

AREVA Activities related to

SynchroPhasor Measurements

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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 rapid growth of PMUs creates a new evolutionary grid operations paradigm

The big question is:

• How will this benefit power system operations?



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 "Phasor1" 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: <u>MW change; 'electrical distance</u> <u>change'</u>

• Refresh rate 2-5 seconds

EMS SCADA data

- 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.





SE's Role in Power System Operations

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



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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



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 <u>advanced SE metrics</u> 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

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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		2		
Company injection deviations		2		
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	2	2		



Valid SE solutions



AREVA T&D Proprietary

Giri, NASPI, Bellevue June 11th, 2008

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Monthly table

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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	100
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Comparing Raw PMU with SE results @ BPA

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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				
YELOWITLP 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				

AREVA

T&D





- 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



<u>New EMS Paradigm</u> <u>Generalized Grid Security Analysis</u>





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





Drill-Down Analysis

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





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



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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





P847 Information

Analog Channels

- Va, Vb ,Vc
- Ia , Ib ,Ic
- \bullet V₁, V₂,V₀
- $\bullet \mathbf{I}_1 \ , \mathbf{I}_2 \ , \mathbf{I}_0 \\$
- 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 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

AREVASynchronising Pulse for P54x Current Differential and P847 Phasor Measurement Unit



Best in Class Accuracy: for Differential, NCIT and PMU



P847 PMU System Integration





Psymetrix-AREVA Partnership

Joint Marketing Arrangement allows both companies to offer integrated solutions



EMS integration

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

(e.g. Oscillatory Source Location)

Deployment in process in South Africa



PhasorPoint Overview

PhasorPoint Wide Area Measurement Systems (WAMS) Software

PhasorPoint Phasor Data Concentrator (PDC) Solution Family





WAI (F	Angle and Frequency Monitoring	System stress indication Blackstart and islanding recovery
Phas S Applio 9al-time	Transient Monitoring	Real-time disturbance indication Post event analysis Pole slip detection
ar à r		
Point ion Soff id Off-lir	Oscillatory Stability Management	Improved power system security Increased secure power flows Damping controller performance enhancement
l le t		
are)	New (TBA)	Flexible, expandable systems
	Psymetrix Consulting	Resolving power system issues Ensuring ROI from StormMinder solutions

T&D





Example: Security Management - Australia

Blackout avoided, Australia, 10 April, 2004

- Instability occurred suddenly on the Australian network in a normally well-damped mode
- **P**symetrix 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 ٠
- Immediate direct feedback of tuning changes ٠
- Simplifies co-ordinated tuning of damping devices ٠
- Local or remote monitoring of device impact on system ٠





Example: Damping Control - Manitoba (2)



T&D



Example: Damping Control - Manitoba (3)

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<u>File View H</u> elp							
Topological View Circuit View Offline Test Bench							
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Company C	-						
Location A Mystery Lake - P19W-230kV							
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Company B 20							
Location A							
Manitoba Hydro							
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	PSS ON						
	Decay Time <2s						
wscc	Damping Ratio >5.5						
07:30 07:40 07:50 8:00 08:10 08:20 08:30 08:40 08:50 9:00 09:10 09:20 09:30 09:40 09:50 10:00 Time	07:30 07:40 07:50 8:00 08:10 08:20 08:30 08:40 08:50 9:00 09:10 09:20 09:30 09:40 09:50 10:00 10:10 10:20 10:30 Time						
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