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Modeling, Simulation, And Optimization for the 21st Century Electric Power Grid

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Improving Transmission Asset Utilization Through Advanced Mathematics and Computing

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Transmission congestion – an ever increasing challenge

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- Incur significant economic cost
  - 2004: $1 billion cost at California ISO due to congestion and reliability must-run requirements [1]
  - 2008: >$1.5 billion congestion cost at New York ISO [2]
- Prevent wind integration
  - Wind generation curtailment due to transmission congestion
- Congestion will become worse and more complicated
  - Uncertainty, stochastic power flow patterns due to changing generation and load patterns, increased renewable generation, distributed generation, demand response and the increasing complexity of energy and ancillary service markets and Balancing Authority (BA) coordination.

[1] California Energy Commission, "Strategic Transmission Investment Plan", November 2005
[2] NYISO, Congestion Analysis Summary for 2008.

Building more transmission lines is not the best option

- Transmission build-out lags behind load growth
  - 1988-98: load grew by 30%, transmission grew by only 15% [3]
  - Resulting in a transmission grid that must operate closer to the maximum limit, and this is expected to compound as demand for electricity is expected to double by 2050.
- Transmission expansion is constrained by:
  - Financial and cost-recovery issues
  - Right-of-way and
  - Environmental considerations

[3] U.S. Department of Energy, "The Smart Grid: An Introduction."

Possibility of utilizing more of what we already have

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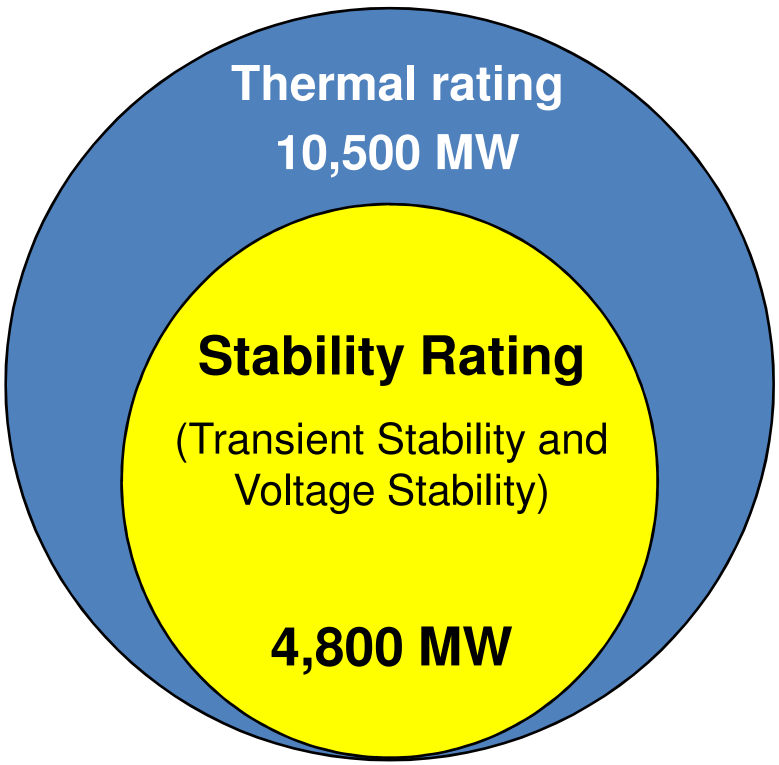
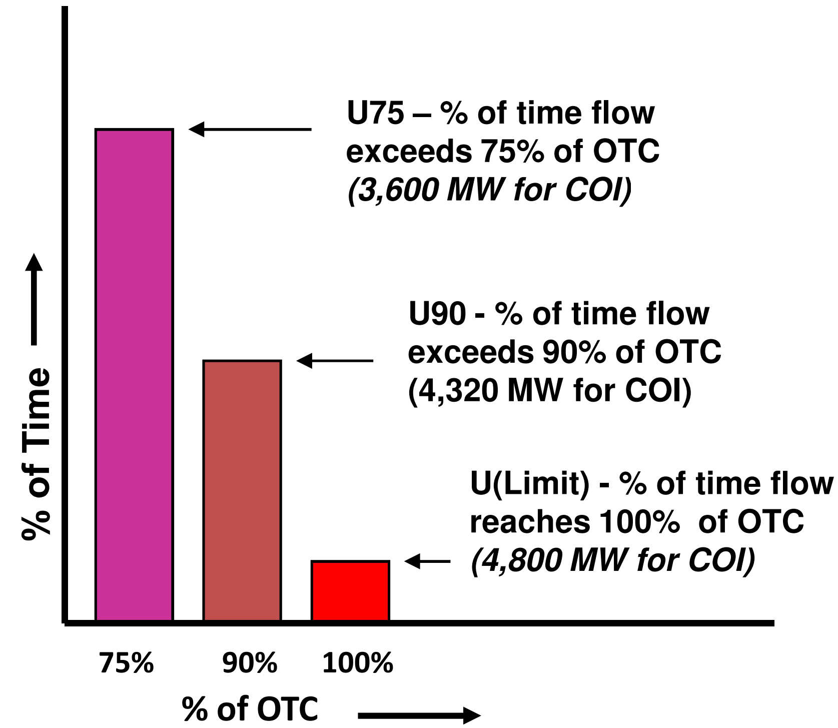
Measurement of Transfer Capacity
Example - California Oregon Intertie (COI) [4]

Path Ratings



U75, U90 and U(Limit)



[4] Western interconnection 2006 congestion management study

Real-time path rating

- Current Path Rating Practice and Limitations
  - Offline studies – months or a year ahead of the operating season
  - Worst-case scenario
  - Ratings are static for the operating season

  ➔ The result: conservative (most of the time) path rating, leading to artificial transmission congestion
- Real-Time Path Rating
  - On-line studies
  - Current operating scenarios
  - Ratings are dynamic based on real-time operating conditions

  ➔ The result: realistic path rating, leading to maximum use of transmission assets and relieving transmission congestion

Real-time path rating – case studies

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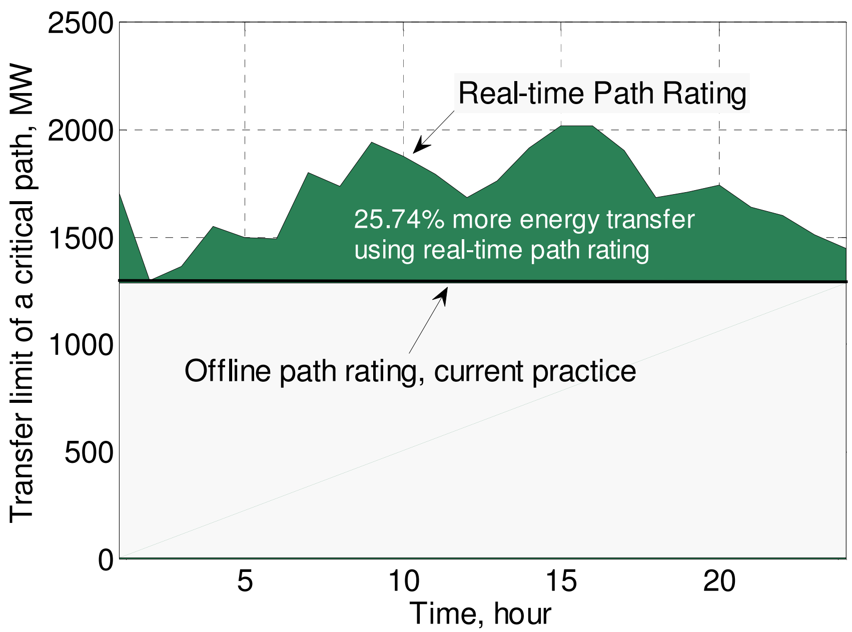
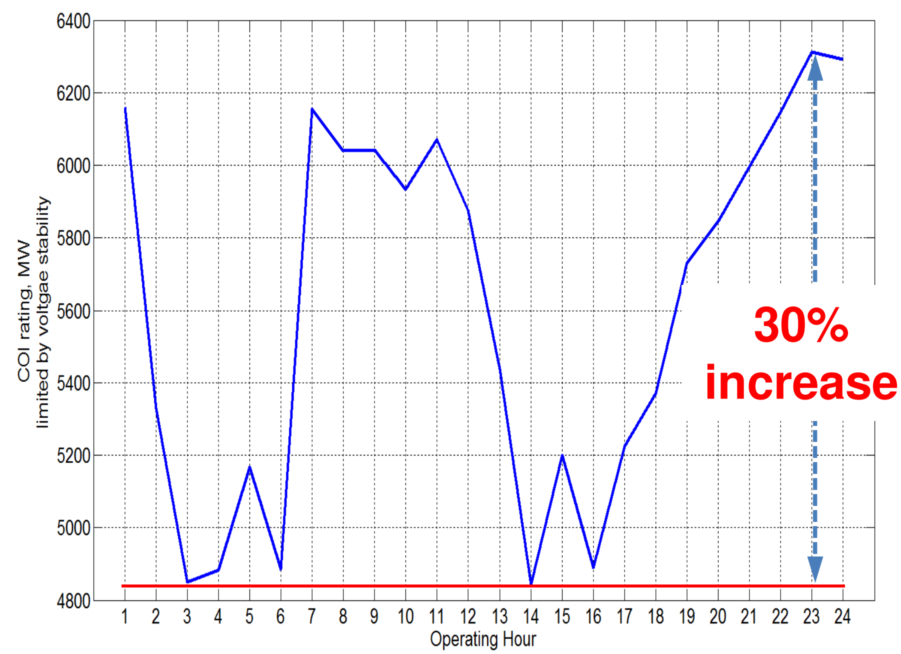
- IEEE 39-bus power system
  - 26% more capacity without building new transmission lines
- WECC COI Line
  - Full study with realistic case and parameters
  - Peak rating increases 30%



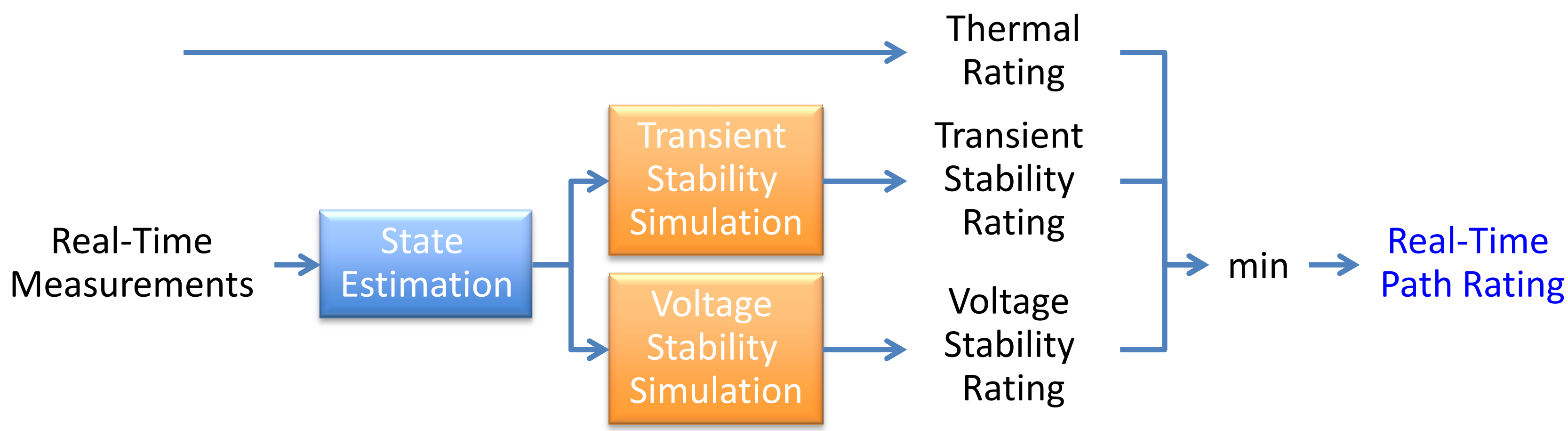


Benefits of real-time path rating

- Increase transfer capability of existing power network and enable additional energy transactions
  - $15M annual revenue for a 1000-MW rating increase for one transmission path in the WECC system, even if only 25% of the increased margin can be used for just 25% of the year
- Reduce total generation production cost
  - $28M annual product cost saving for only one path
- Avoid unnecessary flow curtailment for emergency support, e.g. wind uncertainties
- Enable dynamic transfer
- Enhance system situational awareness
- Defer building new transmission lines

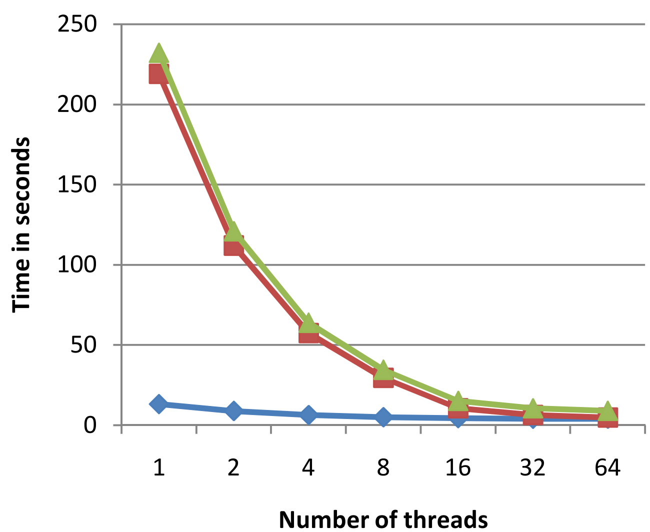
Computational feasibility of real-time path rating

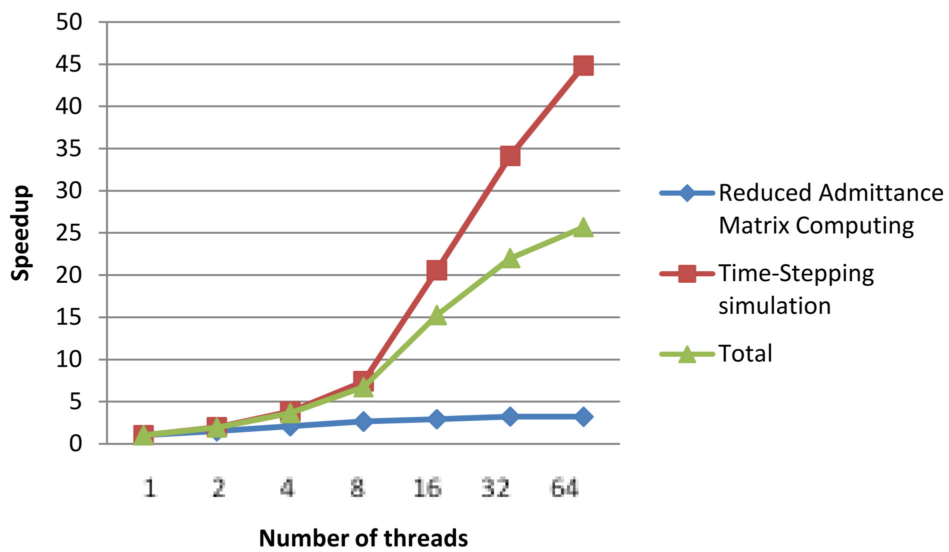
- Computational challenges are the major limiting factor in the current path rating practice
  - ~24 hours for one path rating
  - Target: 5-10 minutes
- Path rating studies involve many runs of transient stability simulation and voltage stability simulation
  - Target: seconds for each run



Fast transient simulation via computational enhancements

- Achieved 26x speed-up for a WECC-size system (16,000-bus) using 64 threads compared to the sequential version using 1 thread.
- Only took 9 seconds to run the 30 seconds WECC-size simulation with 64 threads, which is 20 seconds ahead of the real time, and 13x faster than today's commercial tools (which needs 120 seconds after considering the difference between CPU configurations).





Non-iterative voltage stability simulation via mathematical advancements

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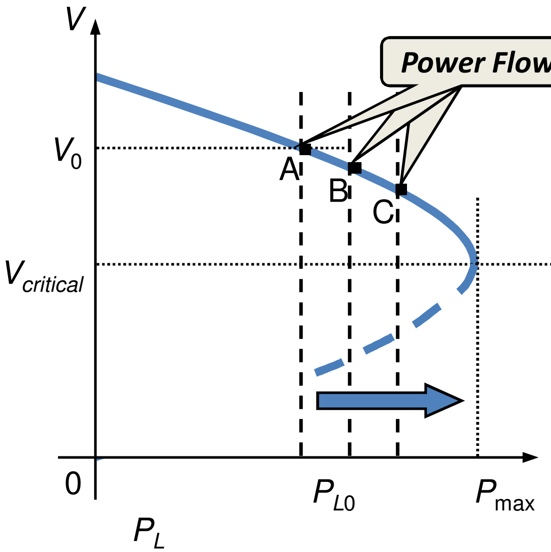
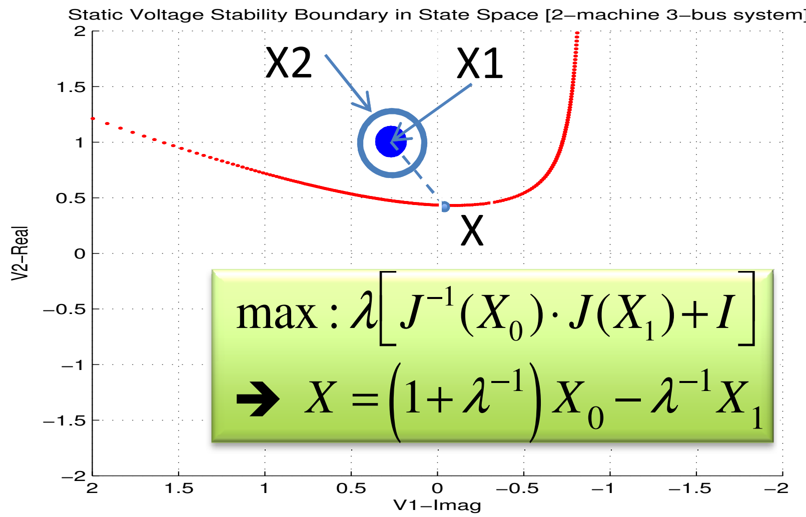
Traditional Iterative Method



Eigenvalue-based Non-Iterative Method



$$\max : \lambda\left[J^{-1}(X_0)\cdot J(X_1)+I\right]$$
$$\rightarrow X=\left(1+\lambda^{-1}\right)X_0-\lambda^{-1}X_1$$

	Iterative Method	Eigenvalue-based Non-Iterative Method	Enhanced Eigenvalue-based Non-Iterative Method
Computational time	61 – 315 sec	4 – 10 sec	2– 4 sec
Speed-up w.r.t. Commercial Tool	---	6 – 78 times	15 – 150 times

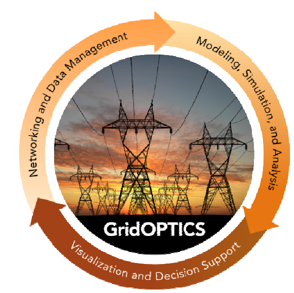
Summary

- Fast transient stability and voltage stability simulations through computational and mathematical advancements are proven feasible.
- Fast simulations enable real-time path rating.
  - Real-time path rating minimizes conservativeness while still maintaining stability.
  - Real-time path rating relieves transmission congestion by increasing usable transmission capacity.
- Real-time path rating improves asset utilization by ~30% in the tested cases.
  - Improved asset utilization brings financial benefits in production cost saving and transaction revenue increase.
  - Improved asset utilization also facilitates integration of renewables (and other new technologies) by minimizing curtailment.

Where we go from here …

Grid is transitioning in three fusions:

- Fusion of **operation** and **planning** to enable more seamless grid management and control
  - Remove overhead in communication between operation and planning
  - Improve response when facing emergency situations
- Integration of **transmission** and **distribution** in managing two-way power flows
  - Understand the emerging behaviors in the power grid due to smarter loads, mobile consumption, and intermittent generation
- Interdependency between power **grid** and **data** network
  - Bring data to applications efficiently and reliably
  - Enable "all-hazard" analysis



GridOPTICS™ – methods and tools to support these three fusions

http://gridoptics.pnnl.gov/

Questions?

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