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Hybrid Simulation/Measurement-Based Framework for Online Dynamic Security Assessment

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High-Performance Hybrid Simulation/Measurement-Based Tools For Proactive Operator Decision-Support 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 contribute to new generation of real-time Dynamic Security Assessment tools

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

Preventive/remedial Actions

Areas of Development

Lawrence Livermore National Laboratory

eMIT

THE UNIVERSITY of TENNESSEE KNOXVILLE

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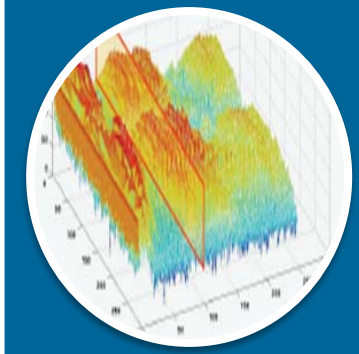
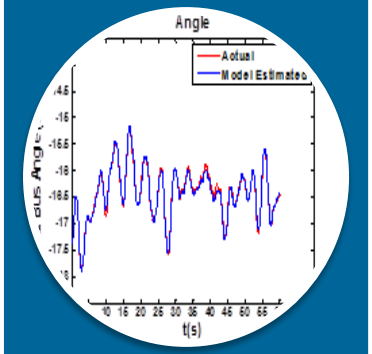
ALSTOM GRID

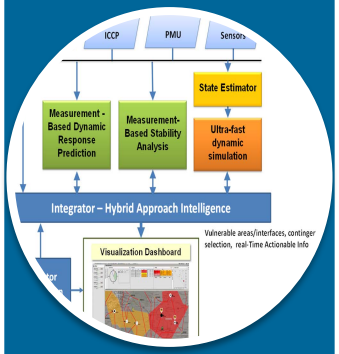
High Performance Dynamic Simulation Software



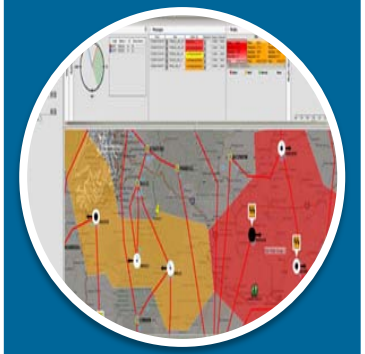
Measurement Based Voltage and Angular Stability Analysis



Measurement Based Dynamic Response Prediction and System Reduction



Hybrid Approach Intelligence



Advanced Visualization

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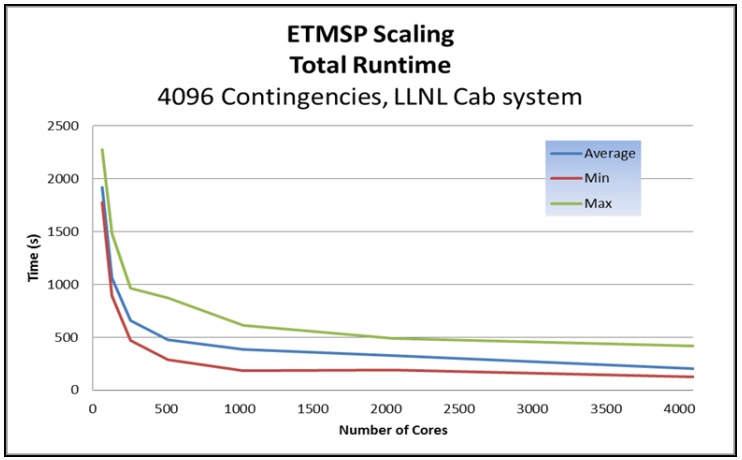
High Performance Dynamic Simulation Software

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

Identified bottlenecks

Parallelization of contingencies



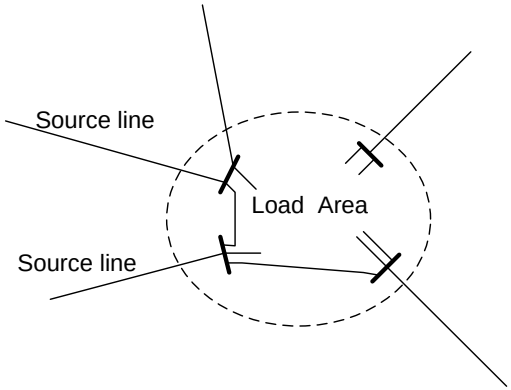
Speedup of single contingency simulation

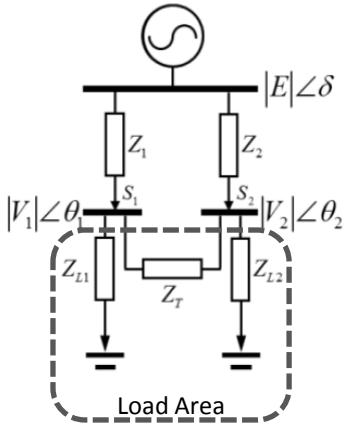
- Reduce time due to Input/Output

- Replace ETMSP's Linear Solver with SuperLU_MT (No significant advantage)
- Use variable time step integration algorithm **(~60% Speedup for a single contingency)**

Measurement-Based Algorithms

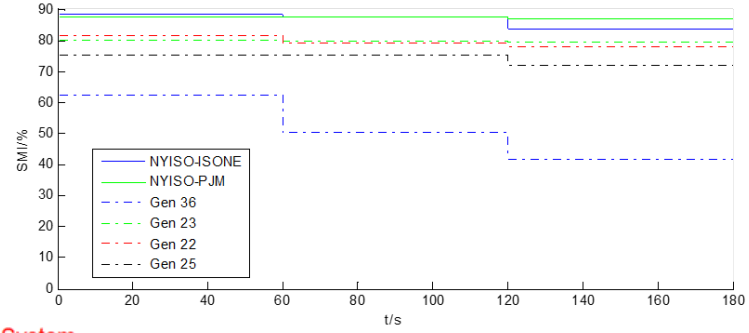
- **Measurement-Based Voltage Stability Assessment**
  - Multi-terminal equivalent.
  - Stability margins are expressed as real and reactive power transferred through the interface of the load area



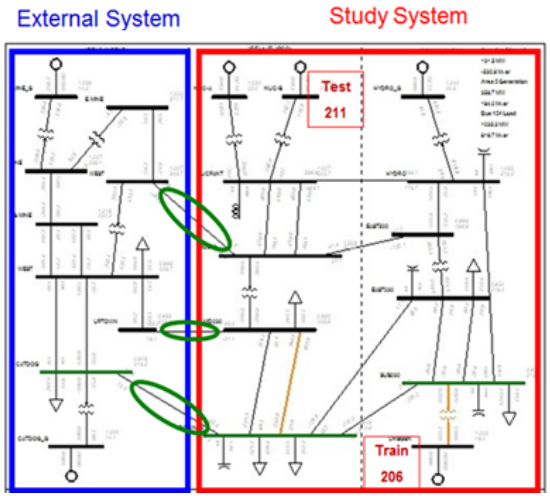


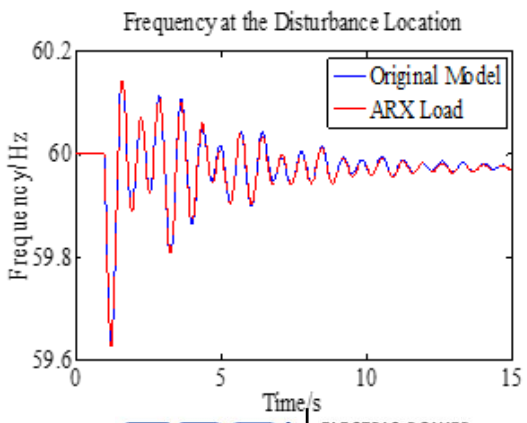
- **Measurement-Based Angular Stability Assessment**
  - Stability margin index based on fluctuation of the oscillation frequency about a dominant mode

$$SMI = \frac{\omega_{\min}}{\omega_{\max}} \times 100\%$$



- **Measurement-Based System Reduction**
  - ARX (transfer function) model used to represent the external system
  - ARX model constructed using synchrophasor data at the interface





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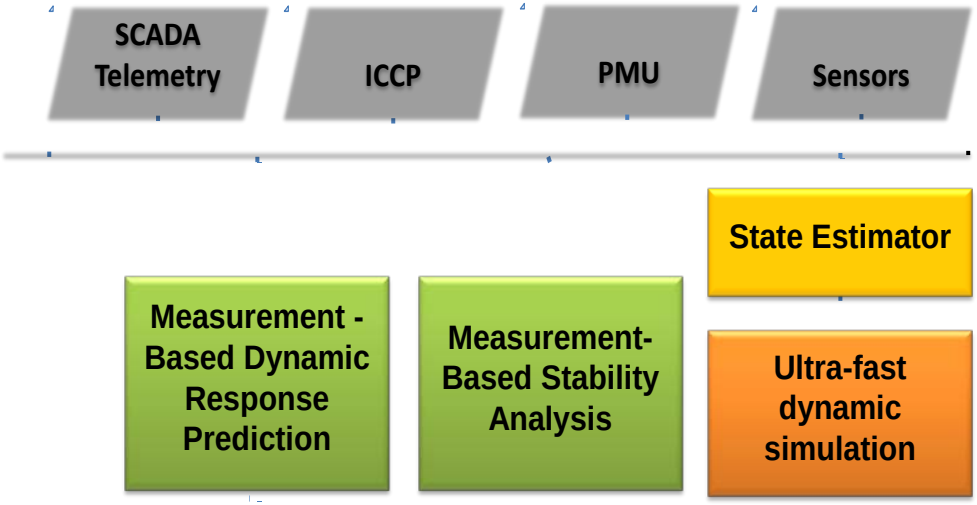
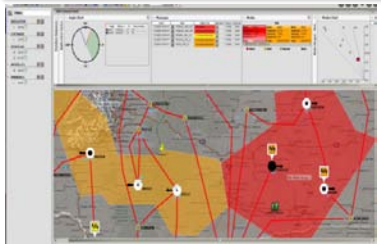
Hybrid Framework



Hybrid Approach Intelligence

- Analyzes, manages, coordinates, and post-processes results from the different modules to generate actionable information
- Provides information for visualizations with focus on the operator needs &perspective

Visualization Dashboard



Vulnerable areas/interfaces, contingency selection, real-Time Actionable Info

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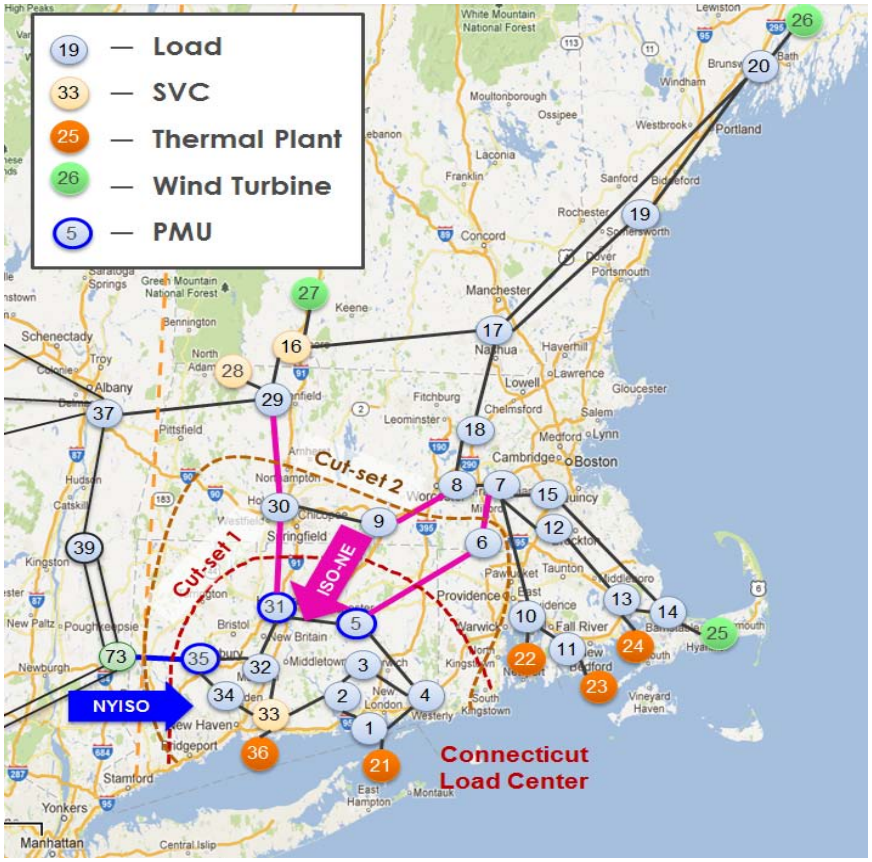
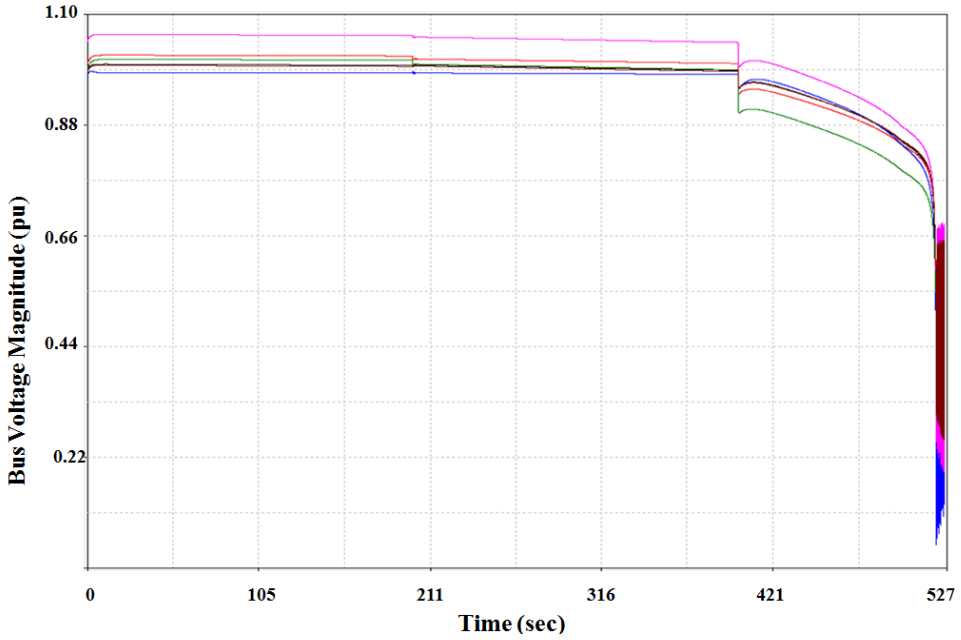
Illustrative Example

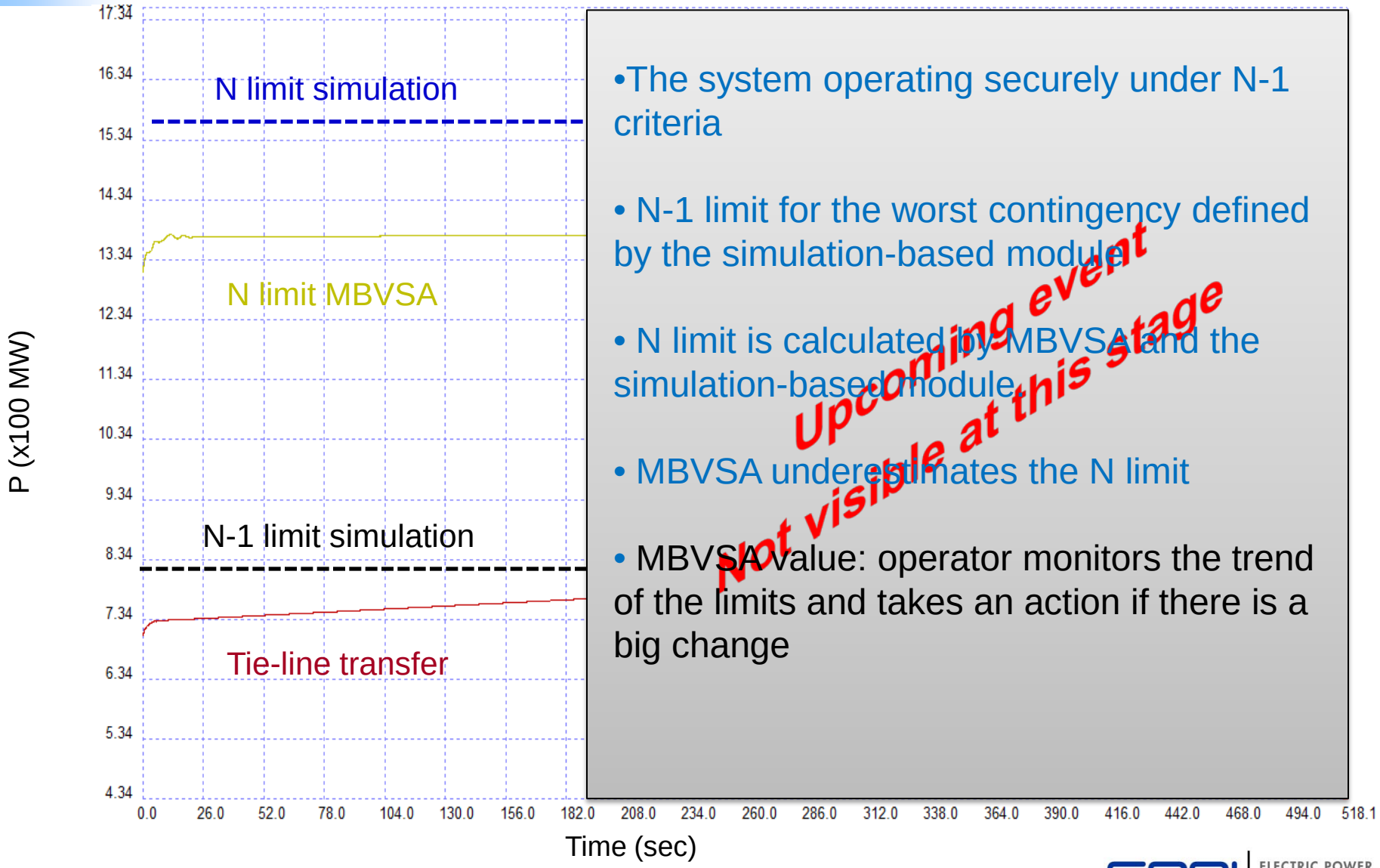


Stage 1	No Contingency
Stage 2	Line 31-32 tripped
Stage 3	Lines 31-32 & 30-31 tripped



- 140 bus benchmark NPCC system
- Focus on the ISO-NE Connecticut Load Center

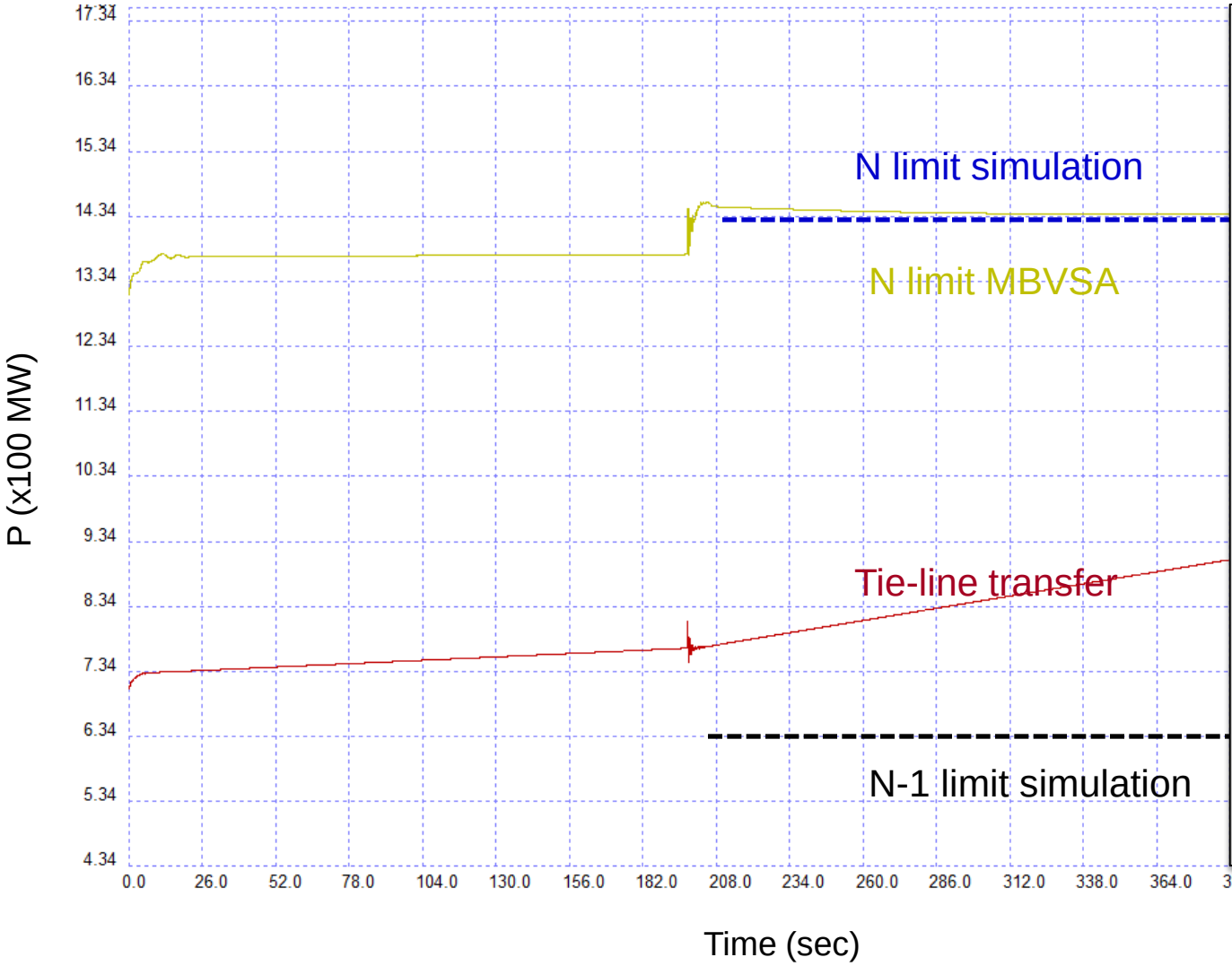
Stage 1



- The system operating securely under N-1 criteria
- N-1 limit for the worst contingency defined by the simulation-based module
- N limit is calculated by MBVSA and the simulation-based module
- MBVSA underestimates the N limit
- MBVSA value: operator monitors the trend of the limits and takes an action if there is a big change

Upcoming event
Not visible at this stage

Stage 2



- Simulation trigger to recalculate N-1 limit
- MBVSA value: immediately after the event, and before the computations performed by the simulation-based module are completed, operator is informed that there is still sufficient margin for the present operating condition.
- N-1 limit violation. Corrective actions are needed.

Upcoming event Not visible at this stage

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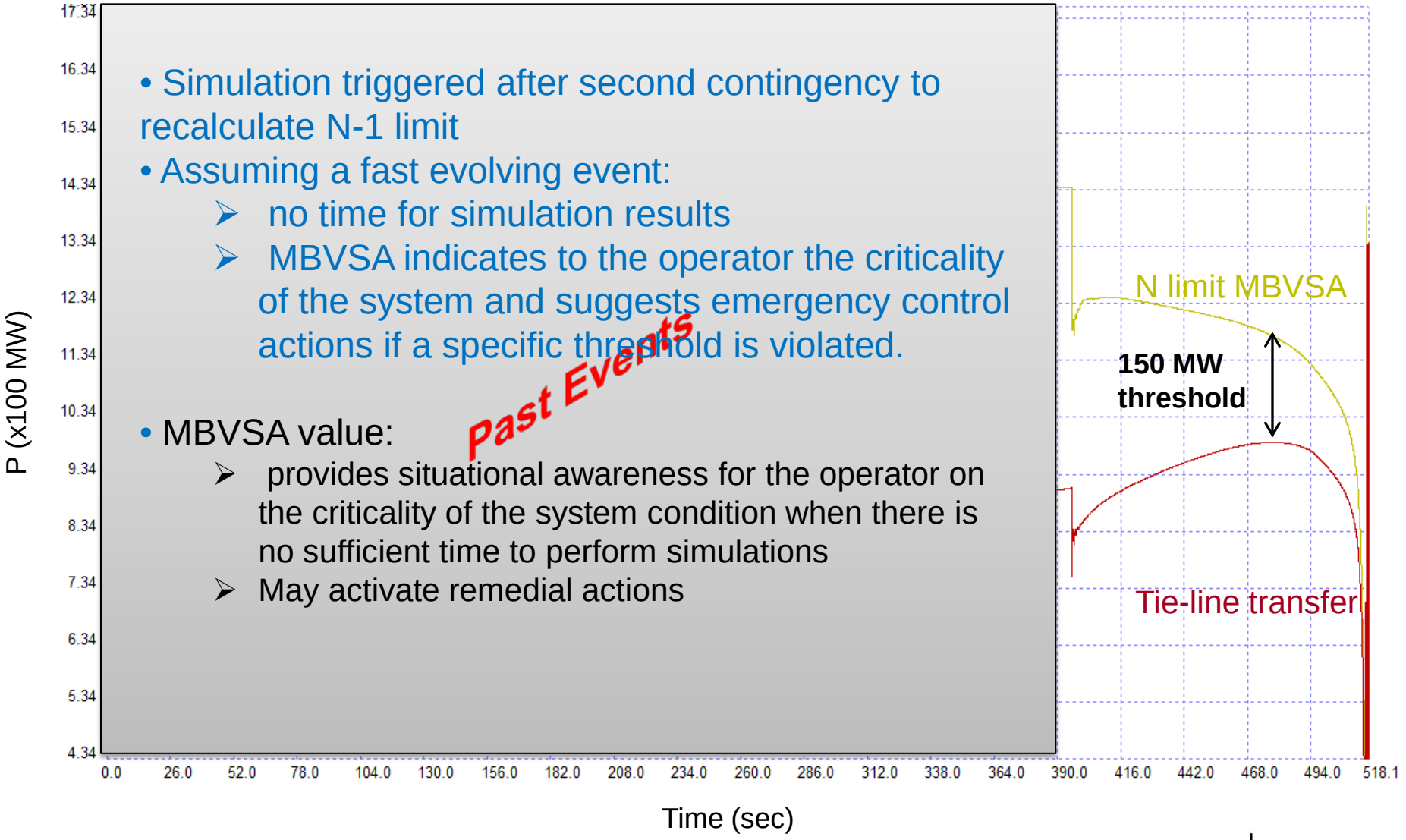
Stage 3

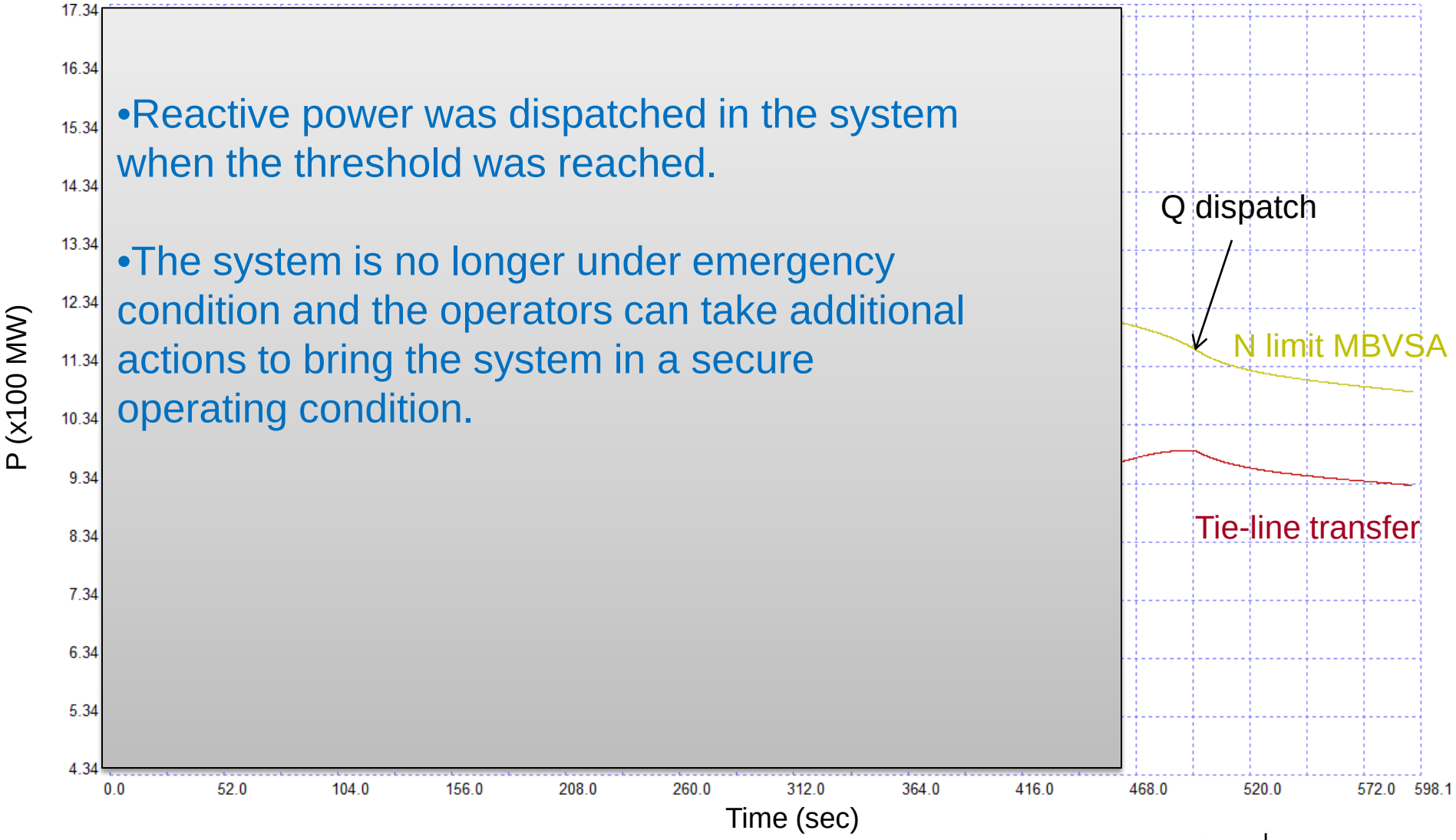
- Simulation triggered after second contingency to recalculate N-1 limit
- Assuming a fast evolving event:
  - no time for simulation results
  - MBVSA indicates to the operator the criticality of the system and suggests emergency control actions if a specific threshold is violated.

- MBVSA value:
  - provides situational awareness for the operator on the criticality of the system condition when there is no sufficient time to perform simulations
  - May activate remedial actions

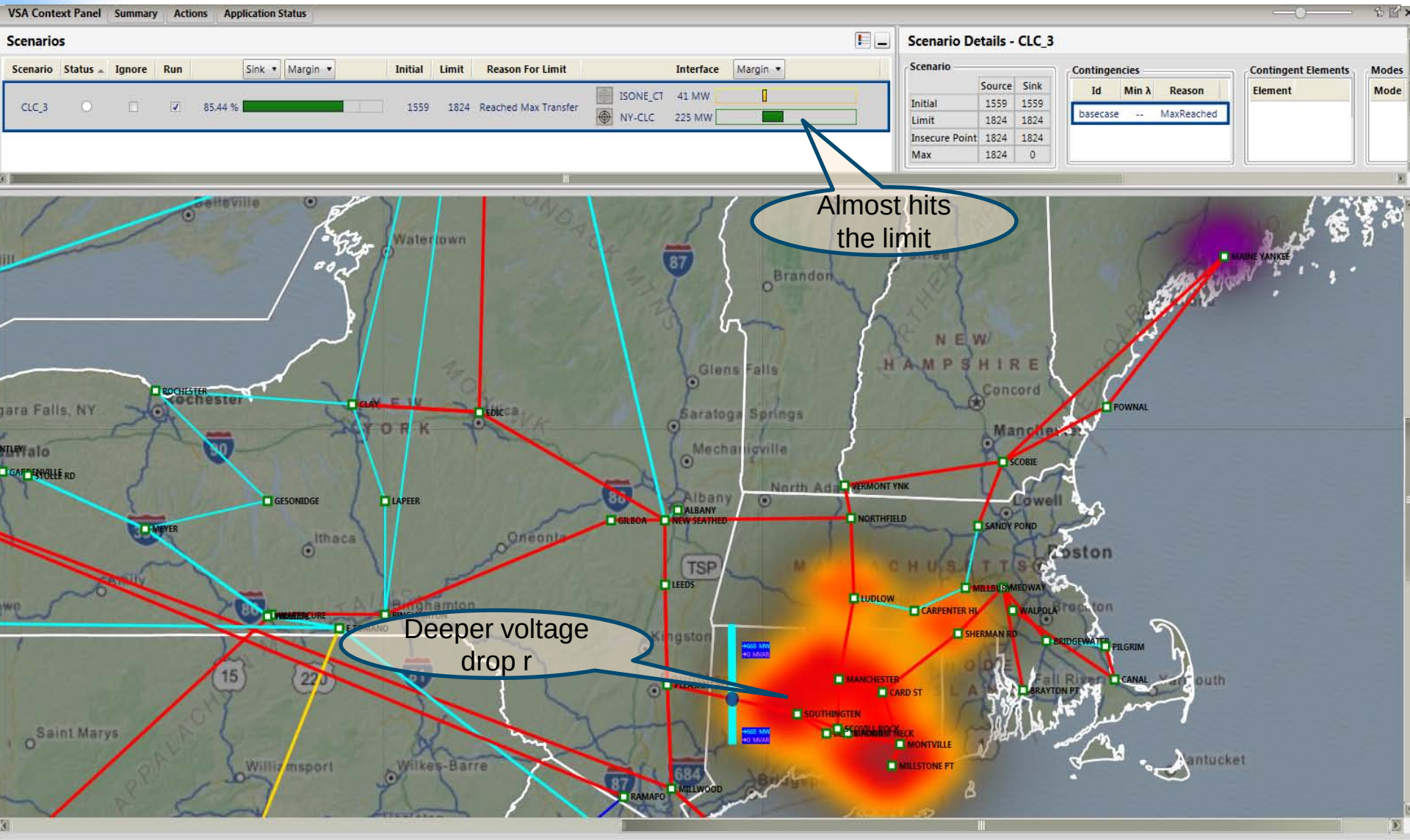
Past Events



Remedial Action Implemented



Visualization of Measurement-Based Voltage Stability Assessment



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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:
  - Proven techniques to achieve faster than real-time simulations
- Improved synchrophasor-based algorithms developed
- A sound approach:

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

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