

Synchrophasor PMU data analysis for enhanced control center operations

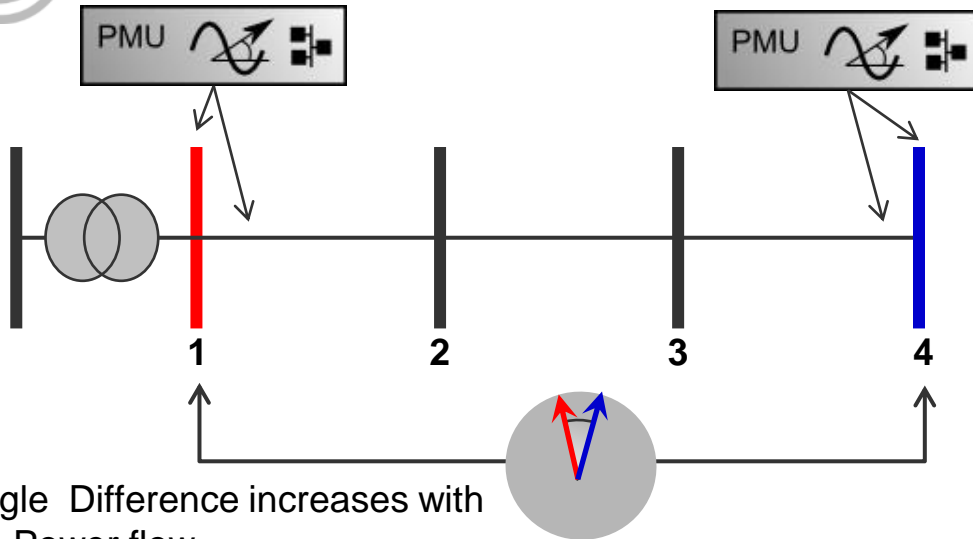
IEEE General Meeting
Smart Grid Panel
Edwin Liu – Chair

July 28th, 2011

Jay Giri

Manu Parashar
Douglas Wilson

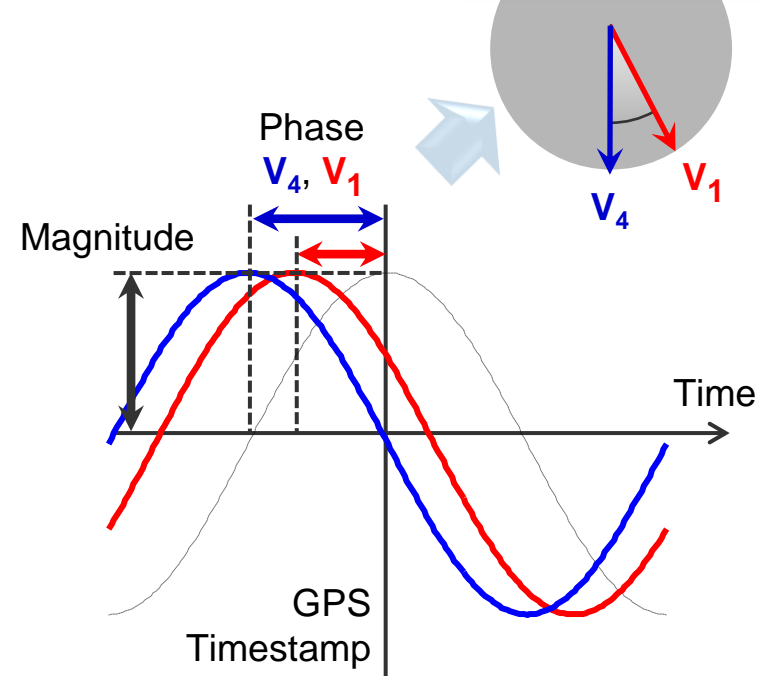
Synchrophasor Measurement



Angle Difference increases with

- Power flow
- Impedance (weakened network)

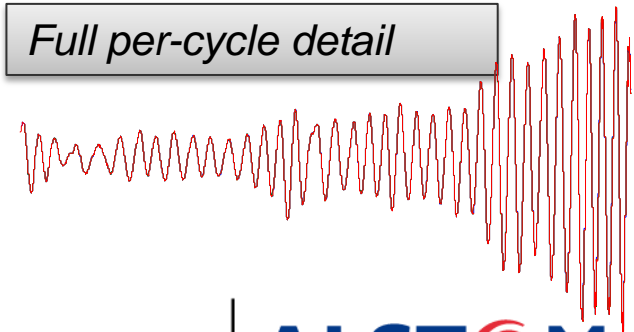
Phasor format



Synchrophasors: Key Features

- ◆ Synchronised V, I & Frq measurements
- ◆ 50/60Hz data captures dynamics
- ◆ 3-phase measurements
- ◆ Real-time streaming

Full per-cycle detail



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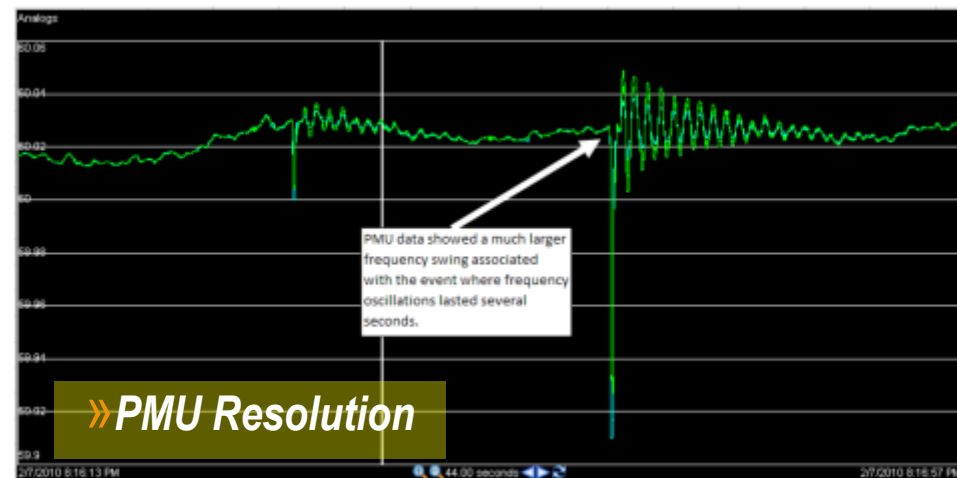
What is SynchroPhasor Technology?



Phasor Measurement Units (PMUs)

- Next generation measurement technology.
(voltages, currents, frequency, frequency rate-of-change, etc)
- Higher resolution scans (e.g. 30 samples/second).
 - *Improved visibility into dynamic grid conditions.*
 - *Early warning detection alerts.*
- Precise GPS time stamping.
 - *Wide-area Situational Awareness.*
 - *Faster Post-Event Analysis.*

“MRI quality (3-D color) visibility of power system, compared to X-ray (2-D b/w) quality visibility of SCADA” – Terry Boston (PJM)



The changing landscape

Synchrophasor measurement devices are being deployed aggressively in the US and globally

- By 2012, will be a five-fold increase in PMUs across US – over 1000 PMUs deployed
- Each PMU provides 10-12 separate sub-second measurements
- Measurements include voltages, currents and frequencies
- Augments traditional 2-4 second SCADA

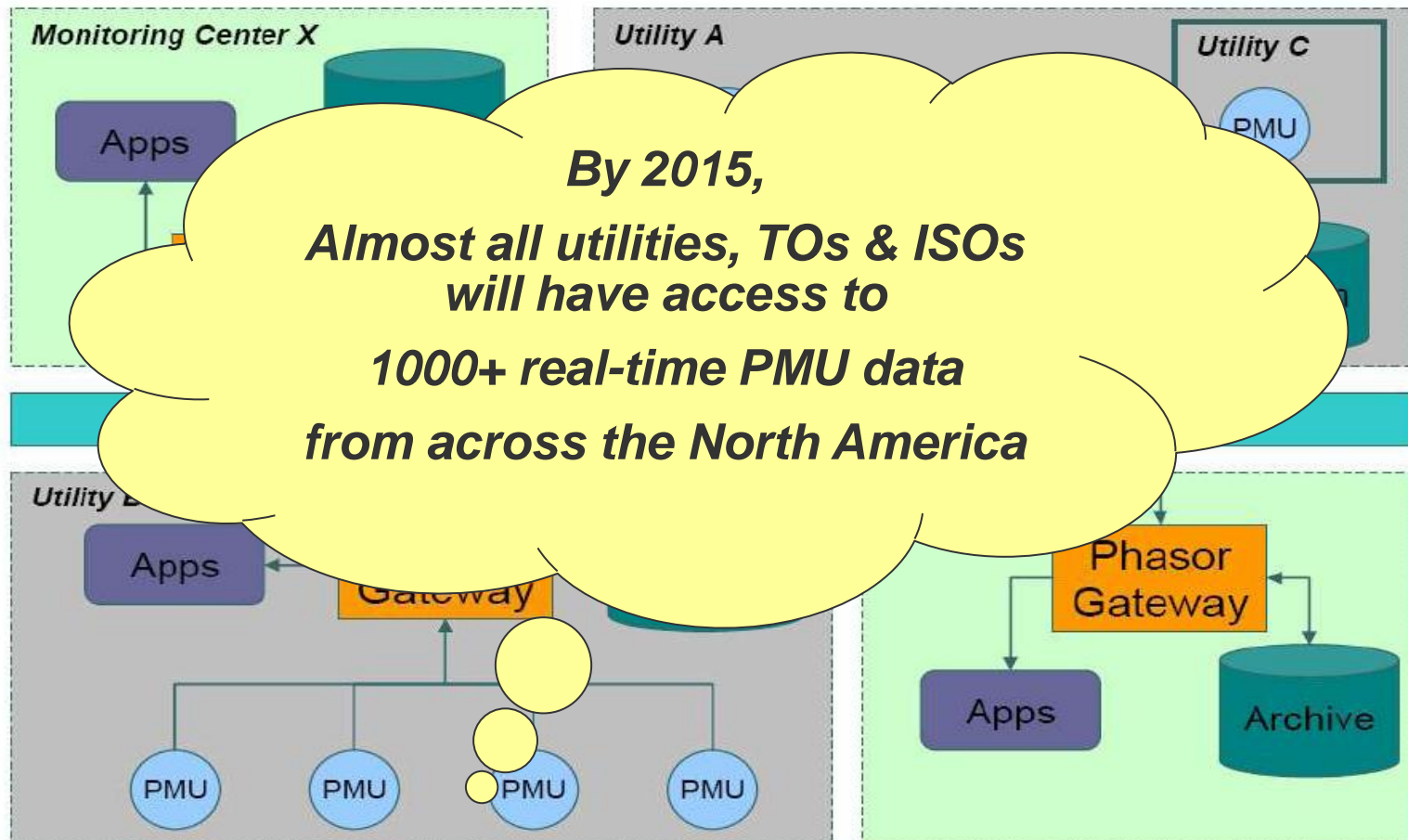
Facilitates wide-area monitoring systems (WAMS) and future wide area control (WAC) - self-healing grid

This is the next SCADA frontier –

“fast, sub-second measurements and fast, automated controls”

NASPInet – Future Vision for North American SynchroPhasor Network

GOAL: Develop an “industry grade” secure, standardized & distributed data communications infrastructure to support SynchroPhasor applications in North America.



Source: NASPI Website (www.naspi.org)

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Phasor Measurements...

Changing Grid Measurements to: higher resolution, more accurate readings.

Benefits:

- More accurate Control Center understanding of the Grid's state
- Faster operator alerts and improved visibility of fast, dynamic grid conditions
- Maximize utilization of congested corridors by operating closer to 'true' operational limits
- Prompt identification of un-damped grid oscillations to prevent outages
- Quick identification of grid disturbance location(s) increasing speed of response
- Quicker post-event re-creation of actual disturbance scenarios

Synchrophasor Impact on Grid Operations

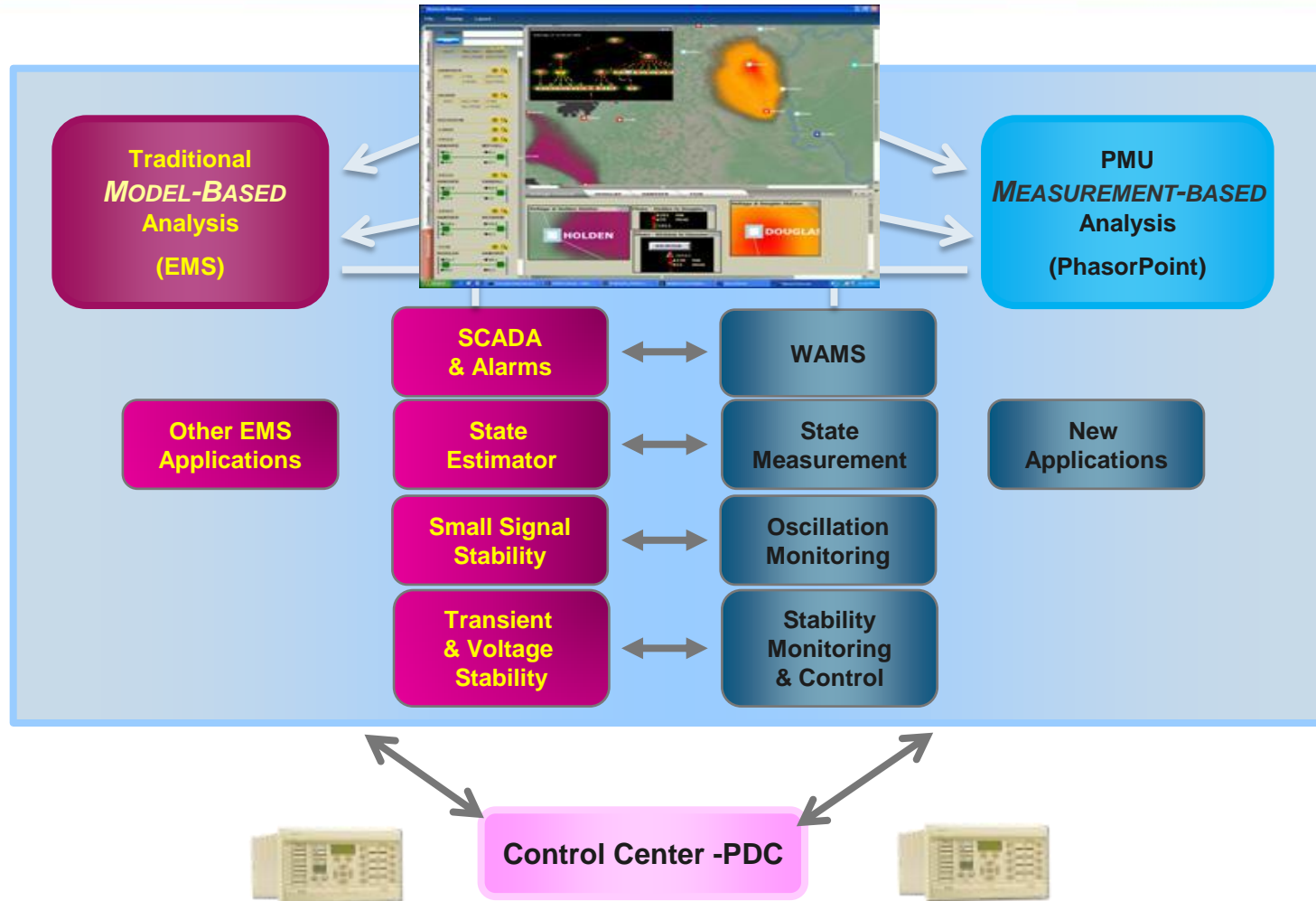
“An Unprecedented Transformational Change

to help operate the grid

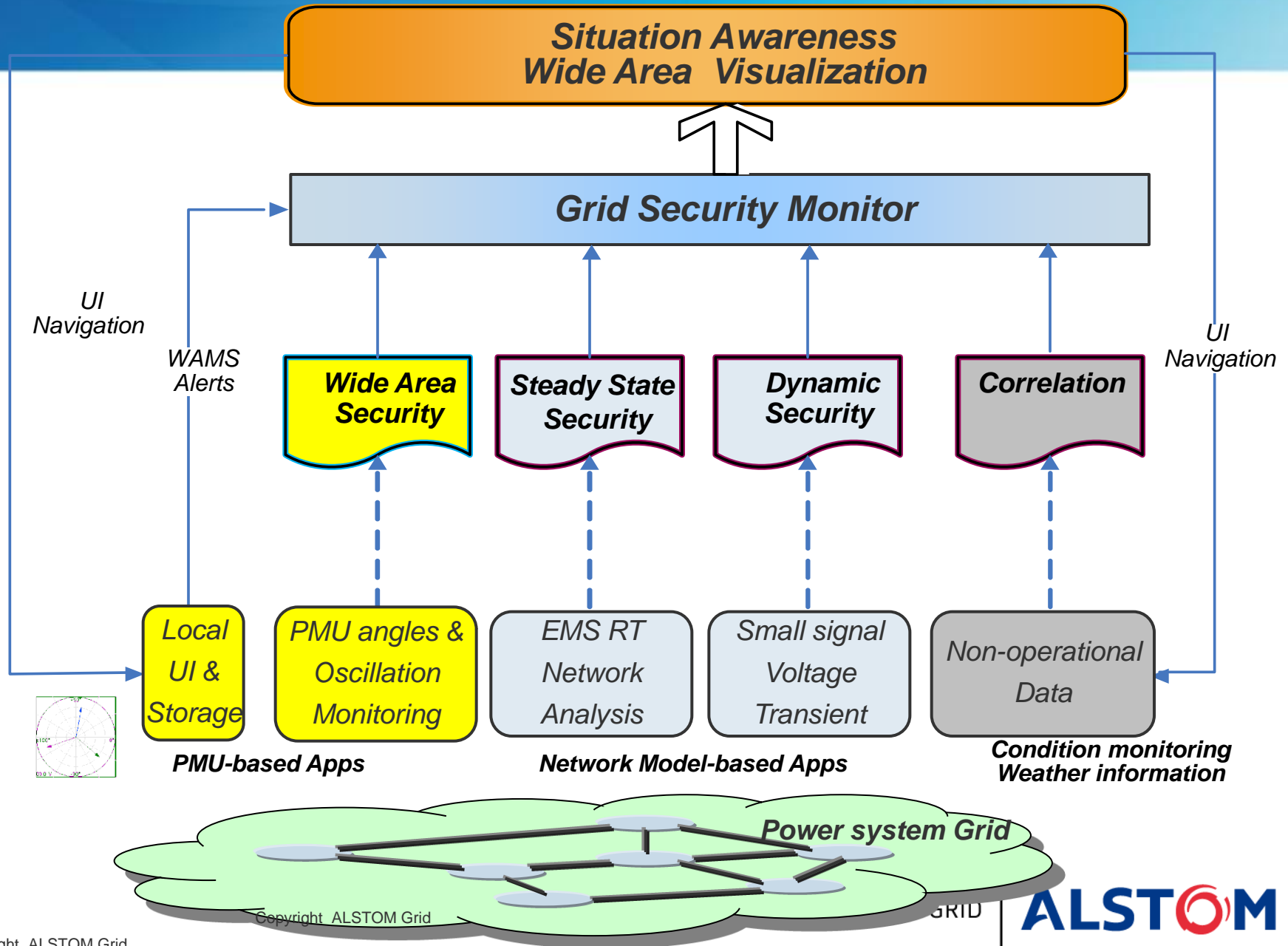
More efficiently, reliably and

to facilitate integration of Green energy resources”

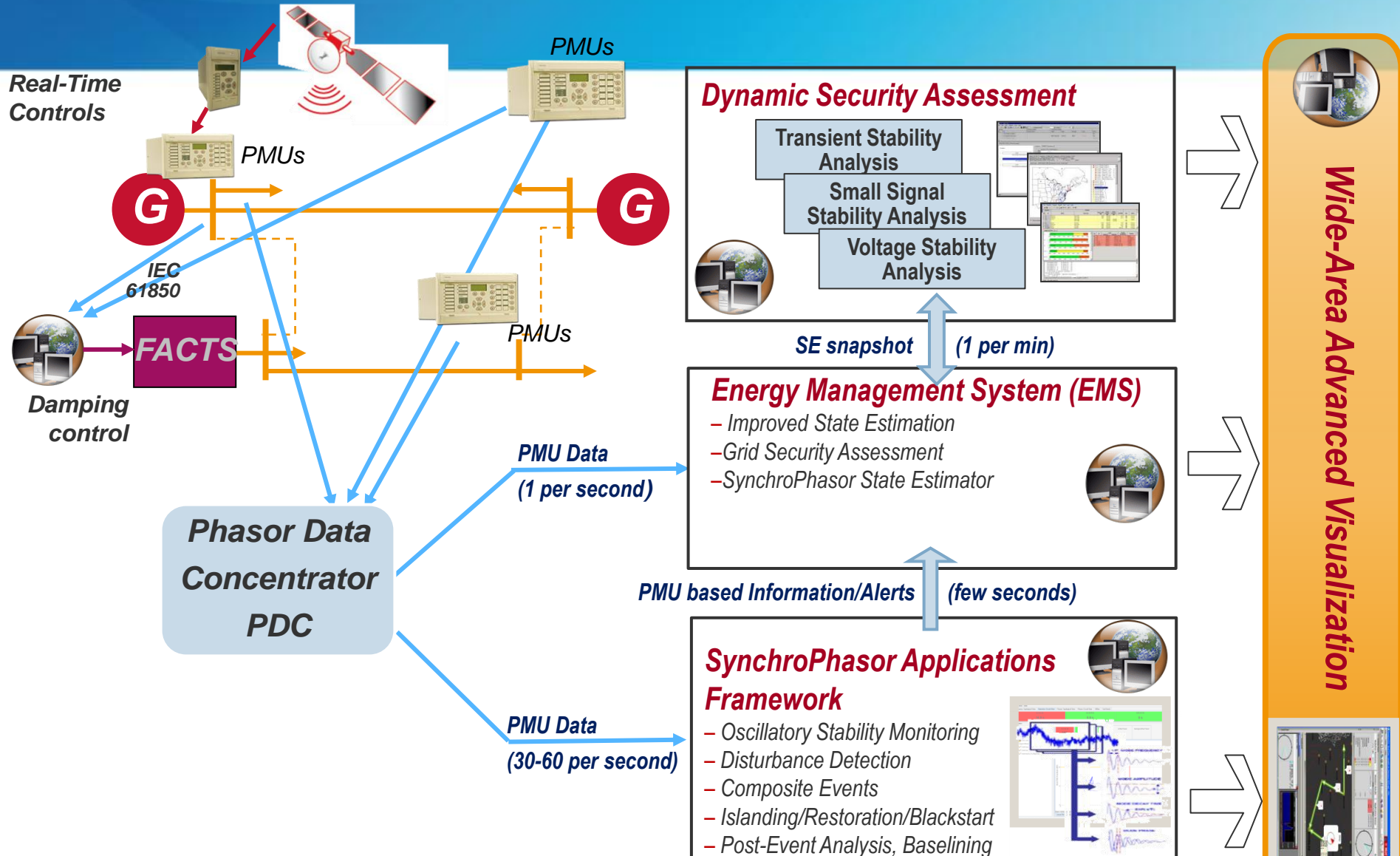
Holistic Generalized Grid Security Analysis



Wide Area Situational Awareness - WASA

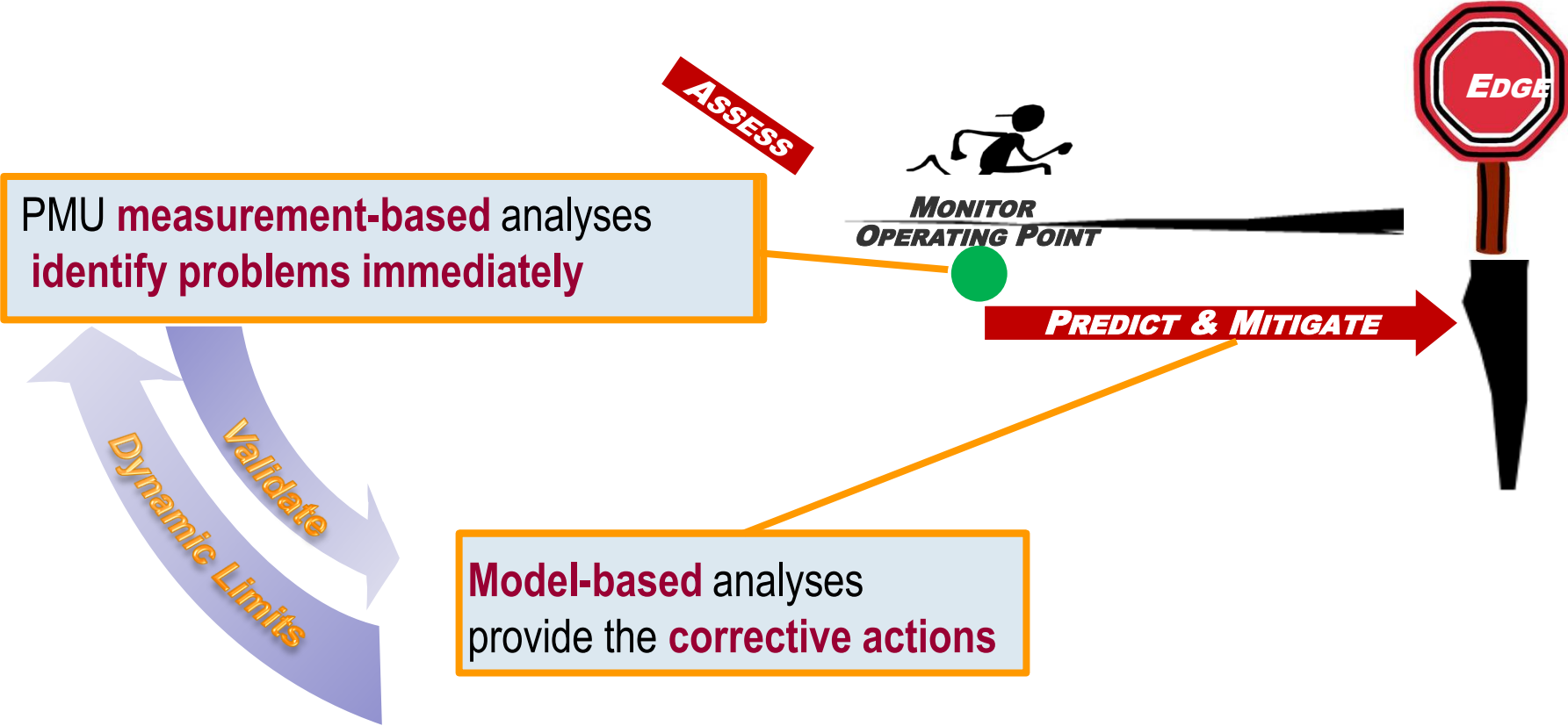


EMS Integrated with SynchroPhasor Solutions



Online Stability Solutions

Integrated measurement-based and model-based stability



ALSTOM Solutions

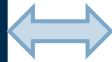
GRID | **ALSTOM**



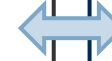
PMU Measurement-based Analyses

PhasorPoint :

Synchrophasor Framework
Synchrophasor Applications



EMS
Applications



Powertech 

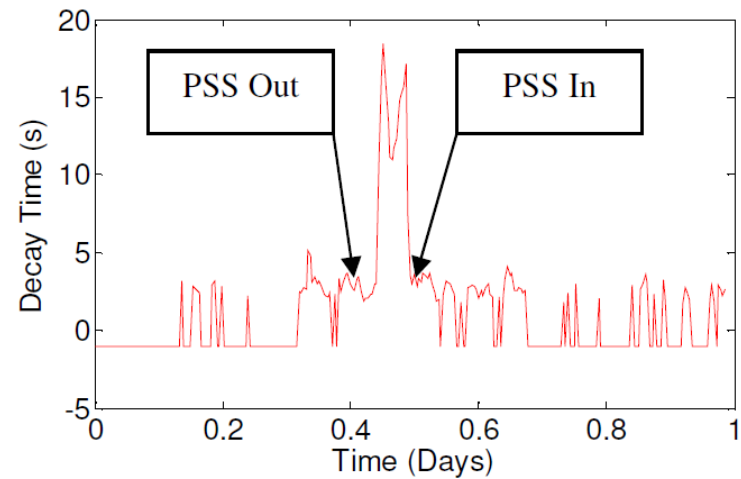
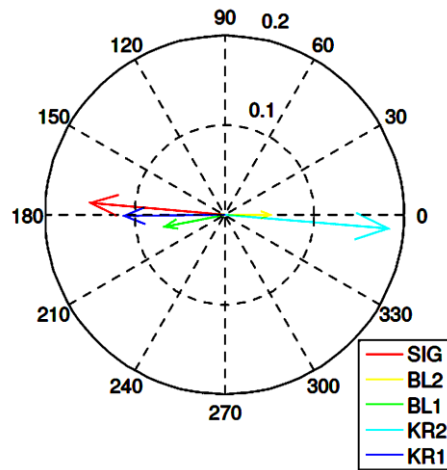
Model-based dynamic analyses:

- Voltage Stability Analysis (VSAT)
- Small Signal Stability Analysis (SSAT)
- Transient Stability Analysis (TSAT)

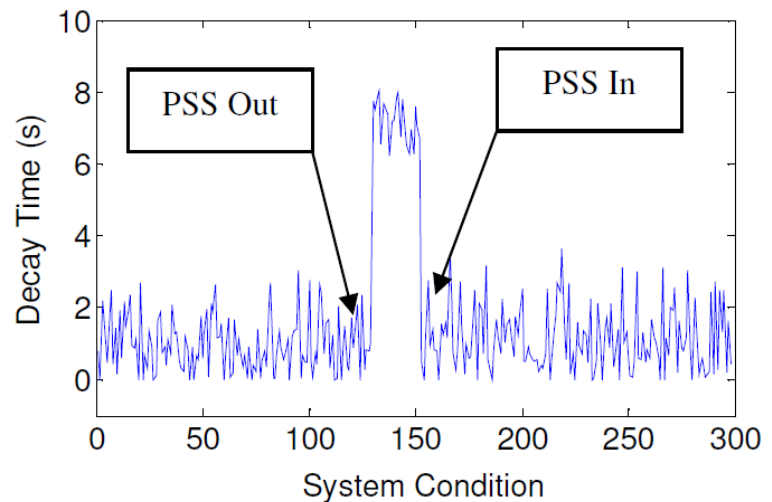
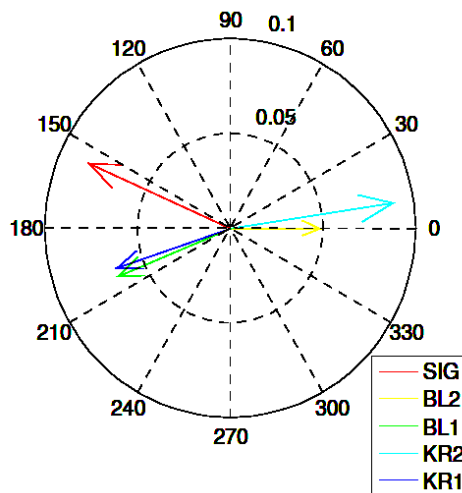
Combined Measurement- & Model-based Approach for Model Validation

0.6Hz mode record including PSS test

Measured



Modelled



Why PMU-based analysis?

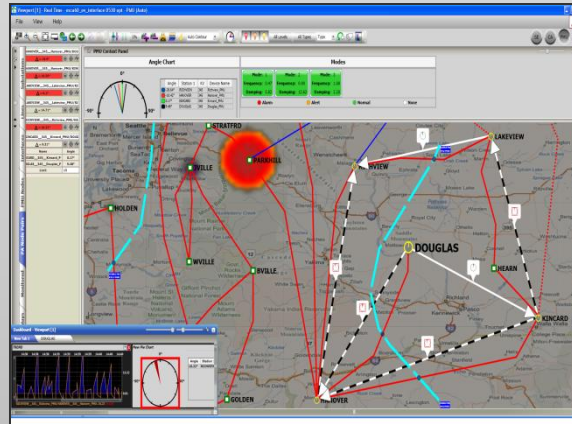
Improve Security

- EARLY WARNING OF INSTABILITY
- SITUATIONAL AWARENESS
- ISLANDING RECOVERY
- BLACKSTART
- SELF-HEALING GRID



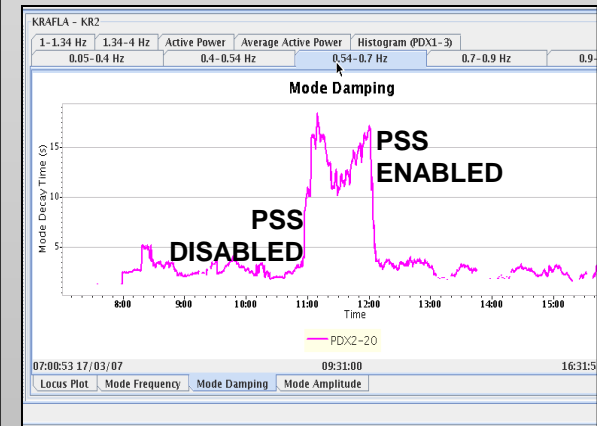
Increase Transfer

- RELIEVE DAMPING CONSTRAINTS
- STATE ESTIMATION & CONTINGENCY ANALYSIS
- IDENTIFY LINE PARAMETERS



System Analysis

- PSS TUNING
- PLANT COMMISSIONING
- POST-EVENT ANALYSIS
- IMPACT OF RENEWABLES
- IDENTIFY DYNAMICS ISSUES



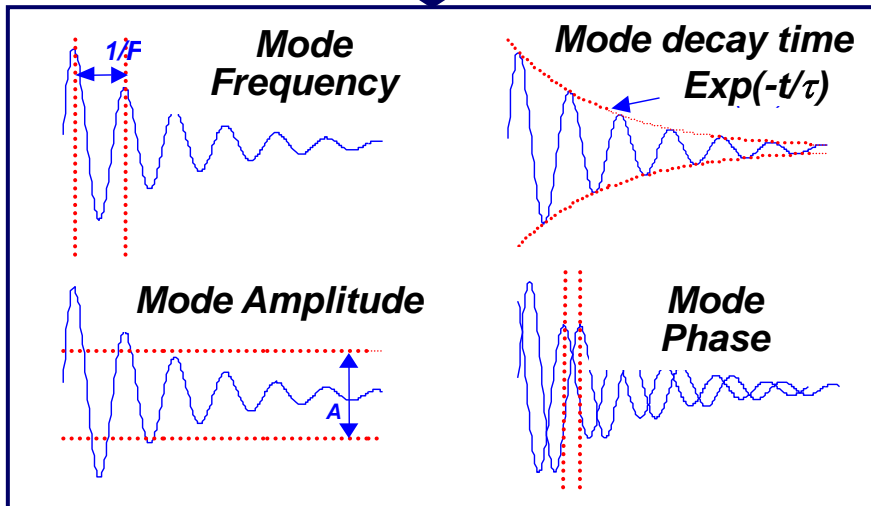
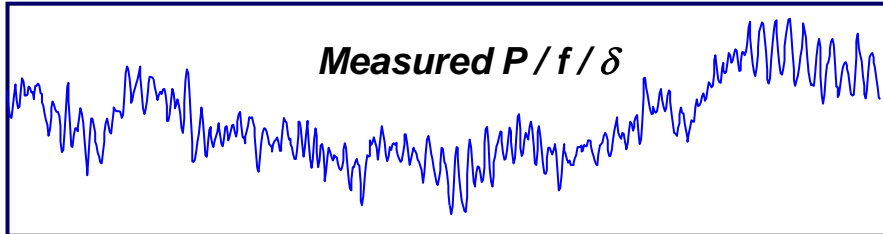
Synchrophasor Applications Framework and Products



Products	Main Features / Options	Delivery
Server	Central PDC (optional) Historian Standard Applications Advanced Applications Integration	Software
Regional PDC	Local Archive (supports automatic data gap filling)	Software
Substation PDC	Local Archive (supports automatic data gap filling)	Firmware & Software
Controller	Protection/Control Applications	Firmware & Software

Oscillatory Stability Management

Simultaneous multi-oscillation detection and characterisation direct from measurements



Fast Modal Analysis: Alarms

Trend Modal Analysis: Analysis

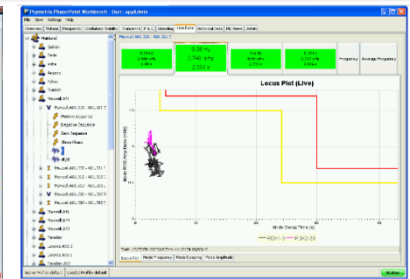
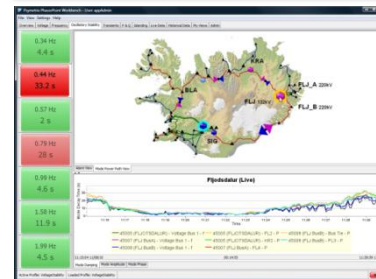
Operations

Early warning of poor damping (2 level alarms)

Unlimited oscillation frequency sub-bands

Individual alarm profiles for each sub-band

**For each oscillation detected, alarm on:
mode damping and/or
mode amplitude for**



Planning & Analysis, Plant Performance

Post-event analysis

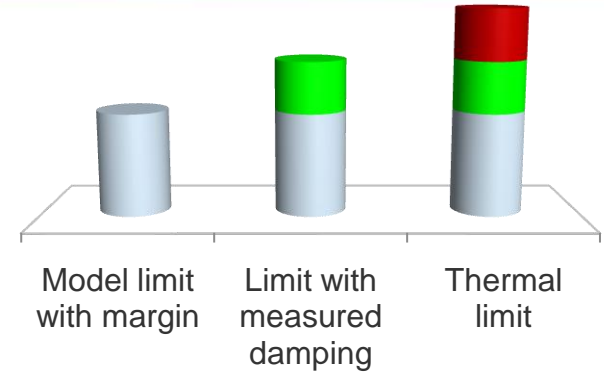
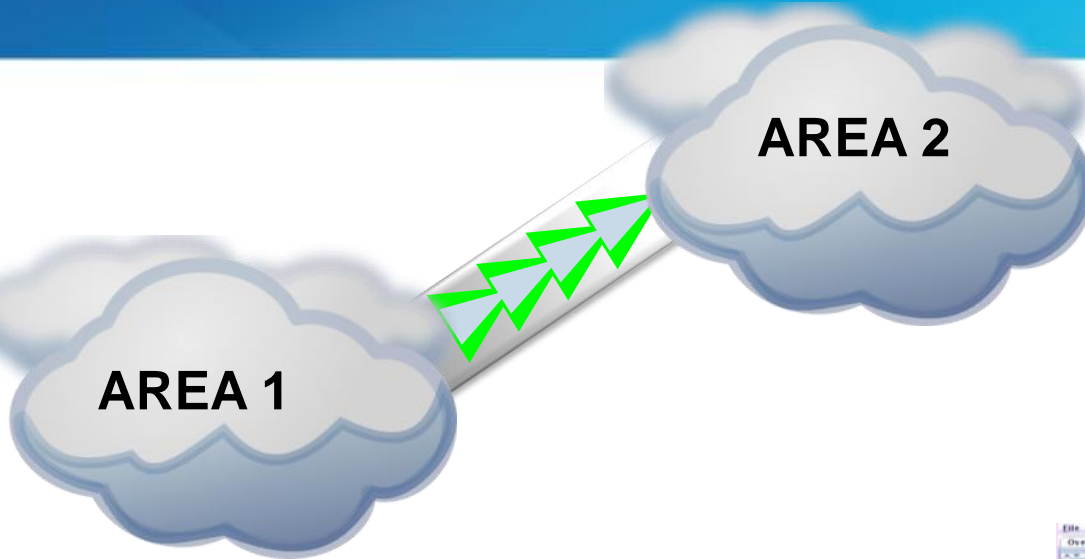
Dynamic performance baselining

Dynamic model validation

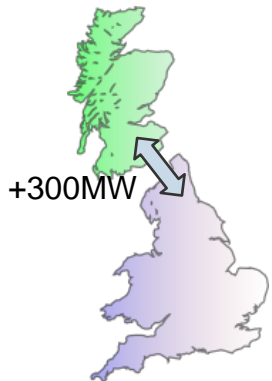
Damping controller performance assessment

Congestion Relief

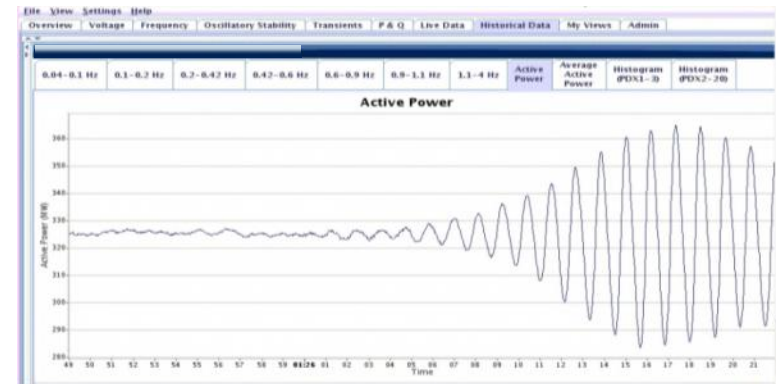
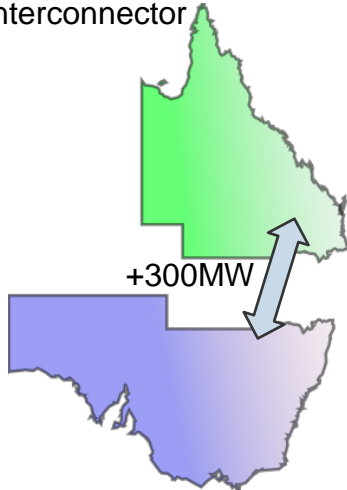
Transmission Corridor Net Transfer Capacity



Great Britain
Scotland – England
Interconnector



Australia
Queensland – NSW
Interconnector



Damping Measurement for Real-Time Constraints

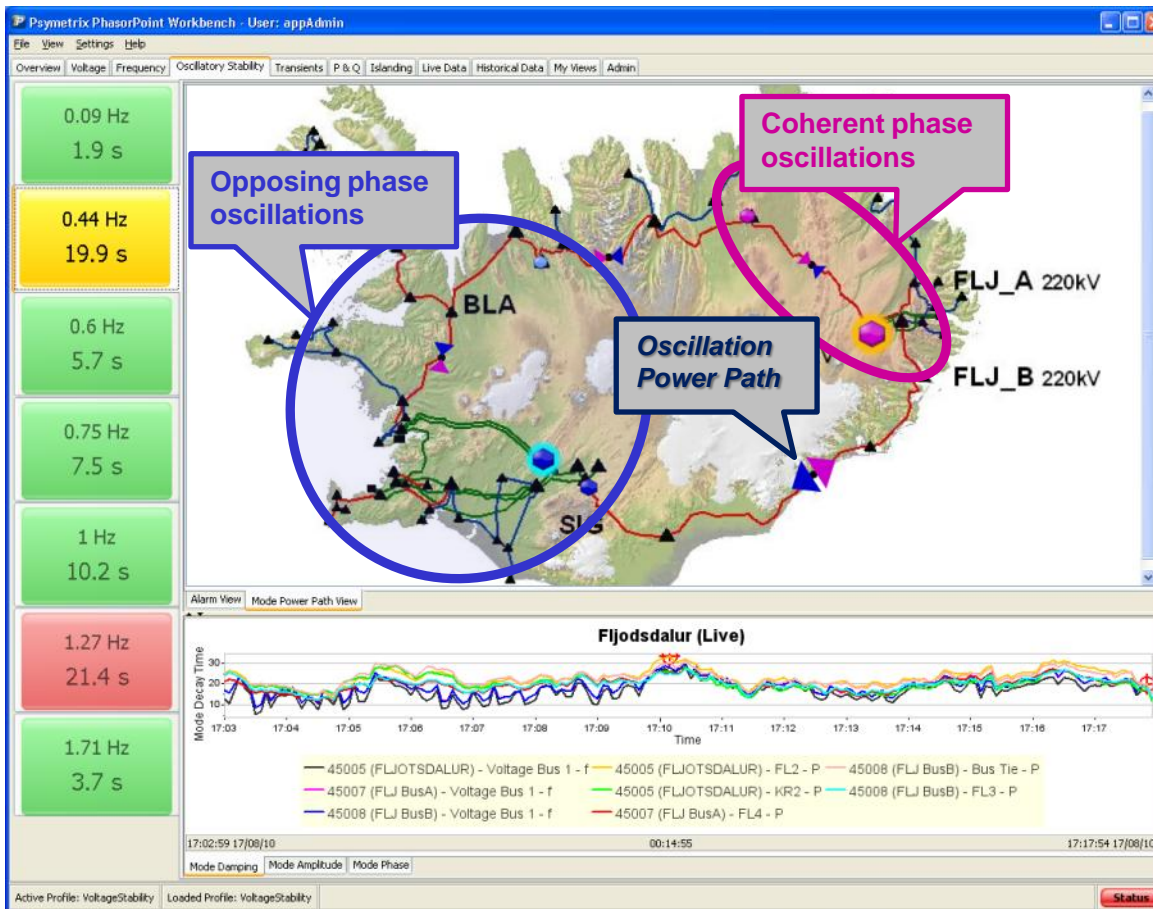
- Modelling uncertainty requires large margin
- Use margin as long as observed damping is good
- Reduce transfer if poor inter-area mode damping occurs

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Improved Reliability: Operator Guidance

Oscillation observability is not sufficient for taking corrective action – you need to know what is contributing to the oscillation's power flow across the grid



Identify sources of oscillation problems

Choose remedial action

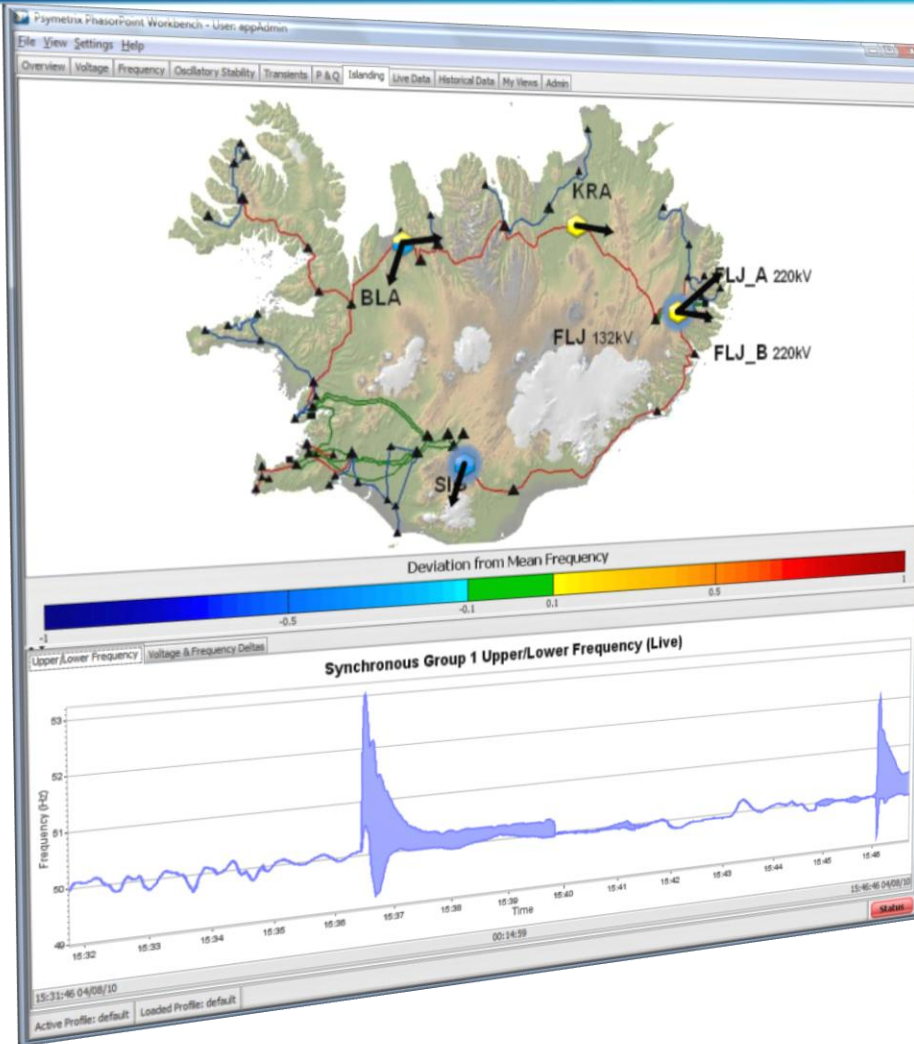
Define longer term performance improvements

Identify contributions to oscillations from regions

“Regions” can be any size

All region boundaries monitored

Islanding, Resynchronisation & Blackstart



Identify islanding quickly

Alarm raised

Islands clearly visualised

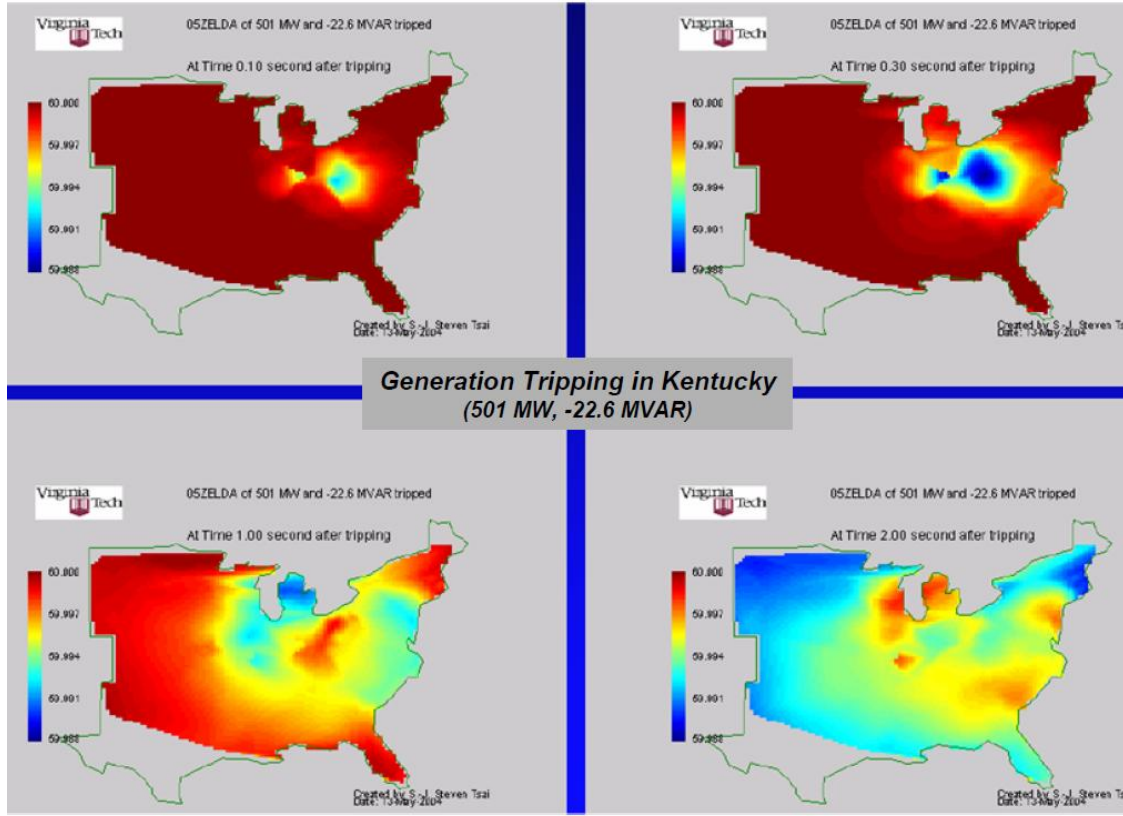
Keep customers connected

Reduce time to resynchronise

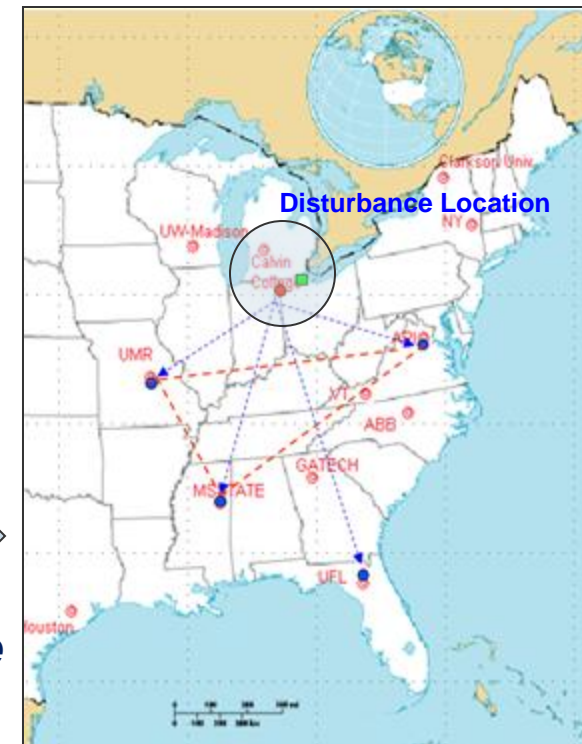
Improve system visibility in blackstart

Disturbance Location

A sudden disturbance causes a traveling wave that can be detected by PMU data across the grid:



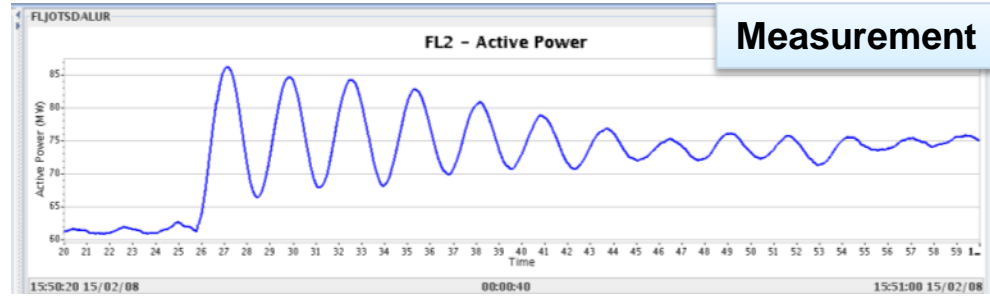
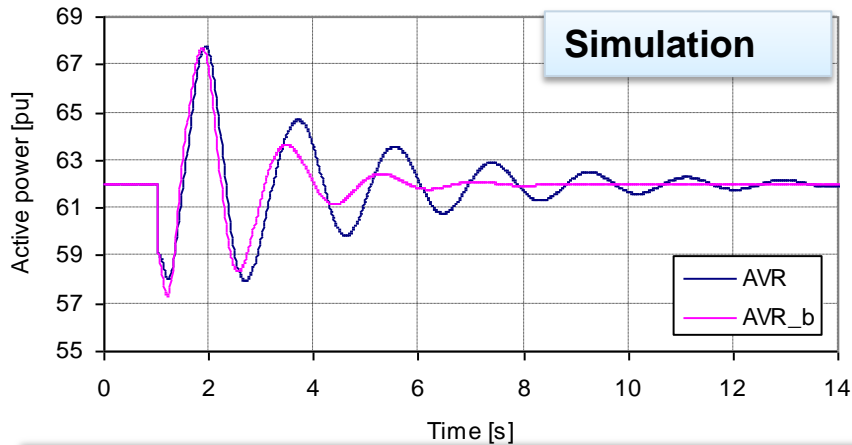
Source: VirginiaTech FNET



Use PMUs and SCADA data to triangulate & precisely locate the origin of the disturbance

Model Validation

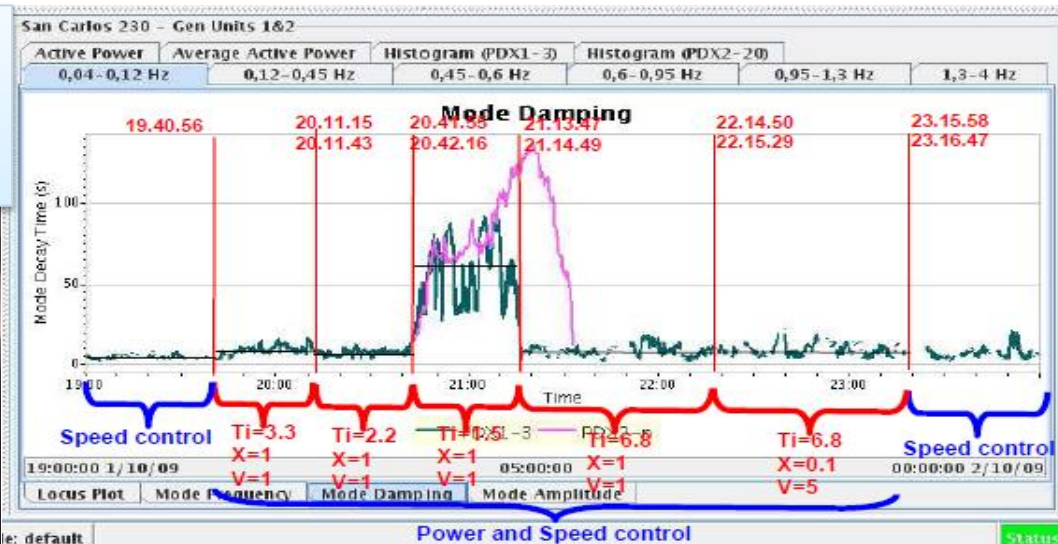
AVR/PSS Model Parameter Identification & Sensitivity



Simulated & Measured Response: Time & frequency domain comparison of expected & measured response

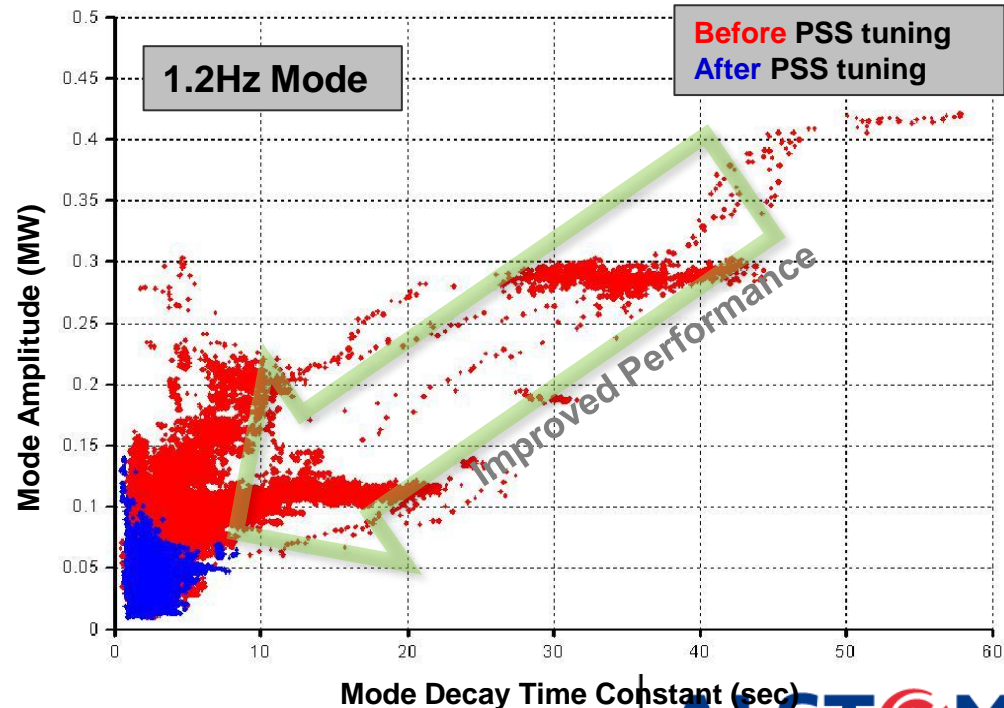
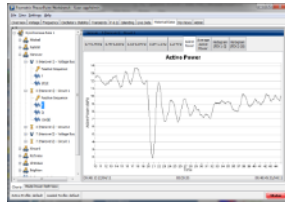
Mode Sensitivity to Governor Parameters

Governor controller tests:
Sensitivity of mode damping / amplitude to governor parameter changes



AVR, PSS and Governor Tuning

Real-time on-line and off-line tools that de-risk, simplify and speed-up the tuning process



Oscillatory Stability Management:

- Wide area real-time damping visualisation and alarms
- Dynamics baselining & trending
- Wide area event analysis

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Wide-Area Composite Alarms

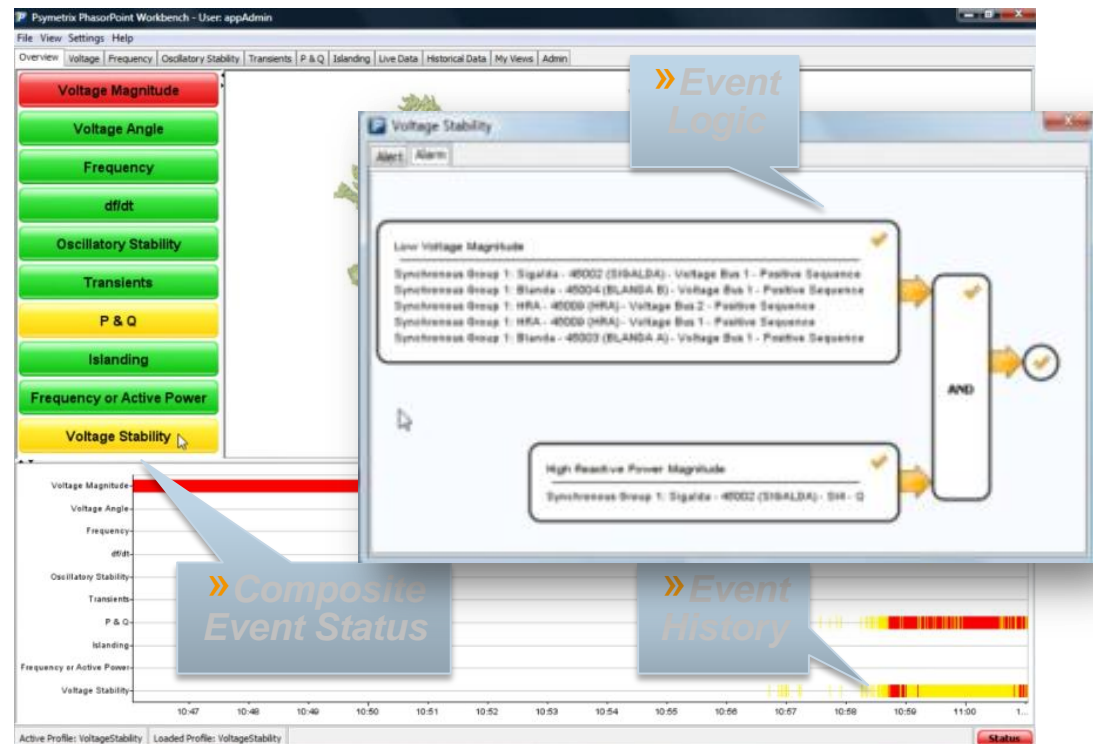
Grid Alarms

- Synchronised data → *synchronised alarms*
- Logical combinations → *wide-area alarms*
- Flexible logic combine alarms to notify *significant threats*
- Applicable to voltage stability alarms

Example: Voltage Instability

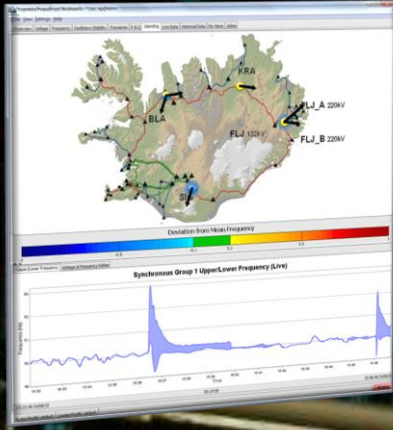
**IF (ANY Sustained voltage slide
OR N+ low voltage detections)**

AND ANY High Q flow



Control Center Deployments

Clear, Actionable Information



Real-time dynamics monitoring in control rooms since 1997

- Transfer constraint updates
- System separations avoided
- Identified and sustained island operation



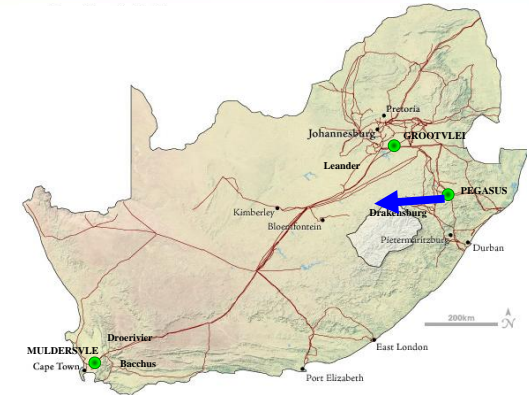
Eskom, South Africa - 2009

Local Modes (various)

Pilot project complete, next stage 4200 phasor system

Key features

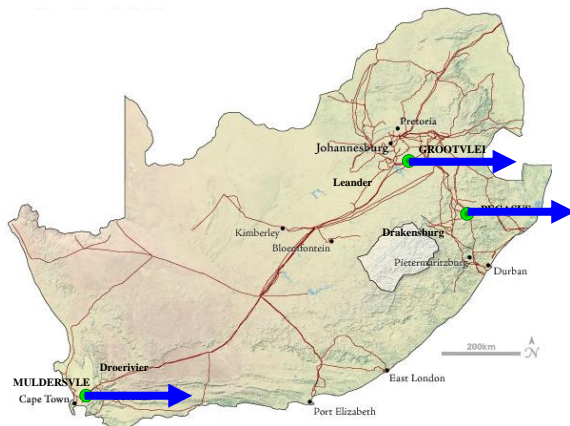
- Flexible user configurable displays (e.g. wallboard)
- Flexible alarms (level, ROC, composite) & notification (via EMS)
- Oscillatory stability
- Disturbance capture & analysis
- High availability



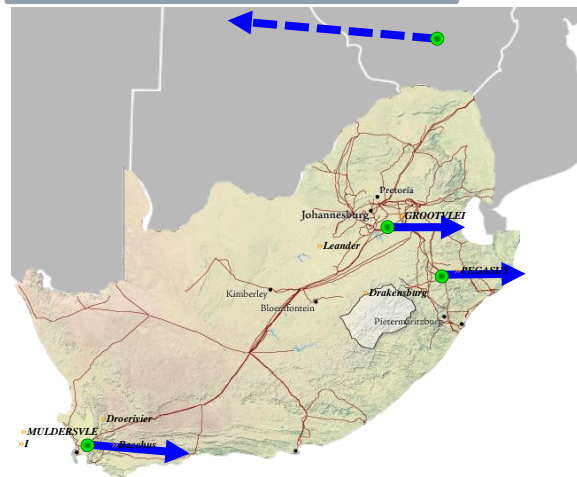
Exploring new application areas e.g.

- Constraining by angle

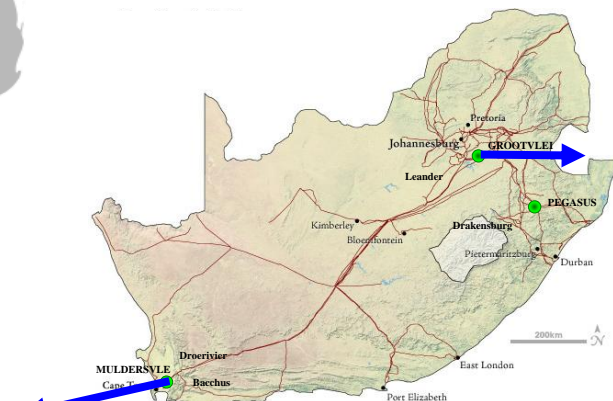
0.05Hz Common Mode



0.3Hz SAPP Mode



0.7Hz Interarea Mode



Landsnet, Iceland 2007

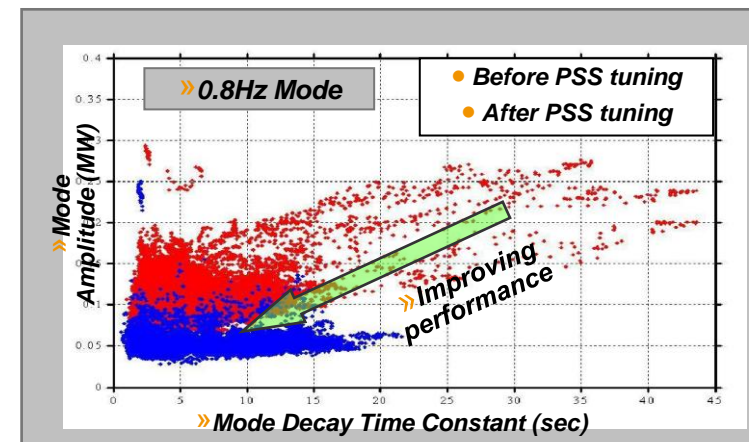
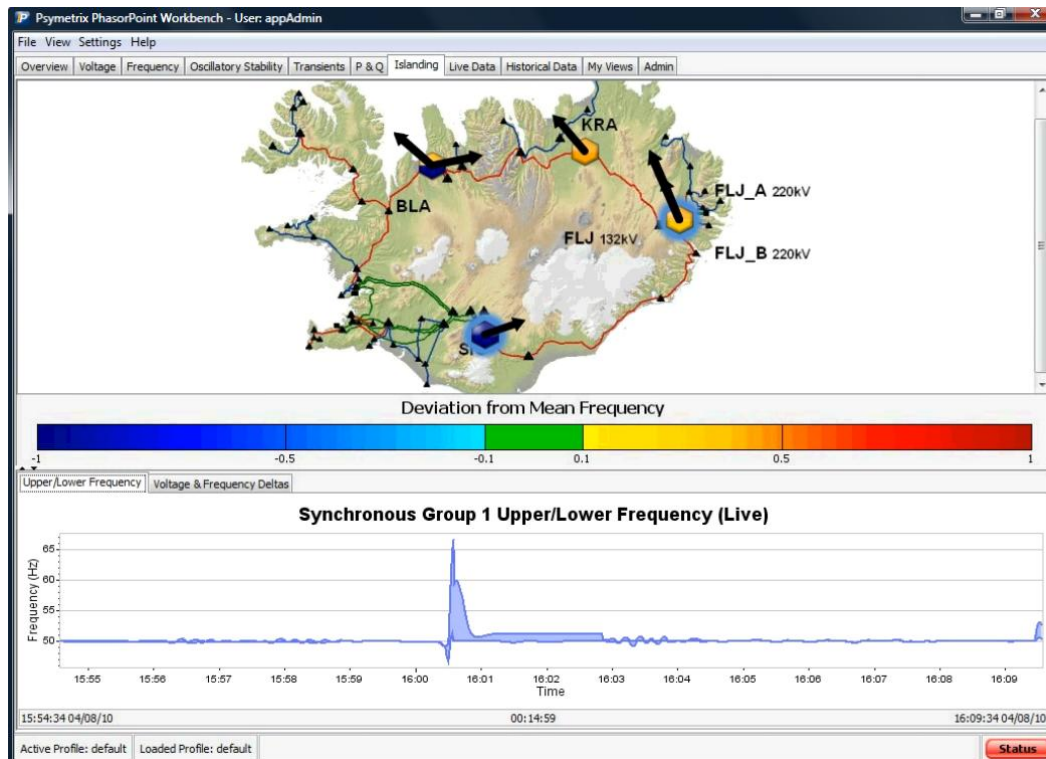
Oscillations & PSS Tuning

Governor stability

Disturbance analysis

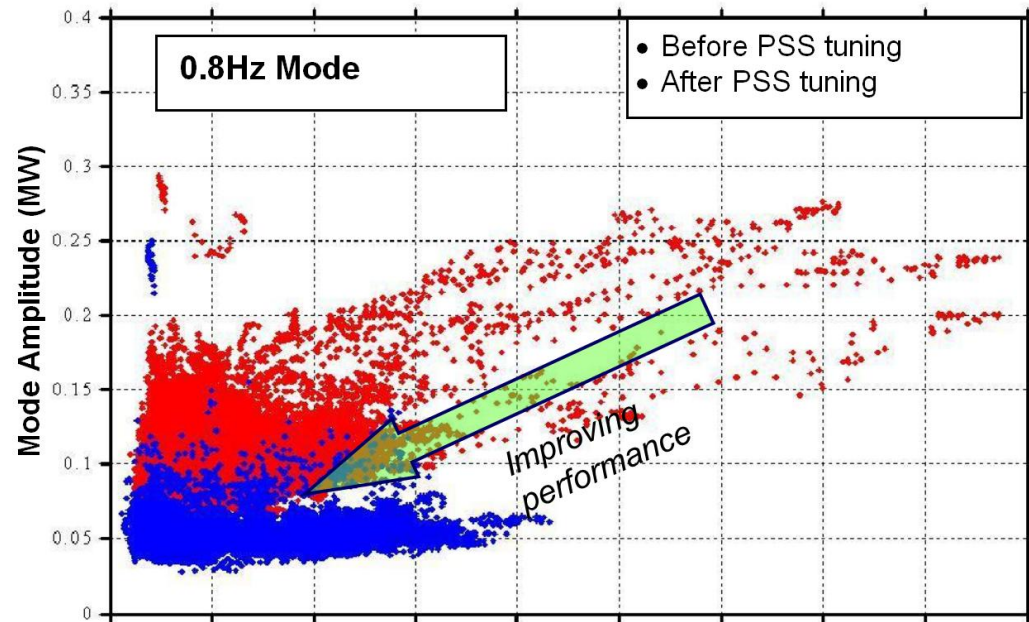
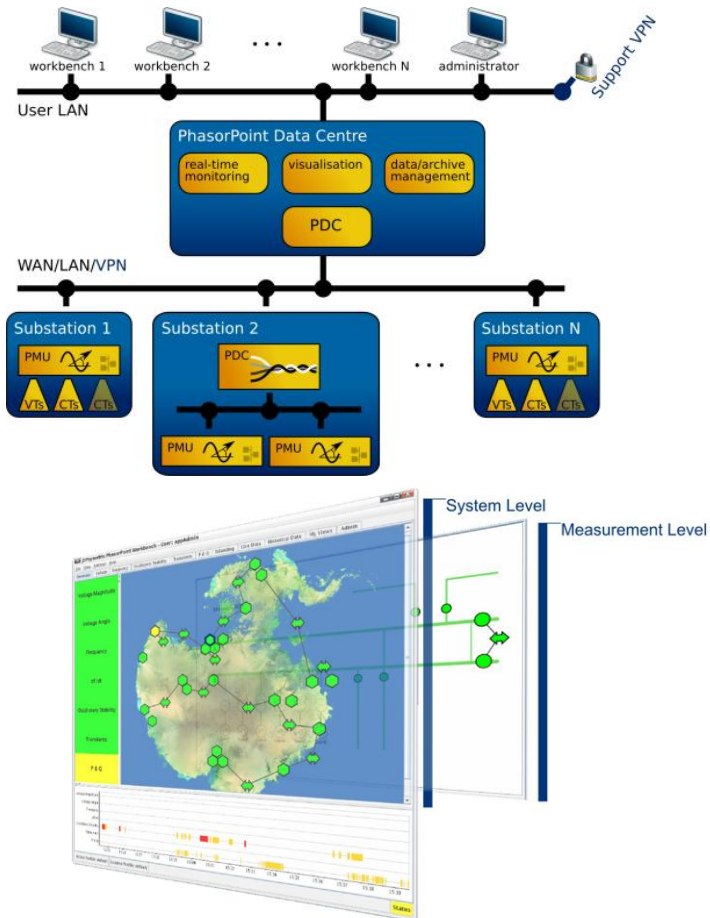
Islanding & Resynchronisation

Planned - Wide Area Defence

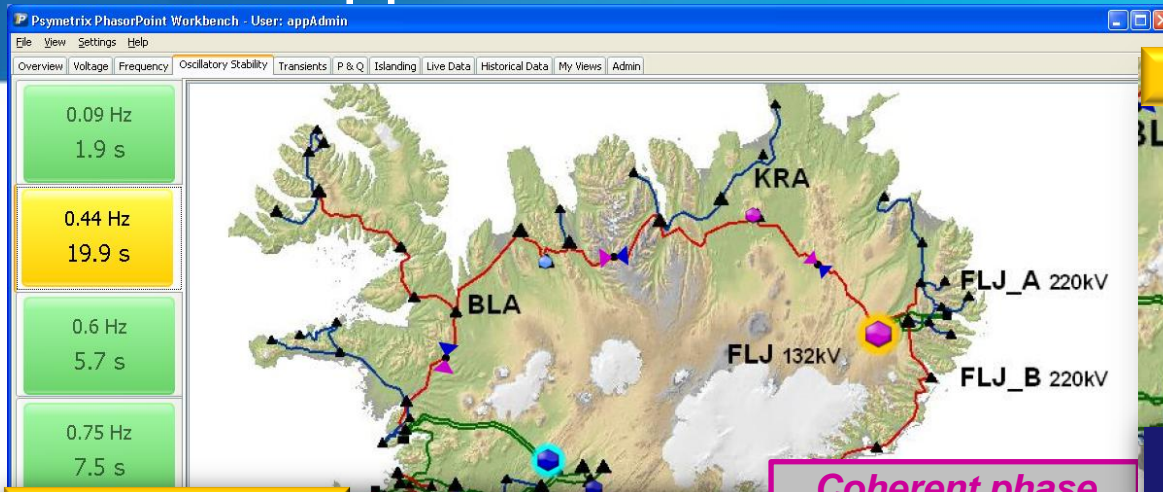


Iceland - 2007

PSS Tuning & Dynamic Model Validation



MPP Application in Iceland

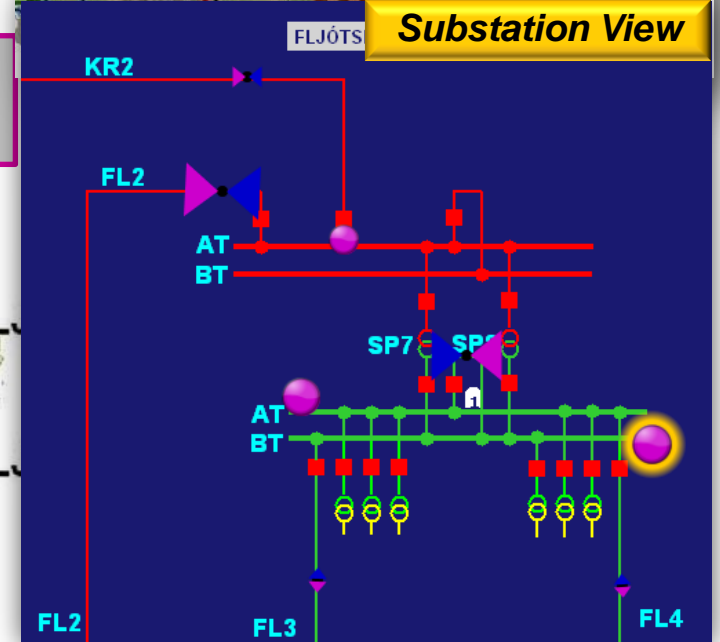
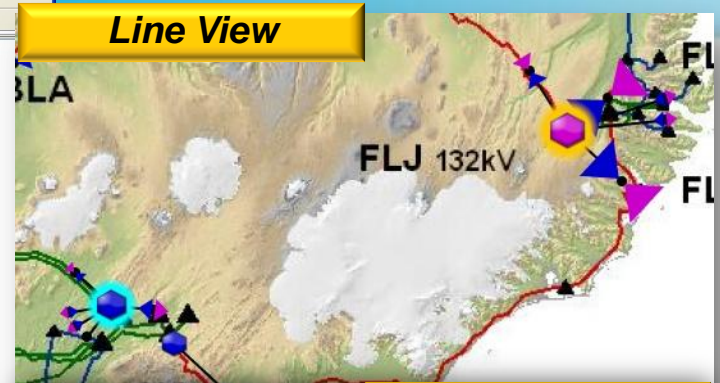


Regional View

Opposing phase oscillations

Coherent phase oscillations

Oscillation Power Path



XM, Colombia - 2009

Identifying & resolving frequency instability

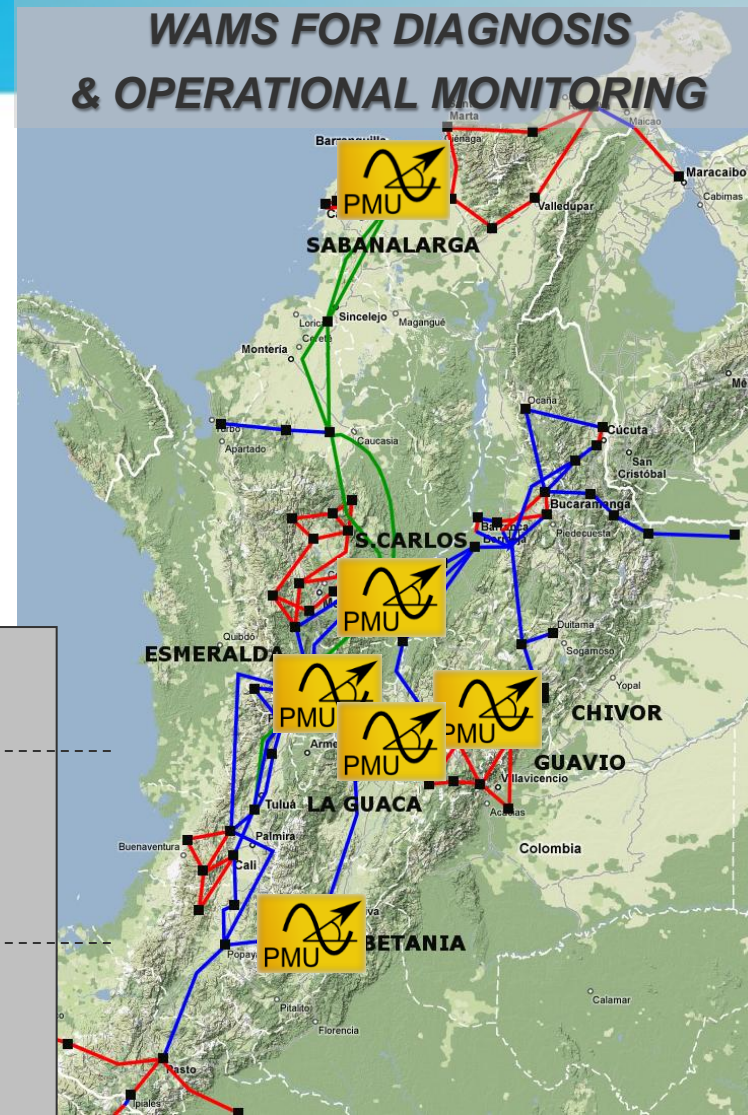
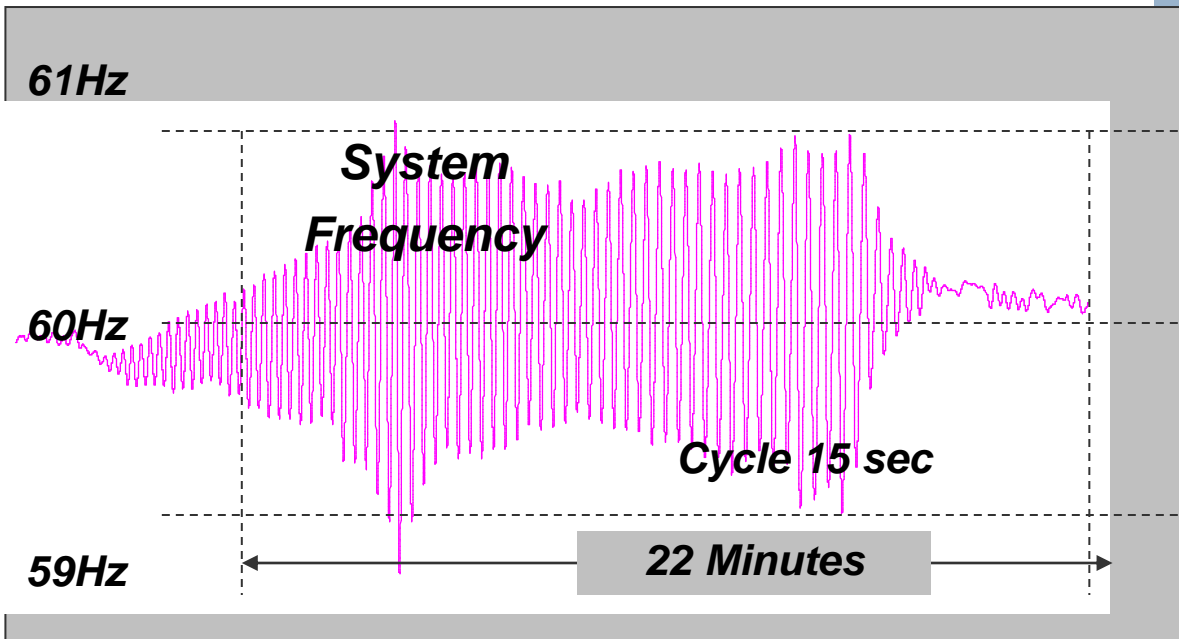
Governor testing & tuning

Islanding, Resynchronisation & Blackstart

Control room warning/response

Planned

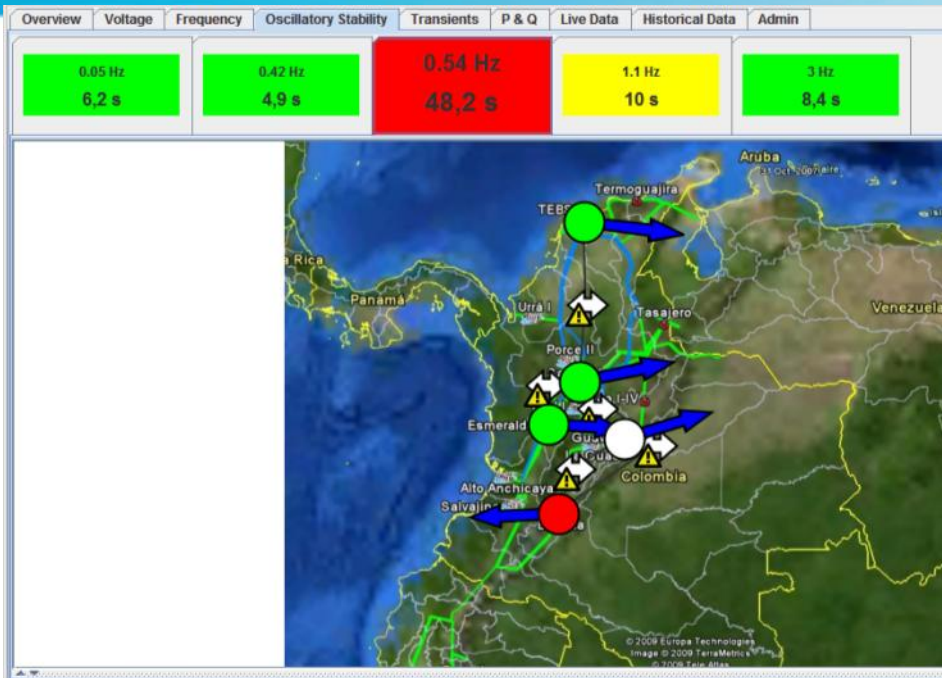
- Generator Modelling & Test tools
- Wide Area Defence Scheme



XM Colombia - 2009

Modes Observed in Colombia (Inter-Area and Common-mode)

*Inter-area mode at 0.49Hz
(Colombia-Ecuador).
Opposing phase in South*

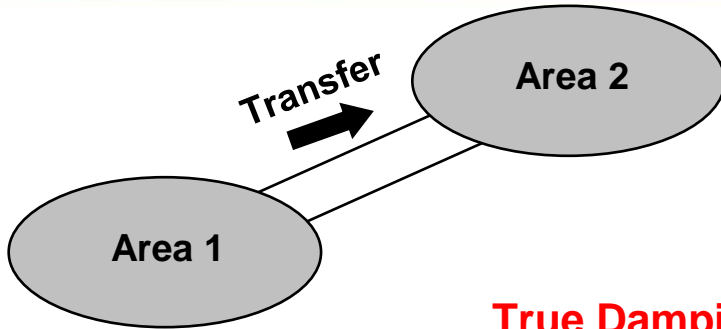


*Governor common-mode:
whole system oscillates in
coherent phase*

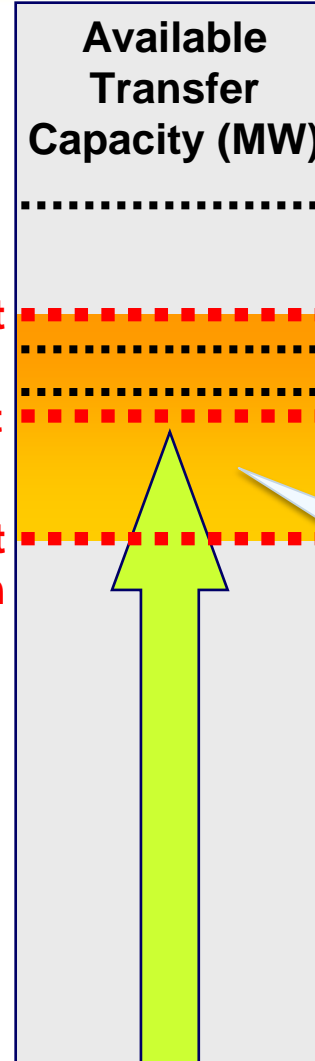
Powerlink Australia - 2000

Transfer Constraint Relief

**Applied in
Australia & UK
+300MW**



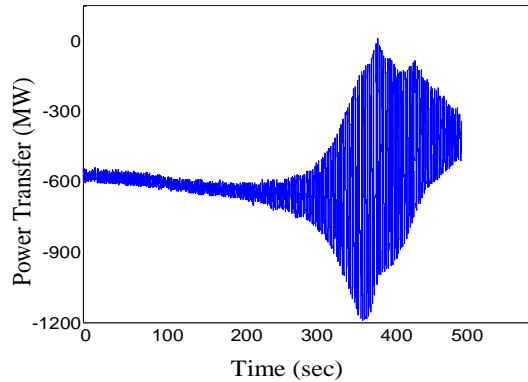
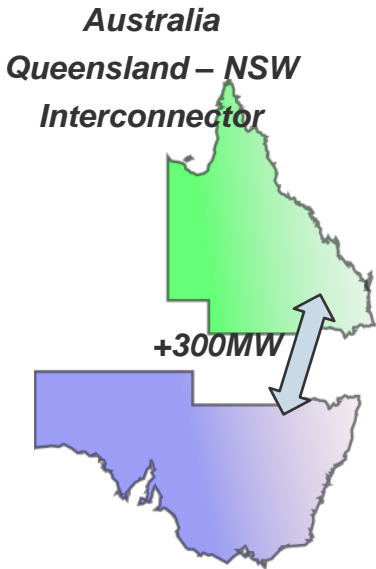
True Damping Limit
Model Damping Limit
Model Damping Limit with Margin



Thermal Limit

Transient / Voltage
Stability Limits

**Capacity available
provided measured
damping is acceptable**

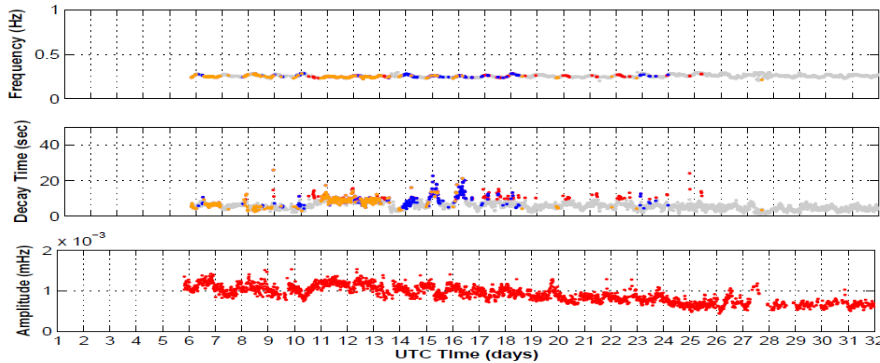


Baselining for Assessment and Issue identification

Assessment: Dynamic Performance Reporting

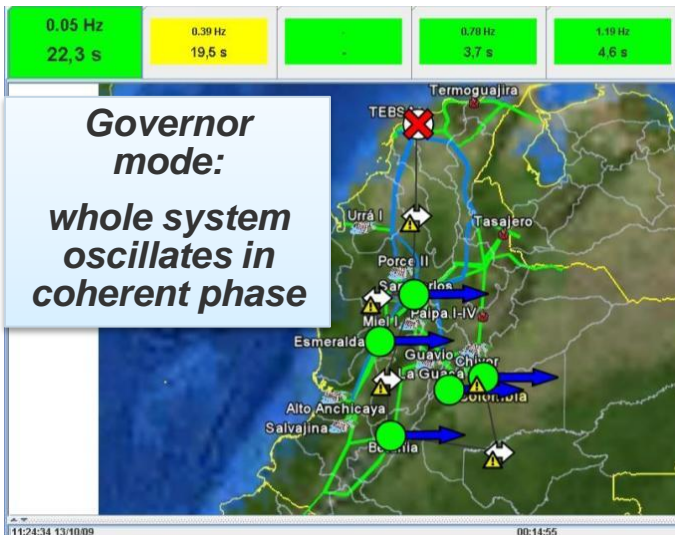
Oscillatory Stability

Mode Behaviour, Band 3 (0.20-0.30 Hz)

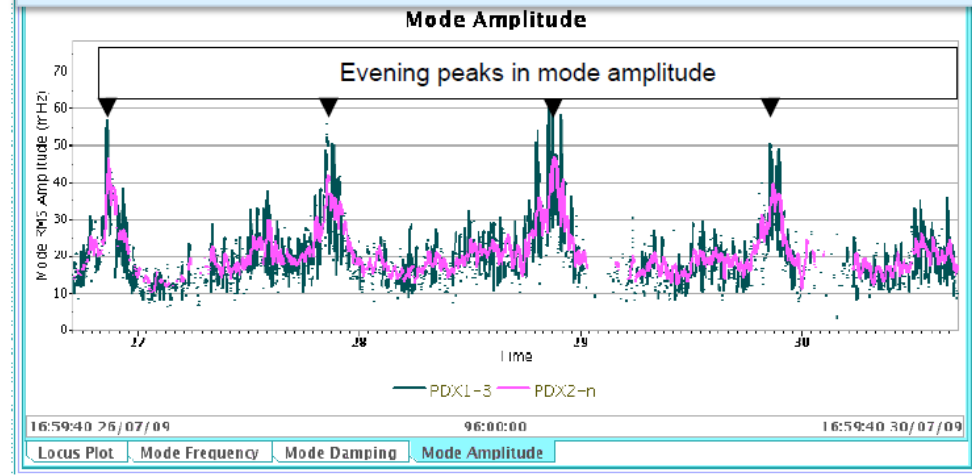


Baselining:
Monthly reports identify normal & unusual oscillation behavior and patterns.

Issue Identification: Governor Stability



Characteristic behaviour pattern



Reporting, Alarm Configuration, Operator Guidance

Reporting

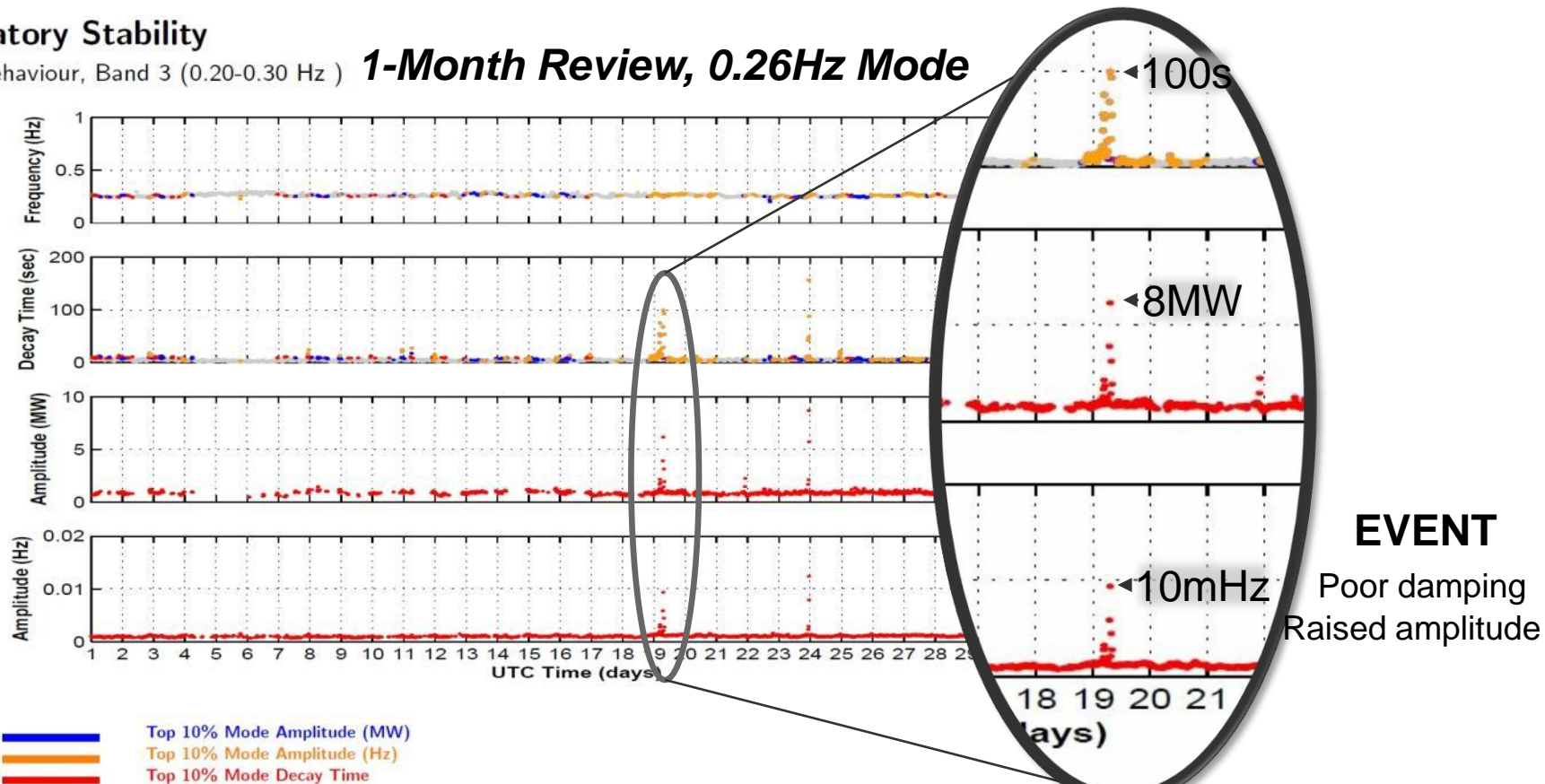
- Monthly dynamics reporting
- Event reporting

Alarm configuration studies

Dynamics interpretation & response guidelines

Oscillatory Stability

Mode Behaviour, Band 3 (0.20-0.30 Hz) **1-Month Review, 0.26Hz Mode**



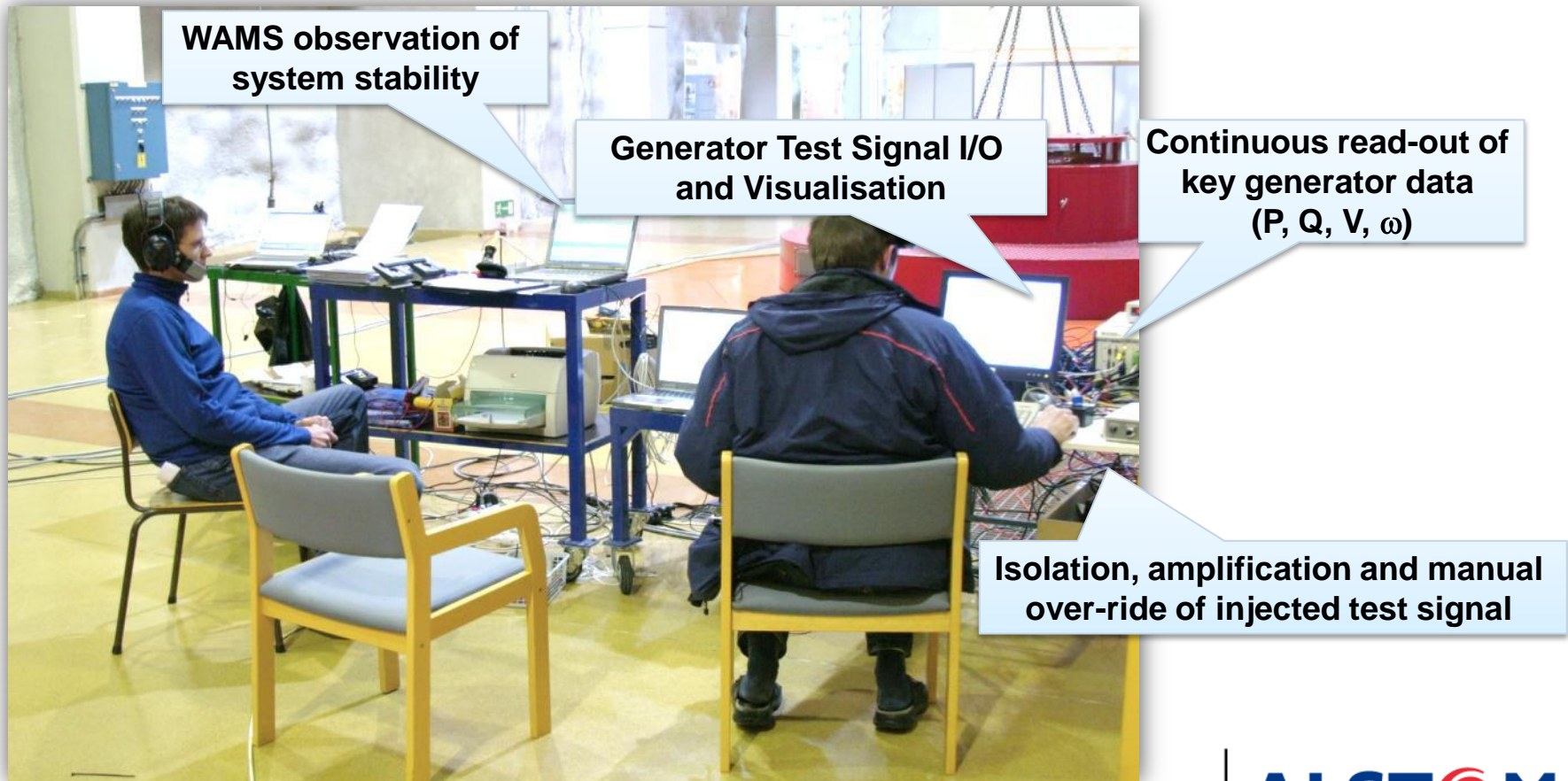
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Control System Tuning

AVR, PSS & Governor Controller Tuning

- System survey and prioritising tuning work
- Model building & validation
- Control system commissioning testing
- Performance review



PG&E SynchroPhasor Project – 2010 to 2013

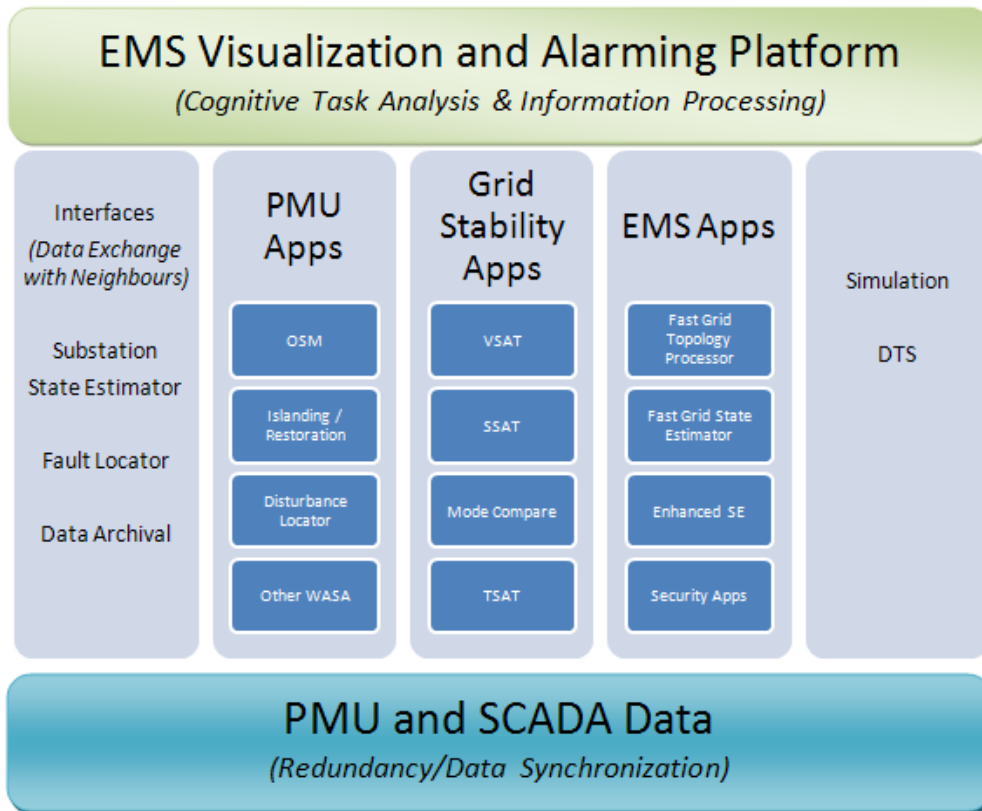
Technical Lead: Vahid Madani, PG&E

Strategic Team:

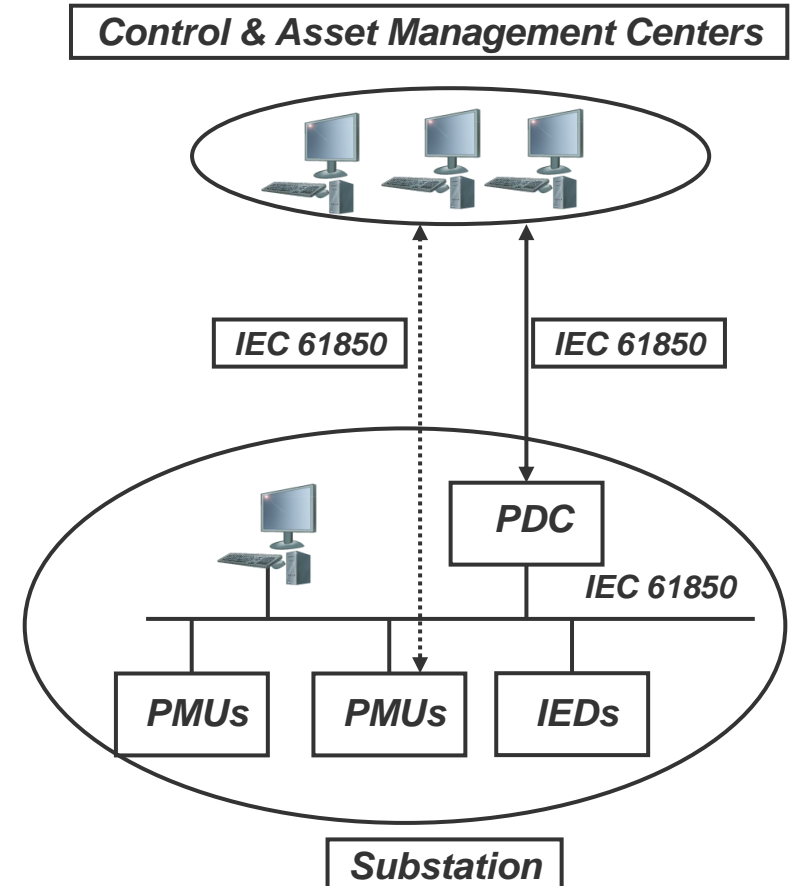
PG&E, ALSTOM, GE, Mississippi State Univ., Quanta

Academic & Testing Partners:

GeorgiaTech, Omnicron/VirginiaTech, Washington State Univ.

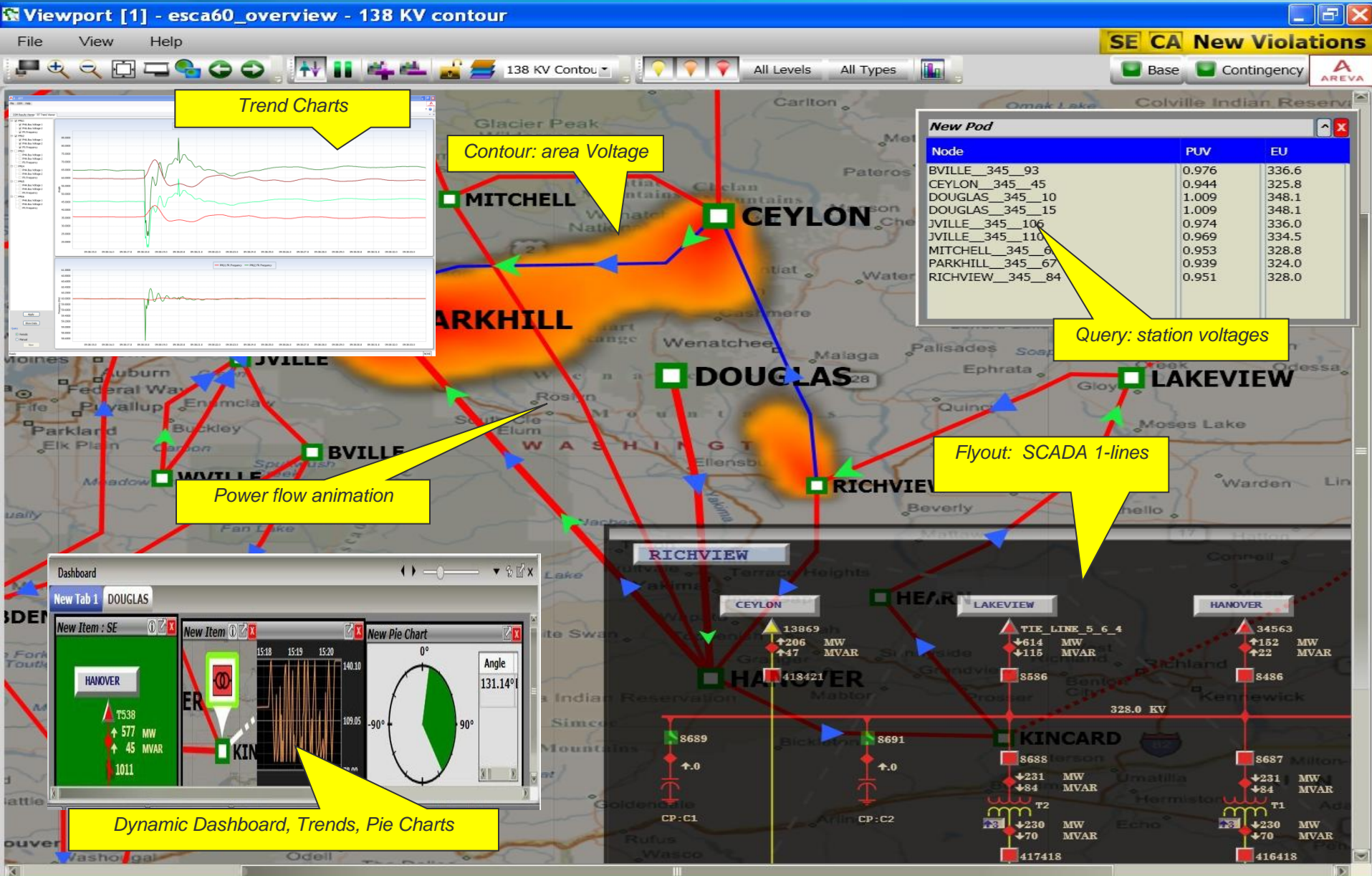


SynchroPhasor Applications for the Control Center



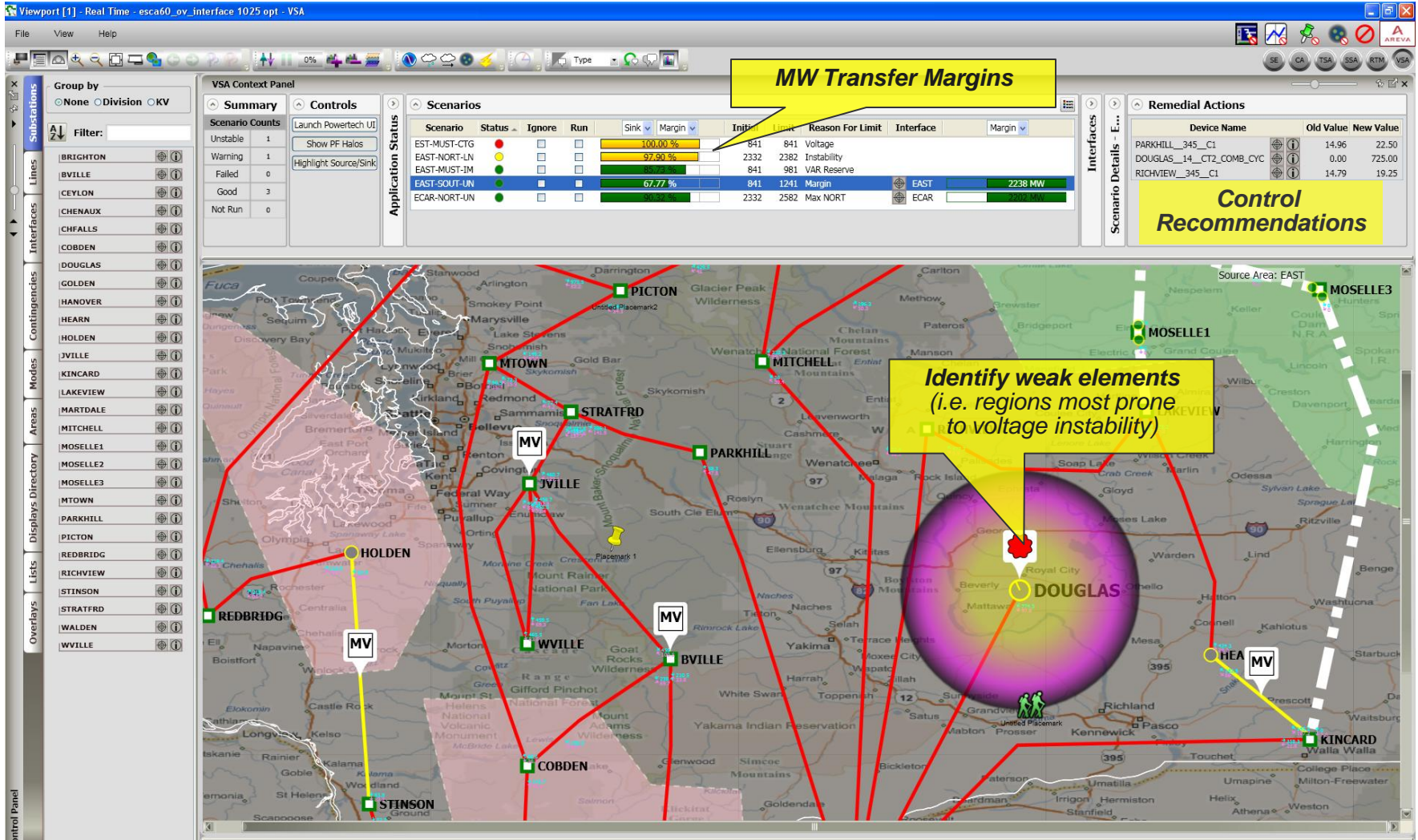
IEC61850 Backbone for Wide Area Automation

Wide Area Situational Awareness Visualization



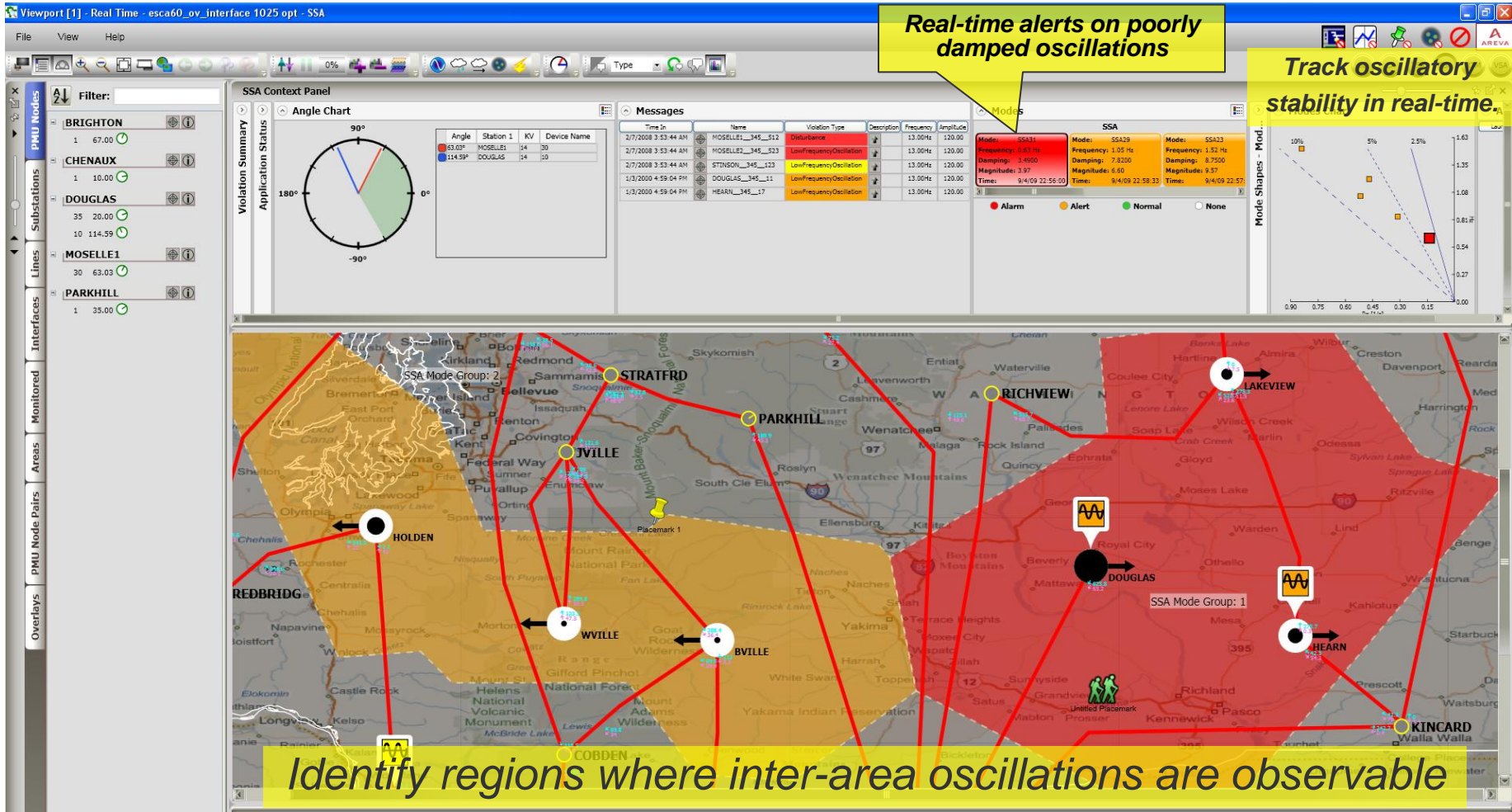
Voltage Stability Assessment

Voltage Contours, MW Margins, Weak Elements, Remedial Actions



Small Signal Stability

Modes shapes, amplitudes, damping, frequency, etc





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THANK YOU

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