Transforming the U.S. Electrical Grid

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PNNL provides the science, technologies and leadership to:

- Move grid control and operation timeframes from minutes to seconds
- Integrate demand response into grid/power markets for efficiency, reliability, PHEVs and carbon offsets
- Enable real-time, wide-area situational awareness for increased reliability
- Innovations to enable renewable generation integration
- Cyber secure grid networks

Add substantial IT "smarts" to bring digital intelligence and real-time communications and control through-out the power system to see and operate the grid as never before.

- Demand-side resources participate with distribution equipment in system operation
  - Consumers engage to mitigate peak demand and price spikes
  - More throughput with existing assets; reduce need for new assets
  - Enhanced reliability: bounds impacts, local resources self-organize to manage contingencies
  - Provide demand-side ancillary services – a boon to wind integration
- The transmission and bulk generation resources get smarter too
  - Improve the timeliness, quality, and geographic scope of the operator's situational awareness and control
  - Better coordinate generation, balancing, reliability, and emergencies
  - Utilizing high-performance computing, sophisticated sensors, and advanced coordination strategies

The challenge ahead is complex

The grid must meet new expectations

Historical Expectations

- Affordable, Power
- Reliable Power
- Secure Power

Emerging Expectations

- Delivering 300 GW of renewable generation by 2025

- Maximize benefits of end-use efficiency and storage

- Electrify transportation sector to reduce dependence on imported oil

- Meet future carbon and emissions constraints

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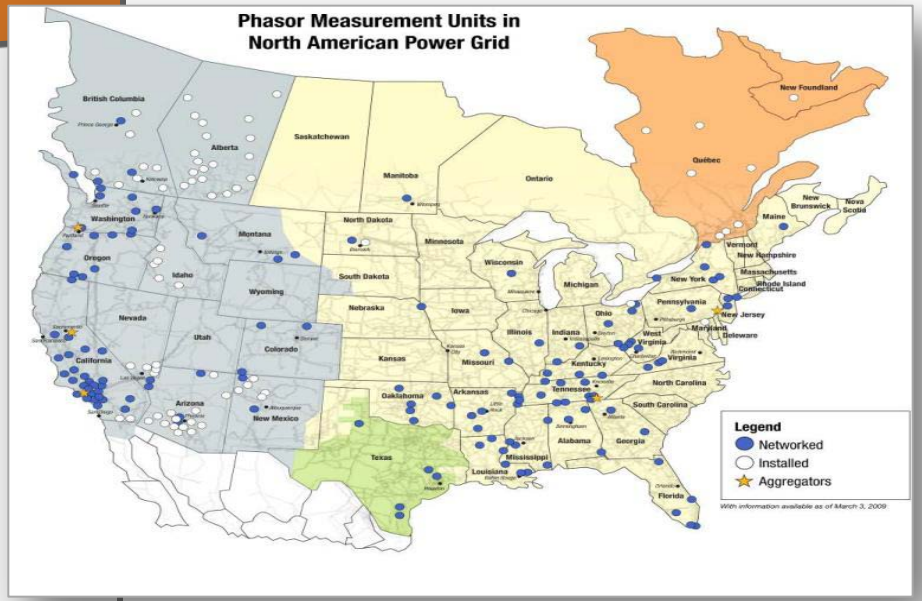
Wide-Area Awareness of Grid Status

North American SynchroPhasor Initiative (NASPI)

- New metering technology takes sampling window from six seconds to 60 times per second …. and a GPS time stamp!
- August 14, 2003 blackout reinforced the value of synchronous measurements for enhanced situational awareness
- DOE and NERC driving a continental system; FERC supportive
- Phasor data will drive a new generation of monitoring, operator decision support and, ultimately, fast real-time controls to improve grid performance



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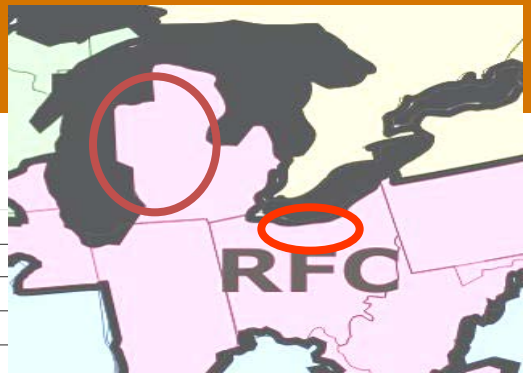
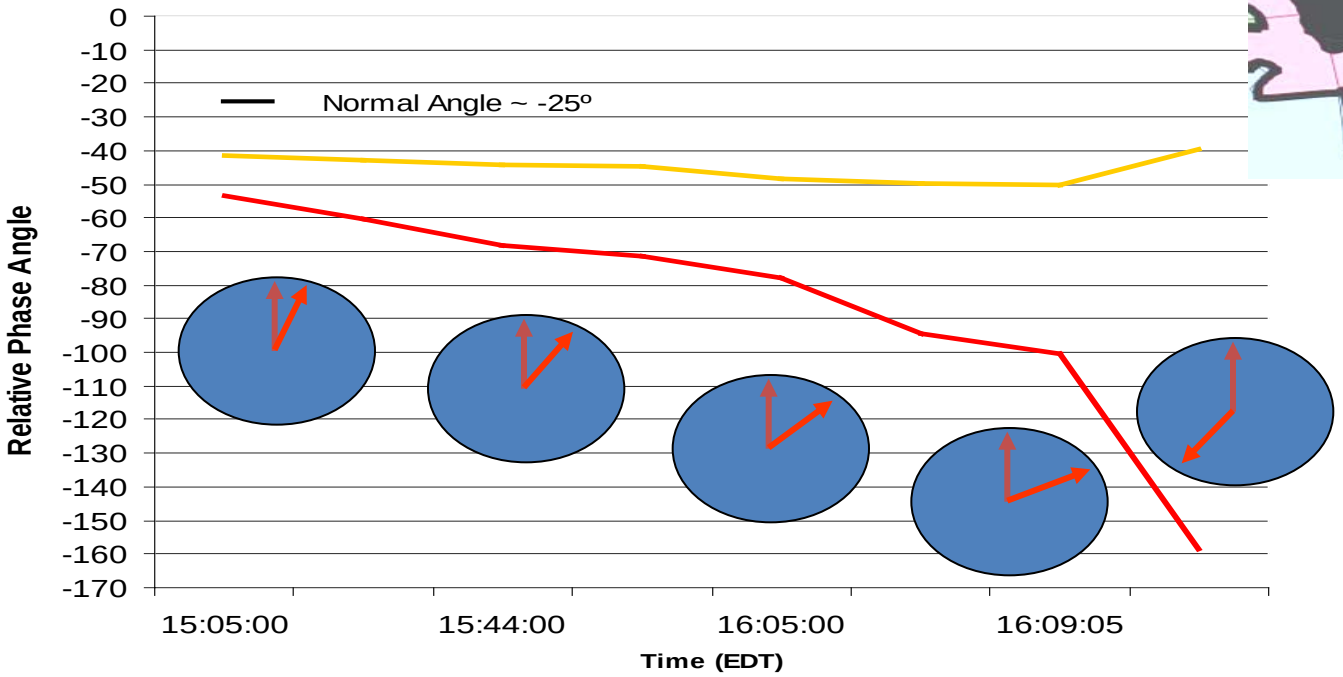
If We Knew Then…

August 14, 2003 Blackout





Reference:
Browns Ferry

Slide Credit:
North American Electric Reliability Corporation (NERC)

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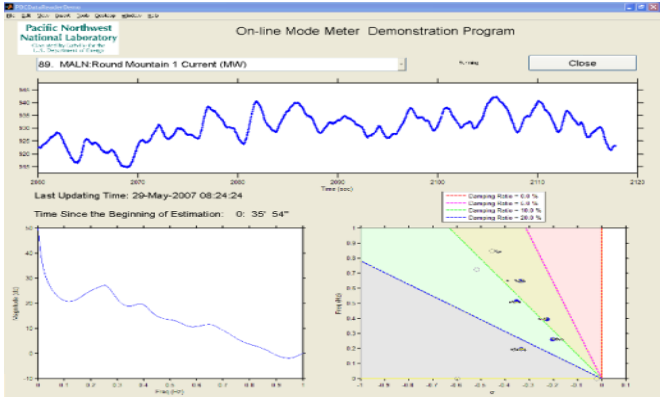
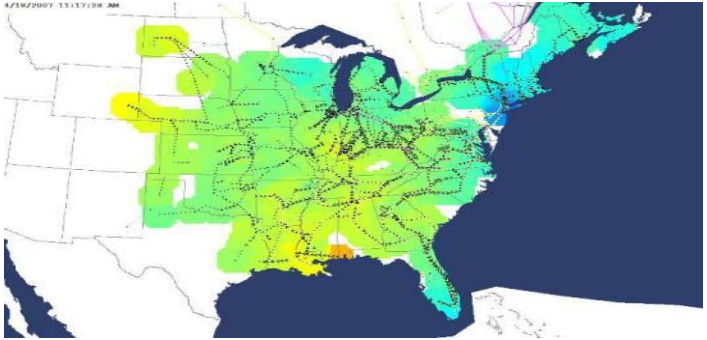
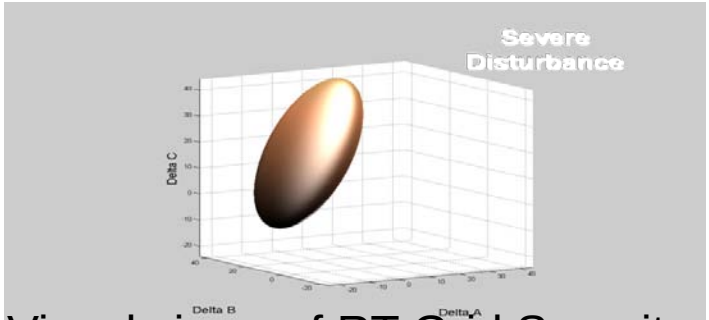
Advanced Tools Highlights



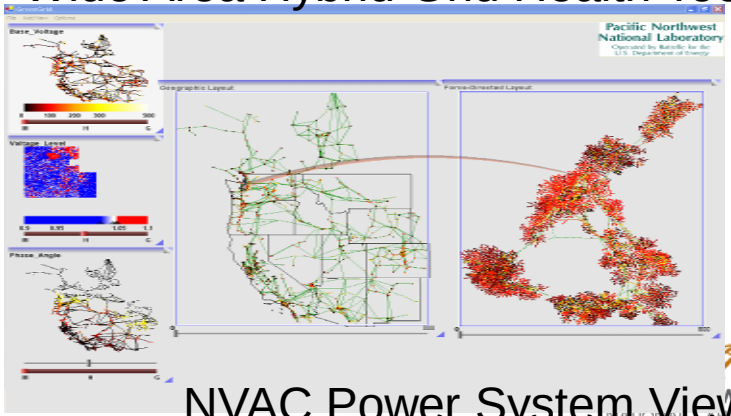
Small Signal Analysis Tool



Wide Area Hybrid Grid Health Tool



Visual views of RT Grid Security



NVAC Power System View

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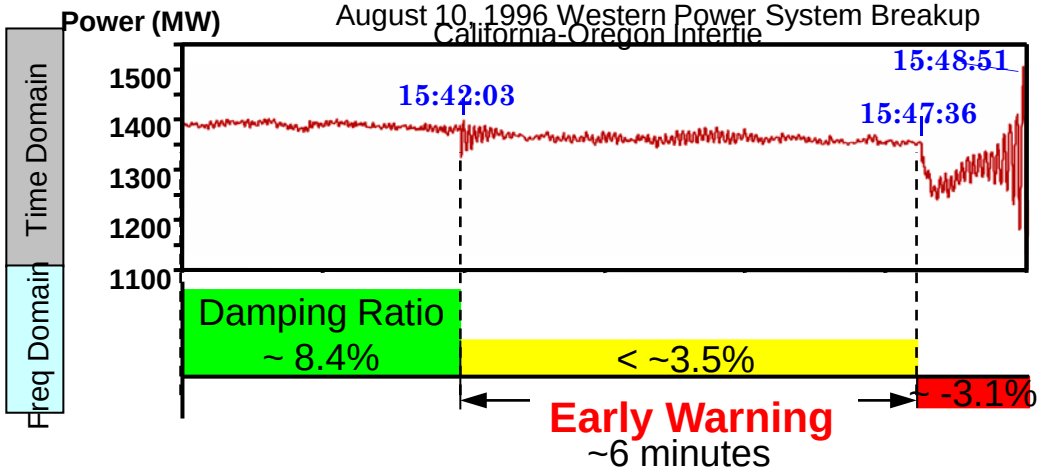
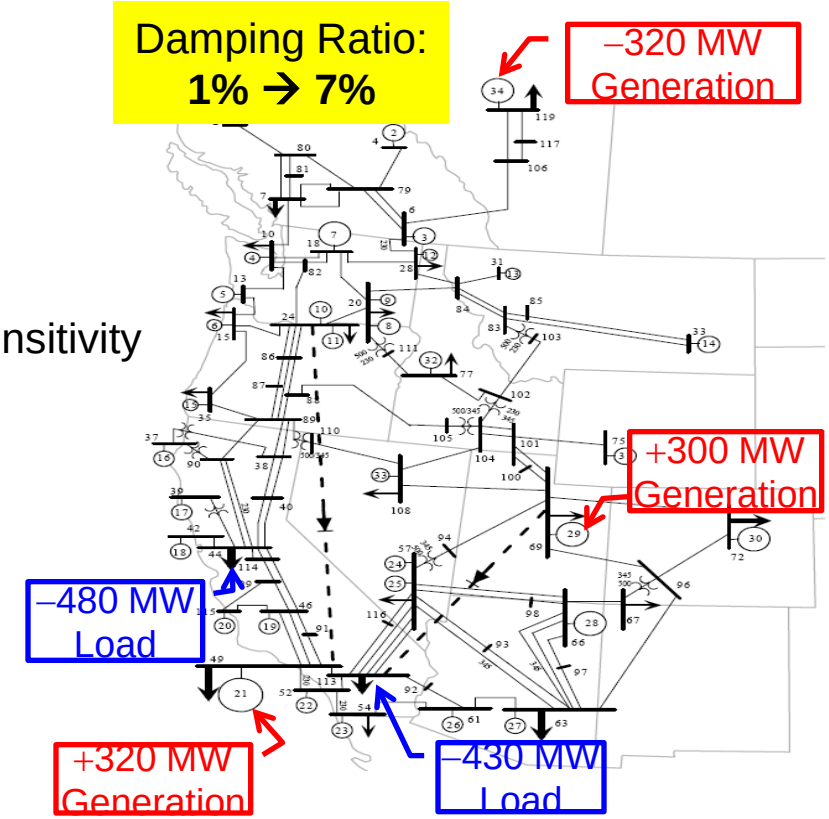
Stability Assessment and Blackout Prevention

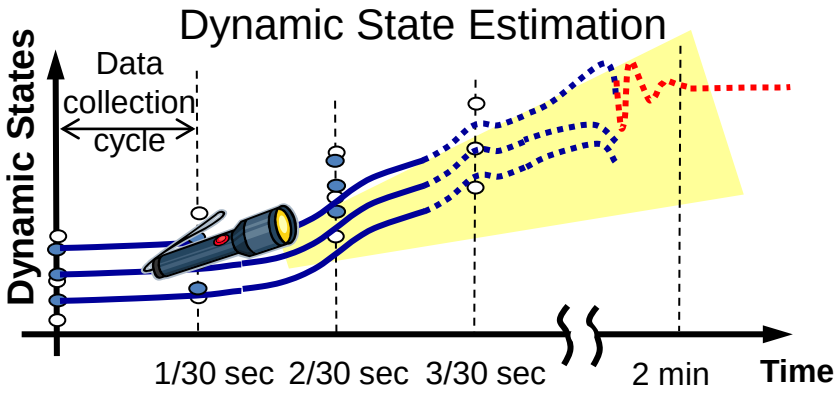
- **Today:** no real-time monitoring of oscillatory stability
- **Tomorrow:** real-time monitoring of oscillatory signatures – frequency and damping ratio –using advanced signal processing techniques
- **Future:** real-time wide-area decision support to prevent oscillations using eigenvalue sensitivity analysis

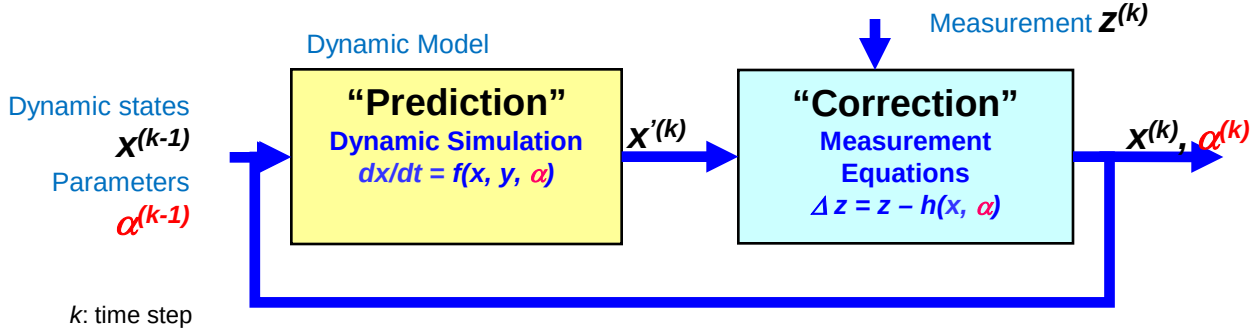




State Estimation for Real-Time Situational Awareness and Responsiveness

- **Today:** static, slow, and local view
  - 2-4 minutes to solve nonlinear equations on single Itanium processor with LU linear solver
- **Tomorrow:** static, but fast and global view
  - 2-4 seconds on parallel computers using parallelized Conjugate Gradient solver
- **Future:** dynamic, fast, global, and predictive view
  - 1/30 second with predictive ability through solving a set of differential algebraic equations using Kalman filter techniques





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Contingency Analysis and Emergency Management

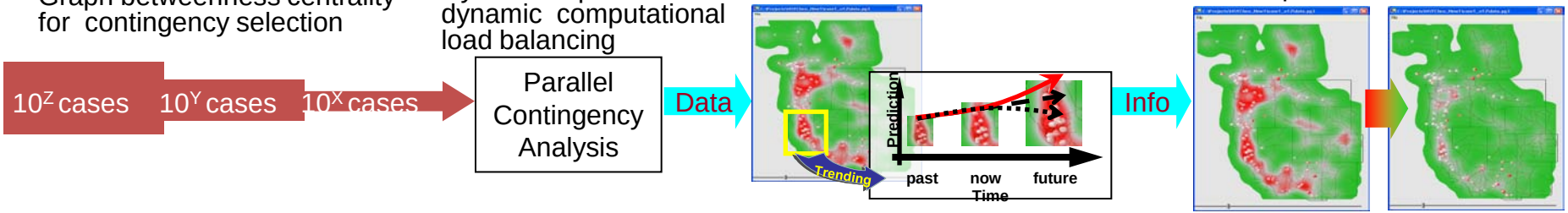
- **Today**: limited “N-1” and “N-2 light” contingency analysis, no decision support
- **Tomorrow:** parallel processing to analyze more contingency cases
- **Future:** parallel massive “N-x” contingency analysis with real-time decision support

Contingency Analysis	Number of cases	Serial Computing on single processor	Parallel Computing on 512 processors	Speedup
WECC N-1 (full)	20,000	4.0 hours	0.5 minutes	469
WECC N-2 (partial)	153,600	25.8 hours	3.1 minutes	492
WECC N-2 (full)	~10^8			
WECC N-3 (full)	~10^{12}			

Graph betweenness centrality for contingency selection

Hybrid computation with dynamic computational load balancing

Visual analytics techniques for information extraction and representation



Multi-Threaded Parallel Machine | Cluster Machine | Multi-Threaded Parallel Machine