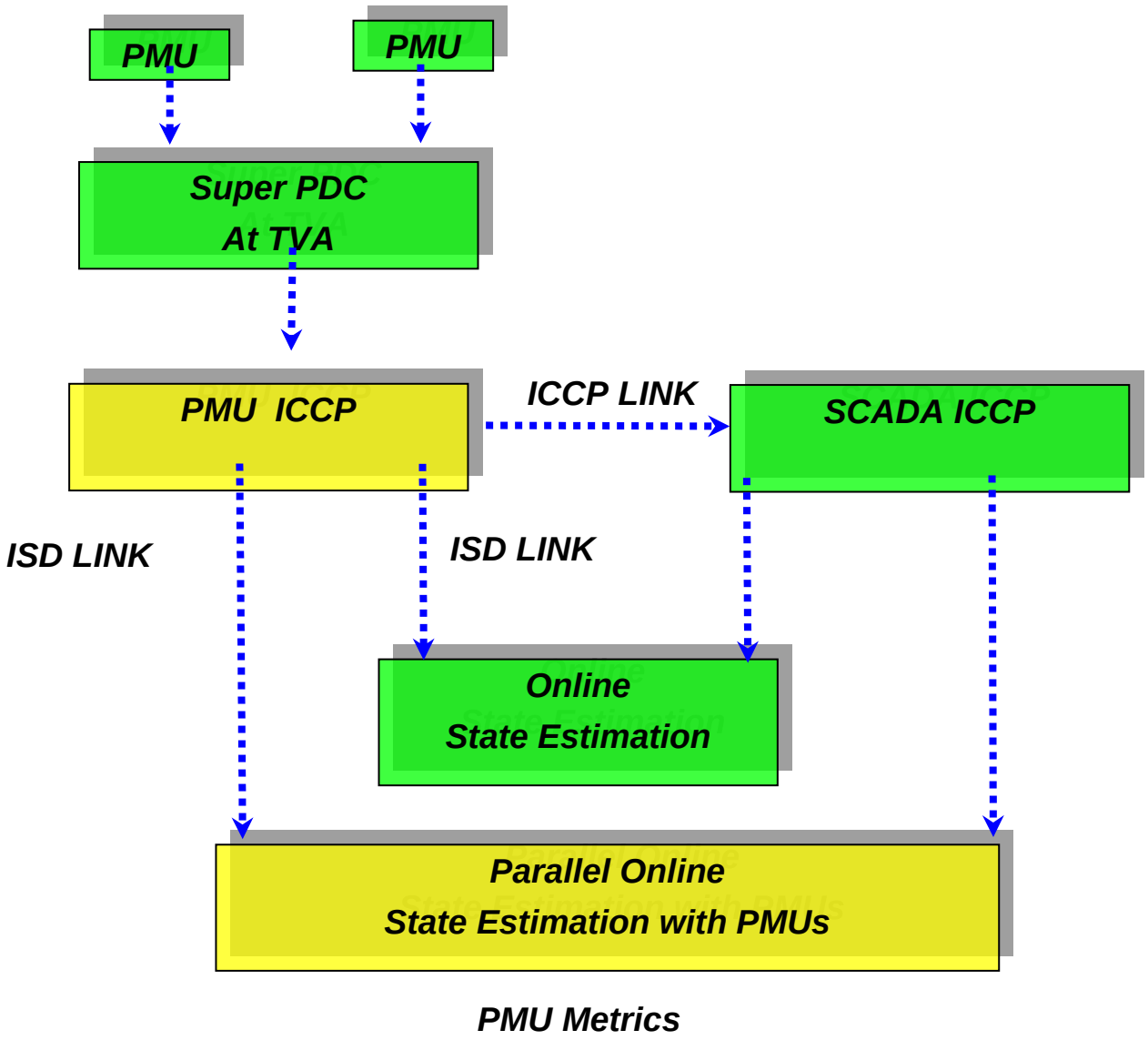
State Estimator Joint Funding Project

- **Objectives**
  - **Implement a parallel online SE in TVA control center**
  - **Simulate growth of PMUs and perform case studies on Entergy database to evaluate benefits**
  - **Implement advanced SE metrics to facilitate comprehensive evaluation of SE performance**

SE JF project participants

- **Participants**
  - **TVA, Entergy, Manitoba Hydro, Idaho Power, PG&E, ORNL, NE University, First Energy, BPA**
- **Primary Utility Sponsors**
  - **TVA – Lisa Beard**
  - **Entergy – Floyd Galvan**
- **Primary Technical Contributors**
  - **AREVA - Rene Rosales & Mark Rice**
  - **NE University – Prof. Ali Abur**

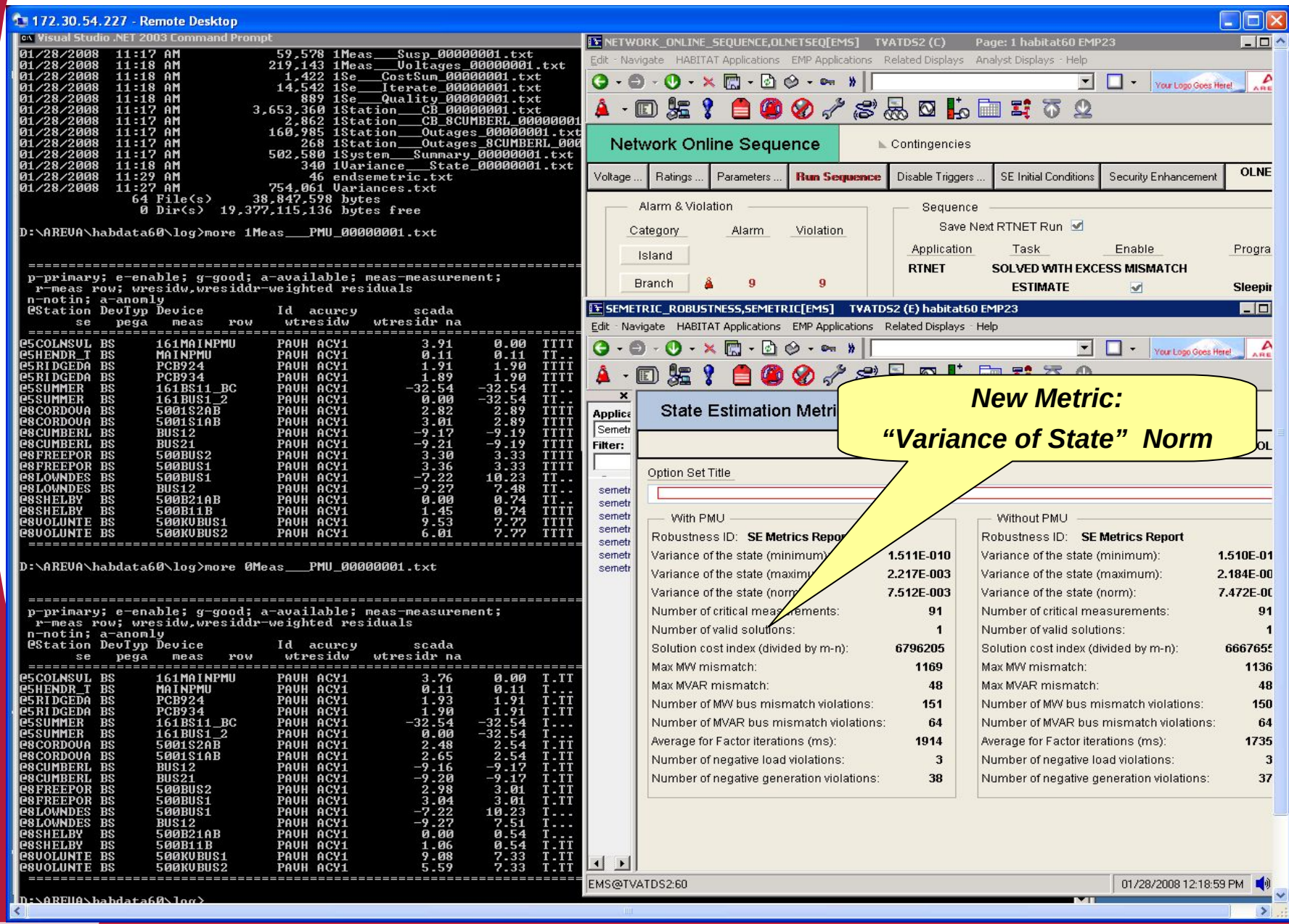
Parallel server configuration at TVA



PMU and SCADA Data Statistics at TVA SE

- 18 PMU angle measurements
- 17000 (approx) SCADA measurements; include:
  - KV, P, Q (flows & injections)

PMU SE results @TVA



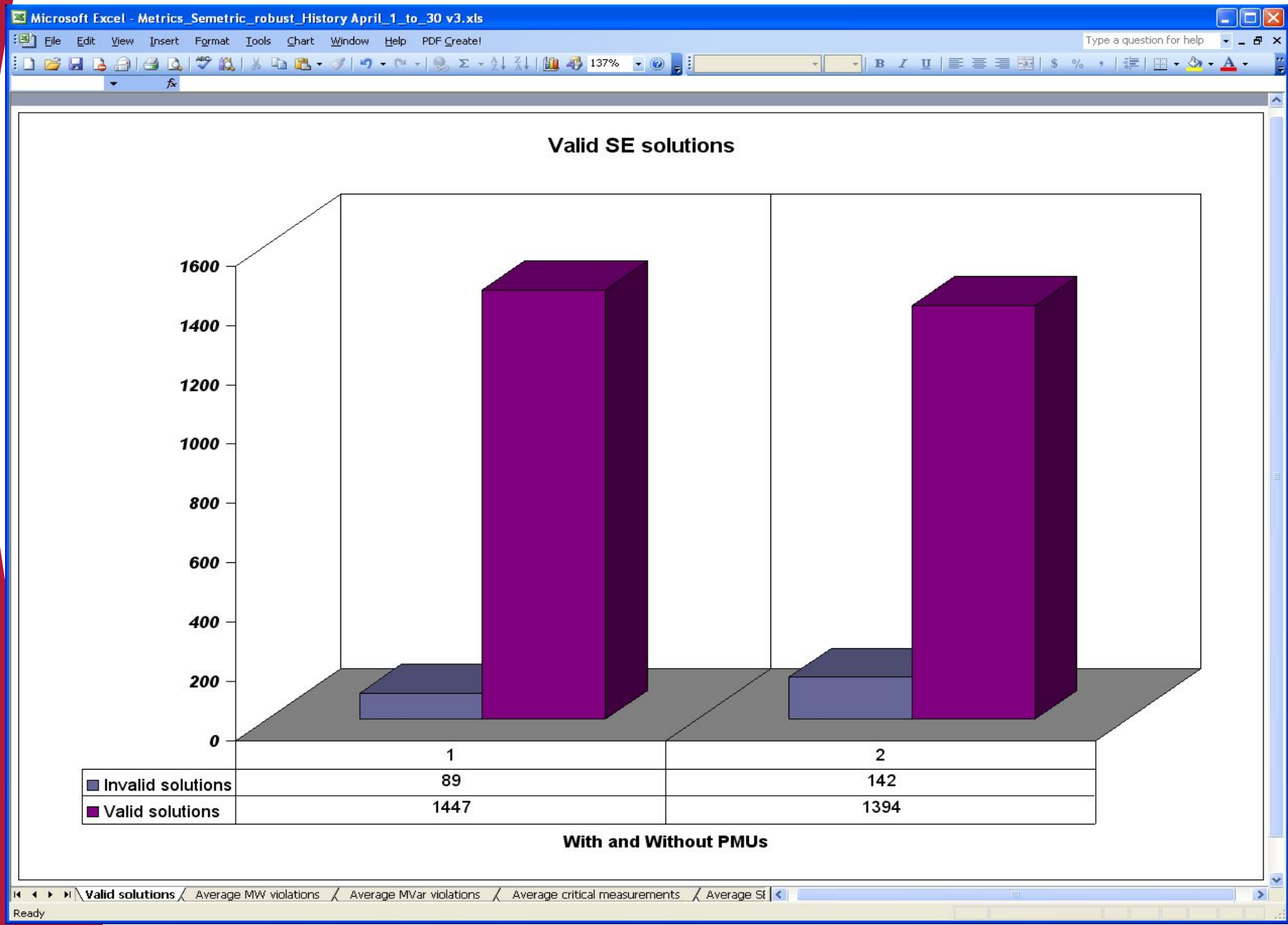
Selected metrics for improvement one month analysis

- **April/1-April/30**
  - **Variance of the state (Min, Max, Norm)**
  - **Number of critical measurements**
  - **Number of valid solutions**
  - **Time to solve SE (factorization)**
  - **Injection errors (negative loads and generation)**

Expected improvement over time

Metric description	Short term effect of PMUs	Direction of improvement (long term)
Variance of the state (G Inverse)	Decrease	Decrease
Critical measurements	Decrease	Decrease
Valid solutions	N/A	Increase
Convergence	Decreased number of iterations	Decreased number of iterations
Bus mismatch errors (total)	Undefined	Decrease
Branch information		
Bus voltage magnitudes outside a Min/Max tolerance		
Identification of bad measurement (Normalized residuals above a tolerance)	Increase	Increase
Solution cost index (divided by m-n)	Closer to 1	Closer to 1
Total unit and tie line MW/MVAR residuals		?
Company injection deviations		?
Percent of data availability		?
Largest MW/MVAR mismatches	Undefined	Decrease
Estimation cost per measurement and no-measurement observable system	Undefined	Decrease
Estimation cost classified by bus, voltage, branch, tap, zero injection measurement	Undefined	Decrease
Negative load	?	?
Negative generation	?	?

Valid SE solutions



Monthly table

Microsoft Excel - New Microsoft Excel Worksheet.xls

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I7

	A	B	C	D	E	F	G	H	I
1	Week	%Valid SE Solutions with PMUs	%Valid SE Solutions without PMUs	Critical Measurements with PMUs	Critical Measurements without PMUs	Variance of the State with PMUs	Variance of the State without PMUs	Average of SE factorization (secs) with PMUs	Average of SE factorization (secs) without PMUs
2	April 1 to 8	99	93	130	130	0.01053	0.01071	1.948	1.891
3	April 1 to 16	92	88	136	139	0.01169	0.01244	1.857	1.861
4	April 1 to 30	94	90	136	139	0.01221	0.01421	1.863	1.863
5									
6									
7									
8									
9									

Monthly table

Ready

Comparing Raw PMU with SE results @ BPA

TELE_PMU_BUS_PDEG_DATA, RTNET [ONLINE] DNB.CCN.BPA.GOV(C) - DNAB

File Navigate PCPrint HAB Application EMP Application Related Displays Analyst Displays Help

nov

Telemetered PMU BUS Data

All | PKV | PDEG

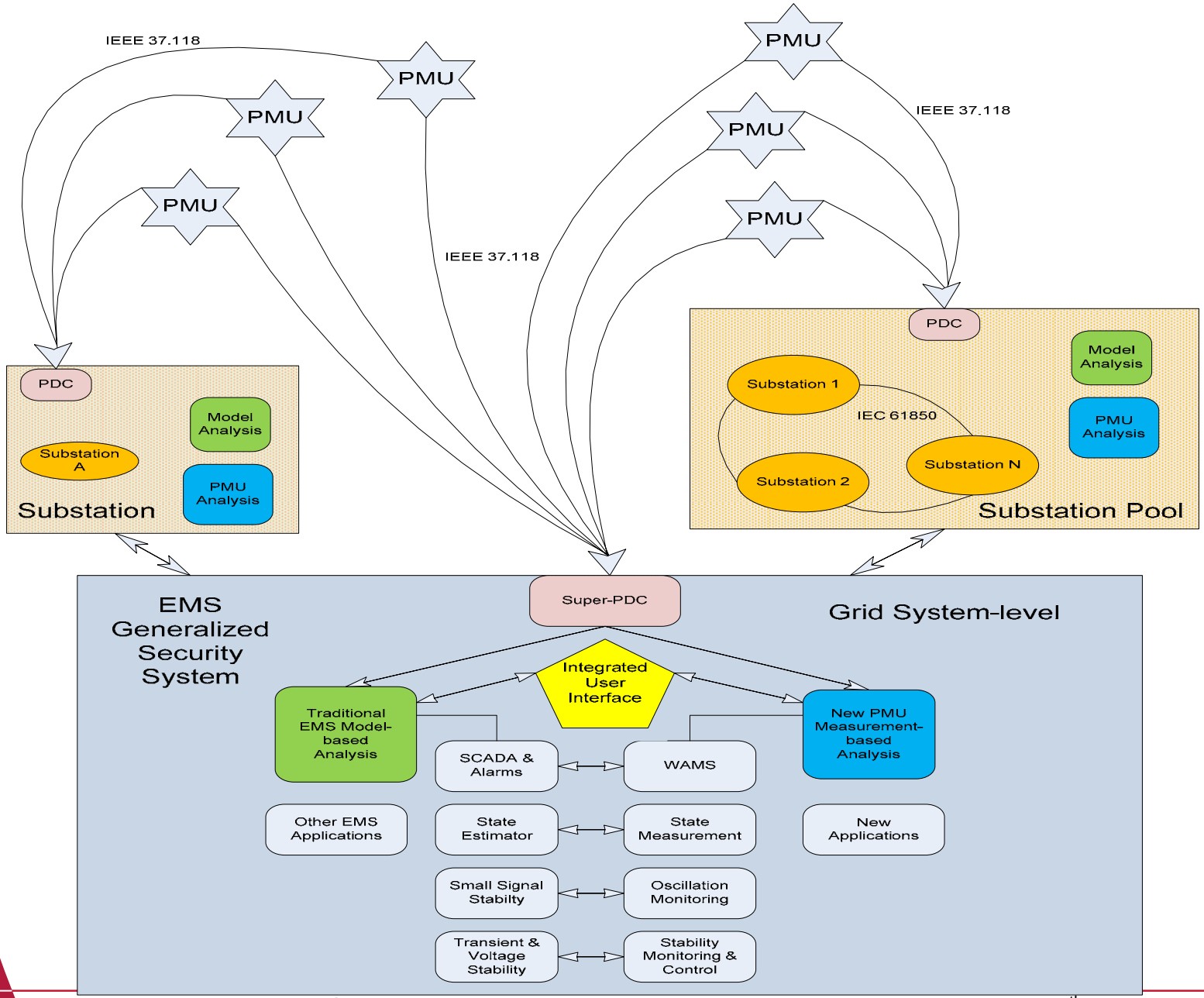
Time: 04-Jun-2007 15:01:48 RTNET REALTIME LOSSES CALC ED

Station	Device Type	Device	Analog	Quality SCADA / Estimated	Value SCADA / Estimated	Weighted Residual	Standard Deviation	Bias	
ASHE	BUS	PMU	PDEG	Good / Available	9.90 / 9.45	0.504	0.044	0.400	Row
BELL	BUS	500_PMU	PDEG	Good / Available	25.80 / 24.01	1.992	0.318	1.606	Row
BELL	BUS	230_PMU	PDEG	Good / Available	28.20 / 26.18	2.248	0.307	1.875	Row
BIG_EDDY	BUS	500_PMU	PDEG	Good / Available	-2.90 / -2.89	-0.015	0.104	-0.028	Row
BIG_EDDY	BUS	230_PMU	PDEG	Good / Available	-7.10 / -5.97	-1.254	0.065	-1.130	Row
CAPTJACK	BUS	PMU	PDEG	Good / Available	-17.00 / -16.02	-1.089	0.319	-1.098	Row
CHIEF_JO	BUS	500_PMU	PDEG	Good / Available	23.30 / 22.81	0.545	0.307	0.312	Row
CHIEF_JO	BUS	230_PMU	PDEG	Good / Available	26.10 / 25.42	0.754	0.302	0.500	Row
CUSTER	BUS	500_PMU	PDEG	Good / Available	7.70 / 8.98	-1.423	0.316	-1.369	Row
CUSTER	BUS	230_PMU	PDEG	Good / Available	6.00 / 7.41	-1.563	0.320	-1.521	Row
GARRISON	BUS	500_PMU	PDEG	Estimated / Unavailable	24.03 / 23.99				Row
GARRISON	BUS	230_PMU	PDEG	Estimated / Unavailable	21.83 / 21.79				Row
G_COULEE	BUS	500_PMU	PDEG	Good / Available	23.60 / 22.97	0.704	0.201	0.568	Row
JOHN_DAY	BUS	500_PMU	PDEG	Good / Available	-0.40 / -0.39	-0.172	0.010	0.002	Row
KEELER	BUS	500_PMU	PDEG	Good / Available	-5.50 / -5.30	-0.219	0.184	-0.254	Row
KEELER	BUS	230_PMU	PDEG	Good / Available	-8.00 / -7.61	-0.435	0.235	-0.473	Row
MALIN	BUS	PMU	PDEG	Good / Available	-16.90 / -16.03	-0.962	0.332	-1.084	Row
MAPLE_VL	BUS	230_PMU	PDEG	Good / Available	4.90 / 5.37	-0.522	0.227	-0.486	Row
MCNARY	BUS	500_PMU	PDEG	Good / Available	9.00 / 8.58	0.466	0.391	0.159	Row
MCNARY	BUS	230_PMU	PDEG	Good / Available	8.20 / 7.79	0.459	0.310	0.228	Row
SLATT	BUS	PMU	PDEG	Good / Available	3.20 / 3.09	0.125	0.244	-0.002	Row
SUMMERLK	BUS	PMU	PDEG	Good / Available	-13.90 / -13.21	-0.769	0.305	-0.874	Row
COLSTRIP	BUS	500_PMU	PDEG	Good / Available	38.20 / 34.66	3.936	0.258	3.306	Row
YELOWTLP	BUS	PMU	PDEG	Estimated / Unavailable	16.84 / 16.90				Row
DIABLOPG	BUS	PMU	PDEG	Good / Available	-17.80 / -16.68	-1.247	0.361	-1.452	Row
MIDWAYPG	BUS	500_PMU	PDEG	Good / Available	-21.50 / -24.12	2.909	0.396	2.257	Row
MOSSLAND	BUS	500_PMU	PDEG	Good / Available	-29.70 / -28.70	-1.108	0.370	-1.240	Row
PITSBURG	BUS	PMU	PDEG	Estimated / Unavailable	-33.55 / -33.31				Row
TESLA	BUS	500_PMU	PDEG	Good / Available	-28.60 / -27.57	-1.147	0.383	-1.333	Row
DEVERS	BUS	PMU	PDEG	Good / Available	-31.40 / -30.92	-0.536	0.322	-0.622	Row
SYLMARS	BUS	230_PMU	PDEG	Good / Available	-27.80 / -25.92	-2.086	0.397	-2.289	Row
VINCENT	BUS	PMU	PDEG	Good / Available	-28.80 / -27.54	-1.406	0.330	-1.385	Row
AULT	BUS	PMU	PDEG	Good / Available	23.70 / 19.19	5.011	0.742	4.026	Row
BEARS	BUS	PMU	PDEG	Good / Available	22.20 / 20.96	1.380	0.590	0.888	Row
SHIPROCK	BUS	PMU	PDEG	Good / Available	-2.50 / -2.16	-0.373	0.350	-0.428	Row

Next Steps

- **Next phase of this joint-funding project is being discussed**
- **Primary focus being identifying potential benefits to system operations & grid reliability for a projected larger number of deployed PMUs**

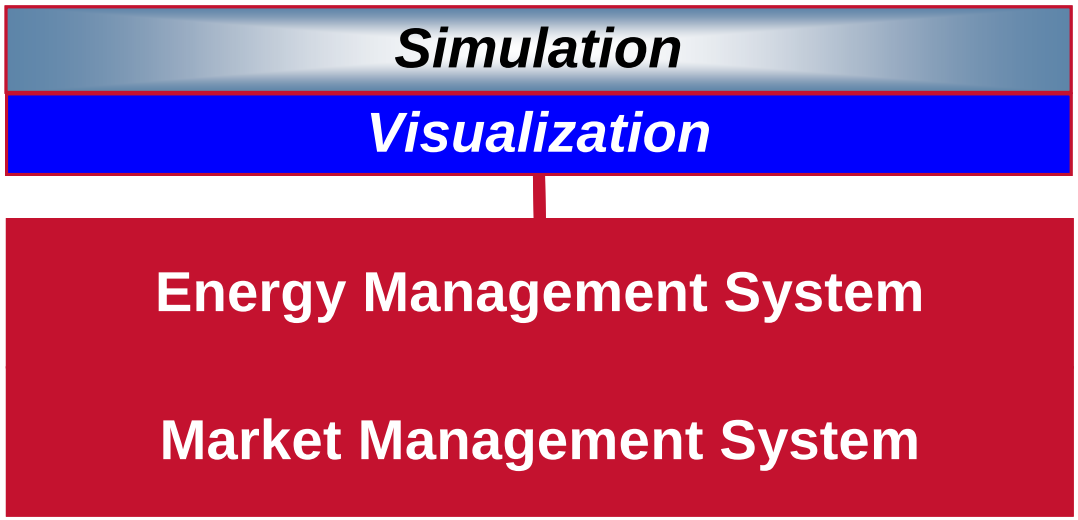
New EMS Paradigm
Generalized Grid Security Analysis



e-terravision

Advanced Visualization Framework

Control Center Decision Support System



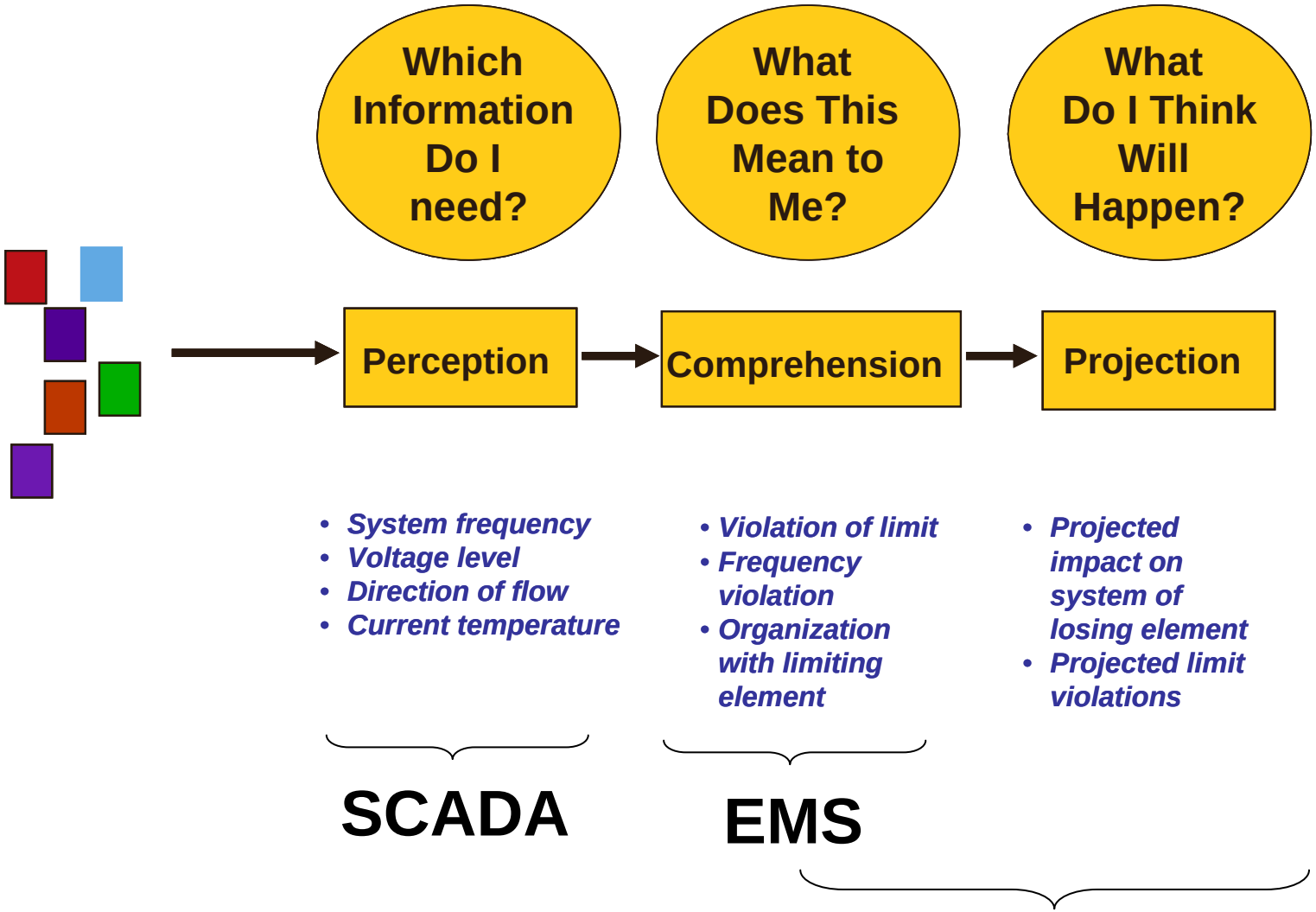
A suite of tools for control centers addressing Situation Awareness:

- Wide area visualization and diagnostics
- Mitigate operational risks
- On-demand look-ahead analysis
- Coordination of control center resources

Key Characteristics:

- Independent of EMS vendors – Use CIM for network model update
- Information is refreshed in real-time
- Designed for minimal cost of maintenance: database, displays, training

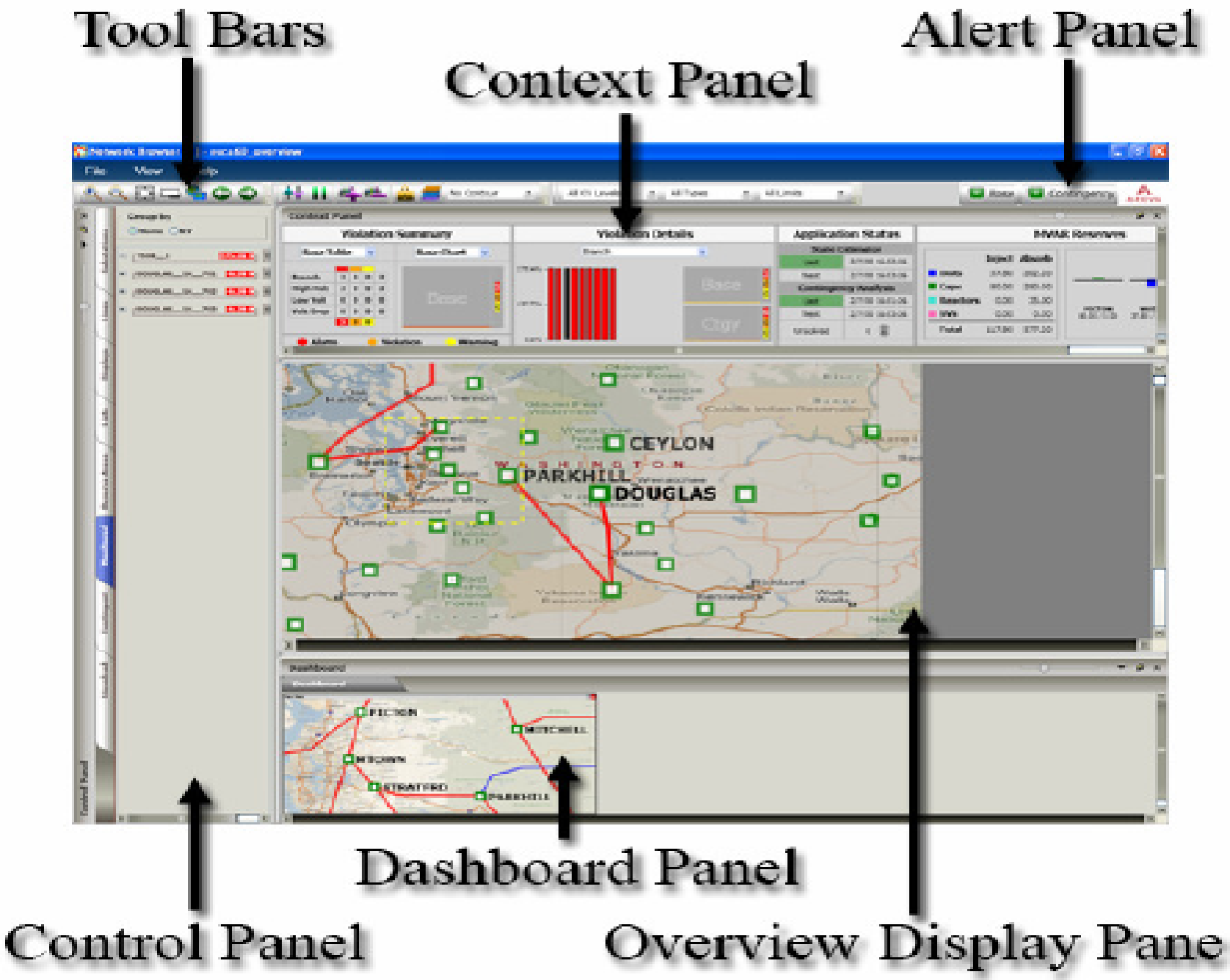
Situation Awareness (SA) in an EMS



e-terra*vision: detect changes*

Drill-Down Analysis

- Focus on a problem in a specific area
- Get data from multiple sources
- Minimize navigation / clicks
- Never lose context


Tool Bars
Context Panel
Alert Panel
Violation Summary
Violation Details
Application Status
CEYLON
PARKHILL
DOUGLAS
Control Panel
Dashboard Panel
Overview Display Pane

e-terravision Features

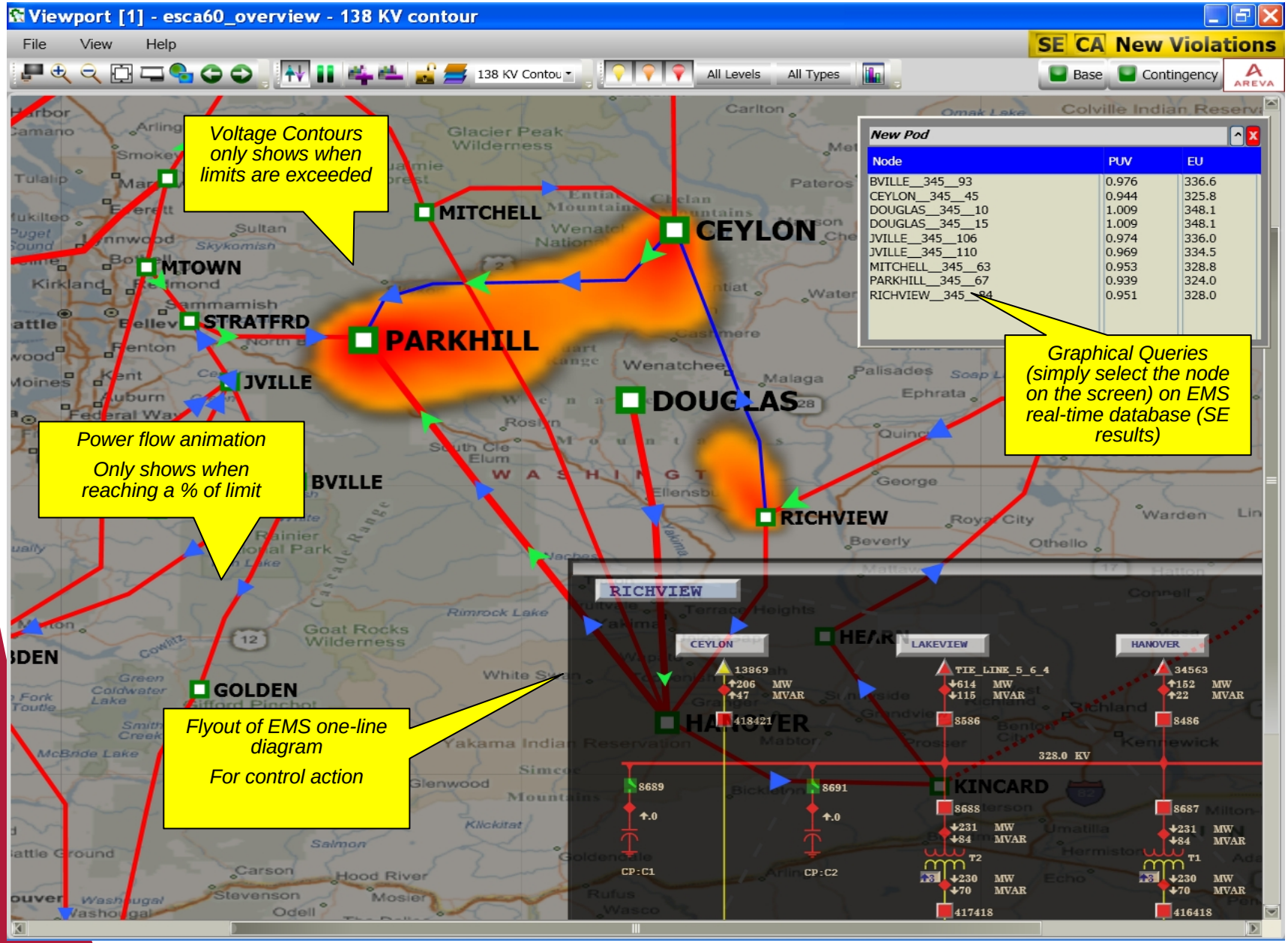
Key Features of e-terravision

1. Dynamic Overviews
2. Designed for Operators
3. High Performance Graphics
4. Real-time Decision Support
5. Graphical Authoring
6. Network Security Analysis
7. High Availability
8. Low Cost of Ownership
9. Collaborate with neighbors
10. Evolution towards Intelligent Decision Support

e-terravision Capabilities

- **Technology: Designed with the latest Microsoft VISTA technology – advanced graphics and full utilization of graphic cards.**
- **Situation Awareness: the sole purpose is to enhance SA in the control room.**
  - **Developed with a group of operators and a SA consultant**
- **High Availability: Redundant 24x7 real-time system for control room environment.**

MONITORING THE GRID



e-terravision demo

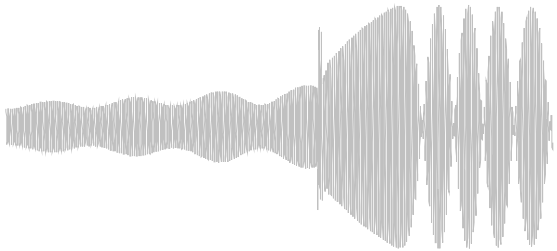
Integrated with PMUs &

PhasorPoint - Oscillation Stability Monitoring

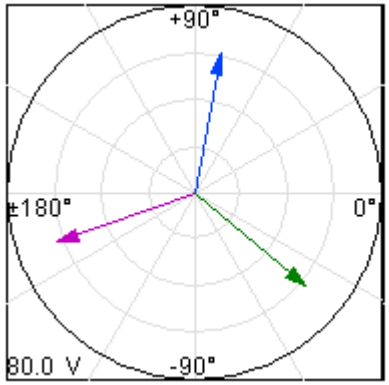
At vendor demo booth

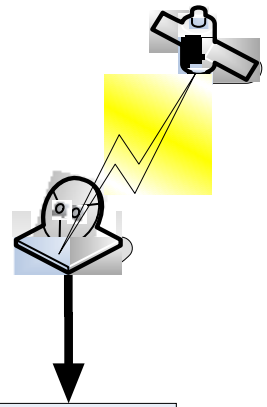
AREVA P847 PMU

Harmeet Kang, Stafford, UK



P847 PMU device basics





GPS Receiver

Oscillator

Anti Aliasing

A/D

Digital

Digitised Samples

Microprocessors

IEEE C 37.118 Data

Data Frame over Serial or Ethernet (TCP /UDP)

Analog

Electrical signal

P847 PMU

P847 Information

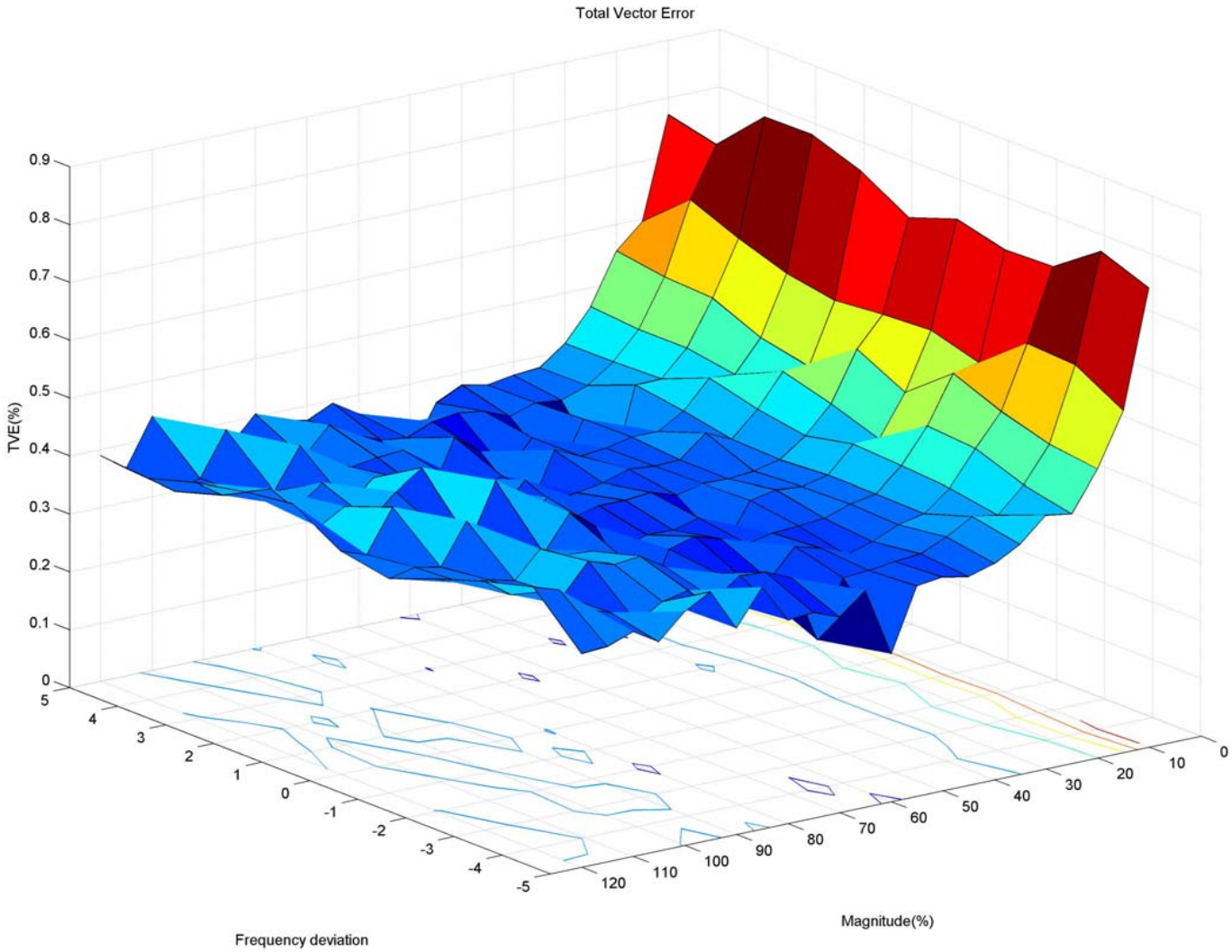
- **Analog Channels**
  - **Va, Vb ,Vc**
  - **Ia , Ib ,Ic**
  - **V_1, V_2,V_0**
  - **I_1 , I_2 , I_0**
  - **Frequency**
  - **Rate of Change of Frequency**

- **Digital Channels**
  - **Selectable – Any 8 status signals available in P847**

P847 PMU features

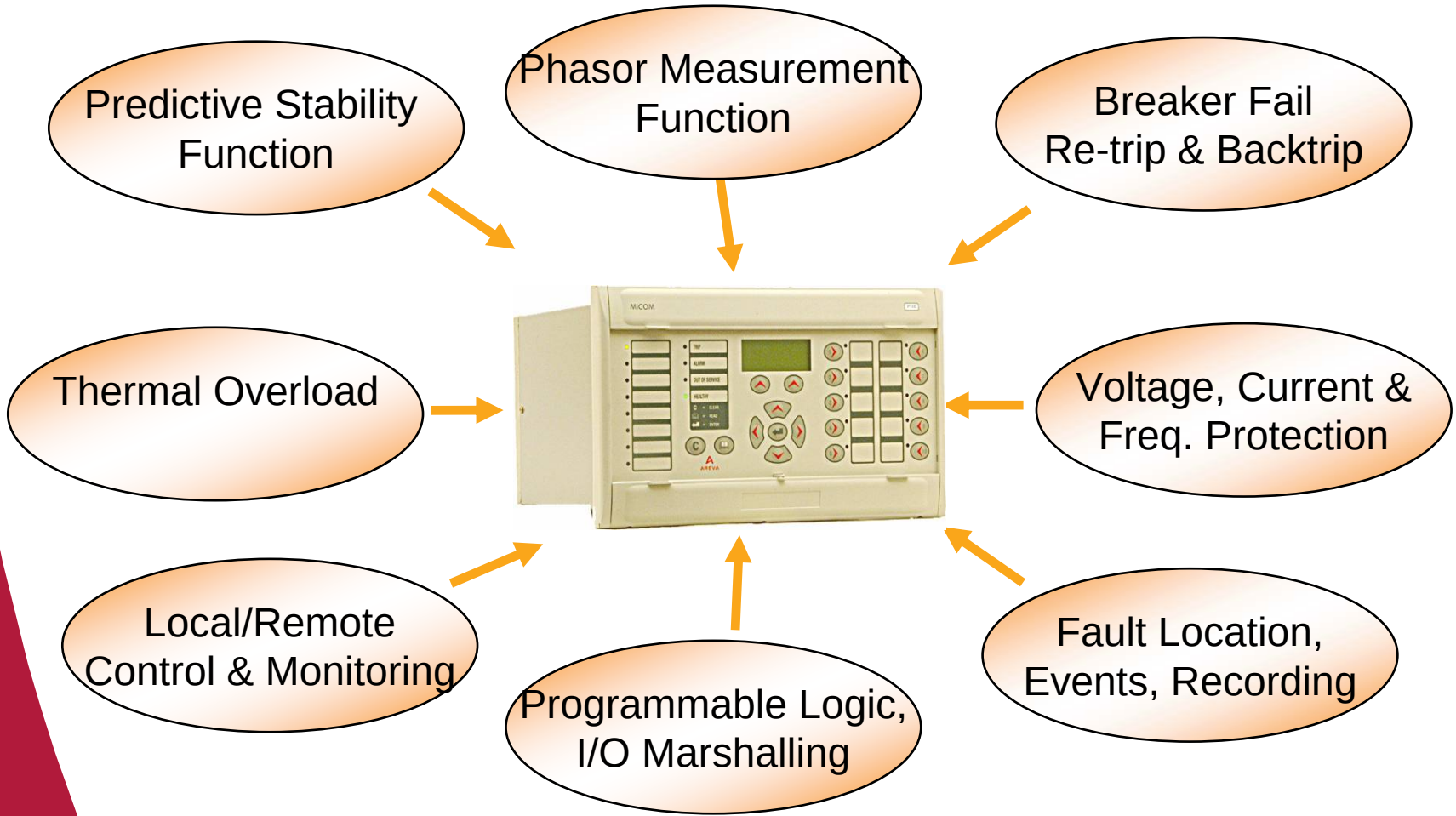
- **Protocols**
  - **Ethernet (TCP / UDP)**
- **Supported Reporting Rates:**
  - **10, 25 or 50 frames per second @ 50Hz nominal**
  - **12, 15, 20, 30 or 60 frames per second @ 60 Hz nominal**
- **Phasor Total Vector Error (TVE) < 1% for steady state conditions, over frequency range f_{nom} ±5Hz & magnitude range 10% to 120%**

P847 PMU – Total Vector Error (TVE)



MiCOM P847 Main Functionality

Multifunctional

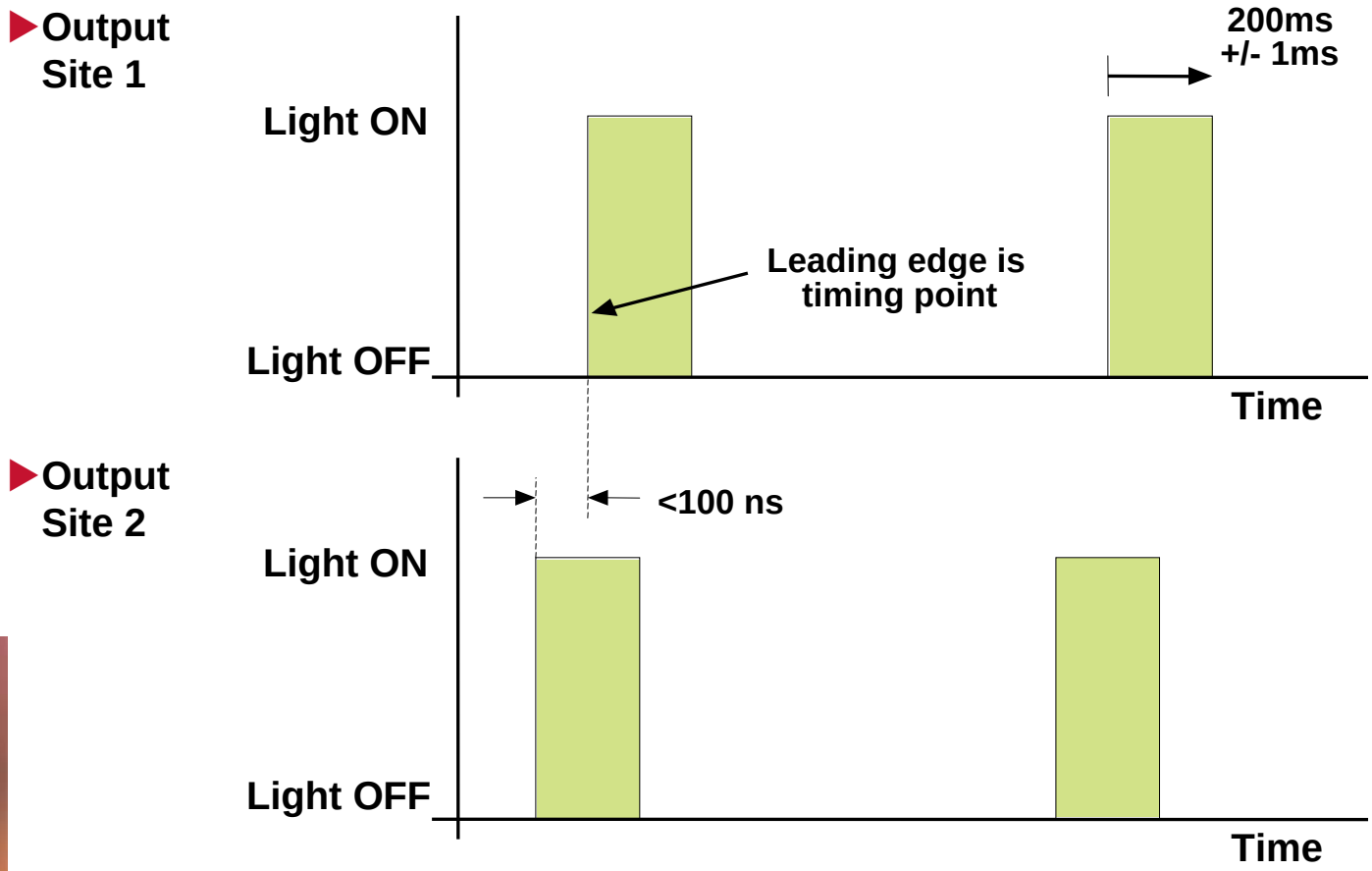


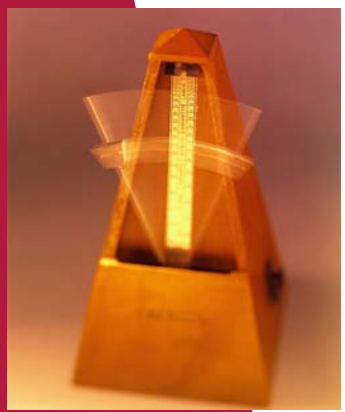
MiCOM P594

- MiCOM P594 is the universal time synchronising unit for the substation
  - Accurate for PMU applications
  - Accurate for GPS line differential
  - Accurate for NCIT merging units
  - Accurate for all other purposes
- Modulated IRIG-B
- Un-modulated IRIG-B
- 4 x 1 PPS fibre outputs to synchronise P54x relays
- P594 Status, Static Output Relays
- Visual time reference on LCD

One Device Synchronises All – One Single Investment

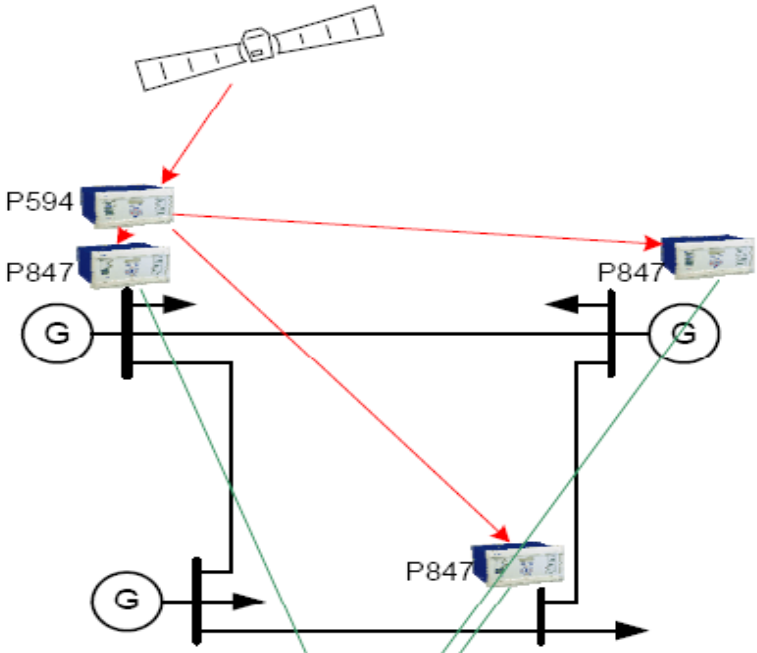
Synchronising Pulse for P54x Current Differential and P847 Phasor Measurement Unit

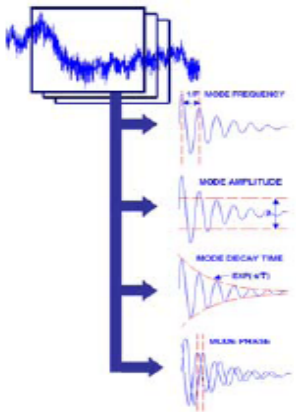




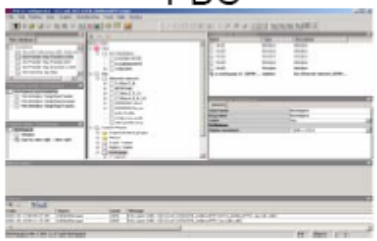
Best in Class Accuracy: for Differential, NCIT and PMU

P847 PMU System Integration





PDC



Psymterix
PhasorPoint®

Raising Transfer Levels
Avoiding Blackouts
Power System Stabilizer Tuning
Interconnector Commissioning
Identifying Causes of Oscillation

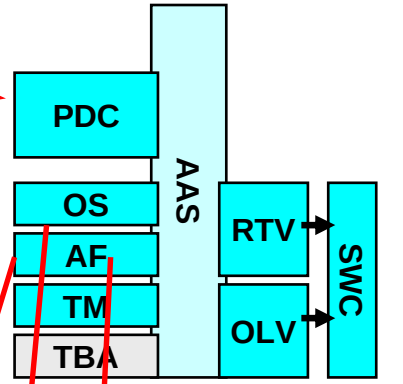
eTerraVison

EMS
Power System Oscillation Presentation

Psymetrix-AREVA Partnership

- **Joint Marketing Arrangement allows both companies to offer integrated solutions**

Micom P847

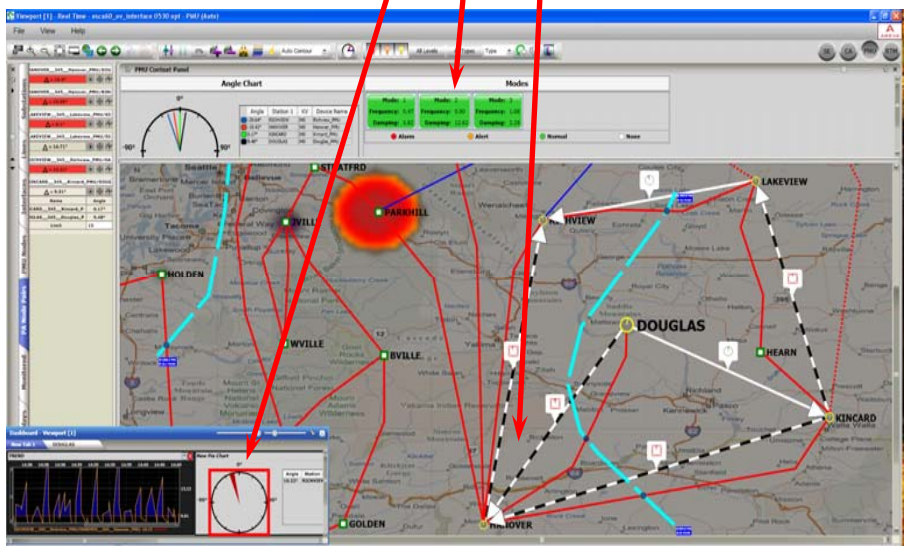


PhasorPoint

- **EMS integration**
  - **Oscillatory Stability and other applications**
  - **Psymetrix PDC family**
  - **Applications using combined SCADA and PMU data**

    (e.g. Oscillatory Source Location)

e-terra*vision*

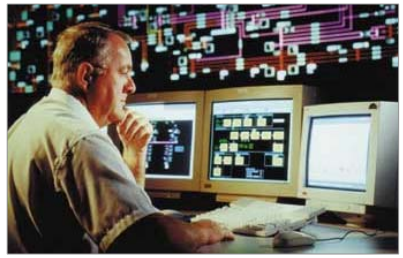


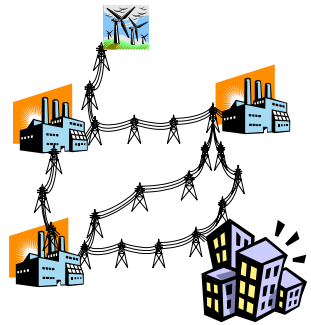
- **Deployment in process in South Africa**

PhasorPoint Overview

PhasorPoint
Wide Area Measurement Systems (WAMS) Software

PhasorPoint
Phasor Data Concentrator (PDC) Solution Family



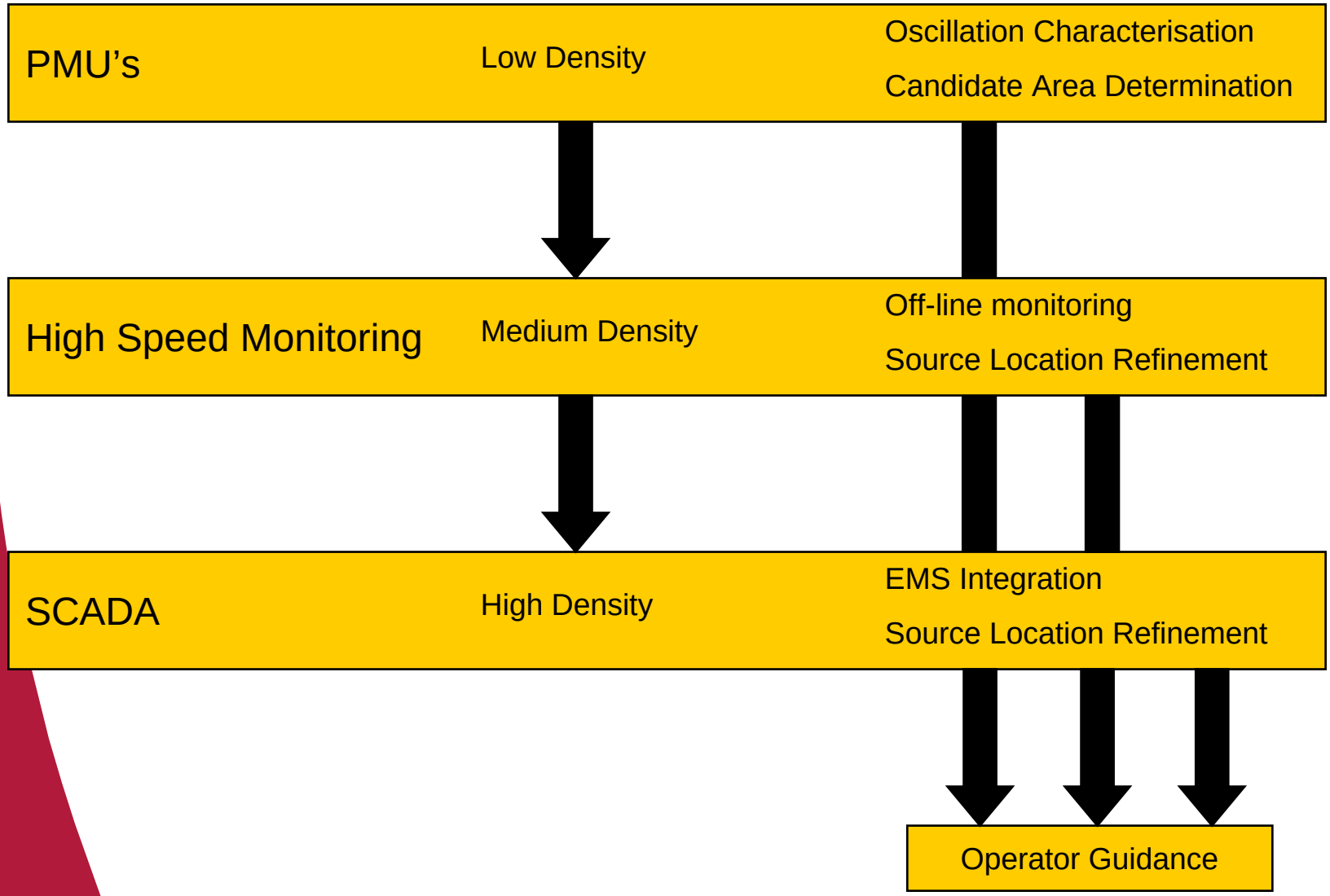


PhasorPoint
WAMS Application Software
(Real-time and Off-line)

Angle and Frequency Monitoring	***System stress indication*** ***Blackstart and islanding recovery***
Transient Monitoring	***Real-time disturbance indication*** ***Post event analysis*** ***Pole slip detection***
Oscillatory Stability Management	***Improved power system security*** ***Increased secure power flows*** ***Damping controller performance enhancement***
New (TBA)	***Flexible, expandable systems***

Psymetrix Consulting	***Resolving power system issues*** ***Ensuring ROI from StormMinder solutions***

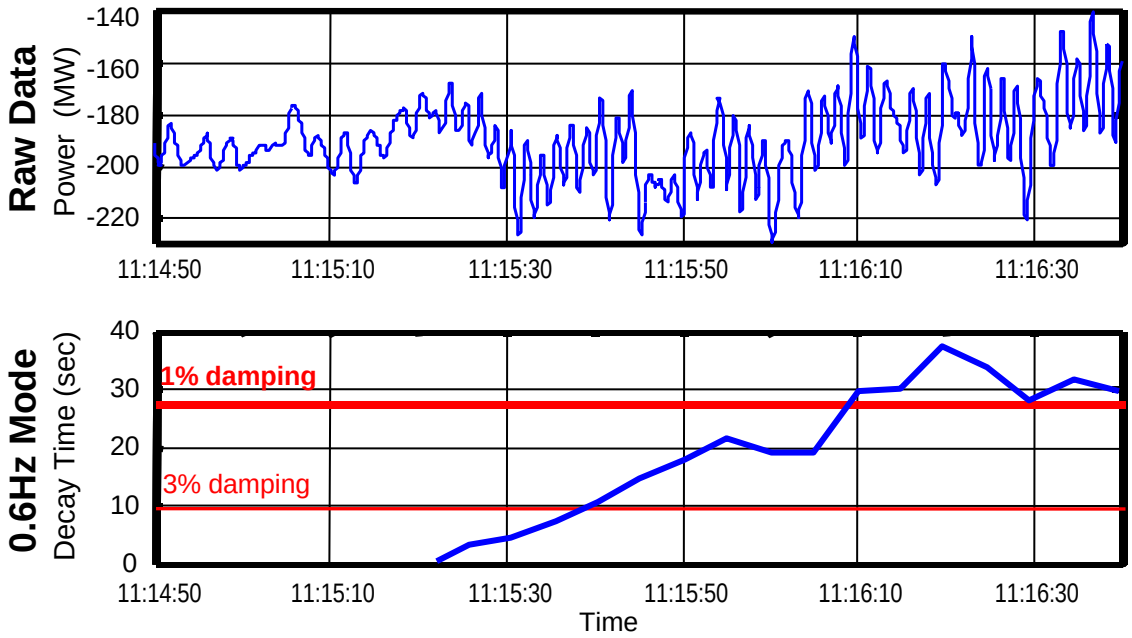
SCADA & PMU combined application example
Oscillation Source Location



Example: Security Management - Australia

Blackout avoided, Australia, 10 April, 2004

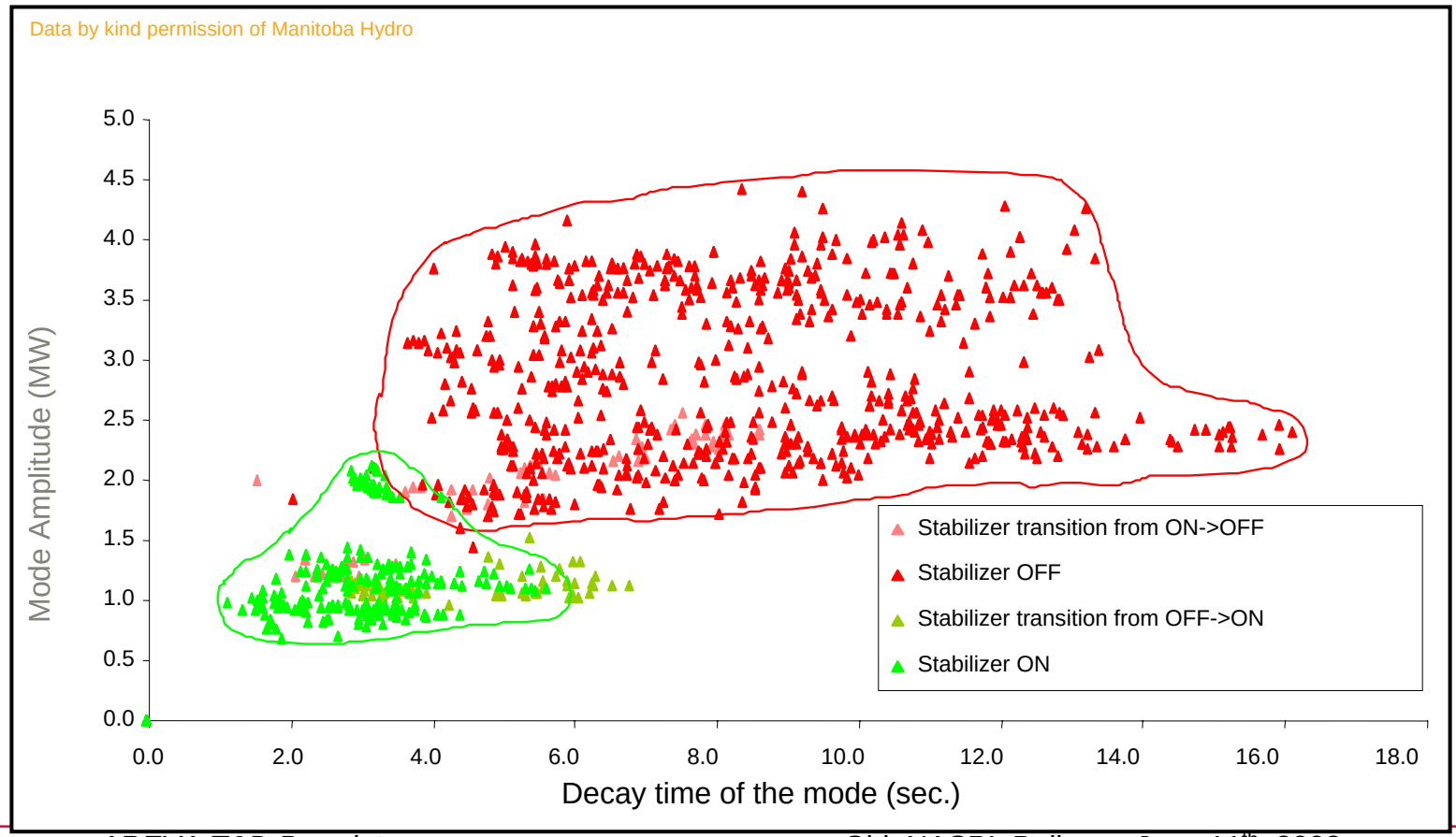
- **Instability occurred suddenly on the Australian network in a normally well-damped mode**
- **Psymetrix PDM system generated an alarm within 90 seconds of the onset**
- **The alarm gave control operators key information on the nature of the problem, so they could take prompt action**
- **The alarm was observed on oscillation damping, not amplitude, because oscillations were large (300MW) close to the source, but small at the point of measurement**
- **System splitting and blackout was avoided**



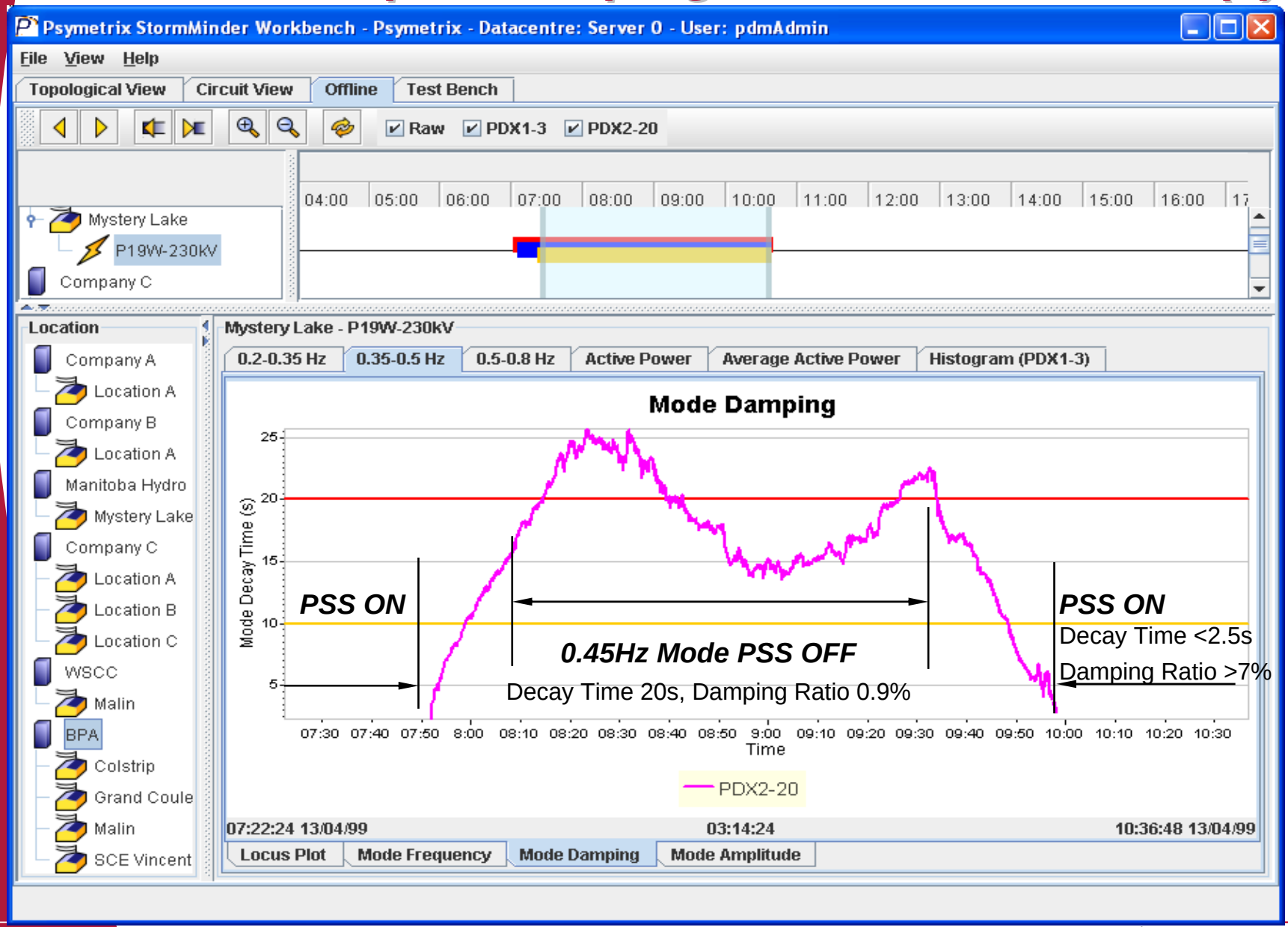
Example: Damping Control - Manitoba (1)

Damping Controller Commissioning & Tuning

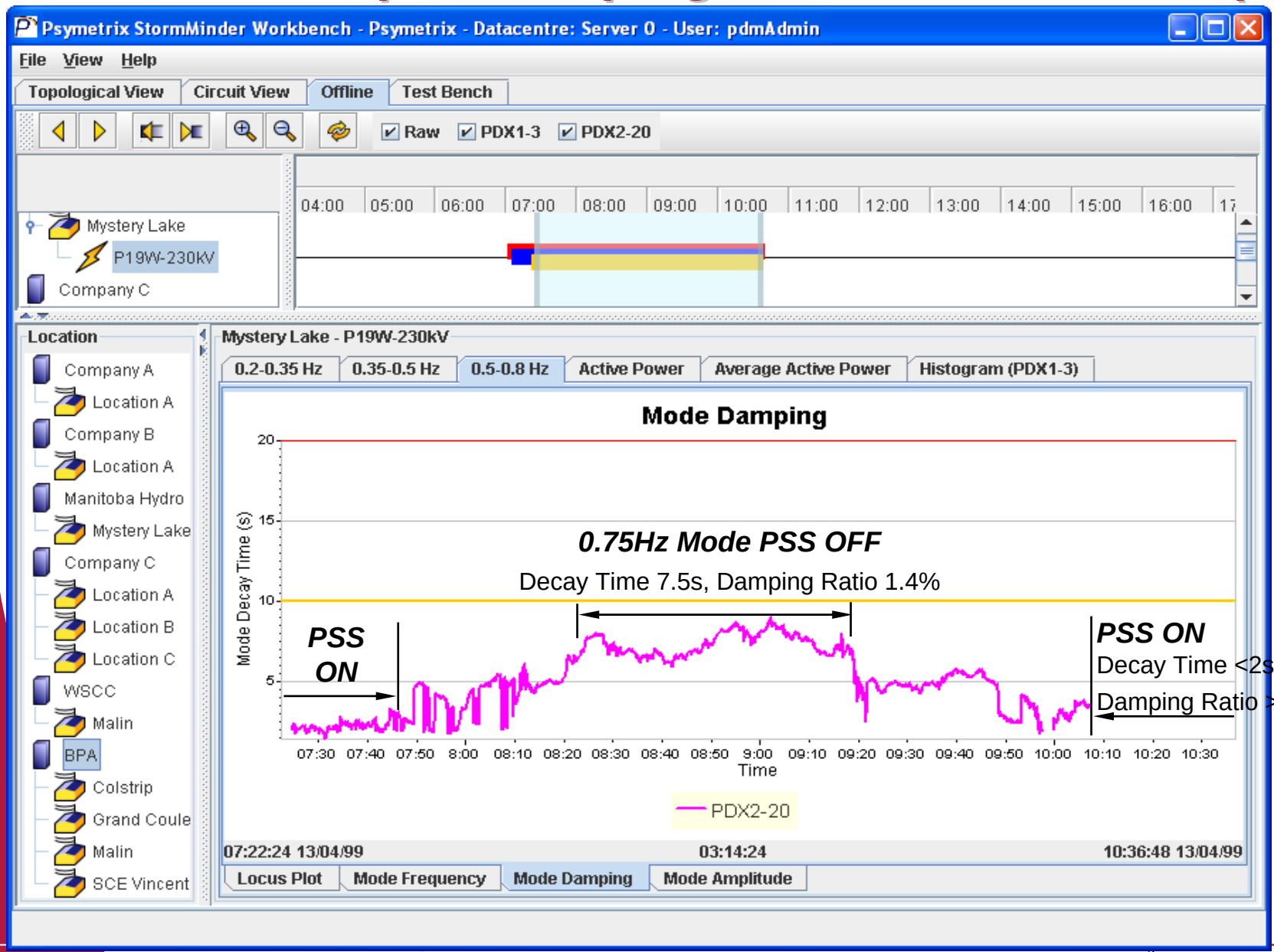
- Non-invasive, on-line, continuous assessment
- Immediate direct feedback of tuning changes
- Simplifies co-ordinated tuning of damping devices
- Local or remote monitoring of device impact on system



Example: Damping Control - Manitoba (2)



Example: Damping Control - Manitoba (3)

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