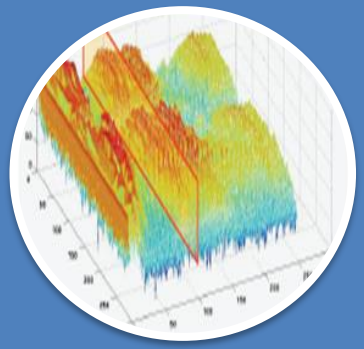


High Performance Computation Tools for Real-Time Security Assessment

IEEE PES GM 2014, Washington, DC Metro Area, July 27-31, 2014

Panel Session: Faster than Real-time Dynamics Simulation

Alberto Del Rosso, PhD
Electric Power Research Institute

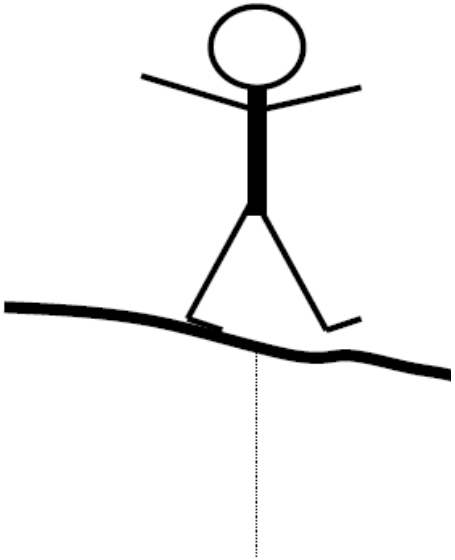
DOE Award # DE-OE0000628

Project Objective and Outcome

- Develop a set of new algorithms and computational approaches for improving situational awareness and support operator decision making by means of:
  - **real-time assessment of system dynamic performance**
  - **operational security risk**
- Outcomes:
  - Computational approach for ultra-fast power-system dynamic simulation
  - Mathematical algorithms for synchrophasor-based and hybrid DSA
  - Specification for advanced visualization software

Outcomes are expected to set a foundation for a new generation of real-time Dynamic Security Assessment tools

Wide-area situational awareness



Measurements give us current system states:

For true situation awareness we need to know;

- Where the edge is
- How close to the edge we can safely (reliably) operate
- Where would the states be during & after the next contingency

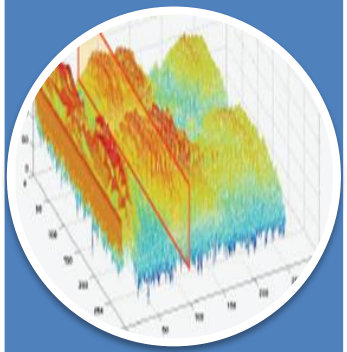
Decision support tool should provide:

- A succinct view of the current status of the power system
- "look-ahead" capability based on "what-if" scenarios

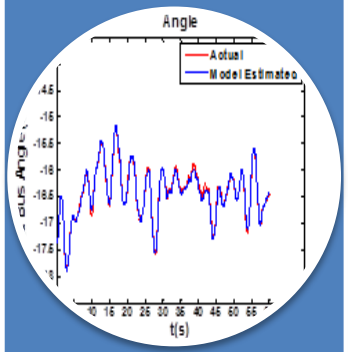
Courtesy of Mahendra Patel

Areas of Development

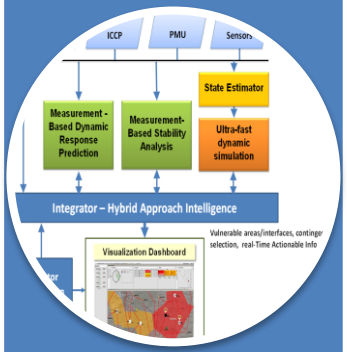
High performance dynamic simulation software



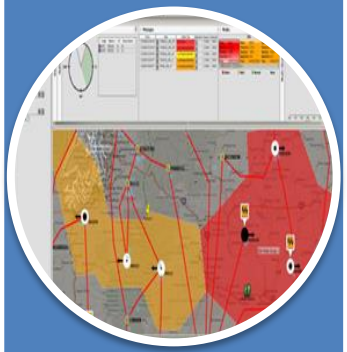
Measurement-based Voltage and Angular Stability Analysis



Measurement Based Dynamic Response Prediction

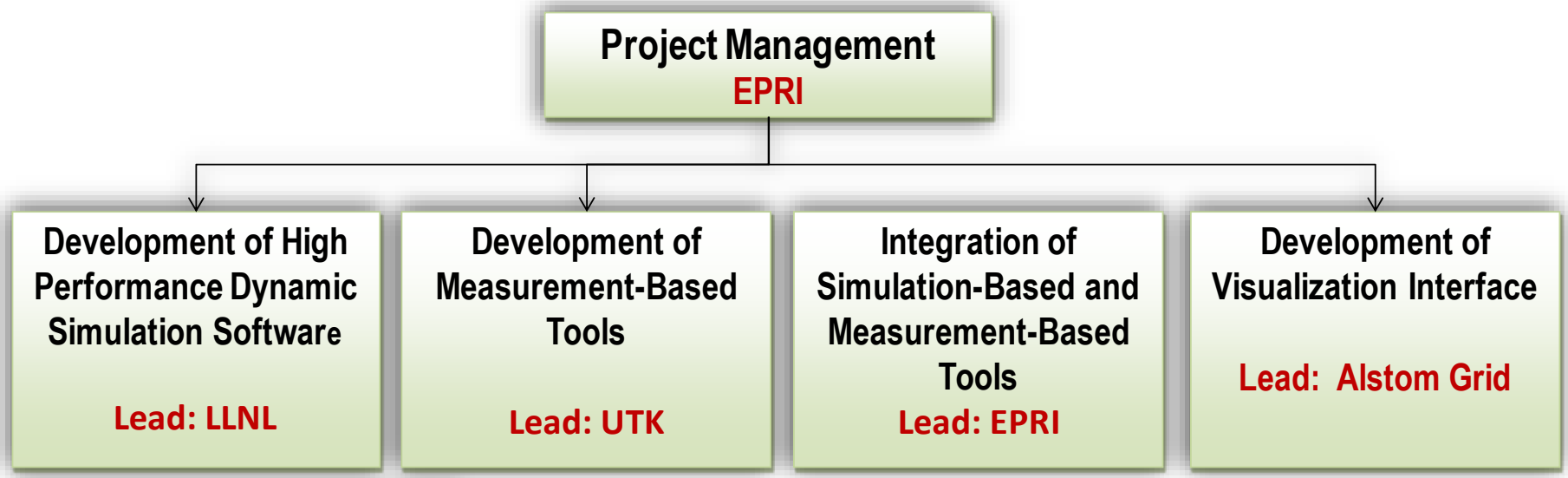


Hybrid Approach Intelligence



Advanced Visualization

Project Participants and Responsibilities



Utility/ISO Participants

Southern Company
American Electric Power (AEP)
PJM Interconnection
Tennessee Valley Authority (TVA)

EPRI: Electric Power Research Institute
LLNL: Lawrence Livermore National Laboratory
UTK: University of Tennessee Knoxville

Project Team

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- Navin Bhatt (EPRI)
- Liang Min (LLNL)
- Carol Woodward (LLNL)
- Steve Smith (LLNL)
- Chaoyang Jing (eMIT)
- Kai Sun (UTK)
- Yilu Liu (UTK)
- Jay Giri (Alstom Grid)
- Manu Parashar (Alstom Grid)
- Jiawei Ning (Alstom Grid)

Technical Approach

Measurement Based Analysis

- Identifies criticality of the system when simulation results are not available
- Identifies vulnerable regions and critical grid components
- Triggers emergency control actions
- Model reduction

Simulation Based Analysis

- "What-if" analysis. Identifies potential N-1 violations
- Preventive control actions recommendations
- HPC enabled faster than real-time performance

Hybrid Approach Intelligence

- Combines strengths of both approaches
- Analyzes, manages, coordinates, and post-processes results from the different modules to generate actionable information
- Information and visualizations with focus on the operator needs &perspective

Real-time Stability Margins

Real-Time Alerts

Emergency Automated Actions

Recommendations on Preventive Actions

High Performance Dynamic Simulation Software

Improvement of EPRI's Extended Transient Midterm Simulation Program (ETMSP)

Identified bottlenecks

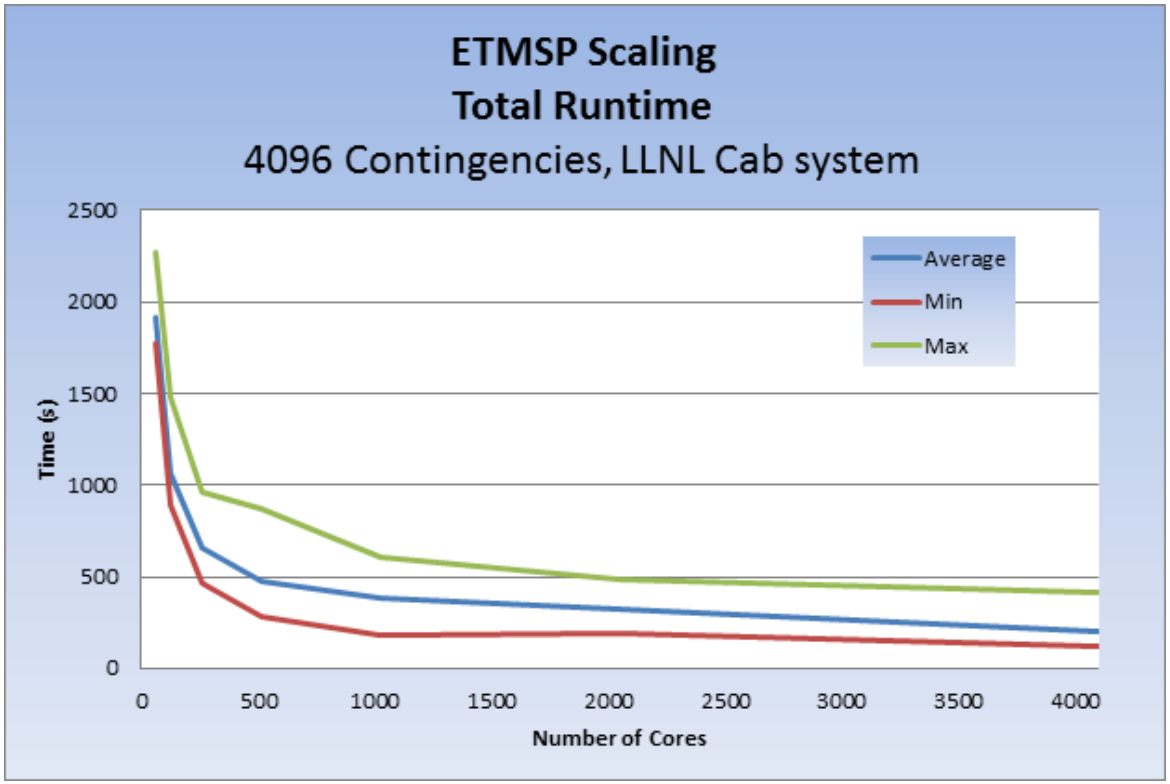
Parallelization of contingencies

Speedup of single contingency simulation

- **Reduce time due to Input/Output**
  - Replace ETMSP's Linear Solver with SuperLU_MT
  - Use variable time step integration algorithm

Parallel Contingency Analysis

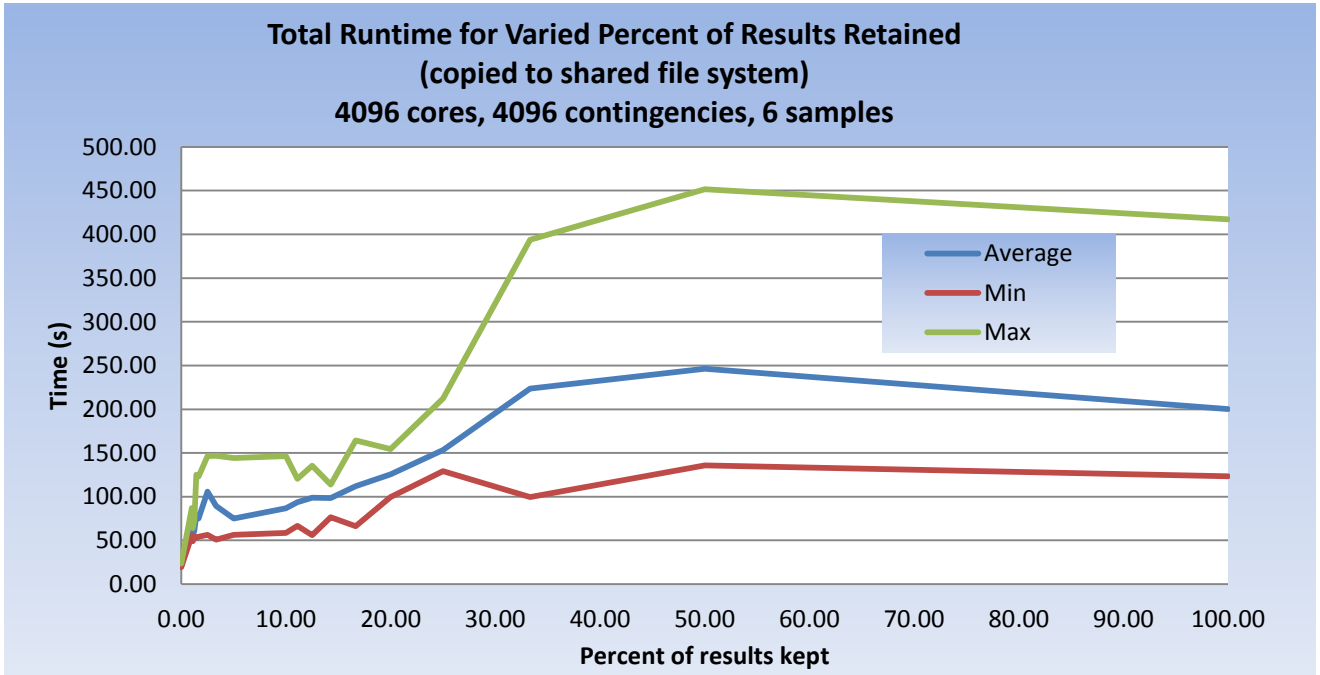
	Total Runtime (s)			
Number of Cores	Average	Min	Max	StdDev
64	1915	1774	2275	184
128	1062	891	1480	211
256	658	469	960	189
512	477	286	869	187
1024	384	183	610	129
2048	324	193	490	96
4096	200	123	417	105



Would take ~20.4 hours on sequential machine

Reducing I/O Bottleneck

- I/O reduction by keeping only results of interest
- Experiments with different % of output results
- Would need to output <30% for this strategy to have a significant impact on performance



Variable Time Step Integrator

- Applied Adams-Bashforth-Moulton predictor-corrector control for differential variables
- Step sizes chosen to minimize truncation error for differential variables

Speedup 59% for 10s simulation on the 25,000 bus test case

Step Size Scheme	Time (s)
Fixed Step	21.0
Variable Step	8.8

Thread-parallelization of Sparse Linear Solver

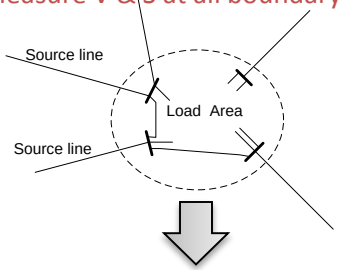
- Test results on 25,000 bus system

Number of Monitored Buses	Original Solver (sec)	SuperLU_MT with 4 Threads (sec)
200	0.8	9.66
2000	4.32	9.69
20,000	10.23	9.71

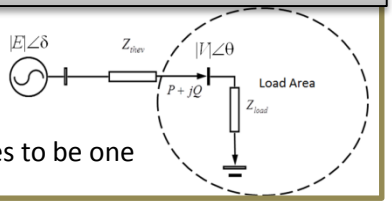
- **No advantage when limited number of buses is monitored**
- Reason: SuperLU_MT does full backward substitution. ETMSP does only partial backward substitution
- Linear solver takes only 10% of overall CPU time

Measurement-based Voltage Stability Assessment

1. Measure V & S at all boundary buses



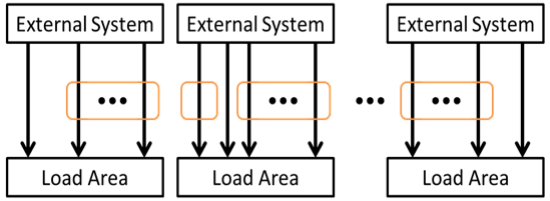
Thevenin equivalent (1+1 buses)

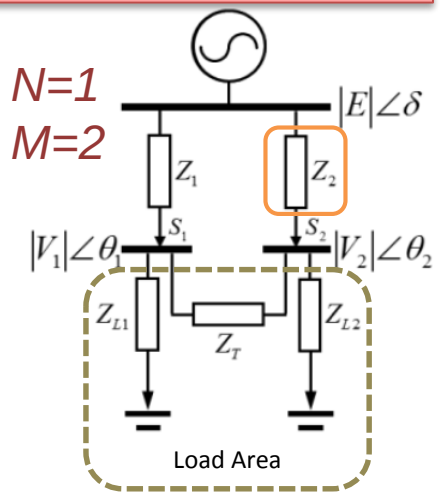


Merge all lines to be one

New multi-terminal network equivalent (N+M buses)

2. Equivalent with details on different transfer paths





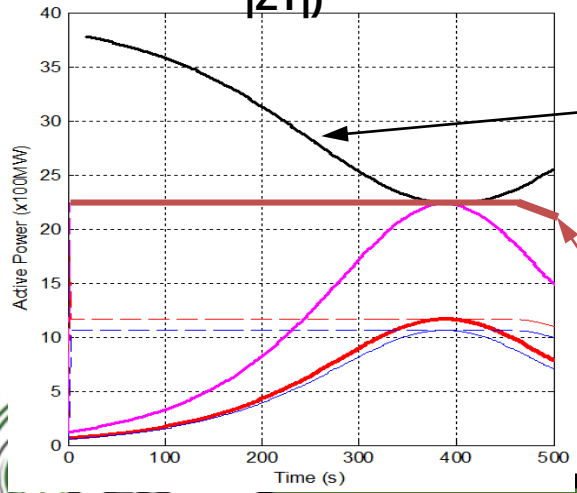
3. Real time estimation for E and Z's

4. Direct transfer limit calculation for each path

$$P_{1\max} = f_1(E, Z_1, Z_2, Z_{L1}, Z_{L2}, Z_T)$$

$$P_{2\max} = f_2(E, Z_1, Z_2, Z_{L1}, Z_{L2}, Z_T)$$

Tight coupling between tie lines (small |ZT|)

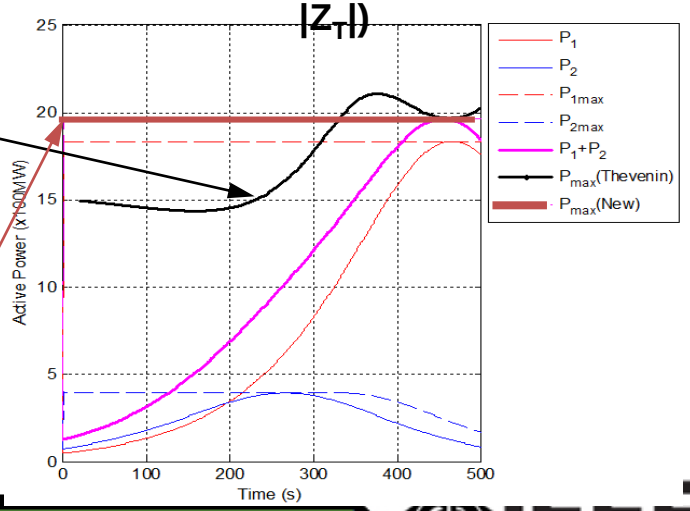


Comparison

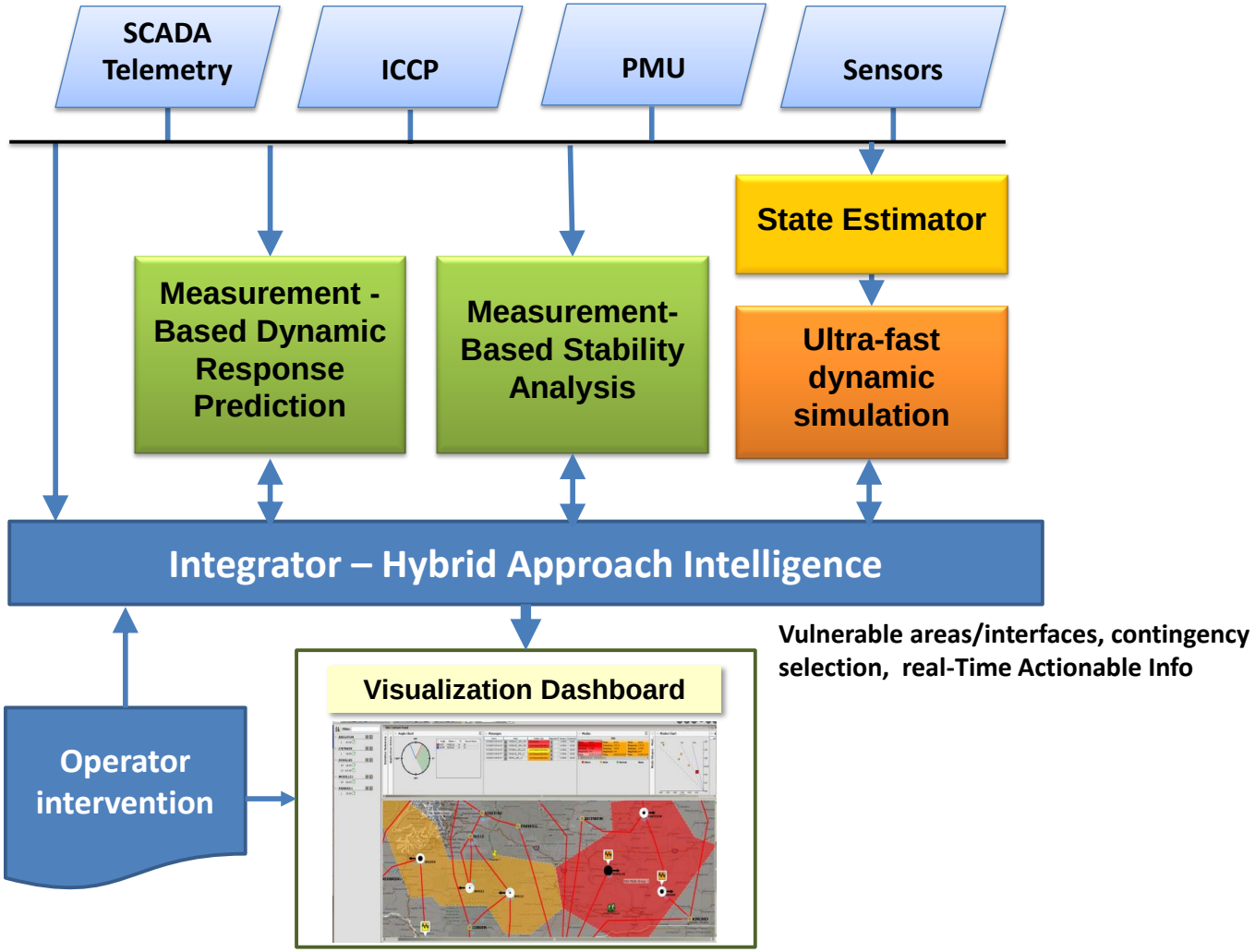
Thevenin approach:
- Inaccurate due to merging all tie lines

New approach:
- accurate total limit
- estimates the limit for each line

Weak coupling between tie lines (large $|Z_T|$)

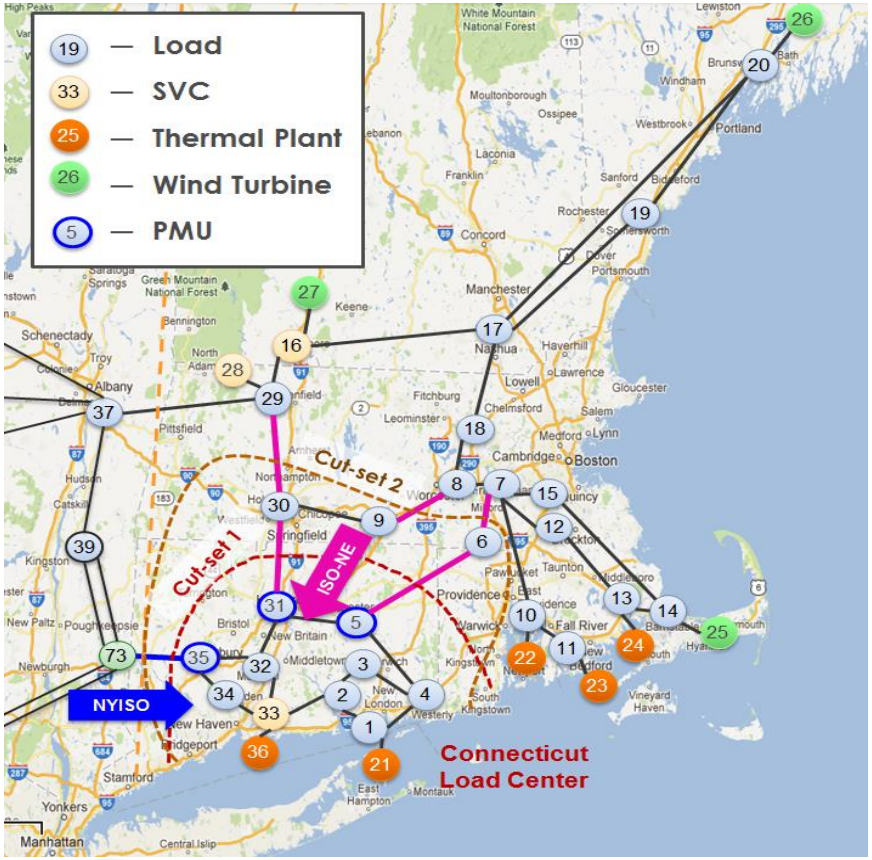


Hybrid Approach Intelligence

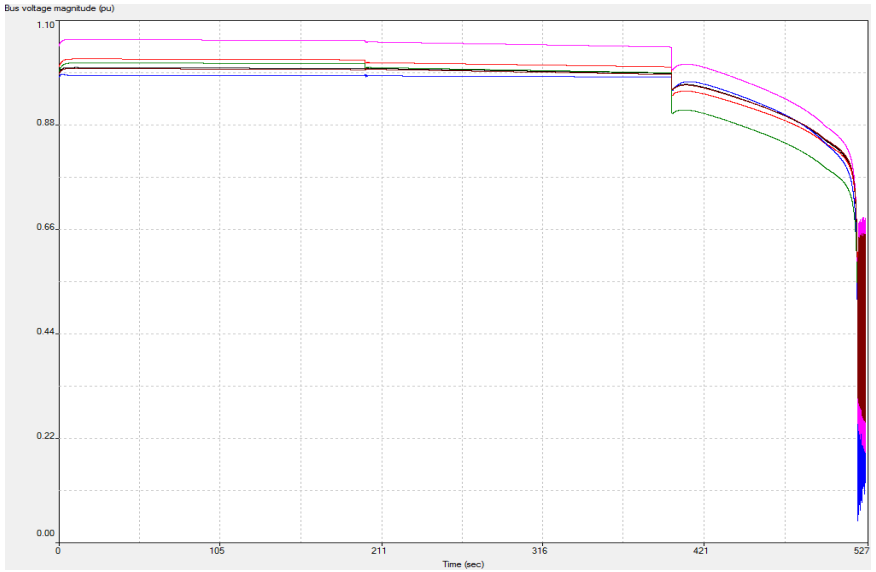


Illustrative Example

Voltage collapse scenario

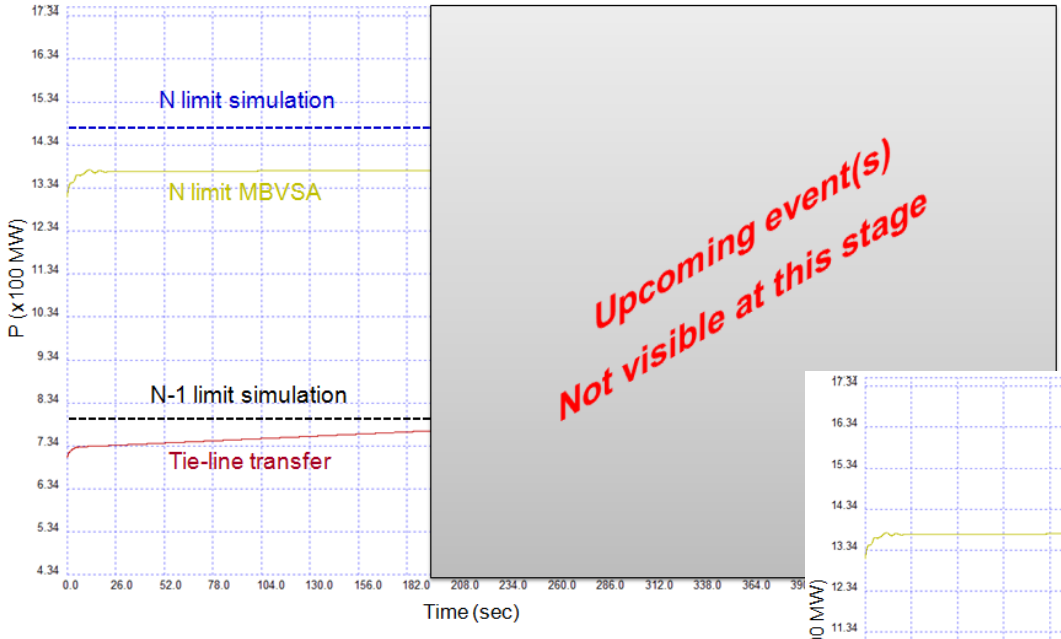


Stage 1	No Contingency
Stage 2	Line 31-32 tripped
Stage 3	Lines 31-32 & 30-31 tripped

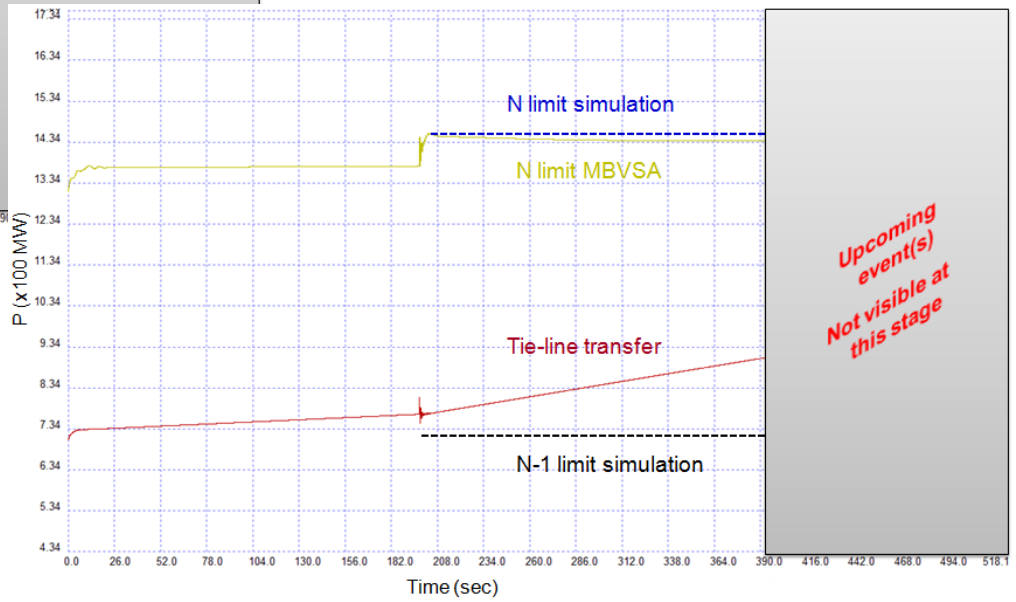


Illustrative Example

Stage 1

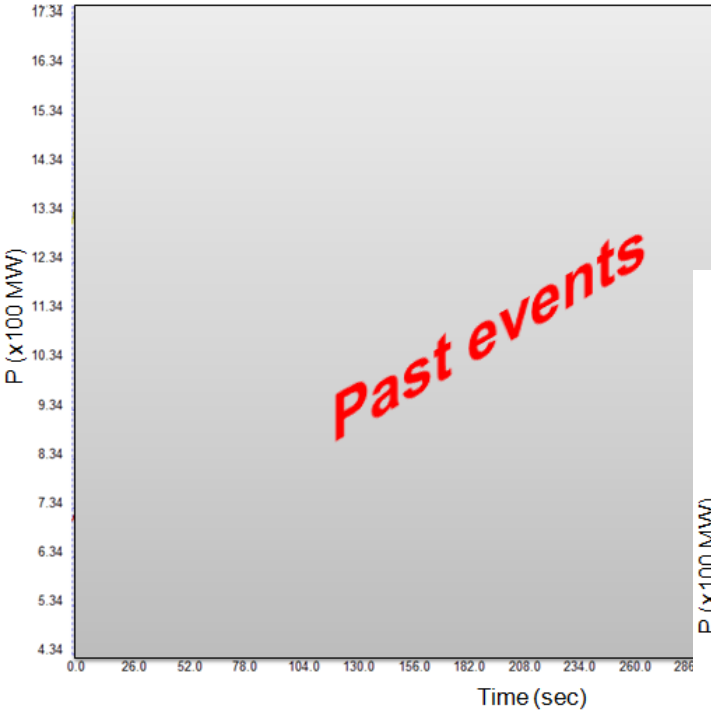


Stage 2

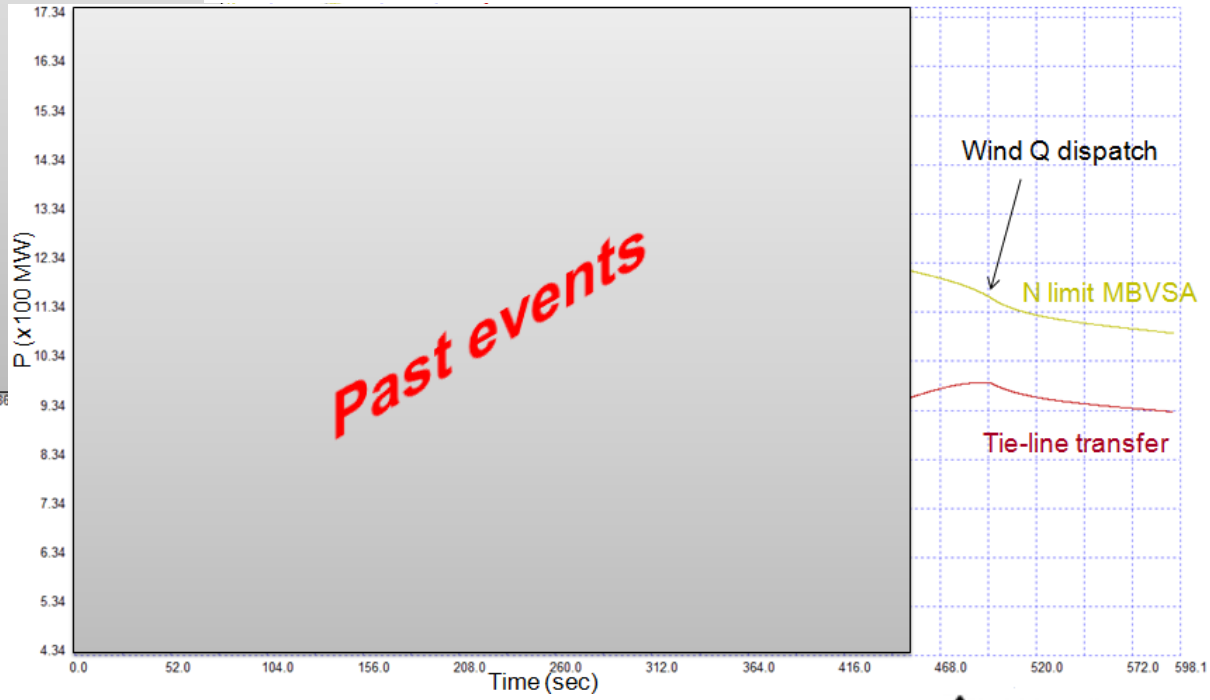


Illustrative Example

Stage 3



Effect of remedial action



Concluding Remarks

- Need for tools to improve situational awareness and operator support decision making
- Existing DSA tools:
  - Mainly based on simulations
  - Not capable to fully respond to operators needs
- High-performance computing technology is accessible
- Improved synchrophasor-based algorithms developed
- A sound approach:

  $\Rightarrow$ **combine measurement-based algorithms with simulation-based tools and advanced visualization**

Thank you!