

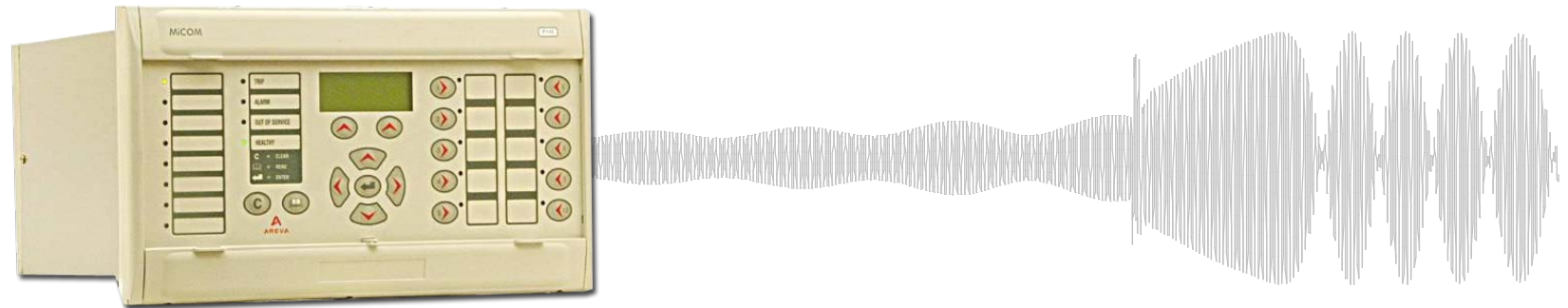
Application of PMUs for Improved Grid Operations

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AREVA, Redmond, WA

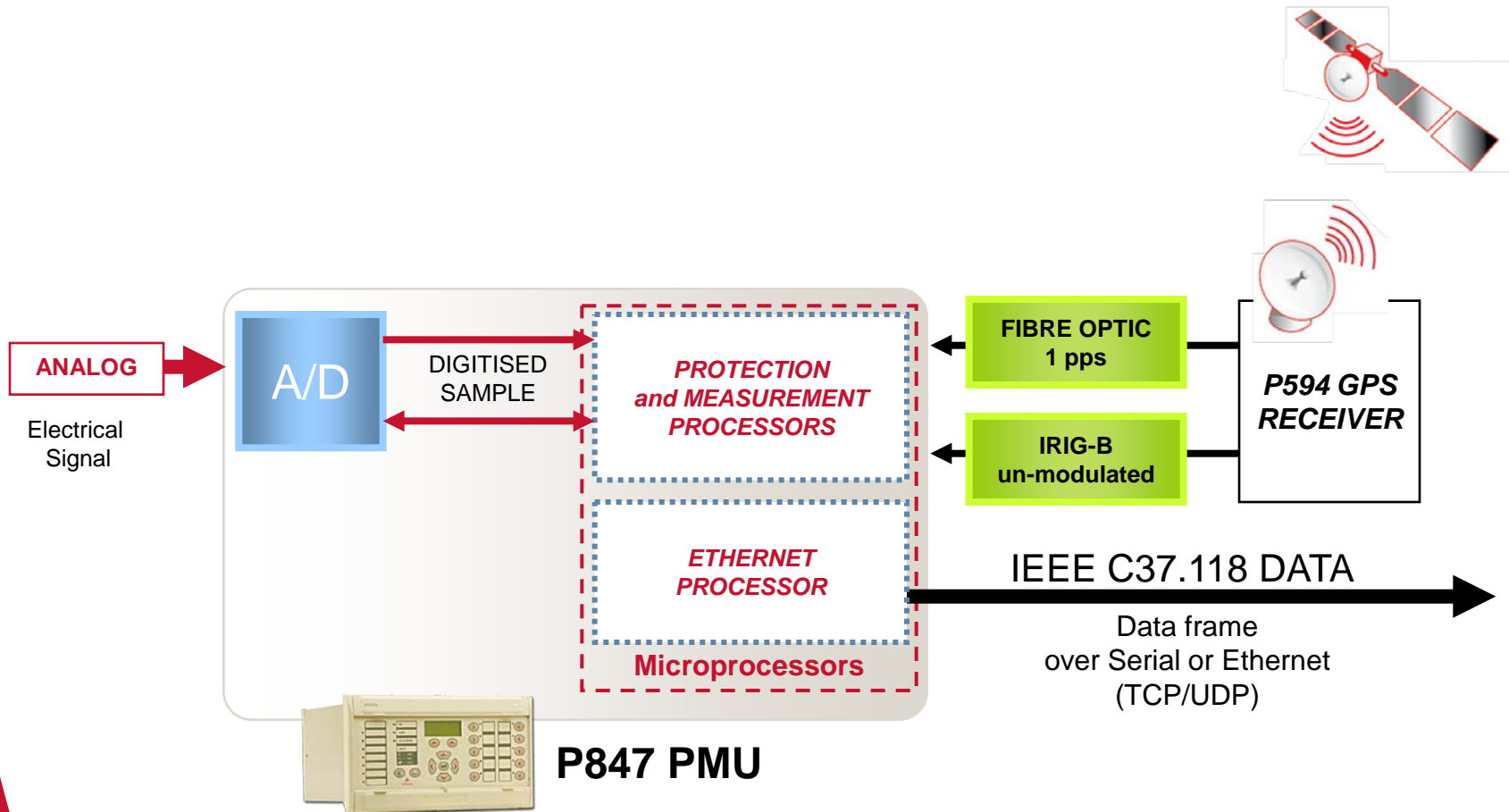
- ▶ **AREVA PMU**
- ▶ **PMU – SE Phase 2 & 3 projects**
- ▶ **Online stability solutions**
- ▶ **AREVA-Psymetrix Integration**
- ▶ **NCG Project**

AREVA MiCOM P847 Phasor Measurement Unit



AREVA Substation Automation Products, Stafford, UK

P847 PMU device basics



Multifunctional

**Phasor Measurement
Function**

Thermal Overload

**Breaker Fail
Re-trip & Backtrip**



**Local/Remote
Control & Monitoring**

**Voltage, Current
& Freq. Protection**

**Programmable Logic,
I/O Marshalling**

**Fault Location,
Events, Recording**

PMU-SE Project

▶ **Participants:**

- ◆ **TVA, Entergy, Manitoba Hydro, Idaho Power, PG&E, ORNL, NE University, First Energy, BPA**

▶ **Utility EMS data used:**

- ◆ **TVA – Lisa Beard**
- ◆ **Entergy – Floyd Galvan**

▶ **Primary Technical Contributors**

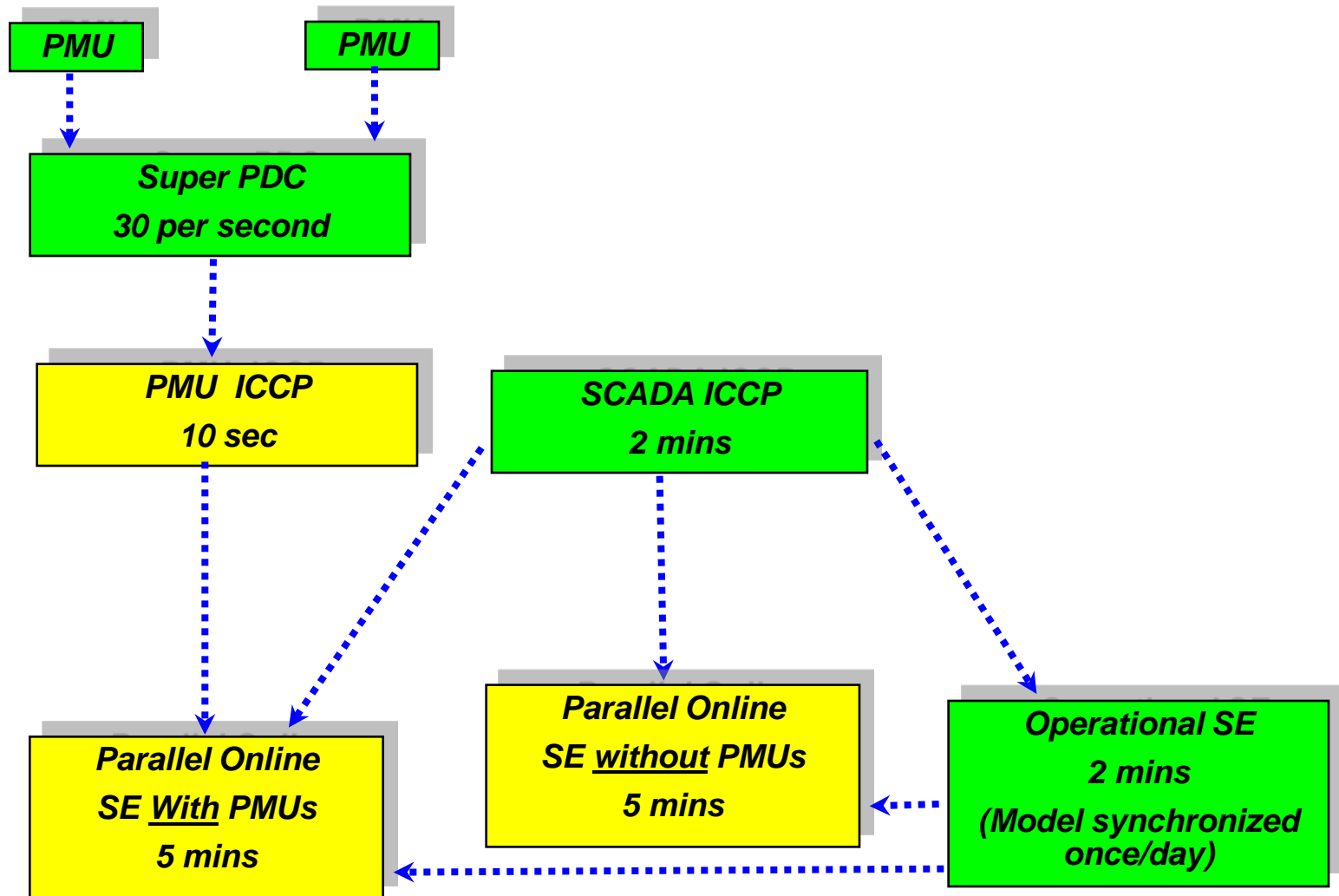
- ◆ **AREVA - Rene Rosales & Mark Rice**
- ◆ **NE University – Prof. Ali Abur**

Impact of PMUs on State Estimation

▶ Objectives

- ◆ Implement a parallel online SE in TVA control center
 - ◆ Simulate growth of PMUs for next few years and perform case studies on Entergy database to evaluate benefits
 - ◆ Implement advanced SE metrics in AREVA product to facilitate comprehensive evaluation of SE performance
- ▶ SE evaluation by comparing two parallel implementations
- ◆ Existing SE with classical SCADA data
 - ◆ Enhanced SE with PMU data
 - ◆ Stream of SE results stored & analyzed

Parallel server configuration at TVA



PMU and SCADA Data Statistics at TVA SE

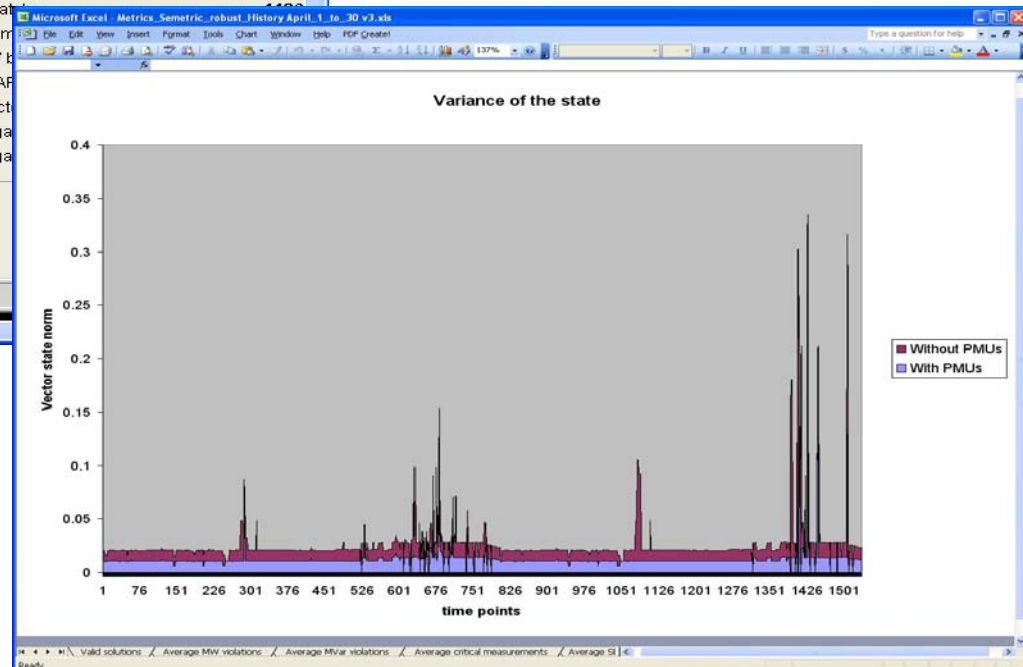
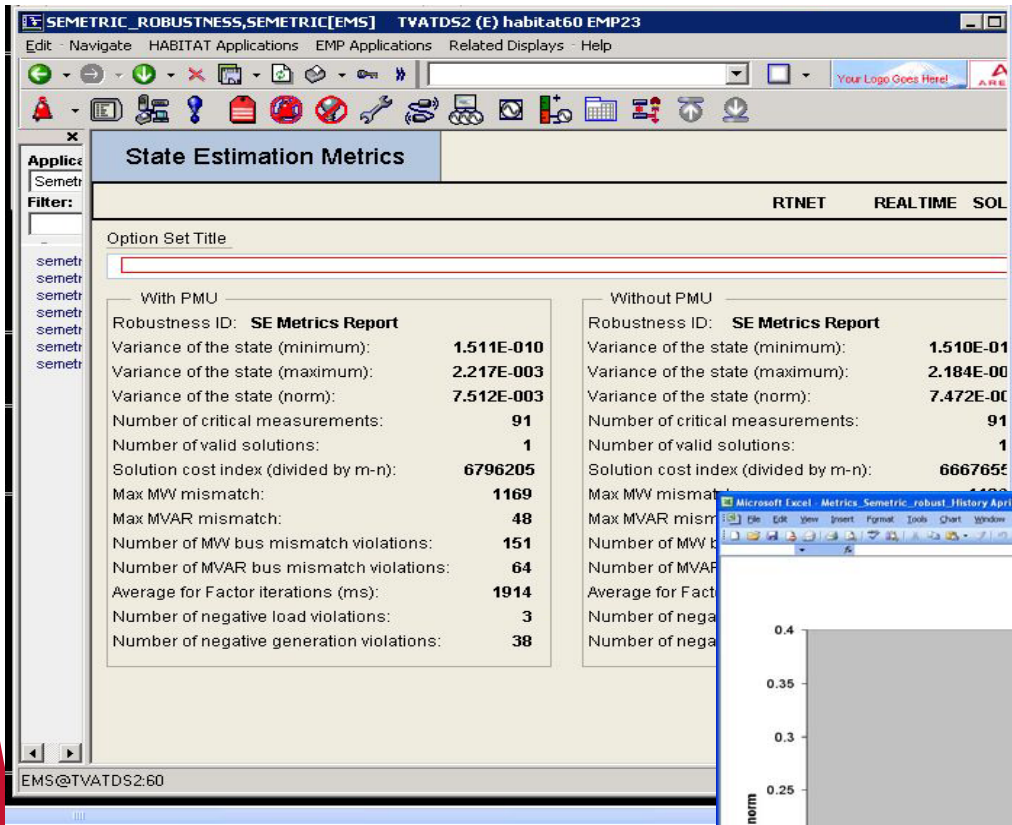
- ▶ **18 PMU angle measurements**

- ▶ **17000 (approx) SCADA measurements:**
 - ◆ **KV, P, Q (flows & injections)**

- ▶ **7000 bus model (approx)**
 - ◆ **90% measurement observable**

STATE ESTIMATION METRICS

- ▶ 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)



$$E((x_i - E(x_i))^2) = \sigma_{ii}^2$$

$$G^{-1} = \text{cov}(\text{error})$$

$$G_{ii}^{-1} = \sigma_{ii}^2$$

Variance of the state

Online SE @ TVA - Monthly table

Microsoft Excel - Monthly Table.xls [Read-Only]

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Σ 100% Arial 10 B I U

	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	At the end of the month	4% Improvement in Valid Solutions		Critical Measurements Reduction with 18 PMUs		State closer to the "true" value with 18 PMUs			
7									
8									
9									
10									
11									
12									
13									
14									
15									

Ready NUM

PMU-SE Phase 2 conclusions

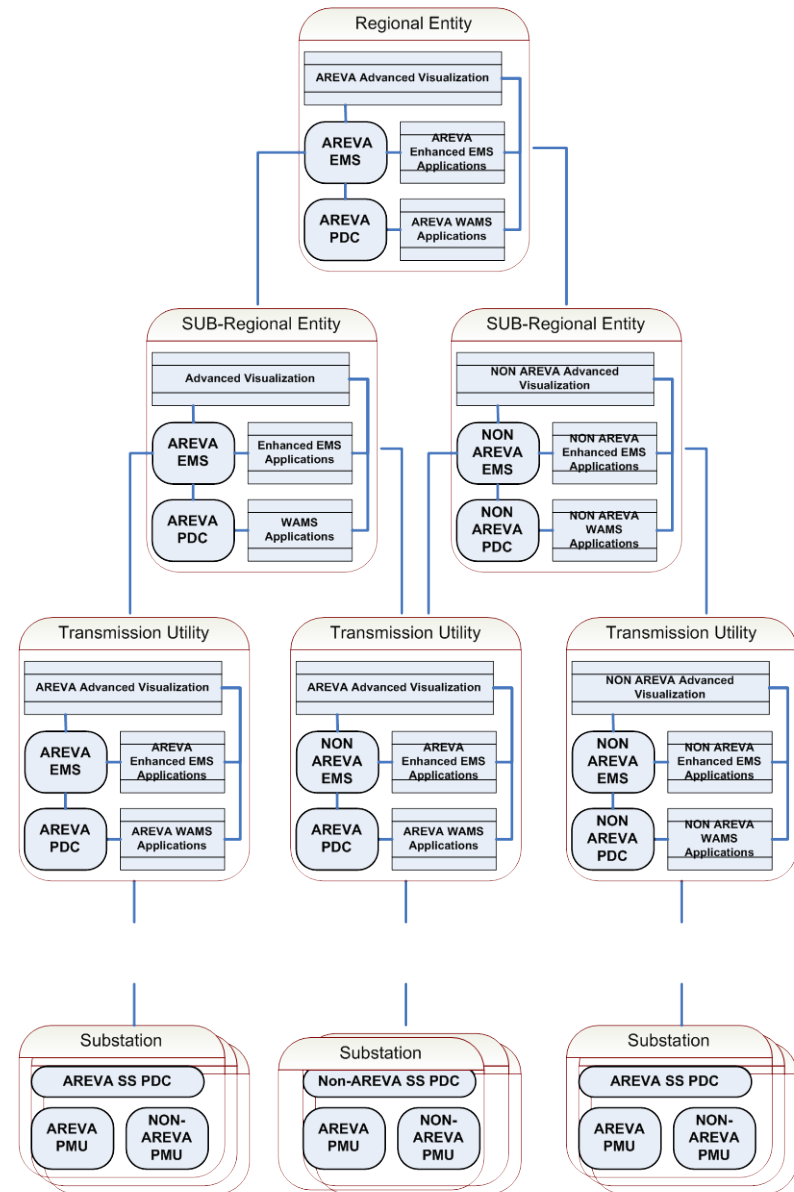
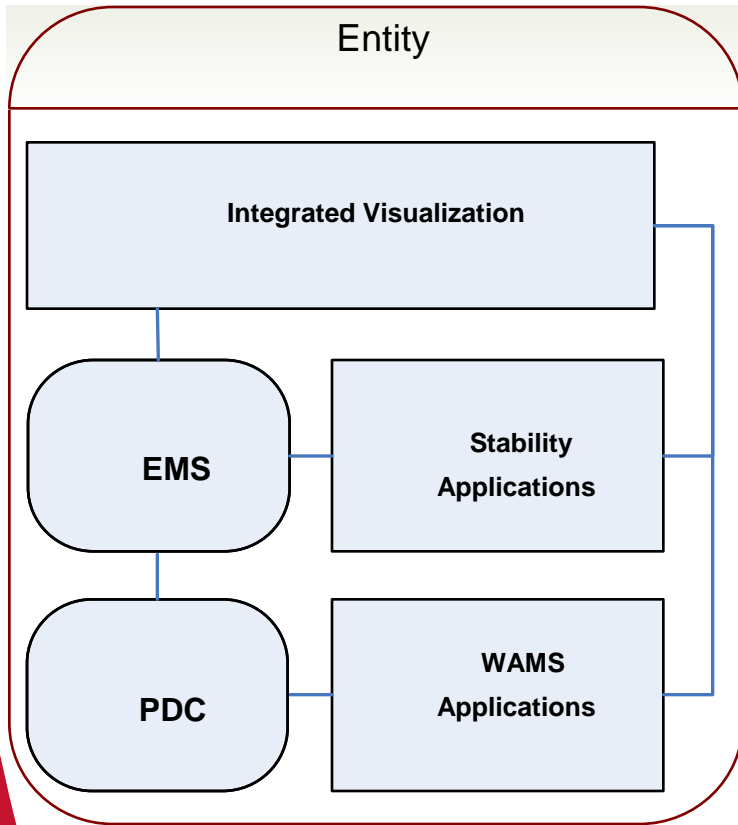
- ▶ Phase 2 completed - final report to participants
- ▶ Cigre Paper summarizing results – August
- ▶ New 'SE solution quality' metric developed (Variance of state)
- ▶ SE results output now includes 'critical measurement locations'
 - ◆ Identifies where new PMUs should be located SE enhancement
- ▶ Since PMUS are being deployed anyway, use them in SE
- ▶ The "SE With PMUs" executions show marginal improvement
 - ◆ PMU measurements are a VERY small % (< 0.2%) of SCADA measurements
 - ◆ 95% Valid solutions "Without PMUs",
99% Valid solutions "With PMUs"
 - ◆ Some Local improvement in accuracy
 - ◆ Greater improvement expected as more PMUs are added

PMU-SE Phase 3 starting now

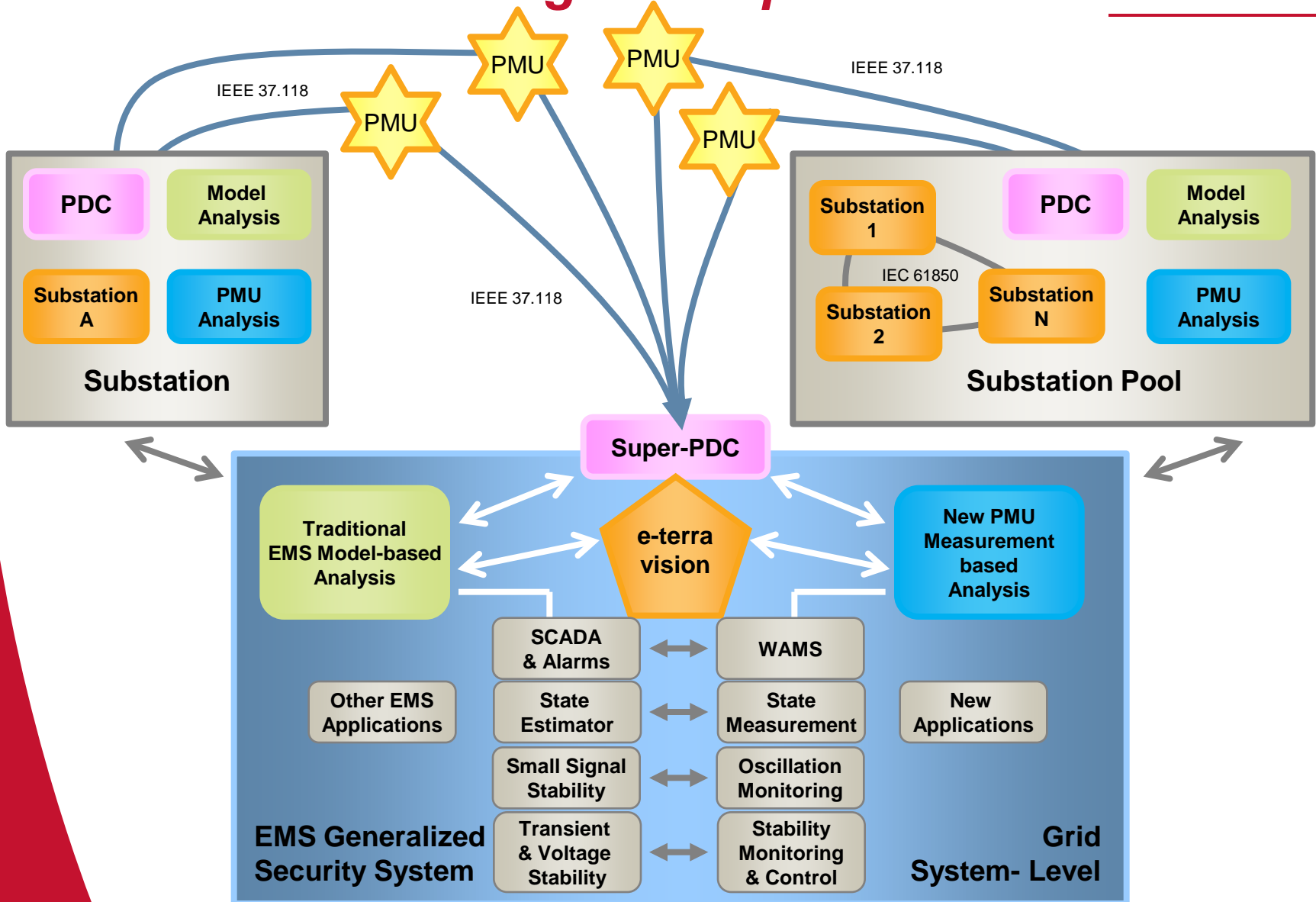
- ▶ **Primary focus being identifying potential benefits to SE for projected larger number of PMUs**
- ▶ **Use the DTS to simulate the growth of PMUs and assess benefits**
- ▶ **Starts Nov 2008 for 6 months**

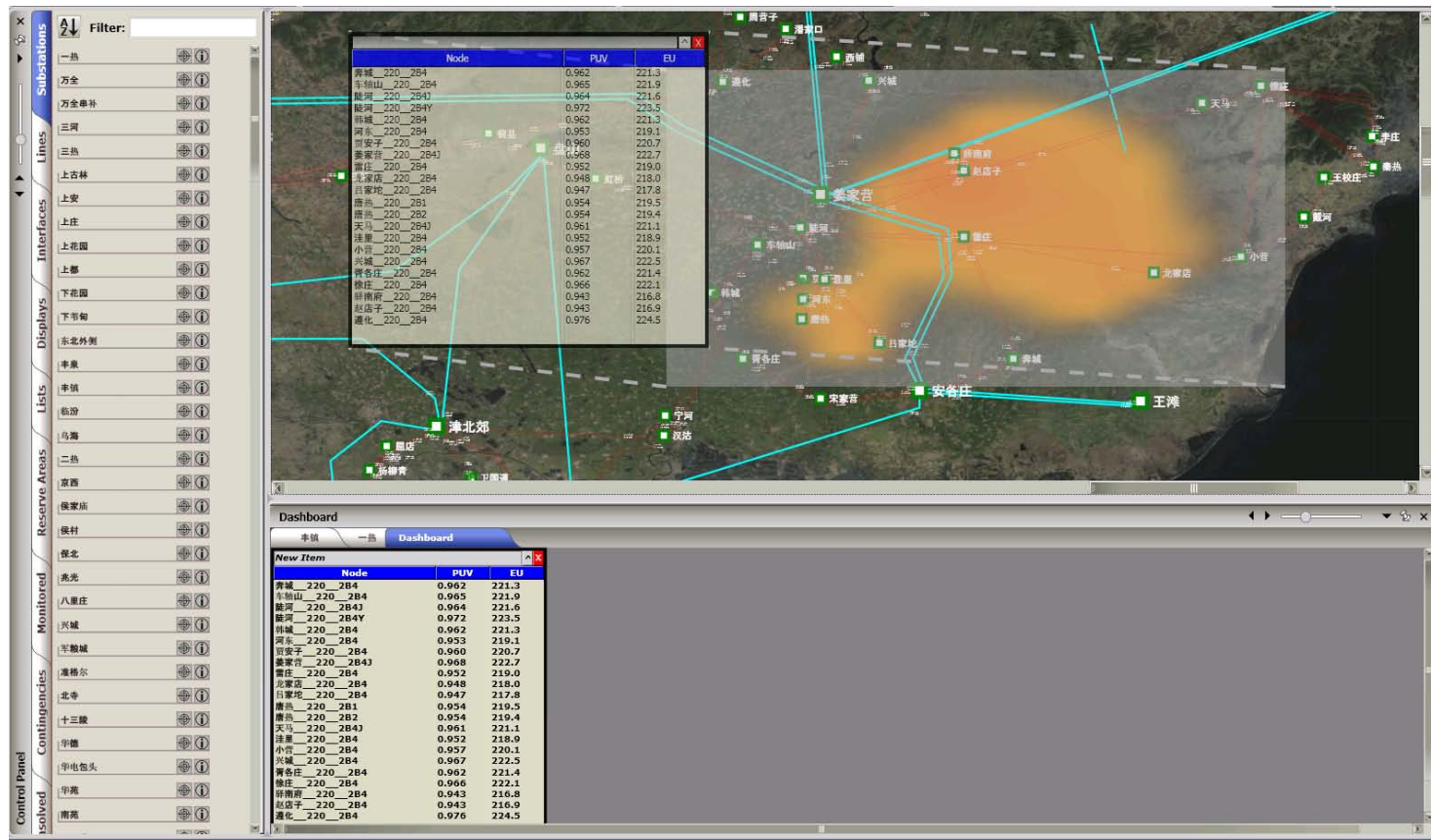
Online Stability Solutions

Stability Solutions Hierarchy for Grid Reliability



Integrated Operator User Interface



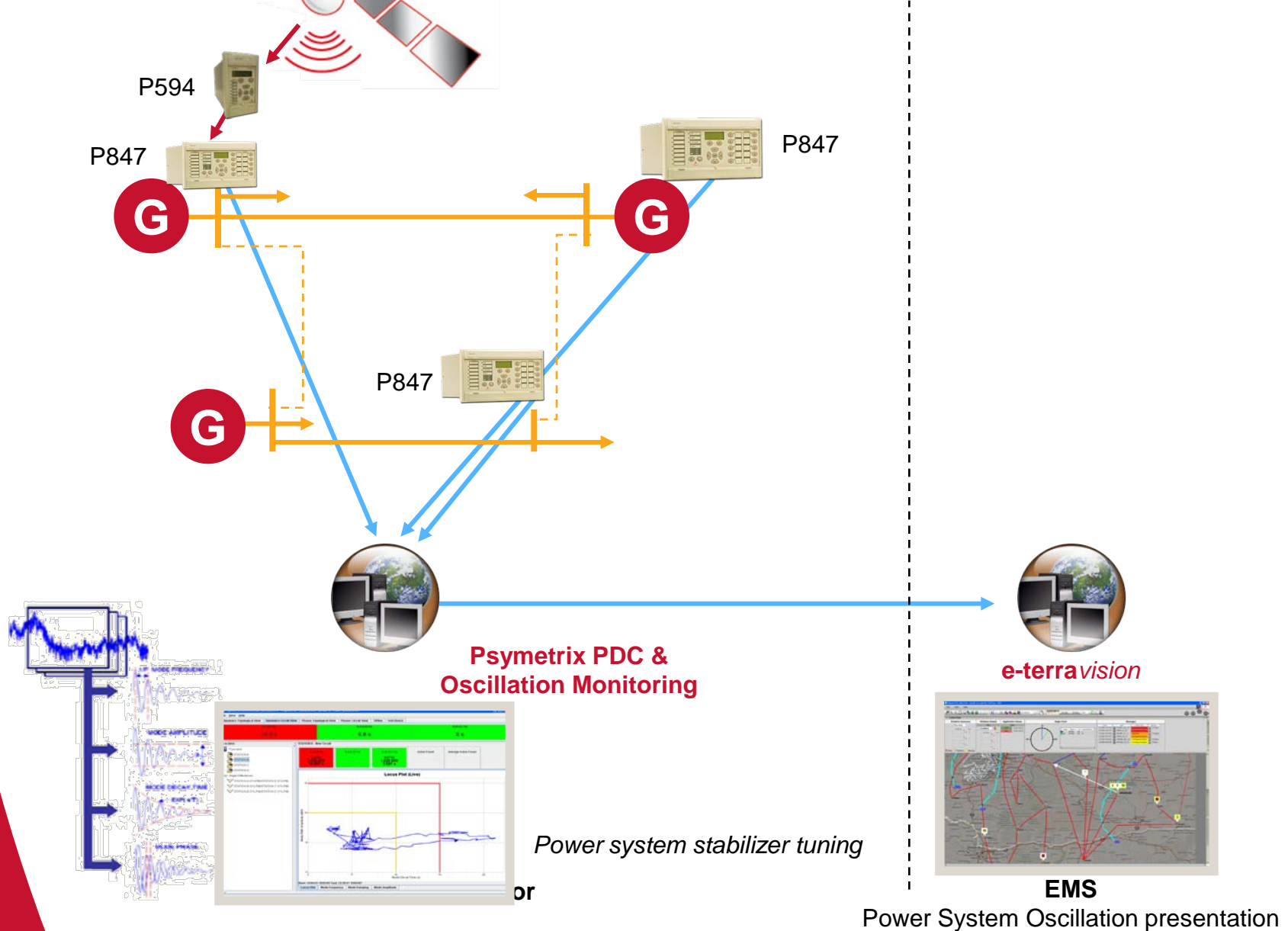


► Situation Awareness – eterraVision Approach (Continued with WAMS)

- ◆ Voltage/LMP Contour by KV Level
- ◆ On-demand List Generated from Graphic Area
- ◆ Quick Allocation of Graphic Element form Control Panel
- ◆ Interface with non-AREVA EMS

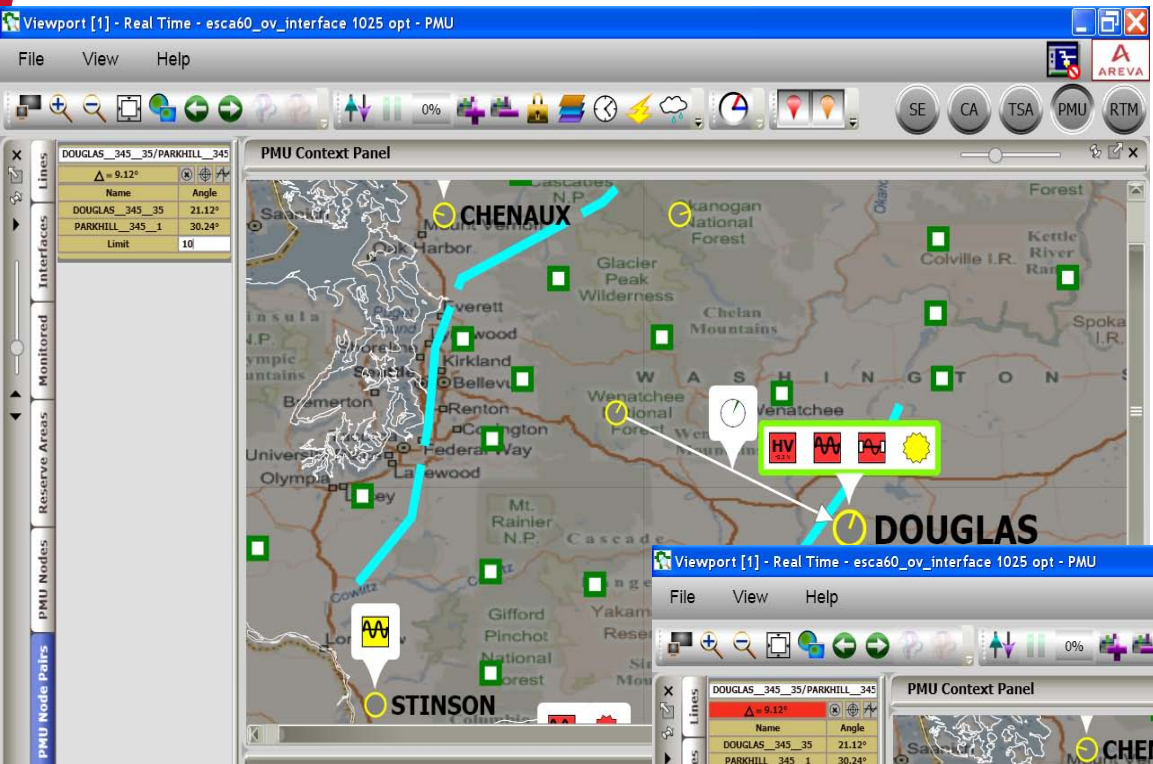
AREVA-Psymetrix projects

AREVA-Psymetrix Integration

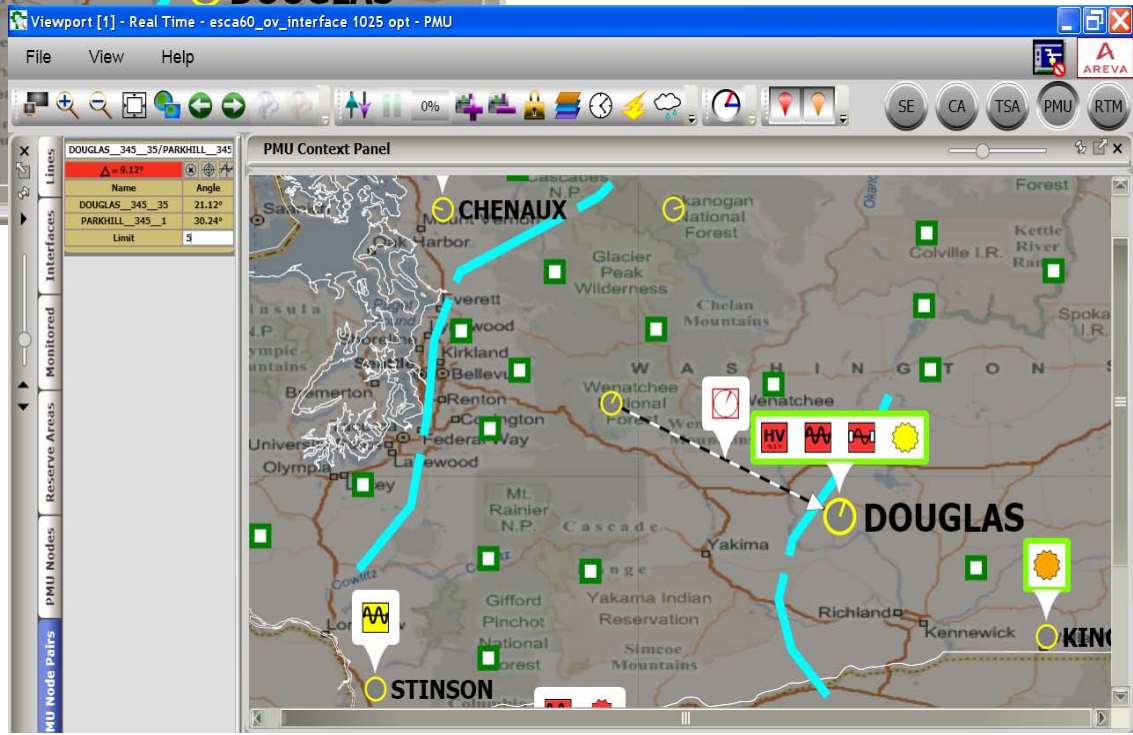


The screenshot displays the PMU Context Panel software interface. At the top, there is a toolbar with various icons for navigation and settings, including a compass, a lock, and a clock. Below the toolbar is the PMU Context Panel header, which includes a search bar and several buttons labeled SE, CA, TSA, PMU, and RTM. The main area is a map of Washington state, showing major cities and geographical features. A cyan line highlights a path across the state. Several PMU locations are marked with green squares. A yellow dashed circle highlights the DOUGLAS node, and a context menu is open over it. The menu options are: Recent, Animation Options..., Create PMU Node Pair, Zoom Ranges..., and Virtual Earth. A tooltip for the DOUGLAS node shows four icons: HV (High Voltage), a waveform, a clock, and a sun. Another tooltip for the KING node shows a sun icon. A tooltip for the STINSON node shows a waveform icon. A tooltip for another node shows a waveform and a sun icon. The bottom of the interface shows a Dashboard section with navigation controls.

Monitoring PMU angle differences



Normal conditions



Alarm conditions

File View Help

PMU Context Panel

Angle Chart

0° 90°

Angle	Station 1	KV	Device Name
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Modes

Mode: 1	Mode: 2	Mode: 3	Mode: 4	Mode: 5
Frequency: 0.20 Damping: 21.50	Frequency: 0.44 Damping: 4.77	Frequency: 0.36 Damping: 4.25	Frequency: 1.20 Damping: 2.65	Frequency: 1.15 Damping: 1.65

● Alarm ● Alert ● Normal ○ None

DOUGLAS

WINSTON

KINCAID

Dashboard

North China Grid Project

Scope

- ▶ **NCG Overview:**
 - ◆ 100+ PMUs in region
 - ◆ 1 of 6 Regional Grid Operators in China
 - ◆ 120 GW Installed Gen (VLPGO)
 - ◆ Directly controls Beijing area (& OLYMPICS)

- ▶ **Solutions provided:**
 - ◆ EMS & eterra-Vision
 - ◆ Their own PMUs & PDC
 - ◆ NCG-NARI Stability applications:
 - ◆ SSA, VSA, TSA

- ▶ **Contract Duration/ Completion:**
 - ◆ Phase 1: 2006-2007 (In Production)
 - ◆ Phase 2: 2007-2008 (In Acceptance Test)



Monitoring PMU angle differences

Context Panel

Violation Summary

Branch	0	0	0
HighVoltage	2	0	0
LowVoltage	0	0	0
VoltageDrop	0	0	0
XF	0	0	0
LowFrequencyOscillation	1	0	1
Disturbance	0	1	1
Interface	0	0	0

Violation Details

Pmu: Disturbance

Application Status

Pmu: Last 3/19/08 08:37:48, Next 3/19/08 08:42:48

Angle Chart

- 10° CHENAUX 345 1
- 20° DOUGLAS 345 35
- 35° PARKHILL 345 1
- 63° MOSELLE1 14 30

Network Diagram

Highlighted path: CHENAUX → BRIGHTON → PARKHILL → DOUGLAS

PMU Detail

Delta: 43°
Limit: 15°
Node 1: 63° MOSELLE1_14_30
Node 2: 20° DOUGLAS_345_35

Dashboard

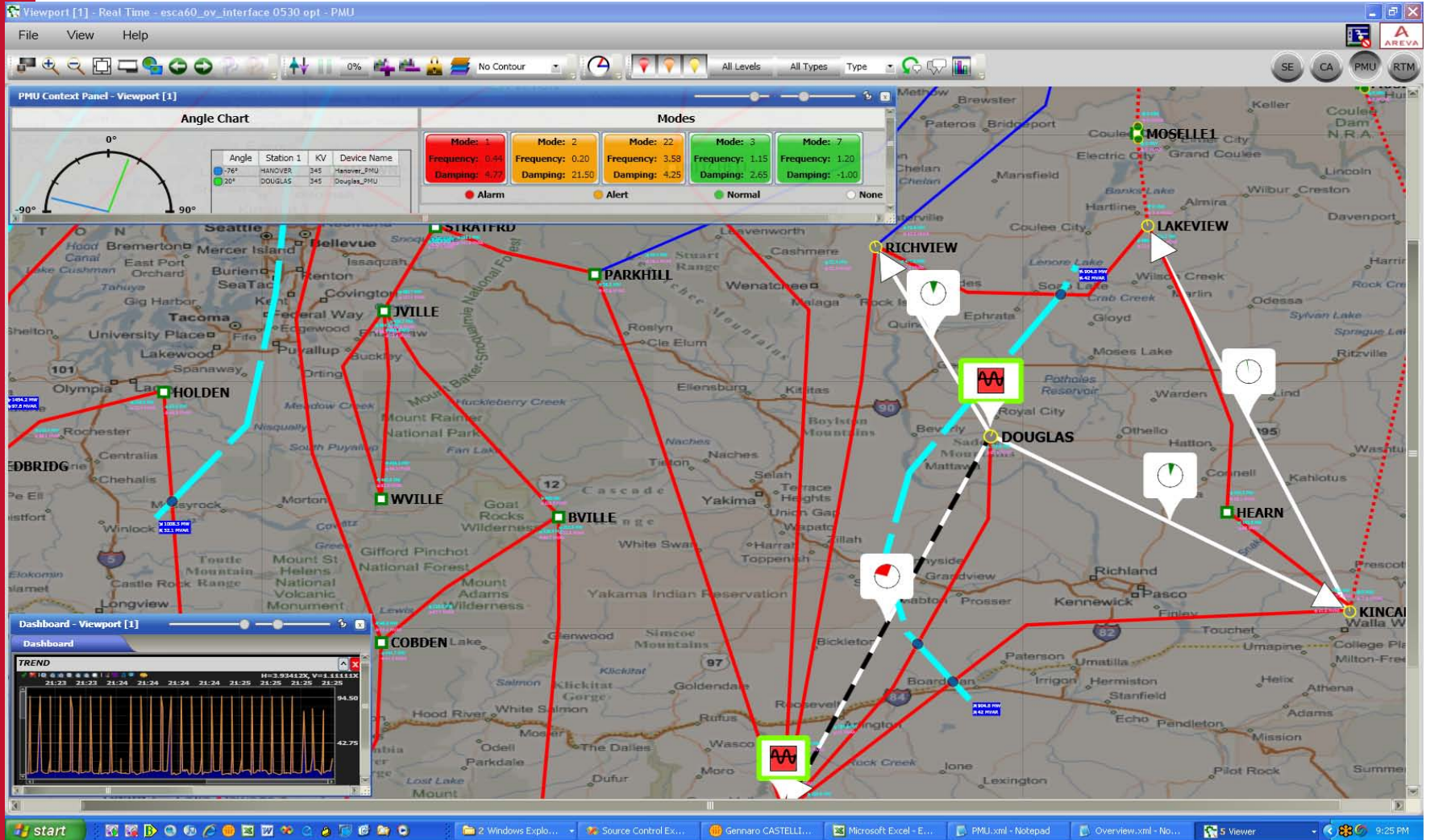
Angle Chart

- 20° DOUGLAS 345 35
- 63° MOSELLE1 14 30
- 114.6° DOUGLAS 14 10

TREND

Time: 15:57 to 16:01
Y-axis: 12.00 to 60.00
X-axis: BRIGHTON_345_1/PARKHILL_345_1: 22.00 | 15.00

Next Phase 3: e-terraVision Extension for Oscillation modes (frequency & damping)



Thank You