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
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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

- 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
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.

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

\[ SMI = \frac{\omega_{\text{min}}}{\omega_{\text{max}}} \times 100\% \]
Hybrid Framework

SCADA Telemetry  |  ICCP  |  PMU  |  Sensors

Measurement-Based Dynamic Response Prediction  |  Measurement-Based Stability Analysis  |  Ultra-fast dynamic simulation

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
Illustrative Example

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

<table>
<thead>
<tr>
<th>Stage 1</th>
<th>No Contingency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 2</td>
<td>Line 31-32 tripped</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Lines 31-32 &amp; 30-31 tripped</td>
</tr>
</tbody>
</table>
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
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.
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
Remedial Action Implemented

- Reactive power was dispatched in the system when the threshold was reached.
- The system is no longer under emergency condition and the operators can take additional actions to bring the system in a secure operating condition.
Visualization of Measurement-Based Voltage Stability Assessment

Deeper voltage drop

Almost hits the limit
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:
  ⇒ combine measurement-based algorithms with simulation-based tools and advanced visualization
Together…Shaping the Future of Electricity