Non-wire Methods for Transmission Congestion Management through Predictive Simulation and Optimization

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Transmission Congestion – an Ever Increasing Challenge

► Incur significant economic cost
  ■ 2012: $193 million import congestion charges of major inter-ties at California ISO, increased by 77.5% from 2010 [1]
  ■ 2010: $ 1.43 billion congestion cost PJM-wide [3]

► Power flow pattern changes impact congestion issues
  ■ Introduction of renewable generation and new markets
  ■ E.g. 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.

Three traditional means of congestion management (all require capital investment) [4]:

- Build more generation close to load centers.
- Reduce load through energy efficiency and demand reduction programs.
- Build more transmission capacity in appropriate locations.

Transmission expansion is constrained by:

- Financial and cost-recovery issues
- Right-of-way issues
- Environmental considerations

New approaches:

- Dynamic Line Rating (DLR), thermal limited
  - Validated at RTE, France and Oncor, TX
- Real-time path rating, security/stability limited
  - Validated the concept at BPA, CAISO and ERCOT in an offline setting
  - No tools available due to intensive computational requirements using existing techniques

Possibility of Utilizing More of What We Already Have

Example - California Oregon Intertie (COI) [5]

Path Ratings

Thermal rating >10,000 MW

Stability Rating
(Transient Stability and Voltage Stability)

<5,000 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)

[5] Western interconnection 2006 congestion management study
Real-Time Path Rating

Current Path Rating Practice and Limitations
- Offline studies with worst-case scenario
- Ratings are static for the operating season
  ➔ The result: conservative (most of the time) path rating

Real-Time Path Rating
- On-line studies with 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
IEEE 39-bus power system

- 26% more capacity without building new transmission lines

![Graph showing real-time path rating compared to offline path rating, with 25.74% more energy transfer using real-time path rating.](image-url)
West of Cascades North
- Full-topology model compared to WECC planning model

May 18 - 19, 2010 WOCN Event

Over 1100 MW

Minimize Real-Time Curtailments
- May 18-22, 2010
  104.5 hrs. X 1,000 MW X $30.36 X 25%
  = $793,000

Northern Intertie
- Full-topology model to study real time
- Sept. 14, 2010 unplanned outage

- Sept. 14, 2010
  Reduced 24 hrs to 2 hrs.
  22 hrs X 1500 MW X $40.36 X 50%
  = $665,000
Technical Approach and Objectives

Technology Summary

1. Develop HPC based transient and voltage stability simulation with innovative mathematical methods
2. Develop HPC based real-time path rating capability with predictability and uncertainty quantification
3. Demonstrate the non-wire method on a commercial software platform with real-life power system scenarios

Technology Impact

- Improve power system transmission asset utilization
- Manage transmission congestion without building new wires
- Facilitate integration of renewable generation and smart grid technologies

Proposed Targets

<table>
<thead>
<tr>
<th>Metric</th>
<th>State of the Art</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation speed</td>
<td>3-5 times slower than real time</td>
<td>10-20 times faster than real time</td>
</tr>
<tr>
<td>Path rating study internal</td>
<td>Months</td>
<td>&lt;10 minutes</td>
</tr>
<tr>
<td>Uncertainty quantification</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Asset utilization</td>
<td>Conservative</td>
<td>Enhanced by ~30%</td>
</tr>
</tbody>
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Objective: “tap into unused capacities” to manage transmission congestion

- Short term goal: develop technologies to determine how much unused capacity.
- Long term goal: integrate unused capacities in power grid operation and markets (beyond the project)
Main Flowchart

PW Simulator

Synergy with other projects, need to develop interfaces

New development

C++ code

MATLAB exe

EMS Interface
Read Current Operating Conditions

Read Study Data required for TTC Calculations including Paths, Sources & Sinks, Contingencies, Study Options, Monitored Areas...

Create one power flow condition from case 0 based on the stress strategy (one stress direction)

Perform contingency analysis at each stress level, parallelized by contingencies (using existing GridPACK MCA module)

Violation/divergence?

Yes

No

Develop Allocation Algorithms for Multiple Processors Based on # of Paths and Contingencies, Types of Violations Considered, etc

Validate Transient Stability at Boundary Points under all (or selected) Contingencies using dynamic simulations, parallelized by both boundary points and contingencies (Using existing GridPACK MCA and dyn sim modules. May need two levels of parallelization)

Boundary point secure?

Yes

No

Create power flow case with reduced stress

Perform transient stability simulation for all (or selected) contingencies (Using existing GridPACK MCA and dyn sim module. May need two levels of parallelization)

Boundary point secure?

Yes

No

Output Calculation Results
TTC, Limiting Contingencies, Limiting Facilities, Nomogram

End

MCA = Massive Contingency Analysis
Parallel computing holds the promise for achieving the 10 minutes goal

**Parallelism:**

1. PF MCA  
   *Parallel over contingencies*

2. Orbiting for each contingency  
   *Parallel over contingencies*

3. Dyn sim test  
   *Parallel over boundary points*

4. Dyn MCA  
   *Two-level parallel*

**PF = Power Flow; MCA = Massive Contingency Analysis; dyn sim = dynamic simulation**
Increasing complexity in power grid models requires more intensive computation
- Model size is ever increasing
- More details being considered
  - Wind/solar models
  - Composite load models
  - Demand response
  - Energy storage
  - Relays
  - UDMs for RAS, SPS, etc.
- Very time consuming to complete one dynamic simulation
  - 100s or more to run a 20s WECC-size no-fault simulation using commercial tools (2.4GHz Duo Core, 4GB of RAM)
Bottleneck Identified

- Most commercial tools used in power industry are optimized for single-processor computers
  - Core algorithms developed 10-30 years ago, with much smaller model size
    - Powerflow analysis
    - Dynamic simulation
    - Small signal stability analysis
- However, CPU clock speed is not increasing as expected
- One popular way of speeding up massive simulations is through distributed computing

![Diagram showing comparison between serial and distributed computing methods]

- Serial computing
- Distributed computing

Limiting factor affecting total computation time
Performance of Massive Contingency Analysis

- Idea: dynamically allocate massive contingency analysis scenarios to different processors based on their availability

- Implemented in GridPACK
  - Tested on a WECC base case
  - 400 contingencies
  - C++ based
  - Computational load balancing using a global counter

![Graph showing speedup vs. number of cores](image)
Performance of Parallel Dynamic Simulation

- **Goal:** Achieve 10x speedup over today’s commercial tool
- **Key algorithms:**
  - Decoupled models for calculating states in parallel
  - Identified a better linear solver for solving network coupling (9.56 ms vs 29.79 ms in PowerWorld for a complete linear solve on a WECC system)
  - 15.82s to complete a 30-s dynamic simulation using 8 cores, on a WECC size system with classical generator model
Dynamic Simulation Procedure

Key steps

- Solve power flow
- Convert loads to constant impedance
- Expand admittance matrix (Y) with load impedance and machine Norton impedance
- Update Y with switching events
- Initialize state variables using power flow solution
- Calculate generator current injection
- Solve network equation for voltages
- Calculate $dx/dt$
- Update $x$

Integration method: modified Euler

$$x_{n+1}^p = x_{n-1} + h \dot{x}_{n-1}$$

$$x_{n+1} = x_n + \frac{h}{2} (\dot{x}_{n+1}^p + \dot{x}_{n-1})$$

Parallel processing
Fast Voltage Stability Simulation

- **Goal:** Develop a non-iterative method to find voltage stability boundaries
- **Developed and combined several methods**
  - Continuation power flow
  - X-ray theorem
  - Orbiting method
  - High-order numerical method
- **Accuracy validated against PW**
- **Only 9.5 s to find a new boundary point after initial point is identified for a WECC-size model** (~10 times faster than today’s approach)
Nomogram Generation

NOJ Interface (100MW) vs COI Interface (100MW)
Current performance progresses well towards the 10 minutes goal.

**Example – BPA Procedure:**
- WECC-size model (16,000-bus)
- 400 PF contingencies
- 5 dyn sim contingencies
- 10 boundary points
- **400 processors**
- Total time: 102 + 95 + 20 + 60 + overhead = 277 seconds + overhead < 5 minutes
- **200 processors**
- Total time: 554 seconds + overhead < 10 minutes

PF = Power Flow; MCA = Massive Contingency Analysis; dyn sim = dynamic simulation
Conclusions

- Transmission congestion is an ever increasing challenge, esp. with new generation and consumption of electricity.
- Real-time path rating could have major impact in congestion management and asset utilization improvement.
- Key simulation engines were successfully developed
  - Fast dynamic simulation
  - Fast voltage stability simulation
  - Massive contingency analysis simulation
- Progress to date indicates the 10 minute performance goal is very well achievable.
Mission
We transform the world through courageous discovery and innovation.

Vision
PNNL science and technology inspires and enables the world to live prosperously, safely and securely.

DISCOVERY in Action

CREATIVITY integrity
Values courage
COLLABORATION Impact