Big Data Analytics for Power Grid Operations

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Agenda

- Big Data in the Energy Industry
- Solution Architecture for Managing Big Data Analytics
- Synchrophasor Data Analytics for Real Time Grid Operations
- Synchrophasor Data Analytics for Offline Engineering Analysis
- Conclusions

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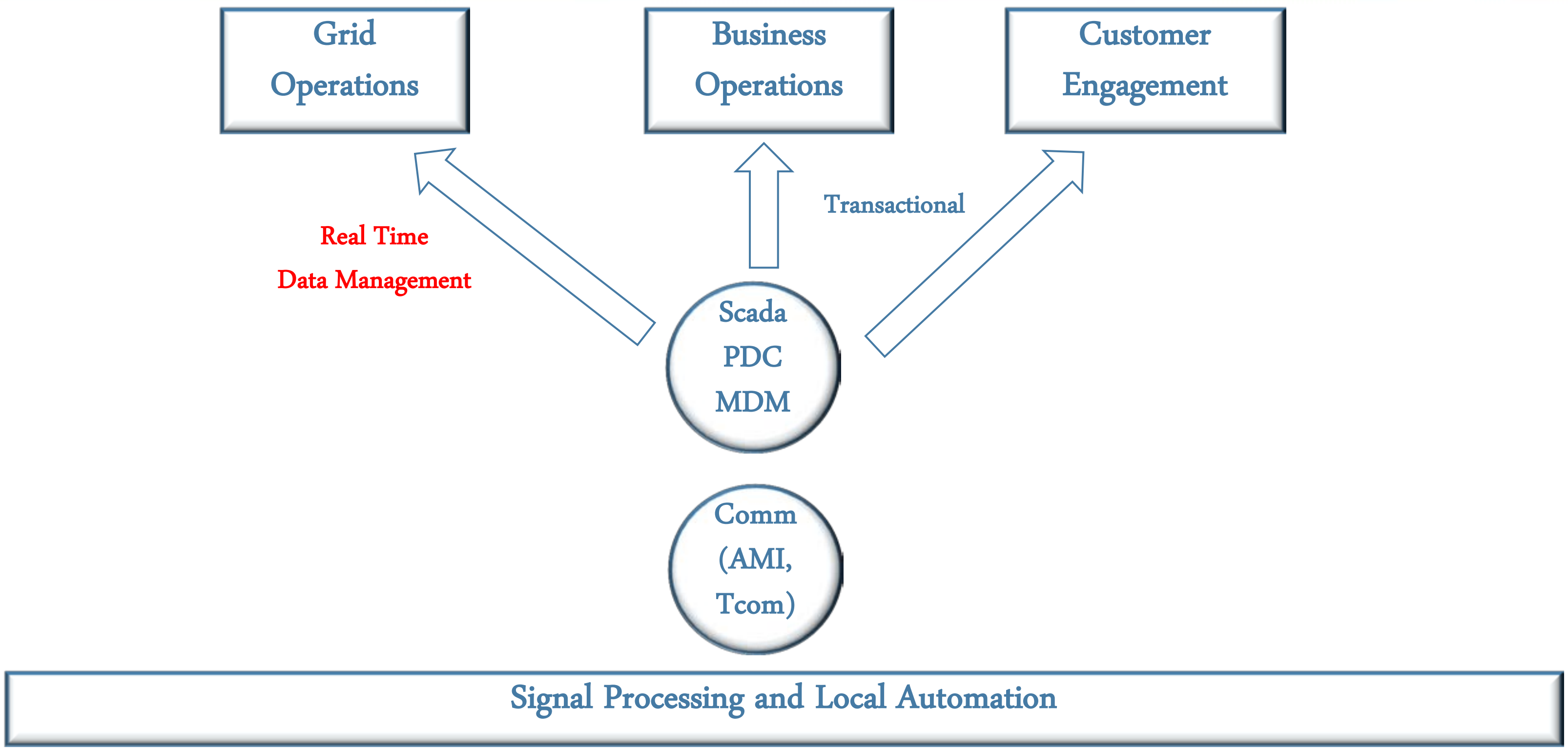
Big Data in the Energy Industry



Field level	PMU	IED	Line sensor	DA	DG	CMU	Meter	HAN	Weather	Files
Qty	1k	100k	10k	10k	100k	10k	10M	100M	100k	100Tb
Time Resolution	1ms	100ms	10k	10ms	1s	10min	1min to 15min	100M	100k	Others photos, videos, labs analysis, site reports, Financial
Type	V I Ph Hz	V I Hz	10k	Sw	MW MVA	T°, Qual	MWh V I ph Hz History	100M	100k	

Big Data Analytics

Measurement to Information Value Chain

Meter

1. Meters
2. Telecom infrastructure
3. Data concentrator and Head end

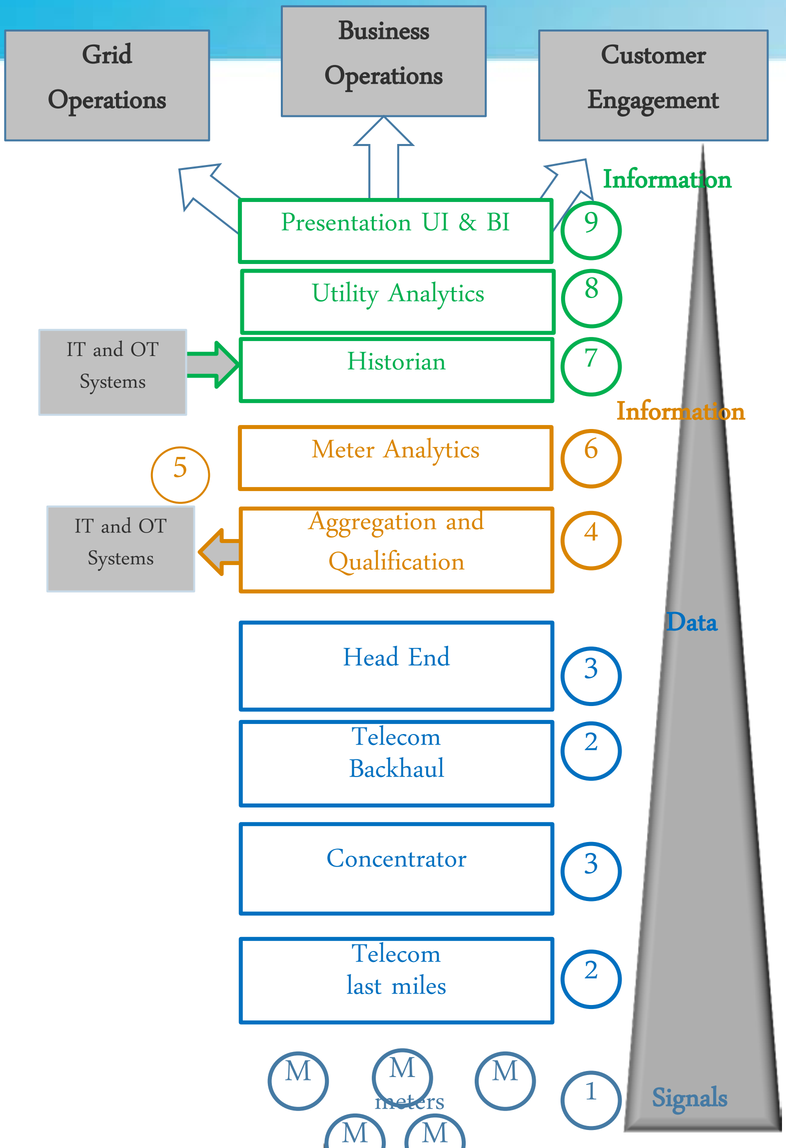
Meter MDM

4. Data Aggregation, qualification, processing
5. Interaction with others utilities IT/OT systems (scada, asset data, weather data, customers data, etc…)
6. Data analytics
7. Historian of large quantity of data from various sources

Master MDM

8. Utility Analytics
9. Presentation : User Interface, Business Intelligence

- Meter Data Management refers to layers 4 - 5 – 6
- MDM as Master Data Management refers to layers 7 – 8 –9



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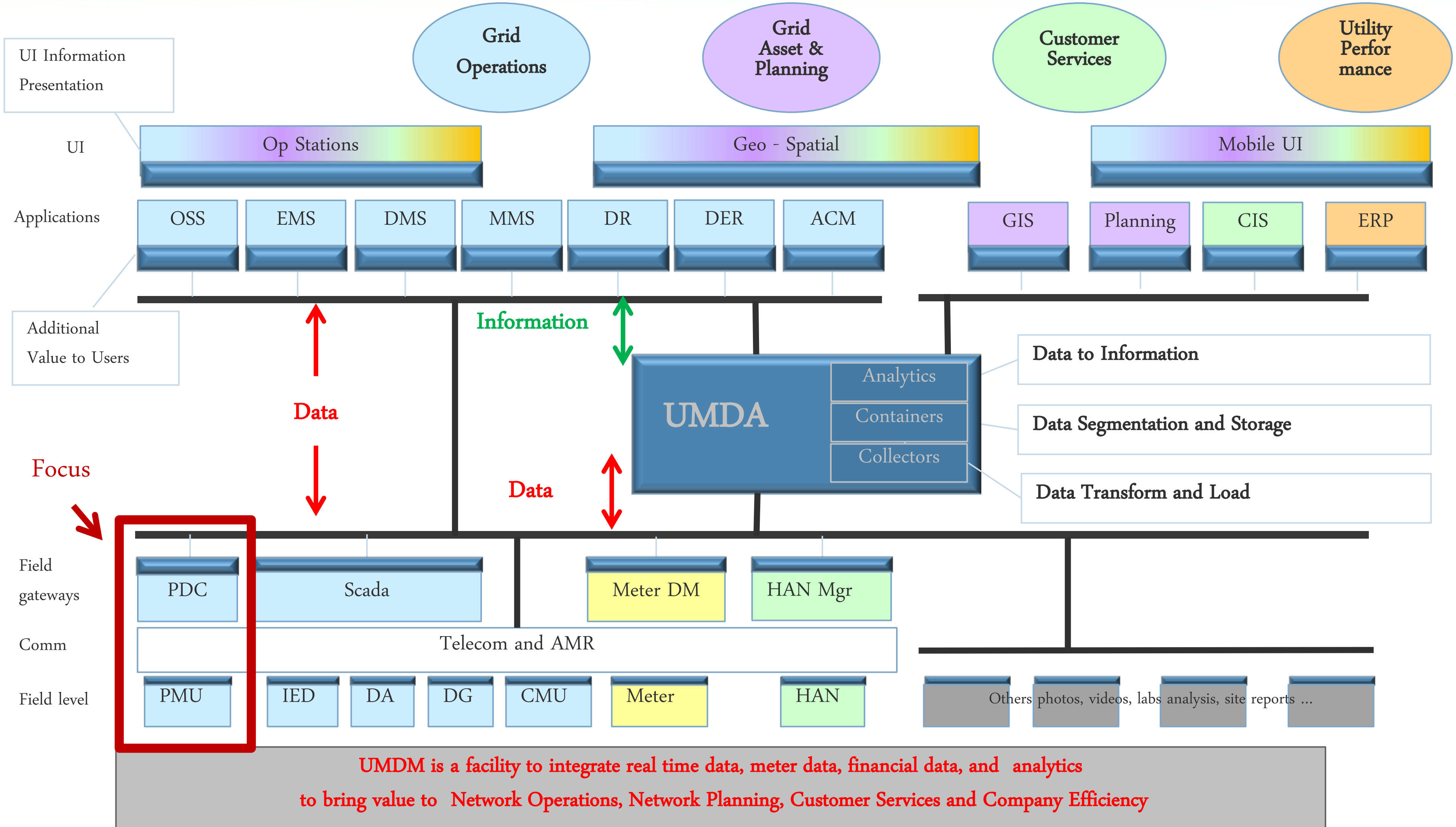
Holistic Approach to Big Data Analytics

A functional transverse layer that pull data from all sources and generate value to each domain



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SynchroPhasor Technology

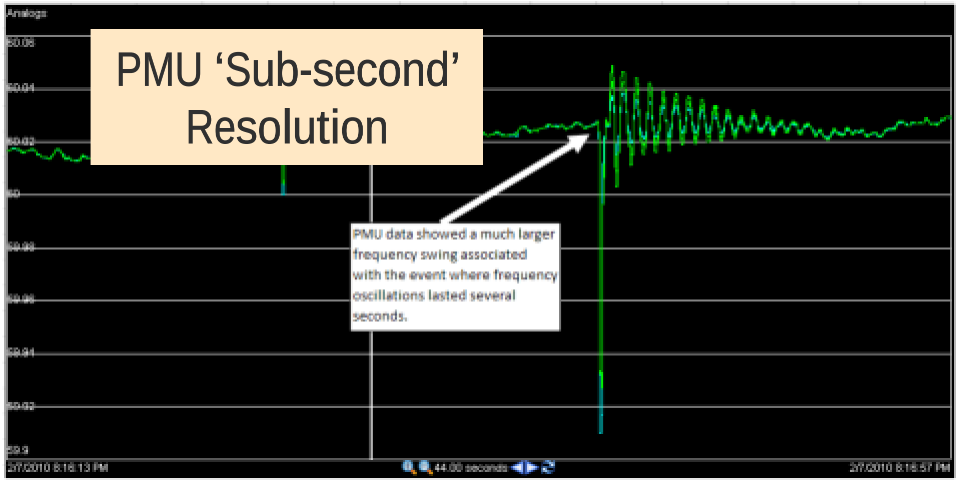
Phasor Measurement Units (PMUs)

- 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.*
  — *Coordinated Wide-area Control Actions.*

"PMUs: MRI quality , color 3-D visibility compared to X-ray quality , B&W 2-D visibility of SCADA"
– Terry Boston (CEO, PJM)



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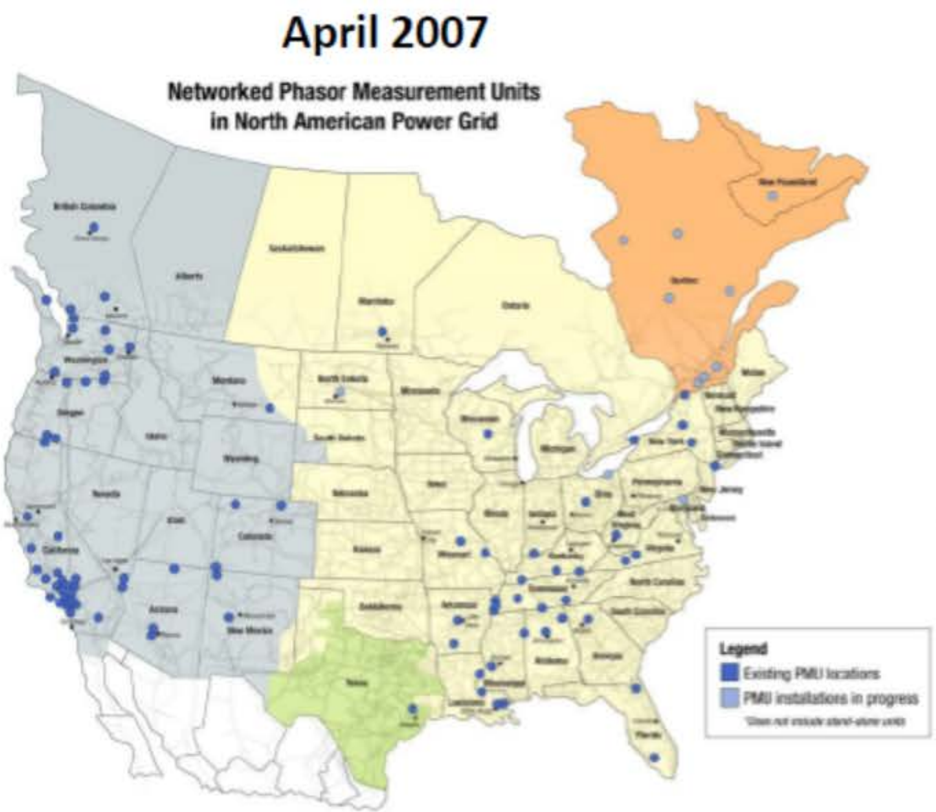
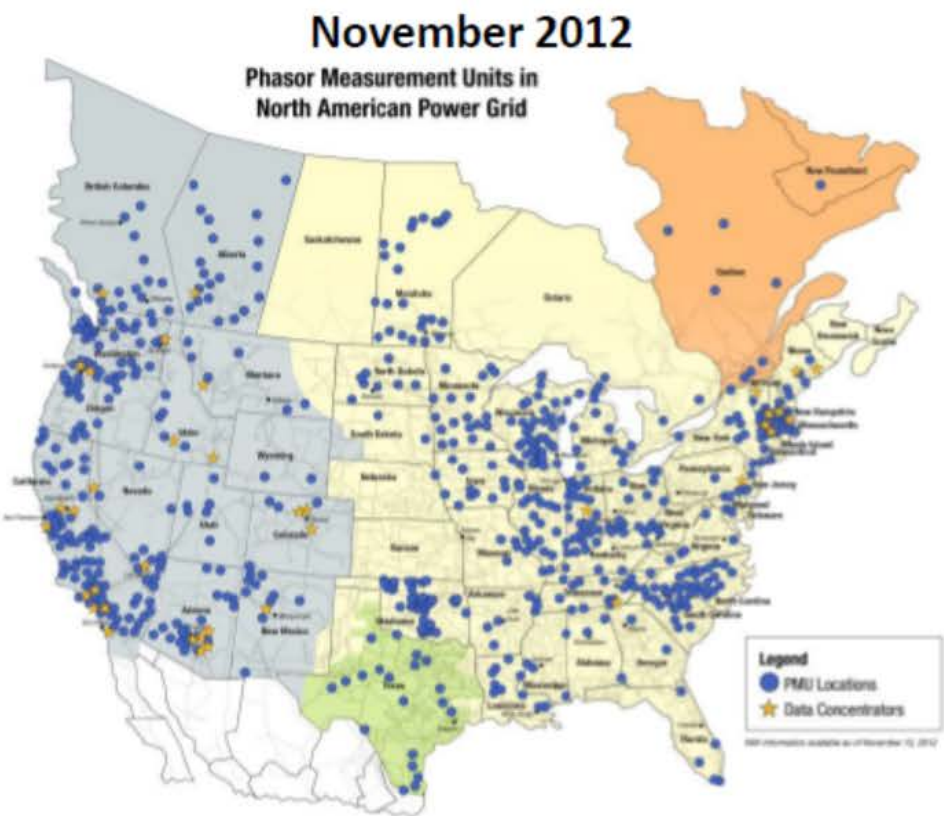
Synchrophasor Deployment in North America
Changing Landscape





Approx. 200 PMUs in 2007

Over 1200 PMU deployed by 2014
(over 10TB/Month of "raw" PMU data)

Source: NASPI Website (www.naspi.org)

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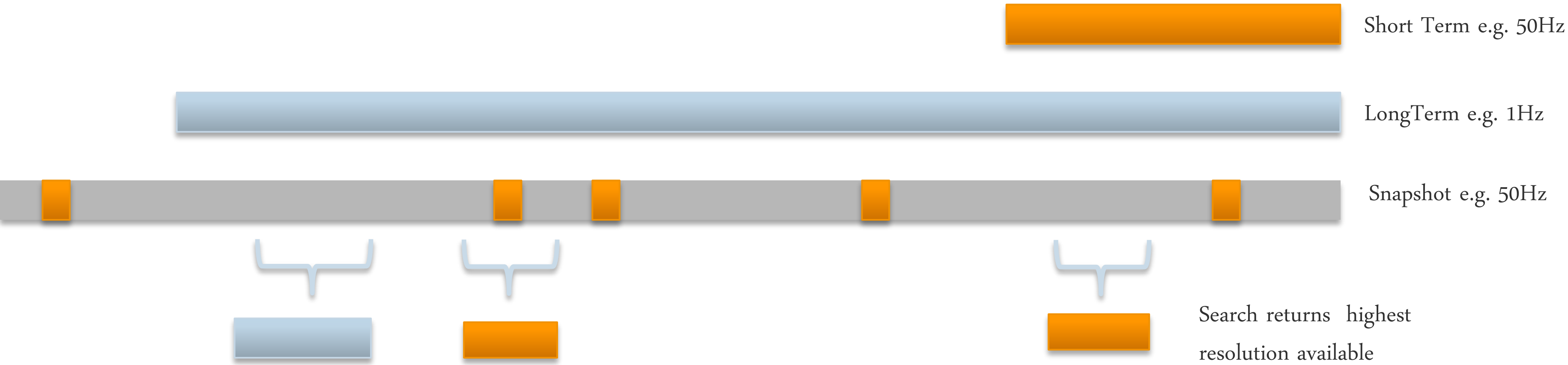
Data Archiving

- Short Term Rolling Buffer (e.g. 3-12 months)
- Long Term Rolling Buffer (e.g. 1-5 years)
- Event Trigger (Snapshot)
- Transparent to user
- Limited only by hardware
- Flexible data rates



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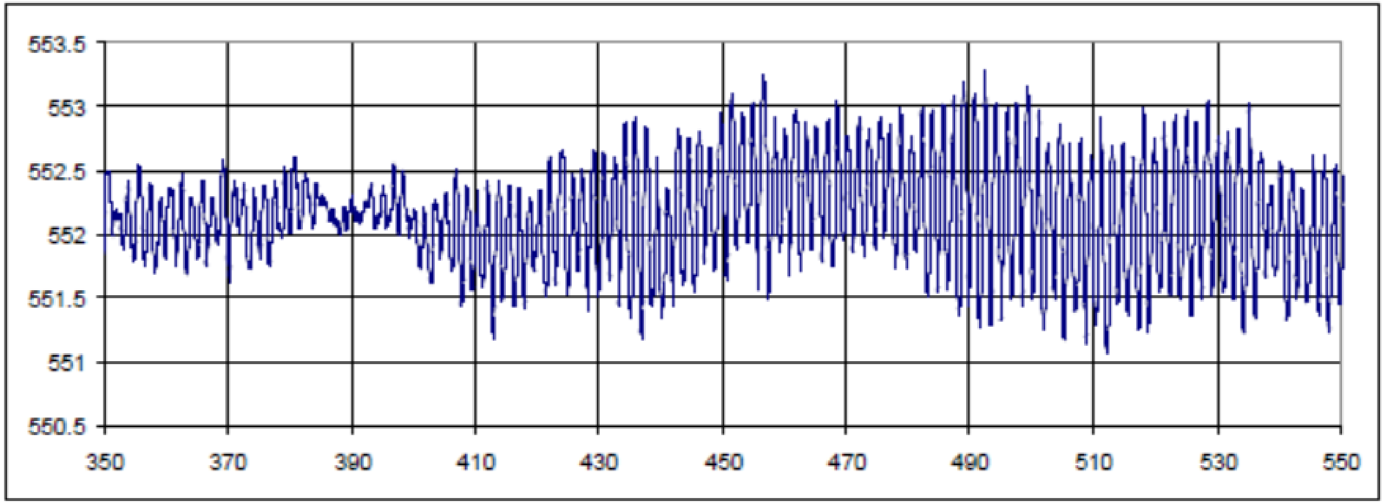
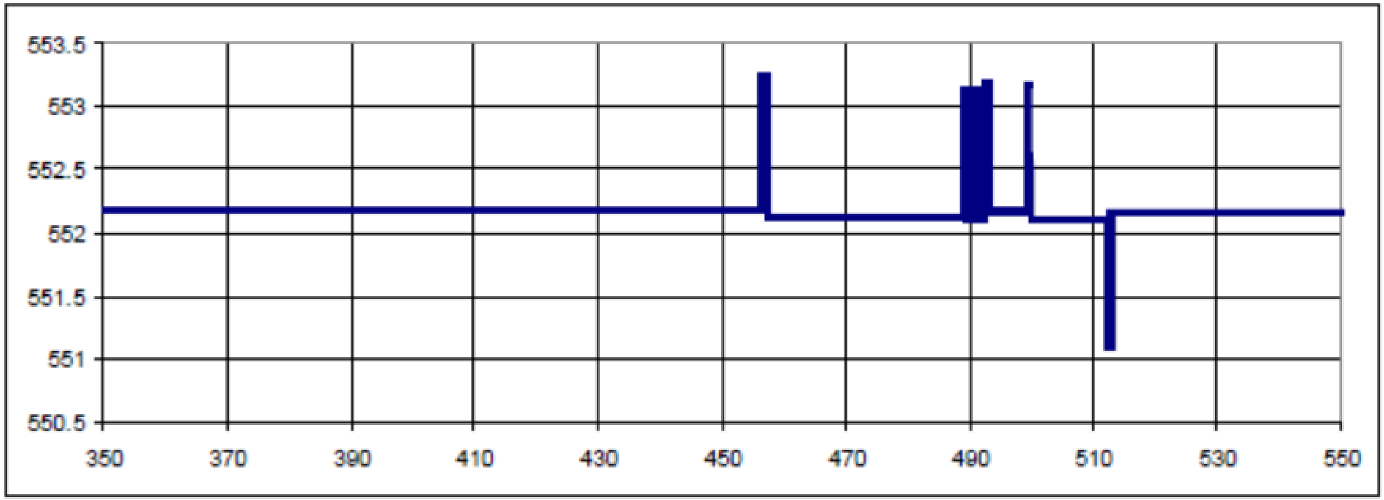
Data Compression (Lossy v.s. Lossless Compression)



Raw

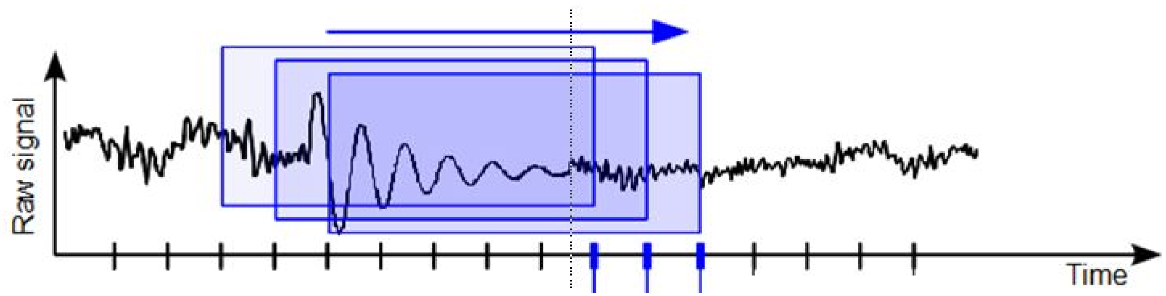


Compressed

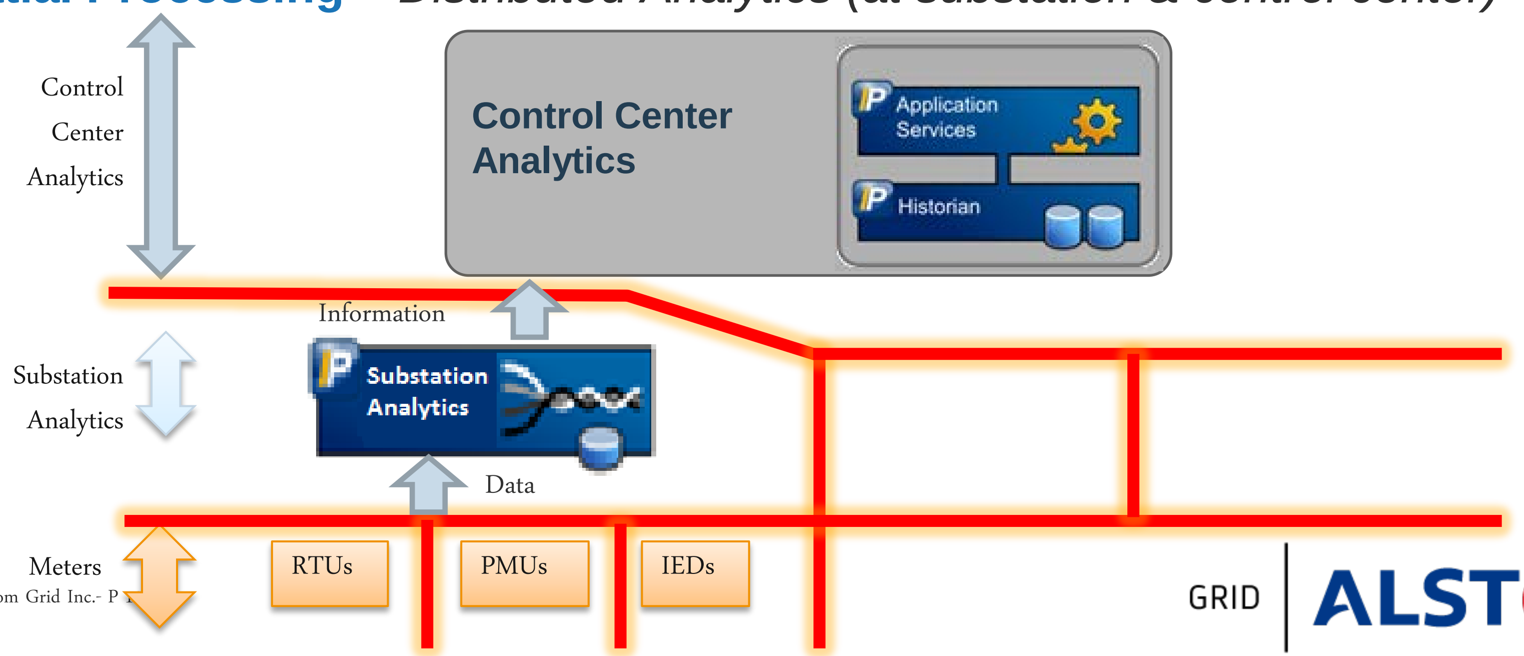
(courtesy Dmitry Kosterev, BPA)

Approaches for Processing Big Data

- **Temporal Processing** *(compression) – Pre-calculated analytics (results archived).*



- **Spatial Processing** *– Distributed Analytics (at substation & control center)*



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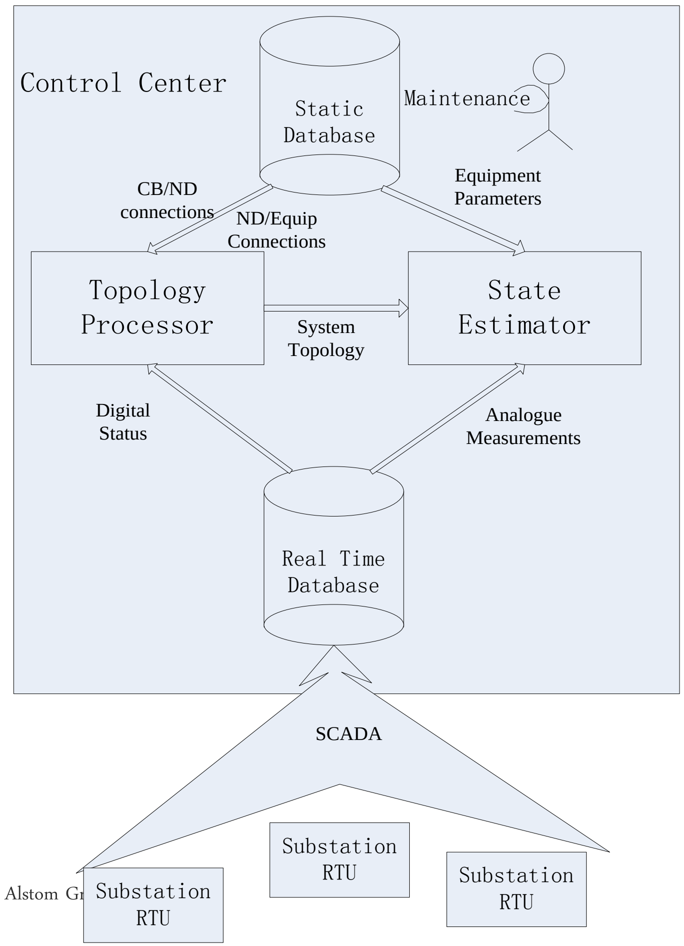
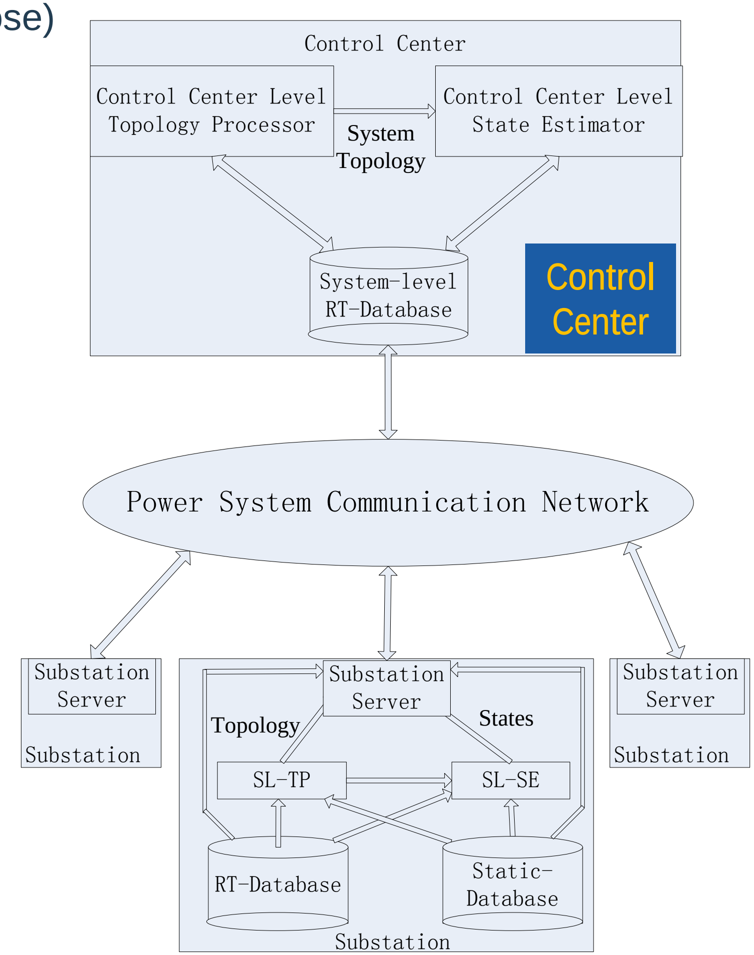
Two-Level Linear State Estimator

Example of distributed analytics

- Currently underway in collaboration with WSU (Prof. Anjan Bose)
- Being deployed at PG&E under their Synchrophasor Project





SL-TP: Substation Level Topology Processor

SL-SE: Substation Level State Estimator

RT: Real Time

Substation

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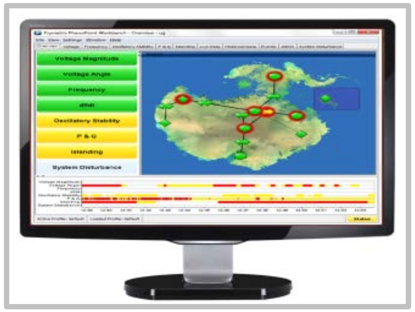
Data Analytics – Modes of Operation

	REAL-TIME	**OFFLINE** *(AFTER-THE-FACT)*
CONTINUOUS *(PUSH)*	▪ Centrally administered (modeled & configured). No end-user intervention. ▪ Continually processed using a '***Time-Window***' of data at periodic update rates. ▪ View-only mode to review the results. ▪ Analysis results may be archived. ▪ Examples: Oscillatory Stability Monitoring.	▪ Typically 'data mining' analytics that "walk-through" large volumes of historical data in smaller chunks (i.e. batch processing). ▪ May require initial metadata from end-user. ▪ Results are presented once the entire processing is complete. ▪ Examples: Baselining.
ON DEMAND *(PULL)*	▪ End-user or event triggered. ▪ Little to none end-user intervention. ▪ Single real-time view of the results. ▪ Results are made available as soon as they are generated. ▪ Examples: Event capture and reporting.	▪ Locally processed by the end-user. ▪ Fully interactive end-user experience; close feedback between data-analytics-UI. ▪ Results are locally archived & presented to the end-user. ▪ Examples: Post-Event Analysis.

Examples of Real-Time Data Analytics



e-terra *Phasor Point*

- System Disturbance Characterization
- Oscillatory Stability Monitoring
- Understanding grid vulnerabilities
- Big data analytics

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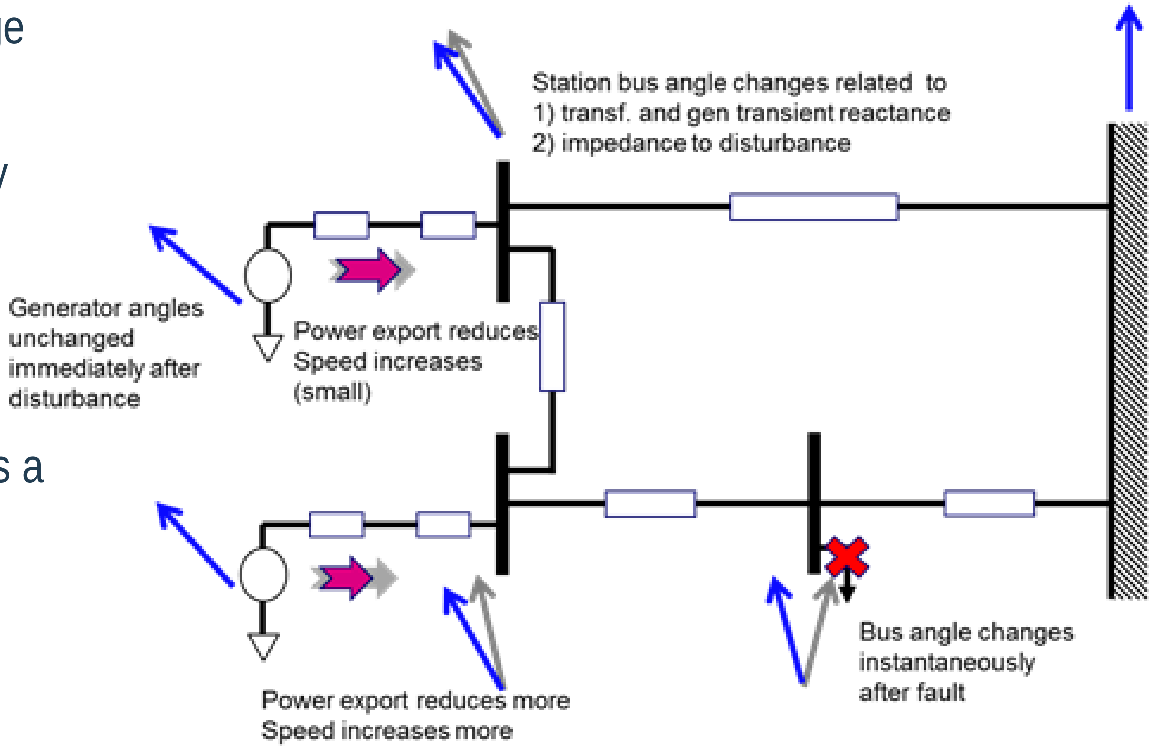
Concept: Illustration of Angle Movement in Response to a Disturbance

- Angle (δ) and Speed (ω) can't change instantaneously at a generator
- δ & ω near a generator influenced by generator angle
- δ & ω move more rapidly near the disturbance than far away
- Disturbance appears to propagate as a kind of "wave"



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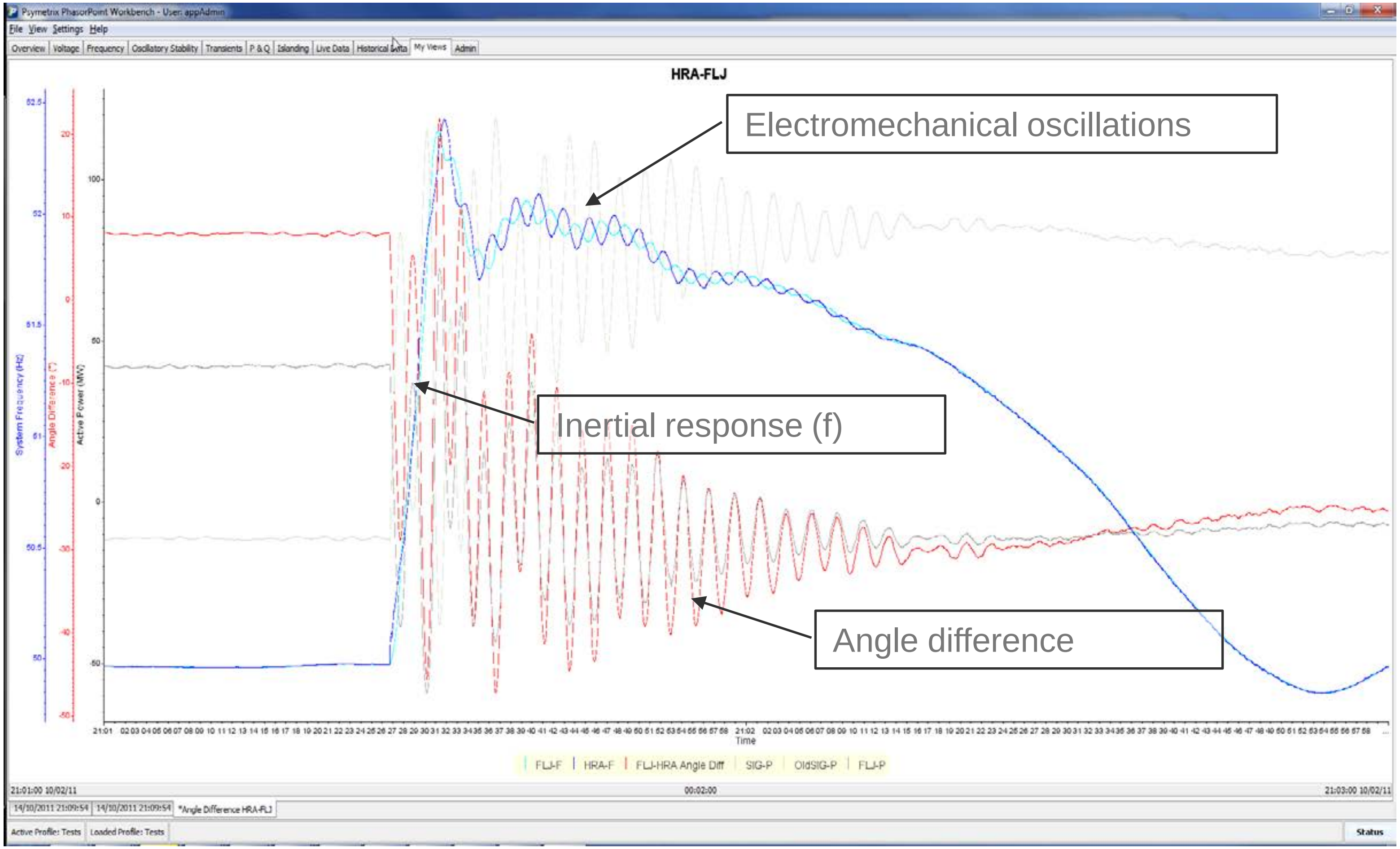
System Disturbance Characterization

Example of "Typical" Disturbance (Load Loss)

"Typical" Disturbance



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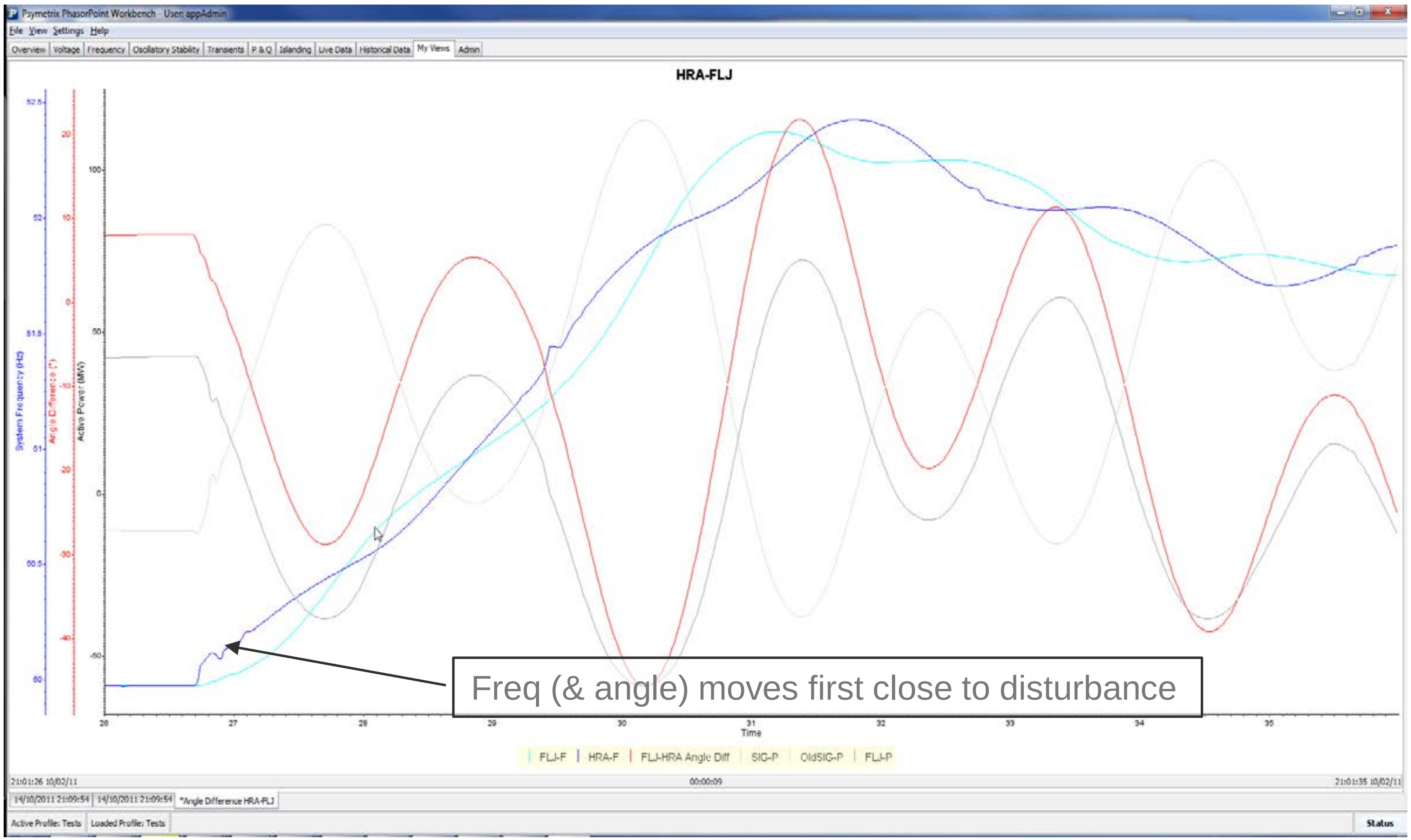
System Disturbance Characterization

Example



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System Disturbance Characterization

Disturbance Characterization

Type	Characteristics
Generation Trip	- Frequency drops initially (RoC α amount of load loss) - First Angle/Frequency changes occurs near the disturbance - Oscillations due to the electromechanical responses
Load Loss	- Similar to Generation Trip, but frequency moves upwards - Positive Frequency RoC
Line Trip	- Increasing angle separation - Change in angle (with ringdown) - Frequency is not affected (but oscillations)
Cascading Failure	Multiples types of disturbances in sequence: - Common mode generation loss - Sequential protection tripping - Storm damage

$$\Delta p = \sum_{i=1}^{N} \Delta p_i = \frac{2\sum_{i=1}^{N} H_i}{f_n} \frac{df_c}{dt} = \xi \frac{df_c}{dt}$$

$$\xi = \frac{2}{f_n} \sum_{i=1}^{N} H_i$$

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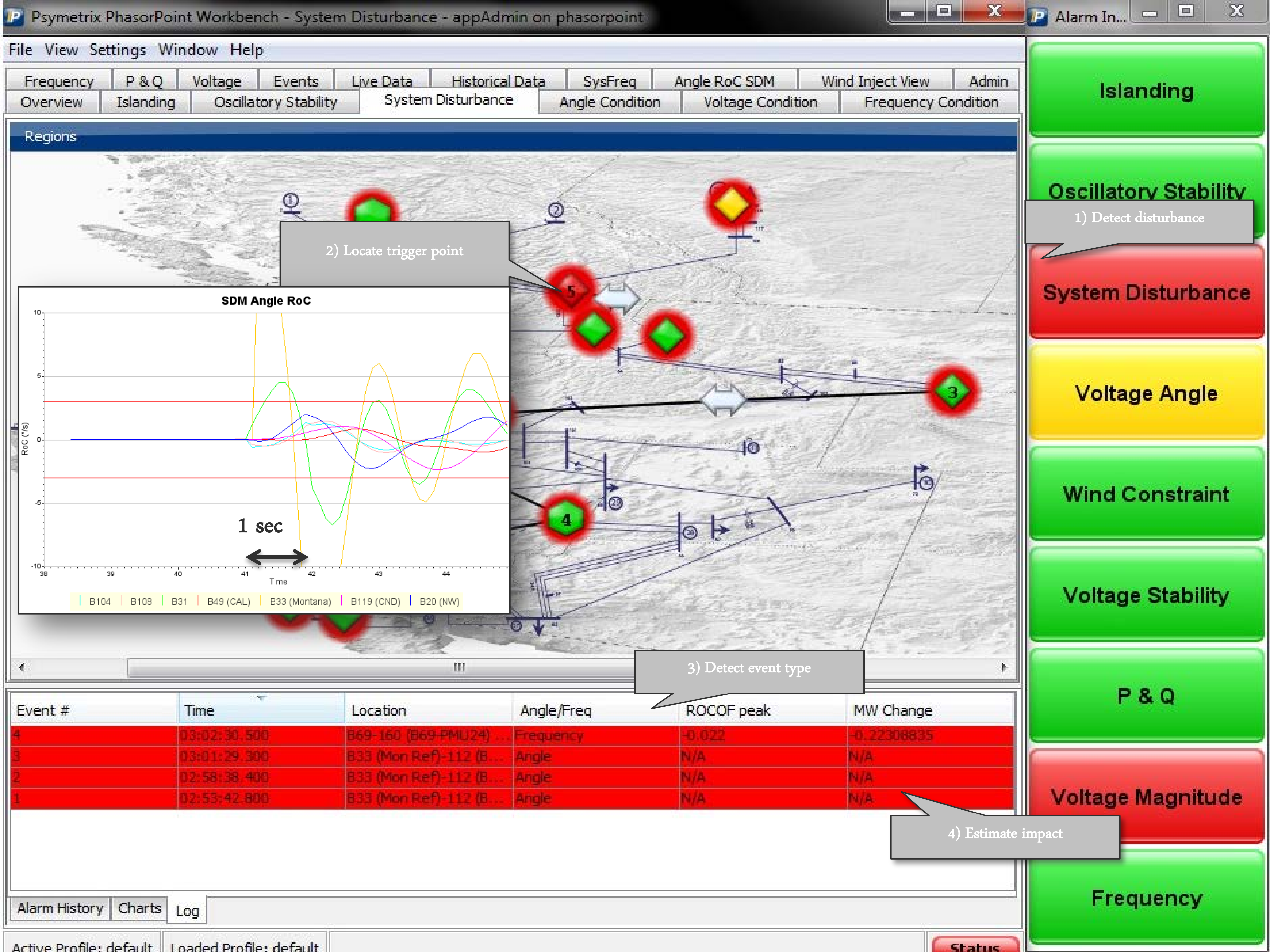
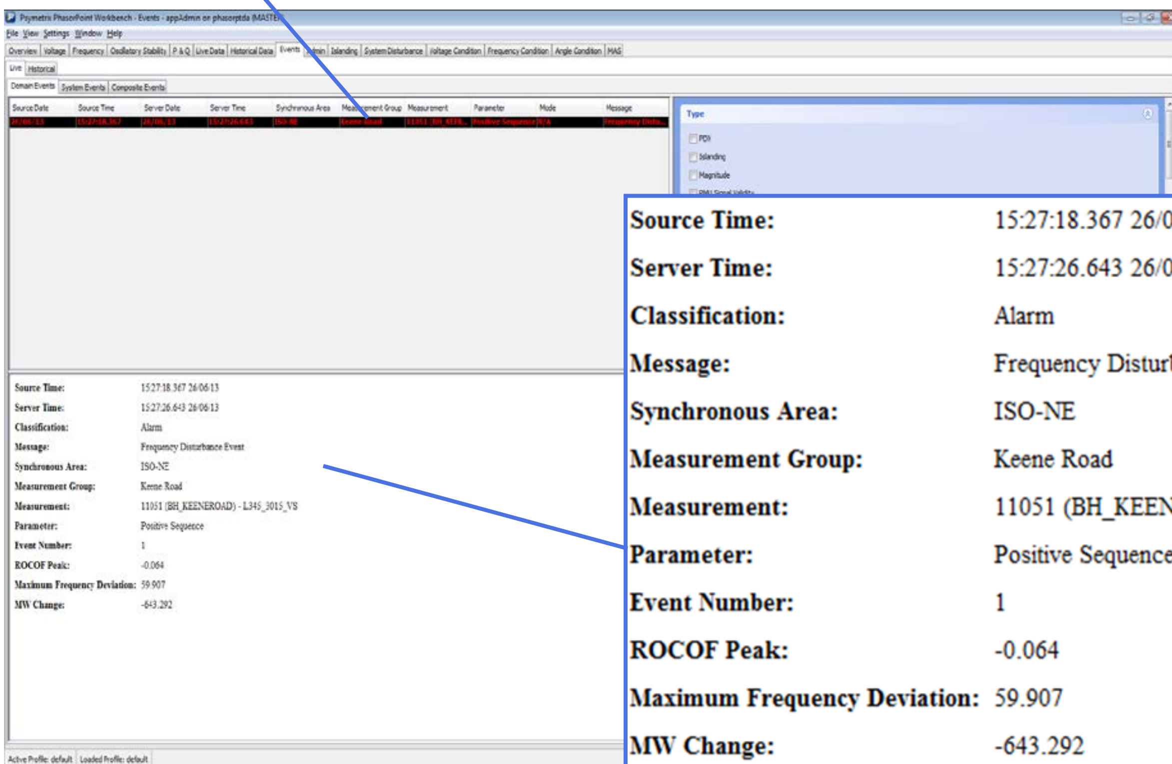


Psymetrix PhasorPoint Workbench - System Disturbance - appAdmin on phasorpoint
File View Settings Window Help
Frequency
P & Q
Voltage
Events
Live Data
Historical Data
SysFreq
Angle RoC SDM
Wind Inject View
Admin
Overview
Islanding
Oscillatory Stability
System Disturbance
Angle Condition
Voltage Condition
Frequency Condition
Regions
2) Locate trigger point
SDM Angle RoC
RoC (°/s)
Time
1 sec
B104
B108
B31
B49 (CAL)
B33 (Montana)
B119 (CND)
B20 (NW)
3) Detect event type
Event #
Time
Location
Angle/Freq
ROCOF peak
MW Change
4
03:02:30.500
B69-160 (B69-PMU24) ...
Frequency
-0.022
-0.22308835
3
03:01:29.300
B33 (Mon Ref)-112 (B...
Angle
N/A
N/A
2
02:58:38.400
B33 (Mon Ref)-112 (B...
Angle
N/A
N/A
1
02:53:42.800
B33 (Mon Ref)-112 (B...
Angle
N/A
N/A
4) Estimate impact
Alarm History
Charts
Log
Active Profile: default
Loaded Profile: default
Status
Alarm In...
Islanding
Oscillatory Stability
1) Detect disturbance
System Disturbance
Voltage Angle
Wind Constraint
Voltage Stability
P & Q
Voltage Magnitude
Frequency

System Disturbance Characterization Analytic

Source Date	Source Time	Server Date	Server Time	Synchronous Area	Measurement Group	Measurement	Parameter	Mode	Message
26/06/13	15:27:18.367	26/06/13	15:27:26.643	ISO-NE	Keene Road	11051 (BH_KEEN...	Positive Sequence	N/A	Frequency Distu...



Source Time:	15:27:18.367 26/06/13
Server Time:	15:27:26.643 26/06/13
Classification:	Alarm
Message:	Frequency Disturbance Event
Synchronous Area:	ISO-NE
Measurement Group:	Keene Road
Measurement:	11051 (BH_KEENEROAD) - L345_3015_VS
Parameter:	Positive Sequence
Event Number:	1
ROCOF Peak:	-0.064
Maximum Frequency Deviation:	59.907
MW Change:	-643.292

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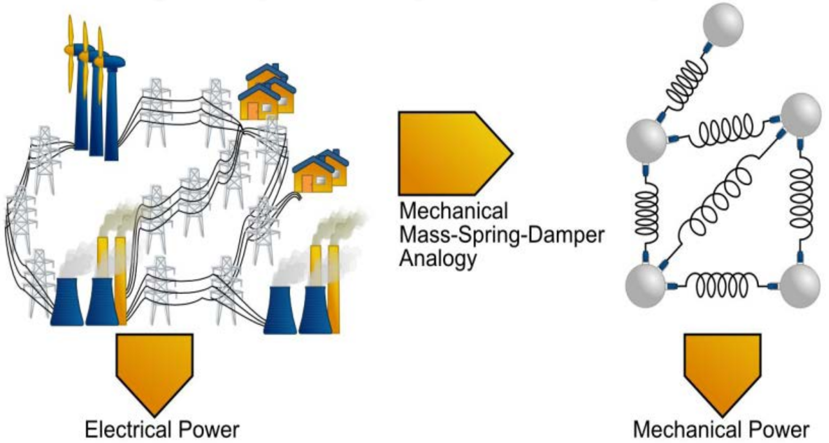
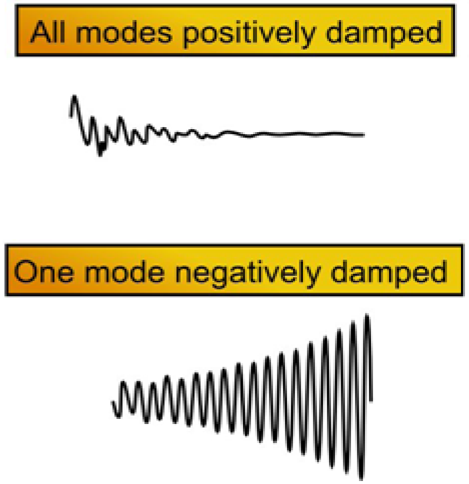
Dynamic (Oscillatory) Stability Management

“The interconnected electric power grid is one of the largest dynamic system of today”



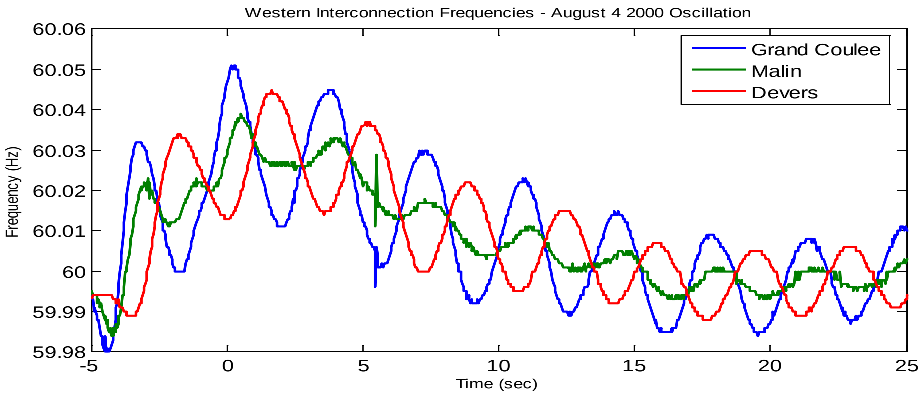


Oscillations seen by SCADA and PMU data

- Numeric SCADA displays today

Rapidly changing digits on a numeric display

- With synchro-phasors – high resolution trend display



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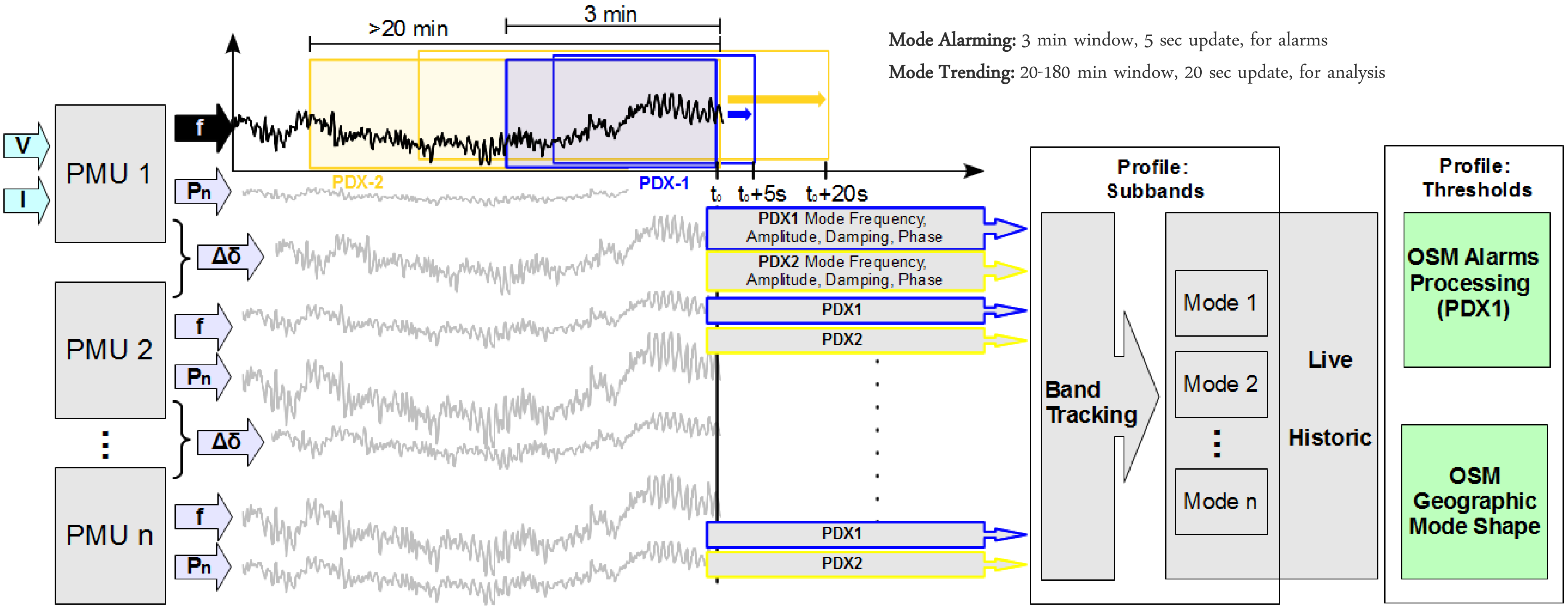
Oscillatory Stability Monitoring Analytics



Mode Alarming: 3 min window, 5 sec update, for alarms

Mode Trending: 20-180 min window, 20 sec update, for analysis

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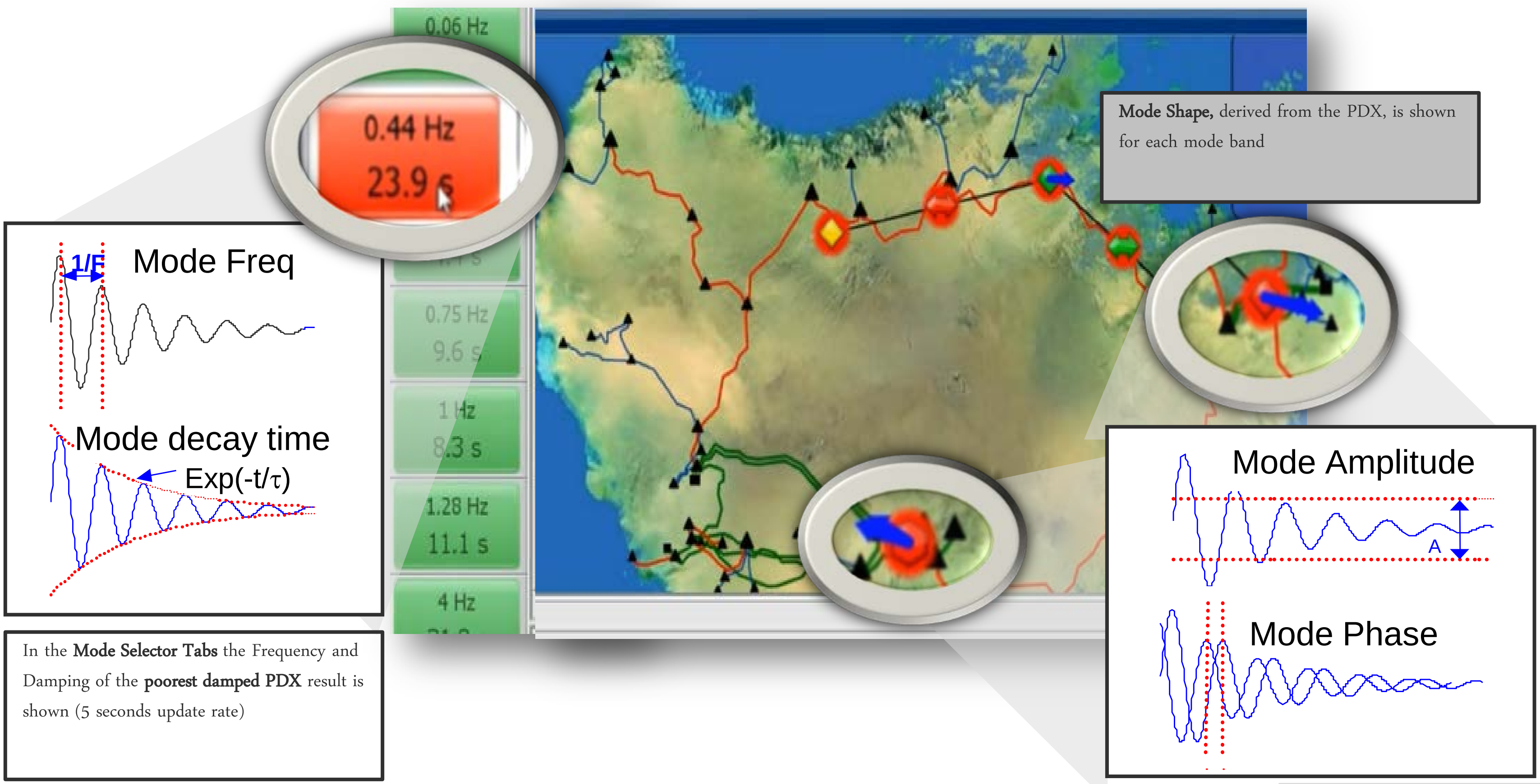
Operational Warnings

- Observe mode behaviour
  - Alarm if Abnormal, Near Instability



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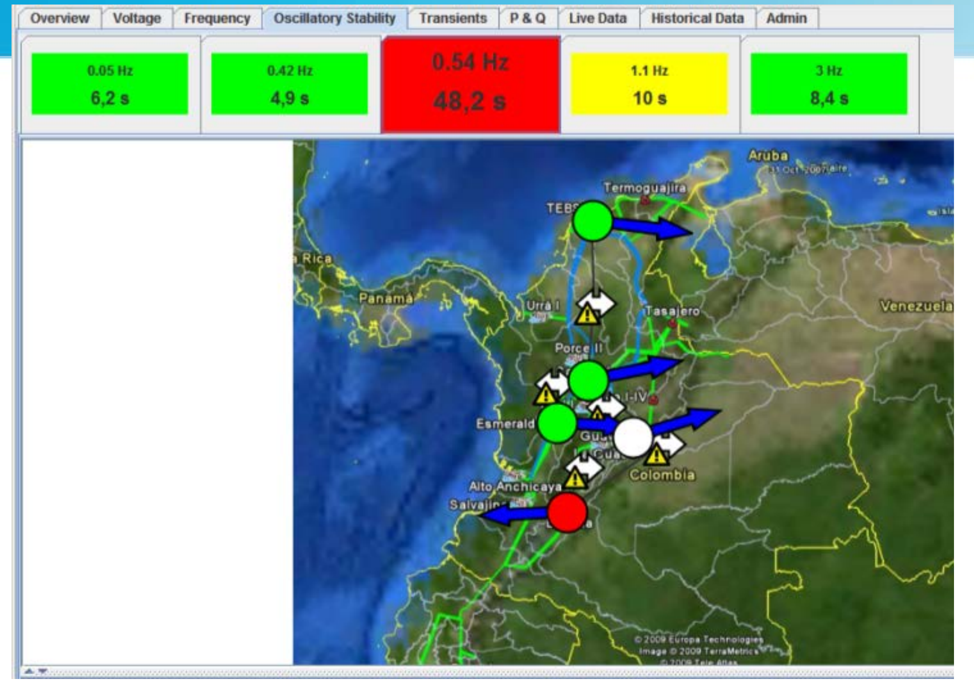
Example: Modes Observed in Colombia



Inter-area mode at 0.49Hz (Colombia-Ecuador).

Opposing phase in South

Governor common-mode: whole system oscillates in coherent phase

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Examples of Offline Data Analytics

- **Model Validation** *(Ringdown Analysis)*
- **Dynamic Perfomance Baselining**
- **Automated Reporting**

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Offline Data Analytics

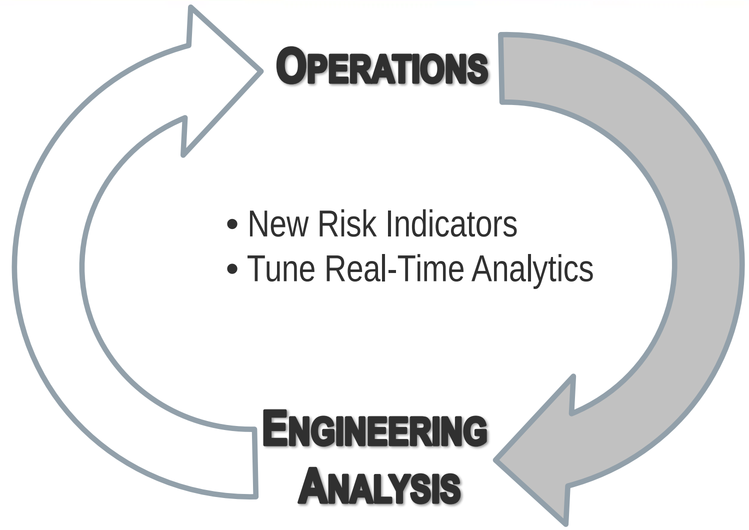
Leveraging Synchrophasors in Operations Planning

Post Event Analysis
- Quicker post-mortem analysis.
- Sequence of events & root cause analysis.

Dynamic Model Validation
- Dynamic model verification.
- Generator model calibration.
- Load characterization.

Baselining
- Assess dynamic performance of the grid.
- Steady-state angular separation.
- System disturbance impact measures.

Compliance Monitoring
- Primary frequency (governing) response.
- Power System Stabilizer (PSS) tuning



Synchrophasor benefits for Post-Event Analysis

In the case of the 2007 Florida blackout, NERC investigators used phasor data to create the sequence of events and determine the cause of the blackout in only two days; in contrast, lacking high-speed, time-synchronized disturbance data it took many engineer years of labor to compile a correct sequence of events for the 2003 blackout in the Northeast U.S. and Ontario.

NERC RAPIR Report, 2010.

Model Validation – Comparison Modes Between PMU data and Simulation Data

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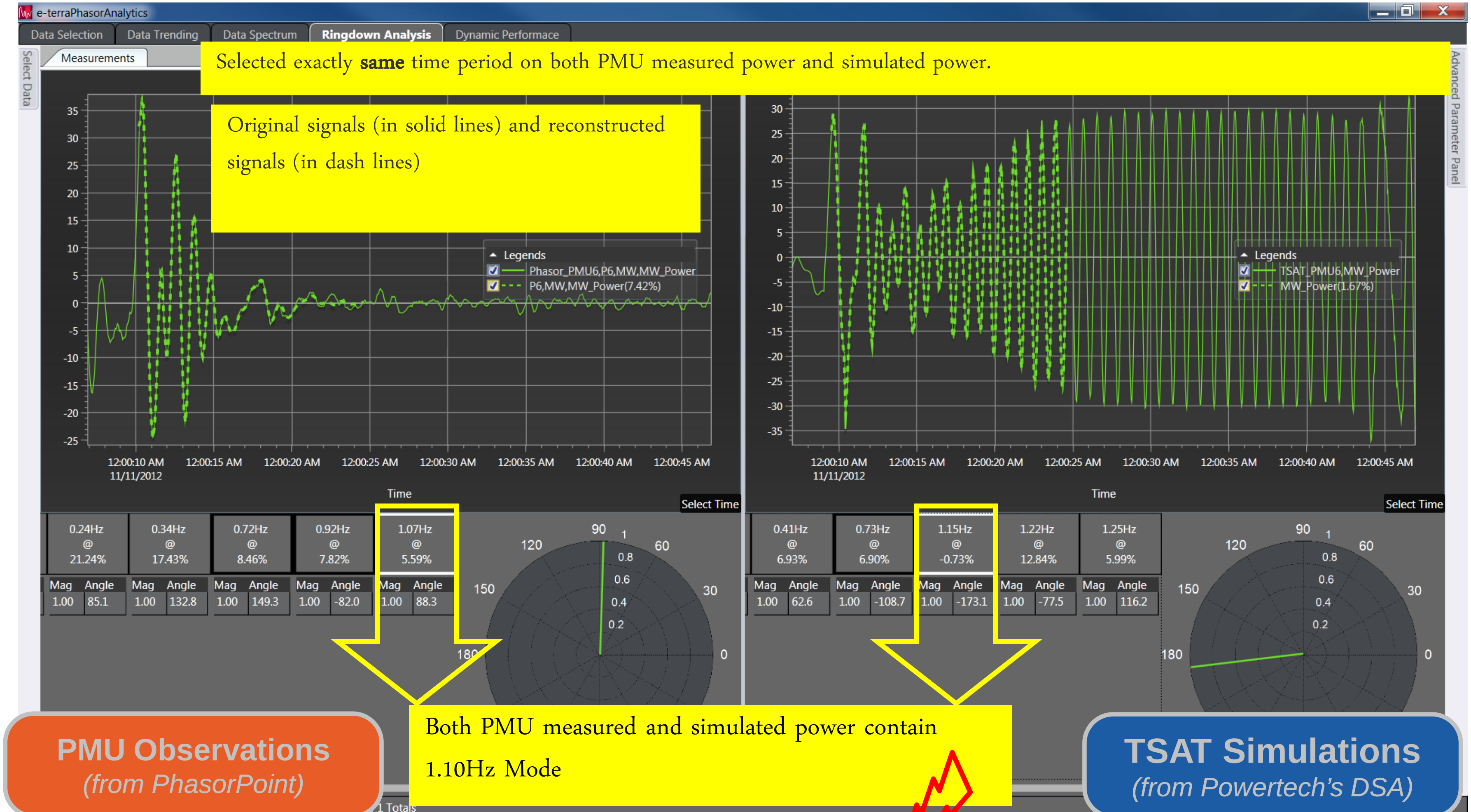
Offline Model Validation with Synchrophasors



Simulation data shows **negative** damping ratio!

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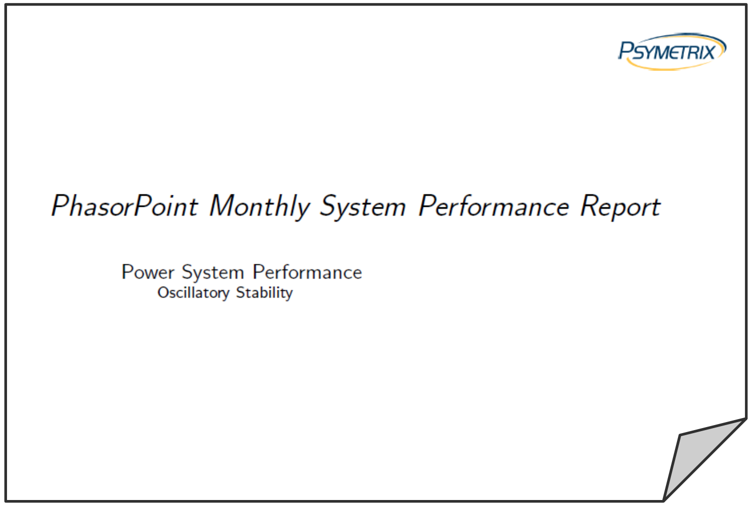
Offline Analysis Application

(Dynamic Performance Trending)

Monthly Performance Report

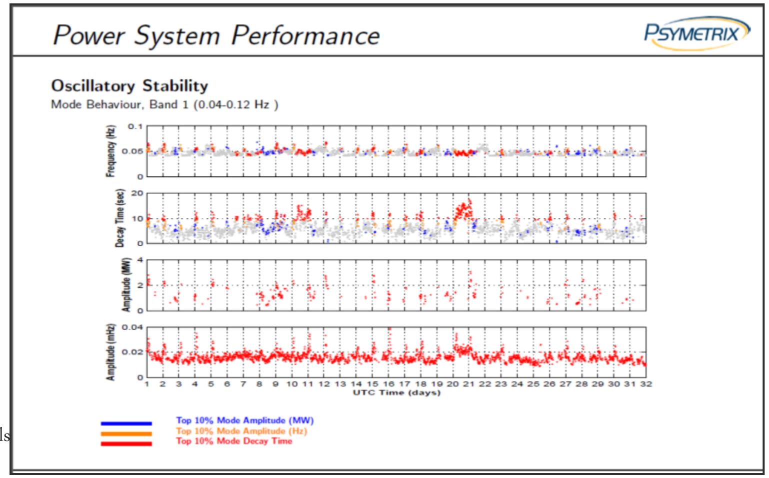
- Review of Modes of Oscillation
  - Baseline - normal behaviour patterns
  - Unusual events – source location
- Review Disturbances
  - Examples of Post-Event Analysis
- Threshold Settings (Statistics)
  - OSM Oscillation Alarms
  - SDM Disturbance parameters
  - Angle Behaviour Templates & Alarms

Regular Monthly Reporting


PSYMETRIX

PhasorPoint Monthly System Performance Report

Power System Performance
Oscillatory Stability

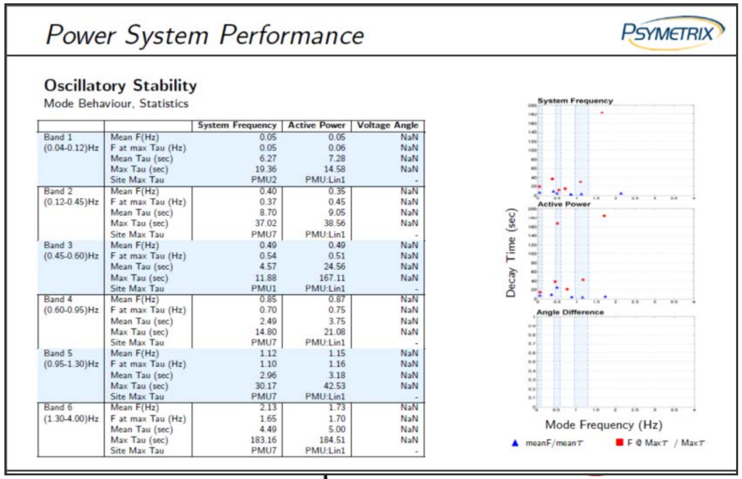

Power System Performance

PSYMETRIX

Oscillatory Stability

Mode Behaviour, Band 1 (0.04-0.12 Hz)

Als


Power System Performance

PSYMETRIX

Oscillatory Stability

Mode Behaviour, Statistics

		System Frequency	Active Power	Voltage Angle
Band 1 (0.04-0.12)Hz	Mean F(Hz)	0.05	0.05	NaN
	F at max Tau (Hz)	0.05	0.06	NaN
	Mean Tau (sec)	6.27	7.28	NaN
	Max Tau (sec)	19.36	14.58	NaN
	Site Max Tau	PMU2	PMU:Lin1	-
Band 2 (0.12-0.45)Hz	Mean F(Hz)	0.40	0.35	NaN
	F at max Tau (Hz)	0.37	0.45	NaN
	Mean Tau (sec)	8.70	9.05	NaN
	Max Tau (sec)	37.02	38.56	NaN
	Site Max Tau	PMU7	PMU:Lin1	-
Band 3 (0.45-0.60)Hz	Mean F(Hz)	0.49	0.49	NaN
	F at max Tau (Hz)	0.54	0.51	NaN
	Mean Tau (sec)	4.57	24.56	NaN
	Max Tau (sec)	11.88	167.11	NaN
	Site Max Tau	PMU1	PMU:Lin1	-
Band 4 (0.60-0.95)Hz	Mean F(Hz)	0.85	0.87	NaN
	F at max Tau (Hz)	0.70	0.75	NaN
	Mean Tau (sec)	2.49	3.75	NaN
	Max Tau (sec)	14.80	21.08	NaN
	Site Max Tau	PMU7	PMU:Lin1	-
Band 5 (0.95-1.30)Hz	Mean F(Hz)	1.12	1.15	NaN
	F at max Tau (Hz)	1.10	1.16	NaN
	Mean Tau (sec)	2.96	3.18	NaN
	Max Tau (sec)	30.17	42.53	NaN
	Site Max Tau	PMU7	PMU:Lin1	-
Band 6 (1.30-4.00)Hz	Mean F(Hz)	2.13	1.73	NaN
	F at max Tau (Hz)	1.65	1.70	NaN
	Mean Tau (sec)	4.49	5.00	NaN
	Max Tau (sec)	183.16	184.51	NaN
	Site Max Tau	PMU7	PMU:Lin1	-

Closing Remarks

- Big data management/analytics require a holistic approach across multiple data sources serving different stakeholders.

- Synchrophasors are increasingly becoming a part of ‘Big Data’ within the energy industry *(next generation SCADA)*

- Approaches to handling big data include:
  - *Temporal processing (compression) – i.e. pre-calculated results/stats.*
  - *Spatially distributed processing – i.e. processing at the meter/substation/control center levels.*

- Big data analytics operate in different modes including real-time, offline, continuous (automated), and on-demand.

  → *combination of “push”/ “pull” mechanisms needed to satisfy these needs.*

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