Improving Transmission Asset Utilization Through Advanced Mathematics and Computing

Henry Huang  
*Pacific Northwest National Laboratory*

Ruisheng Diao  
*Pacific Northwest National Laboratory*

Shuangshuang Jin  
*Pacific Northwest National Laboratory*

Yuri Makarov  
*Pacific Northwest National Laboratory*

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Pacific Northwest National Laboratory
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Transmission congestion – an ever increasing challenge

- 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.

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

Possibility of utilizing more of what we already have

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

Path Ratings

Thermal rating
10,500 MW

Stability Rating
(Transient Stability and Voltage Stability)
4,800 MW

U75, U90 and U(Limit)

U75 – % of time flow exceeds 75% of OTC (3,600 MW for COI)

U90 - % of time flow exceeds 90% of OTC (4,320 MW for COI)

U(Limit) - % of time flow reaches 100% of OTC (4,800 MW for COI)

% of Time
75% 90% 100%

% of OTC

[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

- **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%

![Graph showing real-time path rating compared to offline path rating.]

![Graph showing COI rating, MW limited by voltage stability.]

30% increase
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

### Traditional Iterative Method

![Diagram of Traditional Iterative Method](image)

### Eigenvalue-based Non-Iterative Method

![Diagram of Eigenvalue-based Non-Iterative Method](image)

<table>
<thead>
<tr>
<th></th>
<th>Iterative Method</th>
<th>Eigenvalue-based Non-Iterative Method</th>
<th>Enhanced Eigenvalue-based Non-Iterative Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Computational time</strong></td>
<td>61 – 315 sec</td>
<td>4 – 10 sec</td>
<td>2 – 4 sec</td>
</tr>
<tr>
<td><strong>Speed-up w.r.t. Commercial Tool</strong></td>
<td>---</td>
<td>6 – 78 times</td>
<td>15 – 150 times</td>
</tr>
</tbody>
</table>
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.
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**

Questions?

Zhenyu (Henry) Huang
Pacific Northwest National Laboratory
zhenyu.huang@pnnl.gov
509-372-6781