Panel of Emerging Technology Coordinating Committee
Emerging Technologies in Support of Smart Grids

SynchroPhasor Measurements: System Architecture and Performance Evaluation in Supporting Wide-Area Applications

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Current Development in Phasor Technology

- Massive PMUs are being put in operation
  - Steady increase of PMUs installations
  - Mandatory PMU installations, e.g. in China
  - Conversion of existing measurement devices, e.g. relays
- Higher PMU sample rates are used
  - Sample rate from 25/30 sps to super-synchronous rate, e.g. 100/120 sps.
- Frequency tracking and frequency compensation become popular in phasor algorithms
- Dynamic performance of phasors becomes critical as driven by applications

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Emerging Challenges

- Need capability to handle massive PMUs in phasor networks → new phasor architecture
- Need to evaluate phasor measurement from a dynamic perspective
- Need to evaluate phasor measurement from a system-wide perspective
- Need to study the implication of phasor quality for phasor applications

Phasor Applications

	Class A (e.g. Small Signal Stability Monitoring)	Class B (e.g. State Estimation Enhancement)	Class C (e.g. Post Event Analysis)	Class D (e.g. Visualization)
Low Latency	Critically important	Fairly important	Not very important	Somewhat important
Reliability Availability	Critically important	Somewhat important	Fairly important	Not very important
Accuracy	Critically important	Somewhat important	Critically important	Not very important
Time Alignment	Critically important	Critically important	Not very important	Somewhat important
Message Rate	Critically important	Somewhat important	Critically important	Somewhat important

Legend:
Not very important, Somewhat important, Fairly important, Critically important

* Source: NASPI Data and Management Task Team

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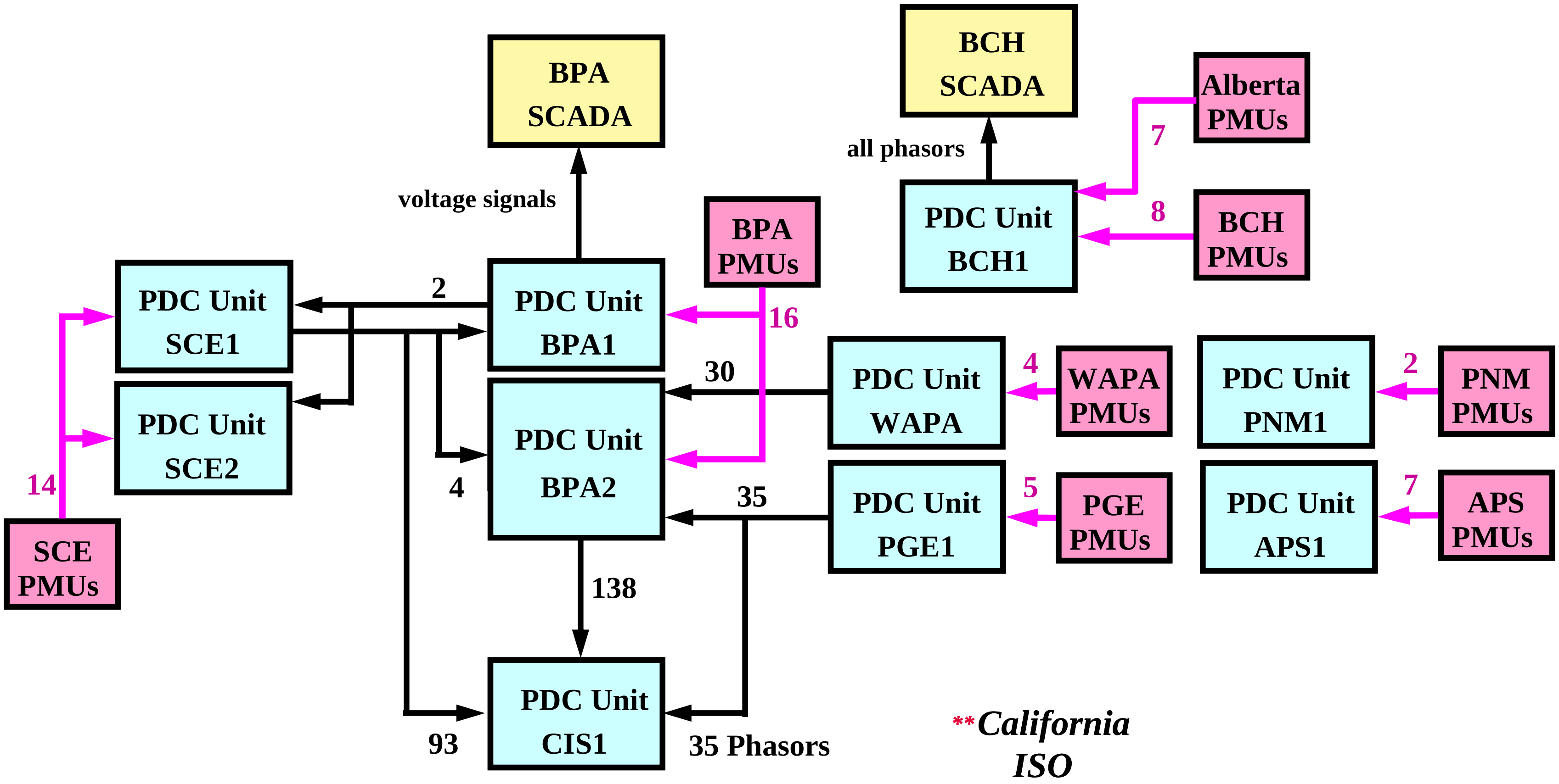
Phasor Architecture – WECC WAMS



* Source: J. Hauer, with modifications

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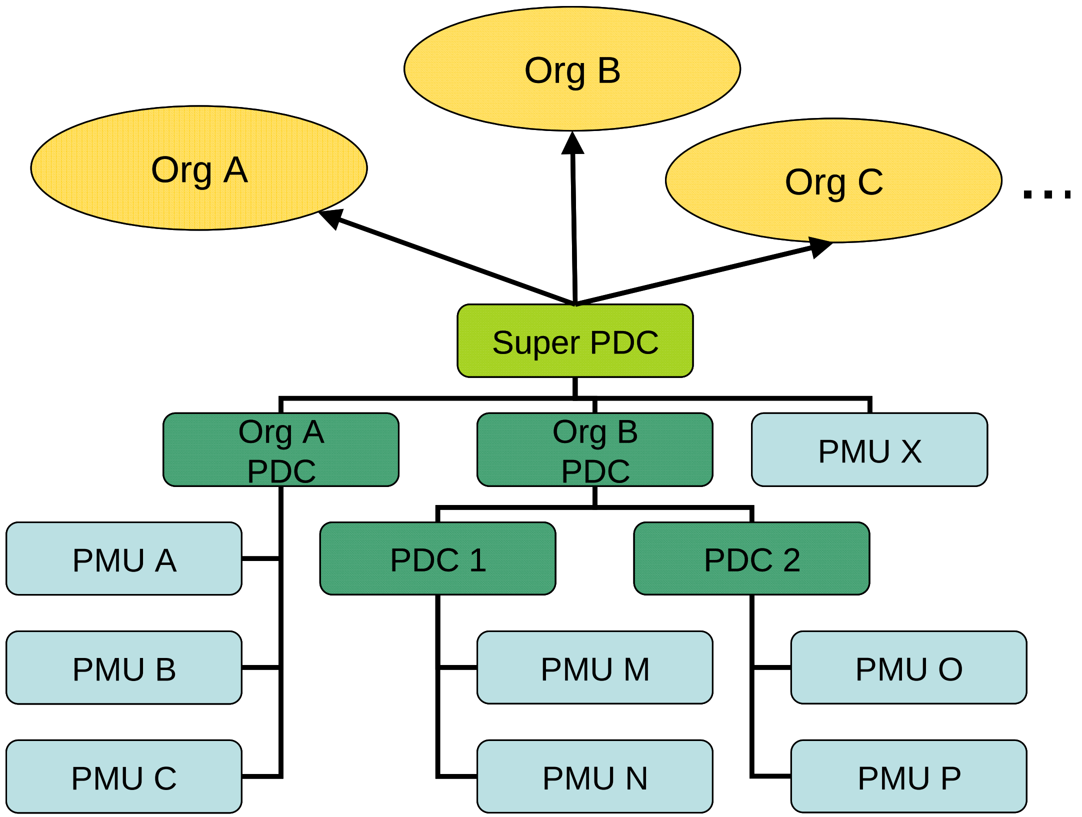
Phasor Architecture – Eastern Interconnection



* Source: NASPI Data and Management Task Team

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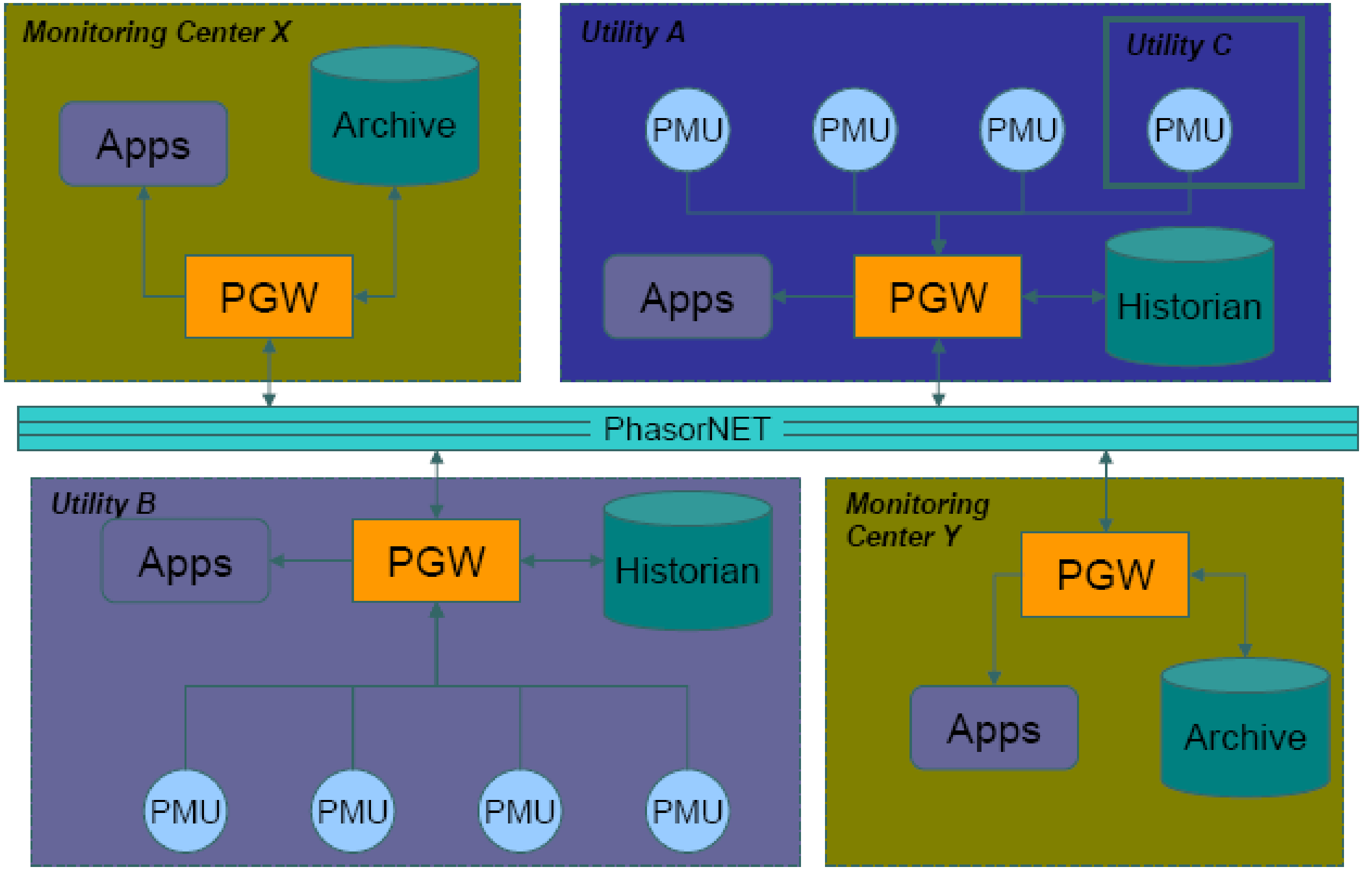
Phasor Architecture – Future



* Source: NASPI Data and Management Task Team

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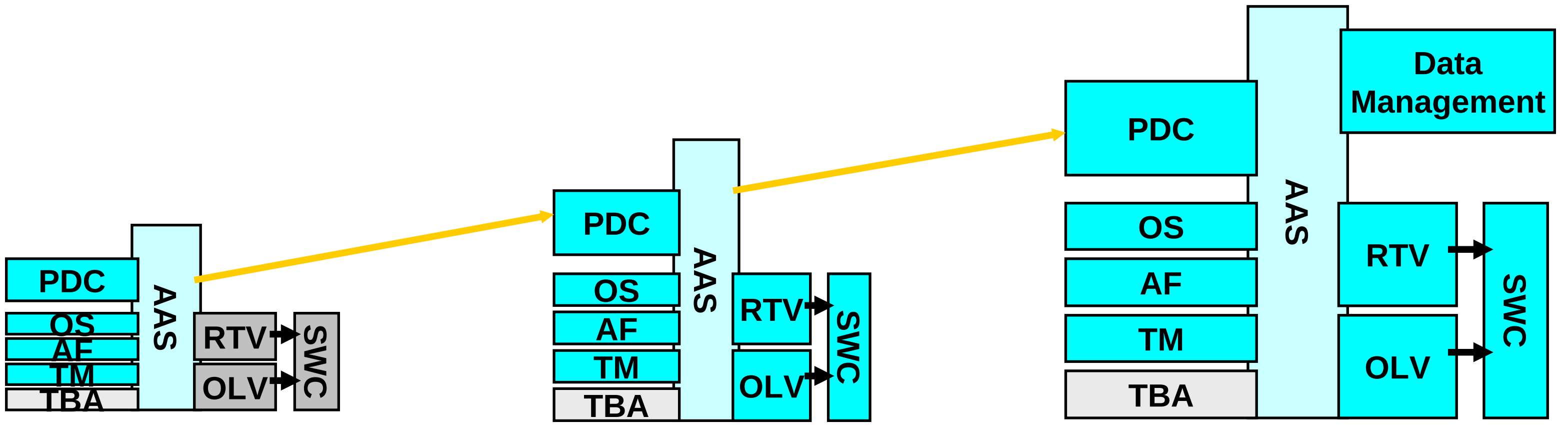
Next Generation PDC



PDC 10^1

- Ruggedised PCs
- Substation Use
- Local buffer
  - Comms failure
  - On Demand
- Hub (Multiple WAMS)
- Limited Applications
- <10 PMUs

PDC 10^2

- Single Datacentre Server
- Regional/National Use
- Variety of Applications
- Offline and Control Room
- <100 PMUs

PDC 10^3

- Multiple Servers
- Large connected areas
- Parallel/redundant use
- Security
- Management tools
- <1000 PMUs

* Source: NASPI Performance and Standards Task Team

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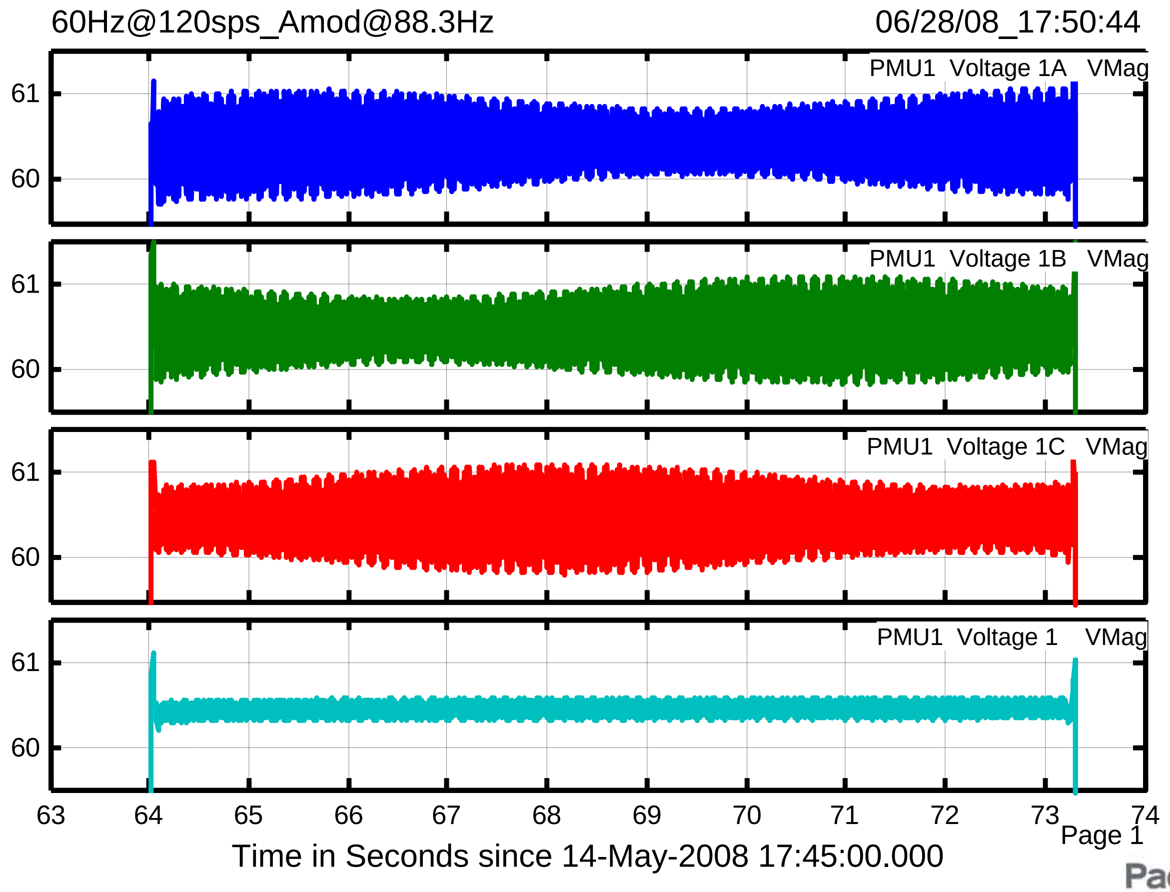
PMU Testing with Super-synchronous Rates
60Hz@120sps Amp Modulation 88.3Hz (1)

- Voltage Channels



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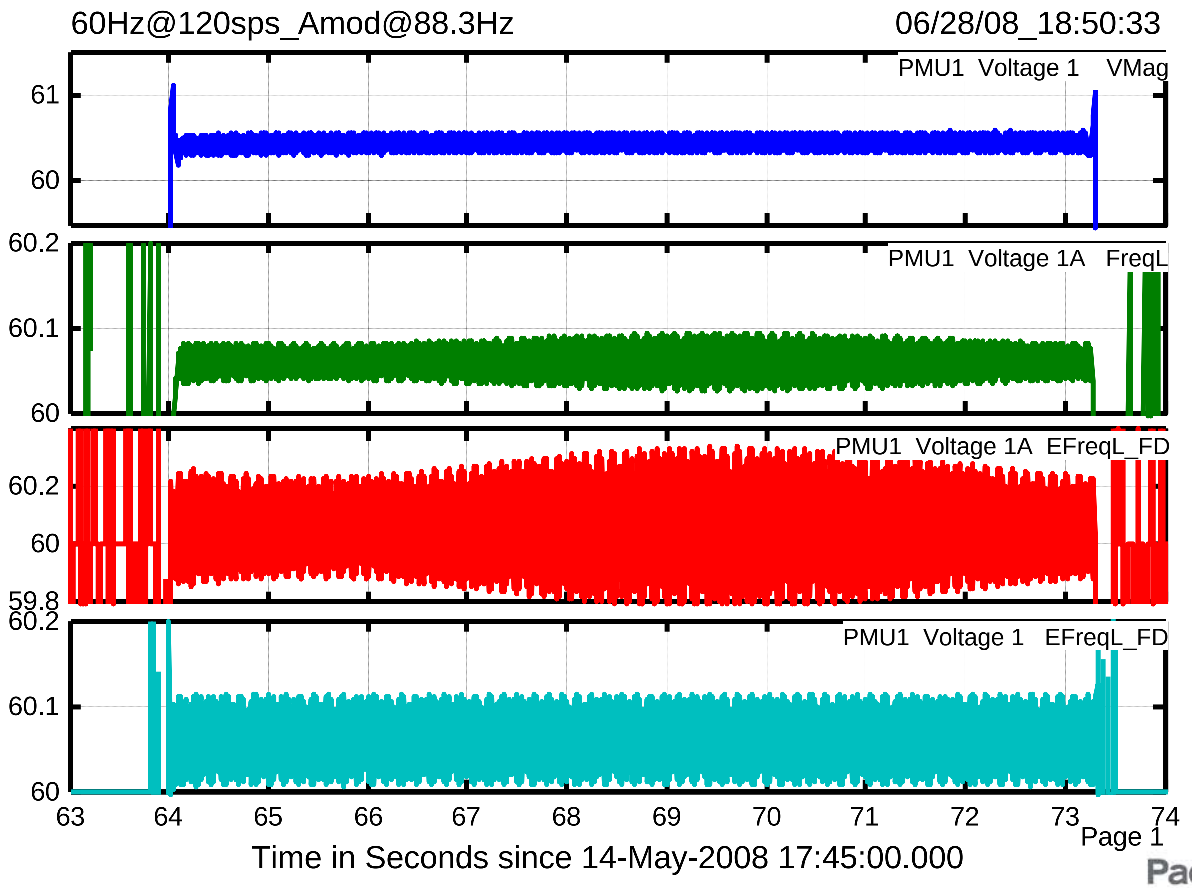
PMU Testing with Super-synchronous Rates
60Hz@120sps Amp Modulation 88.3Hz (2)

- Voltage and Frequency Channels



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Prony Analysis – Modes of Voltages

In CompassPlotsA: caseID=Test080514_120sps casetime=05/19/08_10:11:30

Sorted Mode Table for pole1: Fast noise

Signal			Freq in Hz	Damp Ratio (pu)	Res Mag	Res Angle
PMU1	Voltage 1A	VMag	31.70001919	-0.00001008	0.12587943	47.61523878
PMU1	Voltage 1B	VMag	31.70001919	-0.00001008	0.12446225	47.96357279
PMU1	Voltage 1C	VMag	31.70001919	-0.00001008	0.12298750	47.05455071
PMU1	Voltage 1	VMag	31.70001919	-0.00001008	0.12476979	47.69990087

Sorted Mode Table for pole3: Fast noise

Signal			Freq in Hz	Damp Ratio (pu)	Res Mag	Res Angle
PMU1	Voltage 1A	VMag	31.81987021	-0.00000716	0.50641836	104.01486468
PMU1	Voltage 1B	VMag	31.81987021	-0.00000716	0.50599074	-136.06882188
PMU1	Voltage 1C	VMag	31.81987021	-0.00000716	0.50661187	-15.89264980
PMU1	Voltage 1	VMag	31.81987021	-0.00000716	0.00049901	167.18866719

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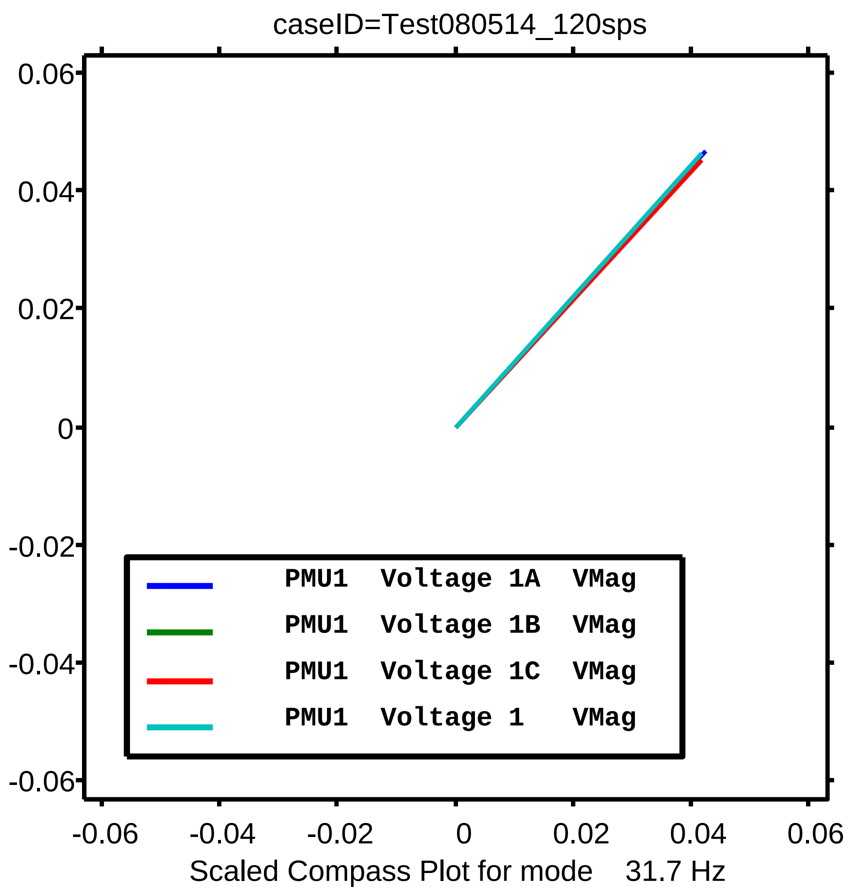
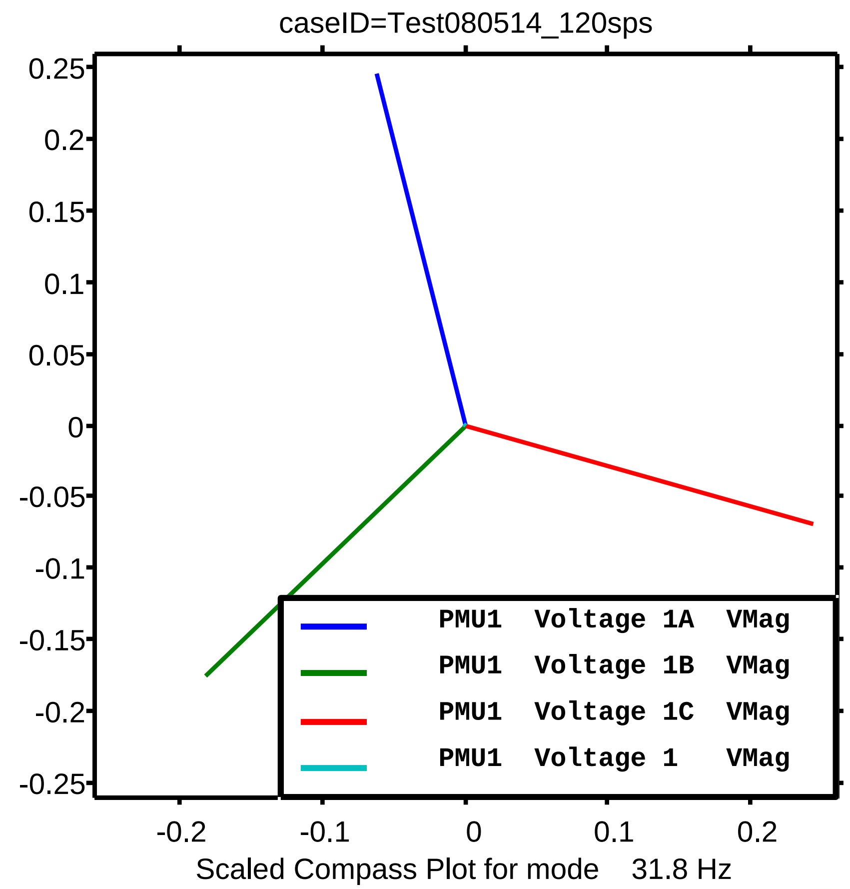
Prony Analysis – Mode Shapes of Voltages





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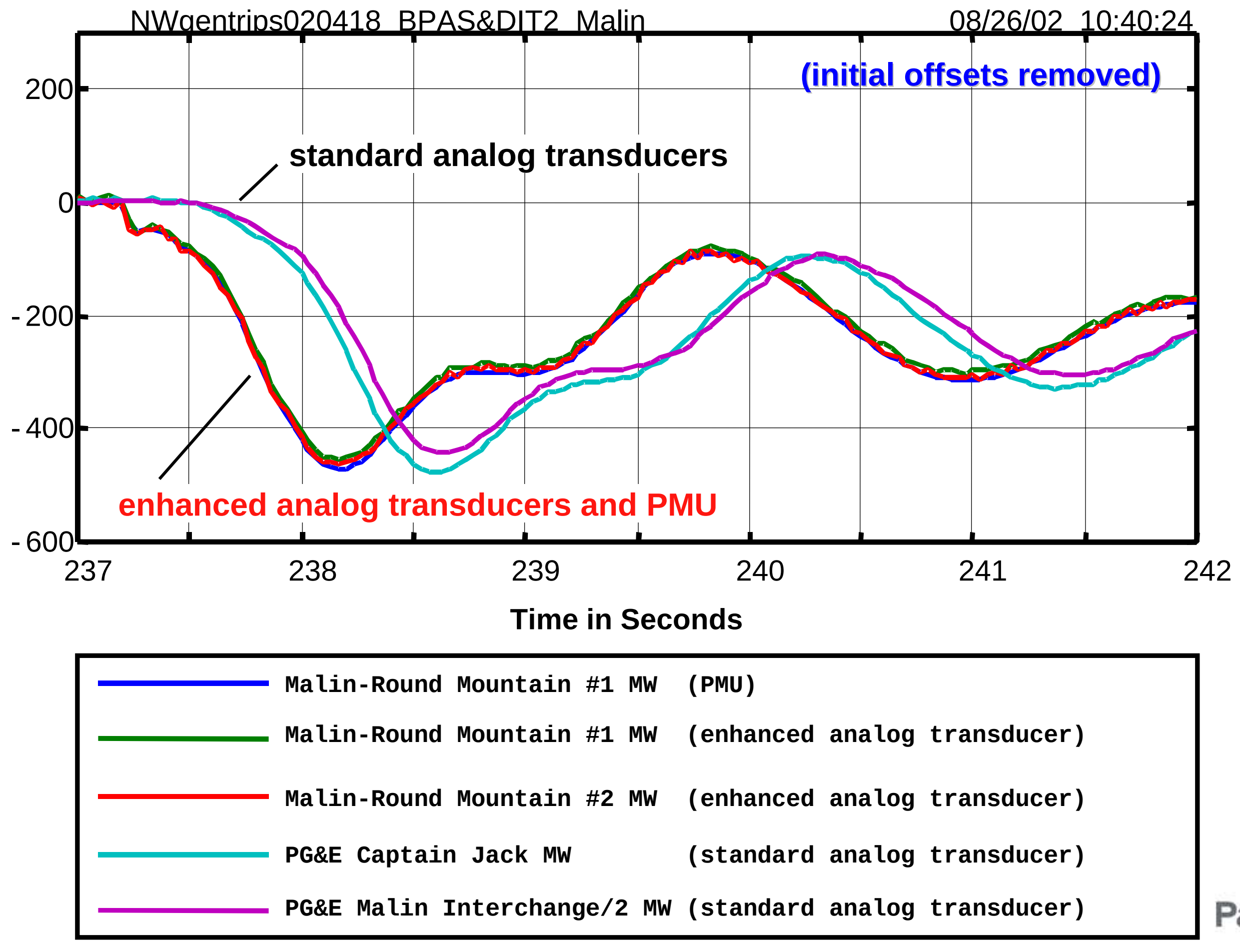
System-wide Phasor Evaluation with Actual Event Data – Timing (1)

- Timing Inconsistency Due to Filtering
  – Northwest Generation Trip Event on April 18, 2002



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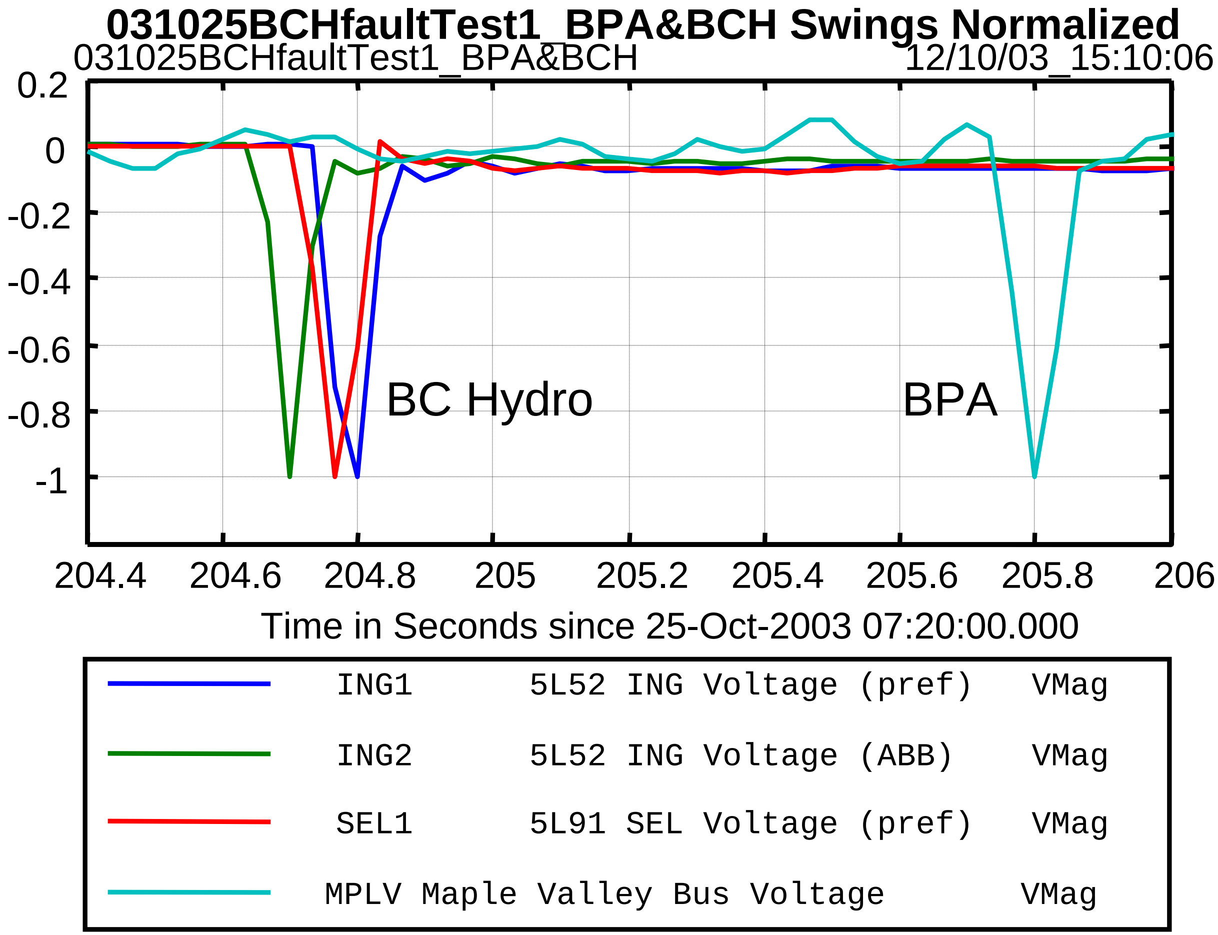
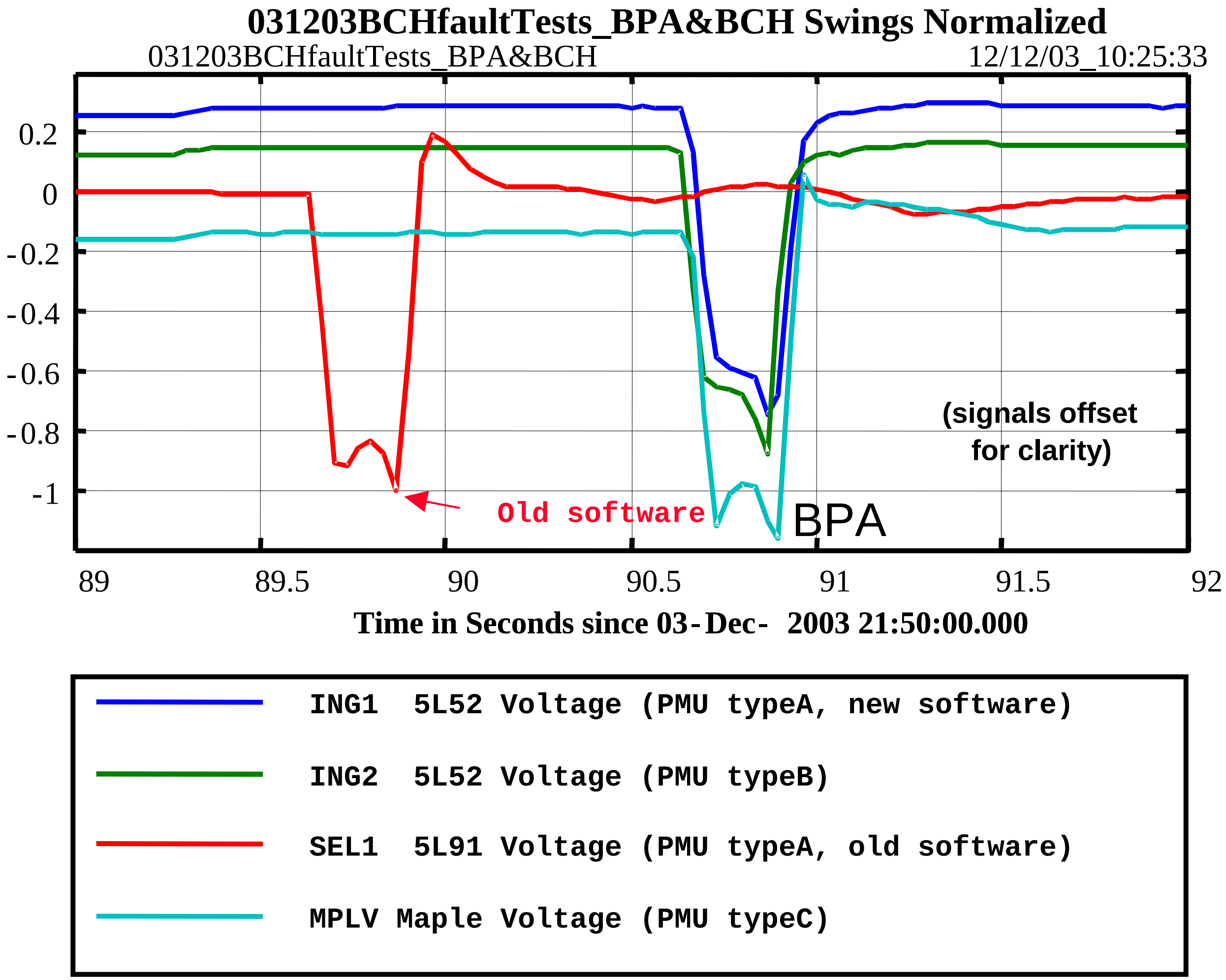
System-wide Phasor Evaluation with Actual Event Data – Timing (2)

- Timing Inconsistency Due to Poor Synchronization
  – BC Hydro Fault Test on October 25, 2003



System-wide Phasor Evaluation with Actual Event Data – Timing (3)

- Improved Timing of Voltage Signals
  - – BC Hydro Fault Test on December 3, 2003



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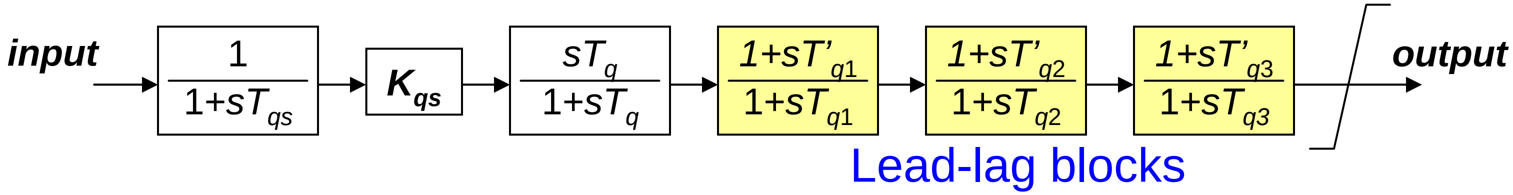
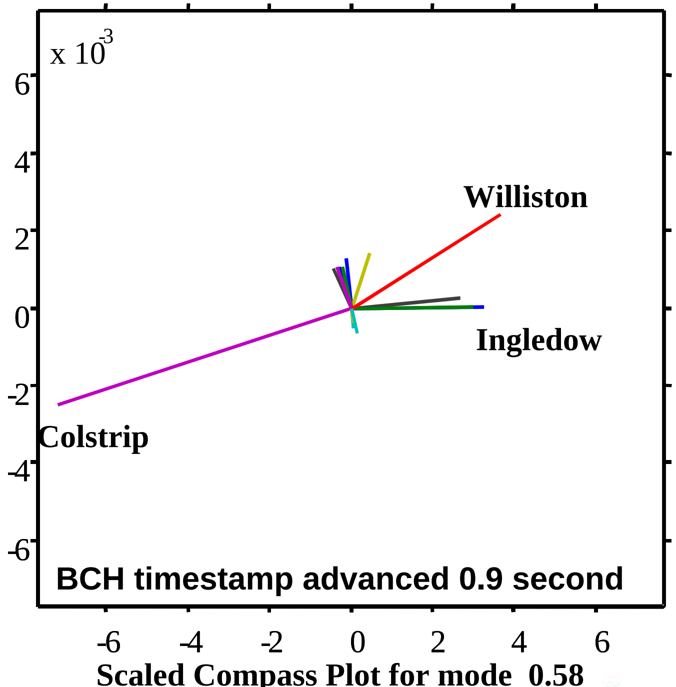
Application Implication:
Mode Shape Analysis to Determine Key Generators for Monitoring & Control

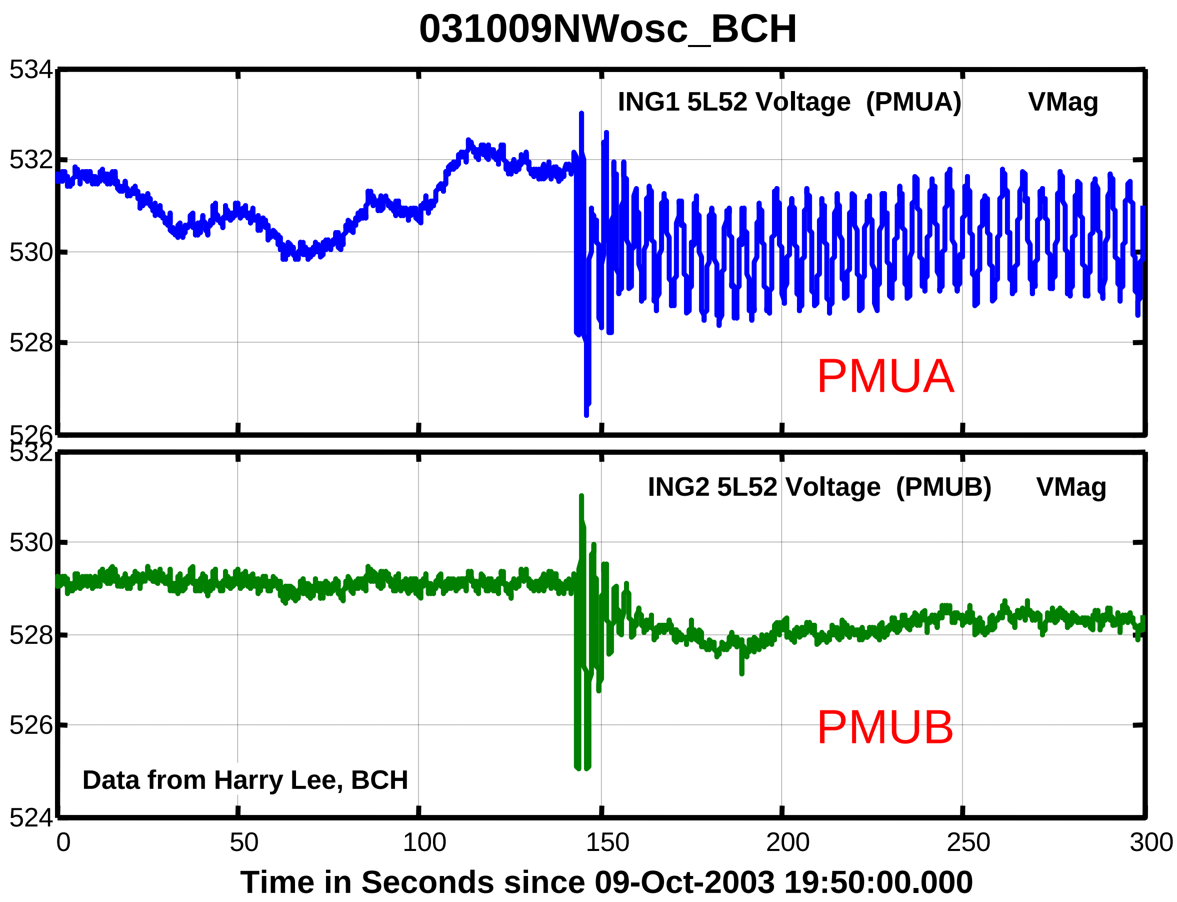


- Delay in input leads to unexpected control output, and thus unexpected (usually deteriorated) control performance
- Constant delay can be compensated with pre-processing logic
- Random delay needs to be accommodated with robust control design



System-wide Phasor Evaluation with Actual Event Data – Parasitic Oscillation

- Parasitic Voltage Oscillations
  - Northwest Oscillation on October 9, 2003



0.22 Hz parasitic oscillations with light damping

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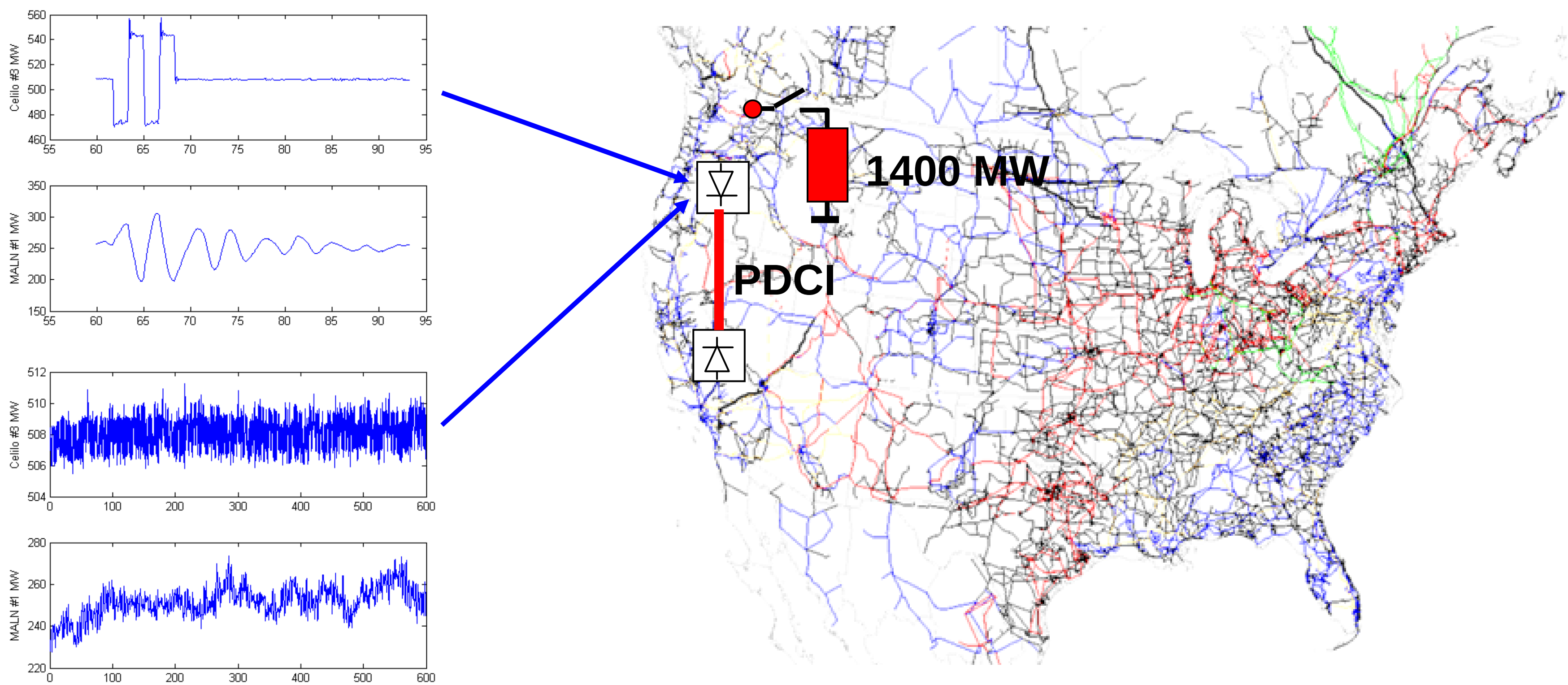
Application Implication:
Modal Analysis for System Monitoring and Control

- Parasitic oscillations lead to false alarming
- Parasitic oscillations lead to false arming of special stability controls

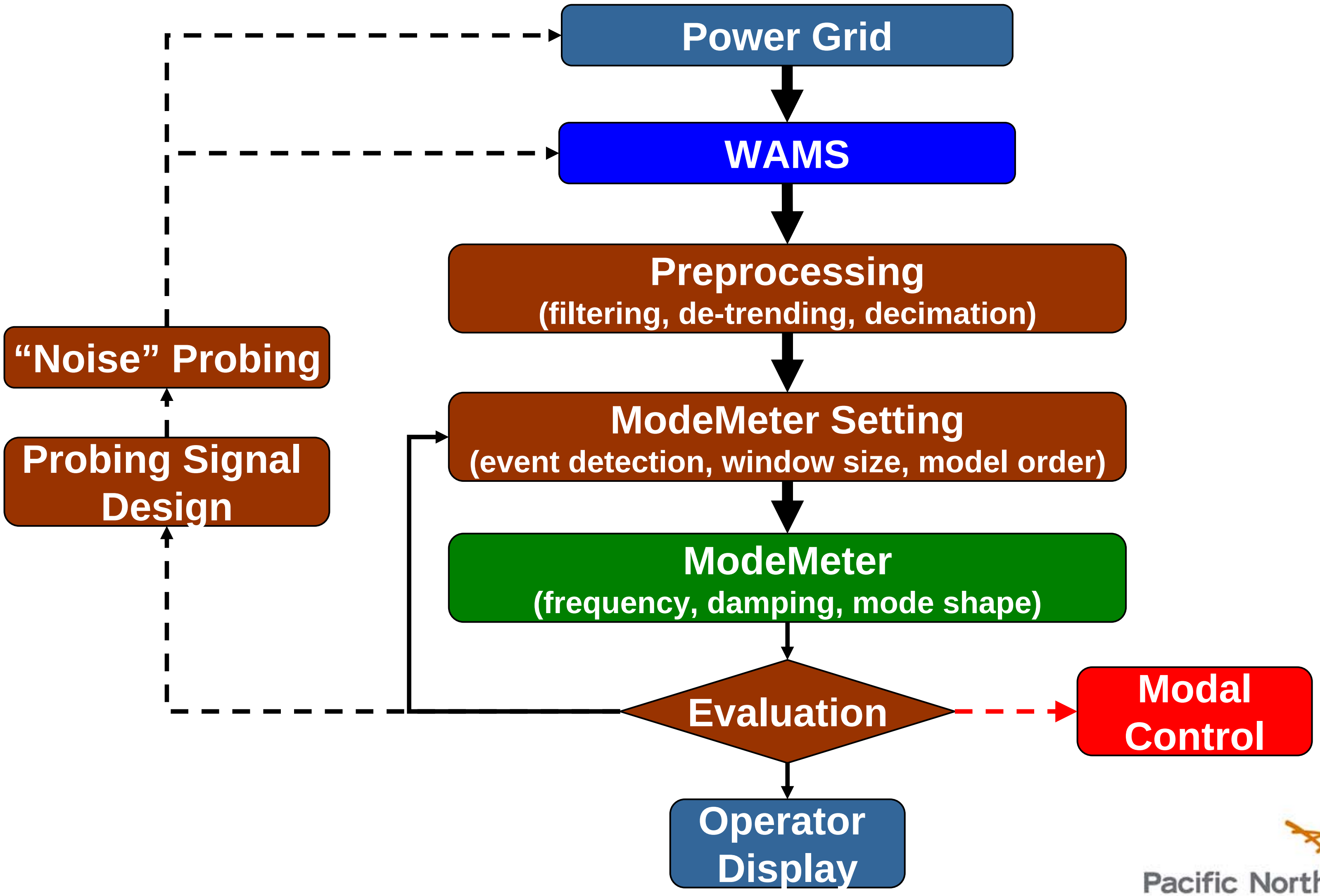
- PMUs need to be tested in a lab environment to determine the level of aliasing
- Parasitic oscillations need to be identified with careful examination of actual phasor measurements
- Lab testing and field measurement examination help to determine PMU setting and, if necessary, to improve PMU logic

System-wide Phasor Evaluation with System Test

- WECC staged system tests
  - Large Disturbance: Chief Joseph 1400 MW Brake Insertion
  - Small Disturbance: ±125 MW HVDC Modulation (PDCI)
  - “Noise” Probing: ±10/20 MW HVDC Modulation (PDCI)



Continuous System-wide Dynamic Monitoring



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Closing Remarks

- Phasor quality has been improved tremendously with the joint efforts of users, vendors and researchers
- New issues are emerging because of new development (e.g. more and faster PMUs)
- Phasor quality affects phasor applications, but in different degrees
- Deployment of phasor measurement units and phasor networks need to consider applications

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- NASPI Data and Management Task Team
- NASPI Performance and Standards Task Team
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Questions?

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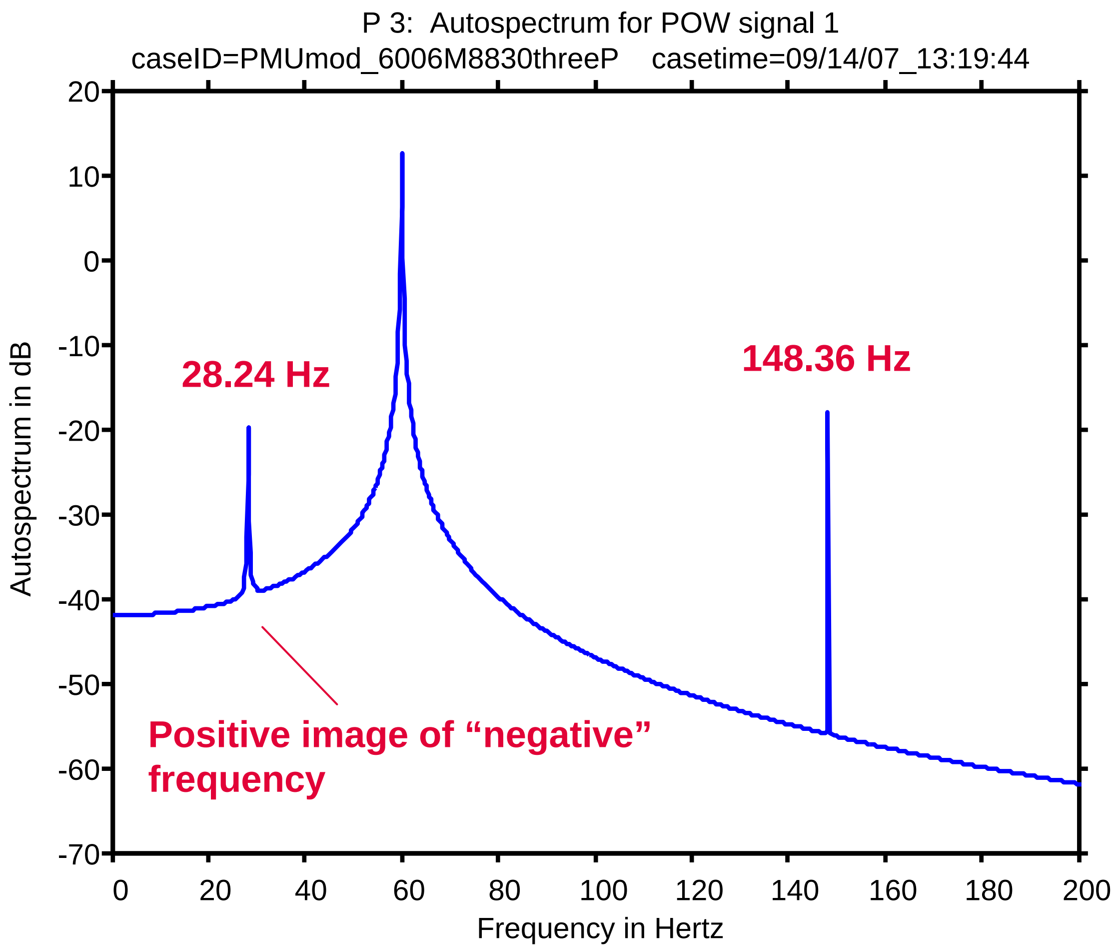
60Hz@720sps Amp Modulation 88.3Hz Model Studies – one-sided spectrum of input signal



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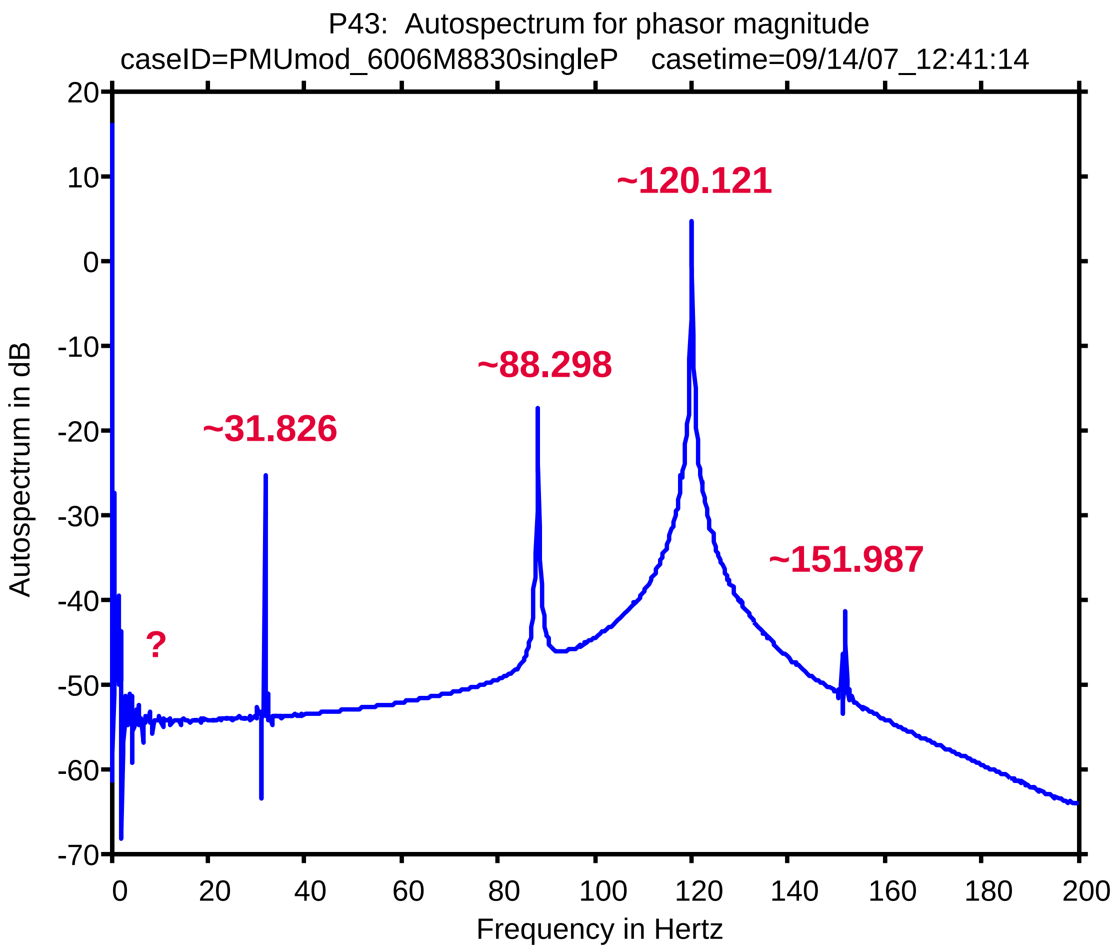
60Hz@720sps Amp Modulation 88.3Hz Model Studies
– one-sided spectrum of single-phase voltage



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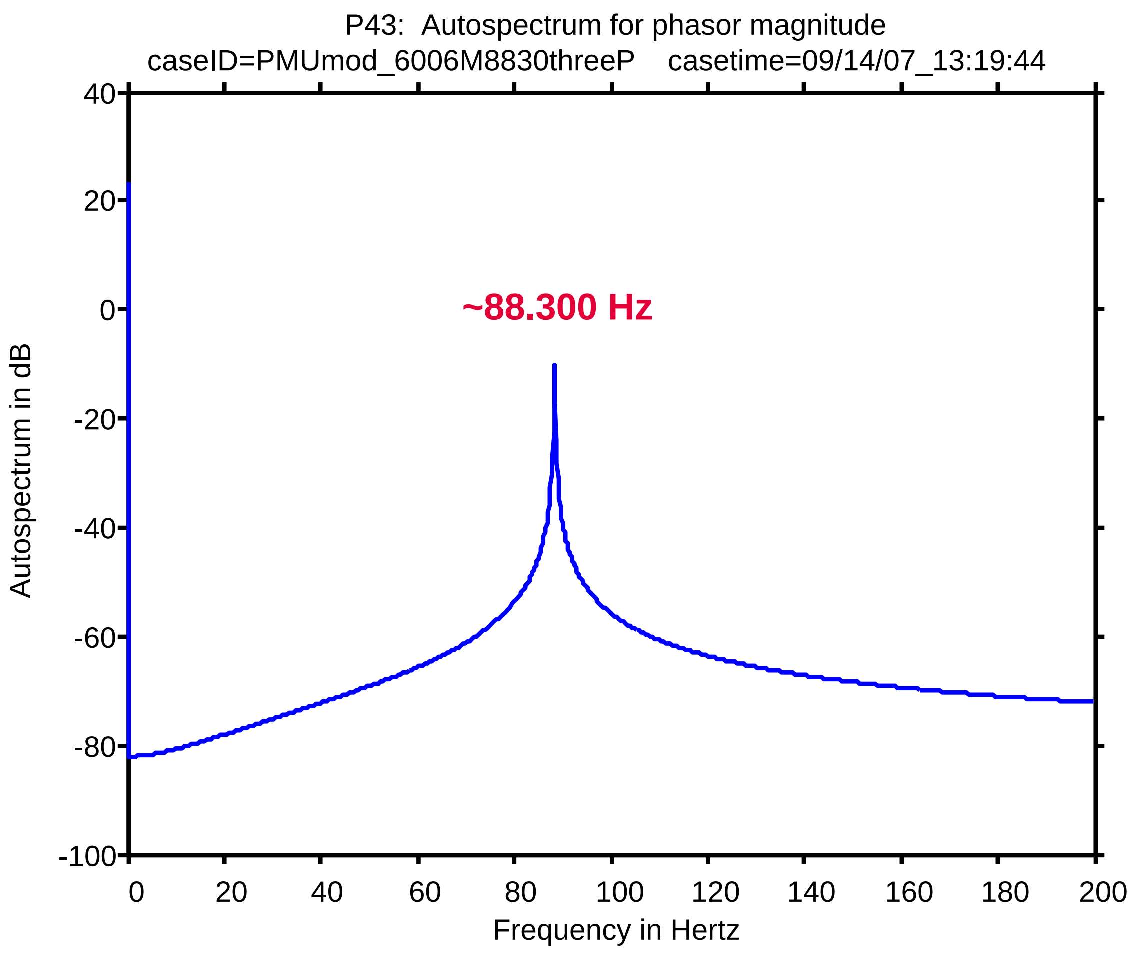
60Hz@720sps Amp Modulation 88.3Hz Model Studies – one-sided spectrum of three-phase voltage



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