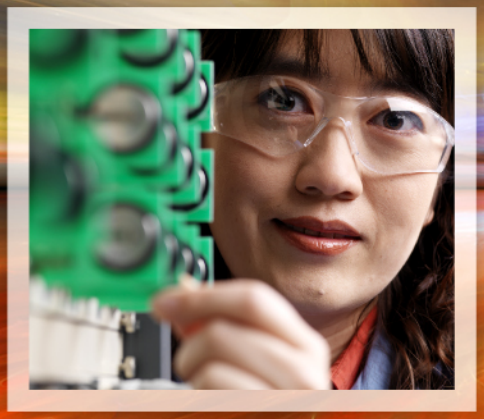

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Non-wire Methods for Transmission Congestion Management through Predictive Simulation and Optimization

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DISCOVERY *in Action*

QUANTA TECHNOLOGY

PowerWorld Corporation
The Visual Approach to Analyzing Power Systems

BONNEVILLE POWER ADMINISTRATION

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: >$1.1 billion congestion cost at New York ISO [2]
  - 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.

[1] California ISO, “2012 Annual Report on Market Issues and Performance”, April 2013
[2] NYISO, “2011 Congestion Assessment and Resource Integration Study”, March 2012
[3] PJM, “Congestion and the PJM Regional Transmission Expansion Plan”, Dec. 2011

Traditional Means of Congestion Management Faces Significant Constraints

- 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

[4] 2012 National Electric Transmission Congestion Study. David Meyer, U.S. DOE, August 2012.

Possibility of Utilizing More of What We Already Have

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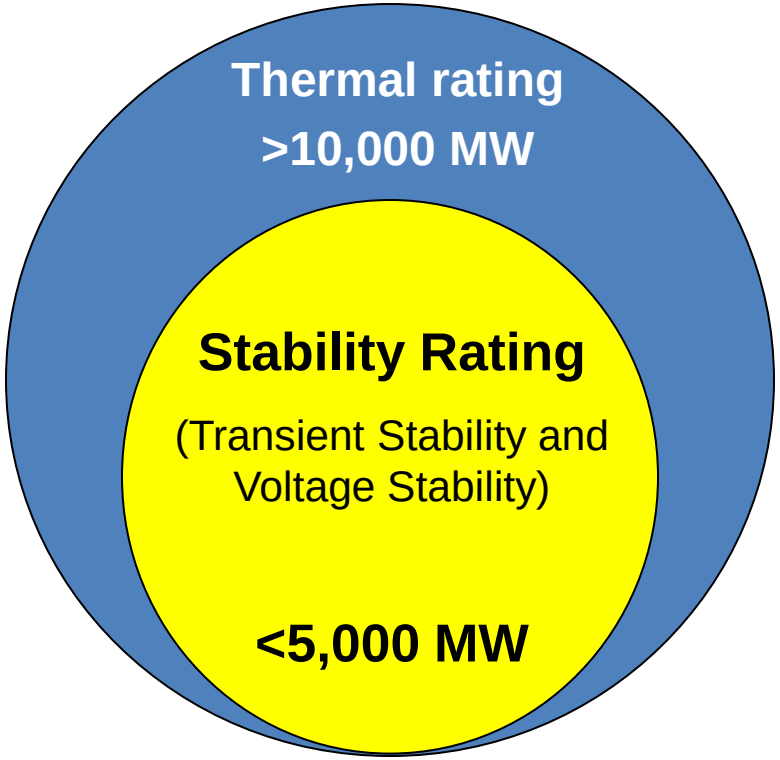
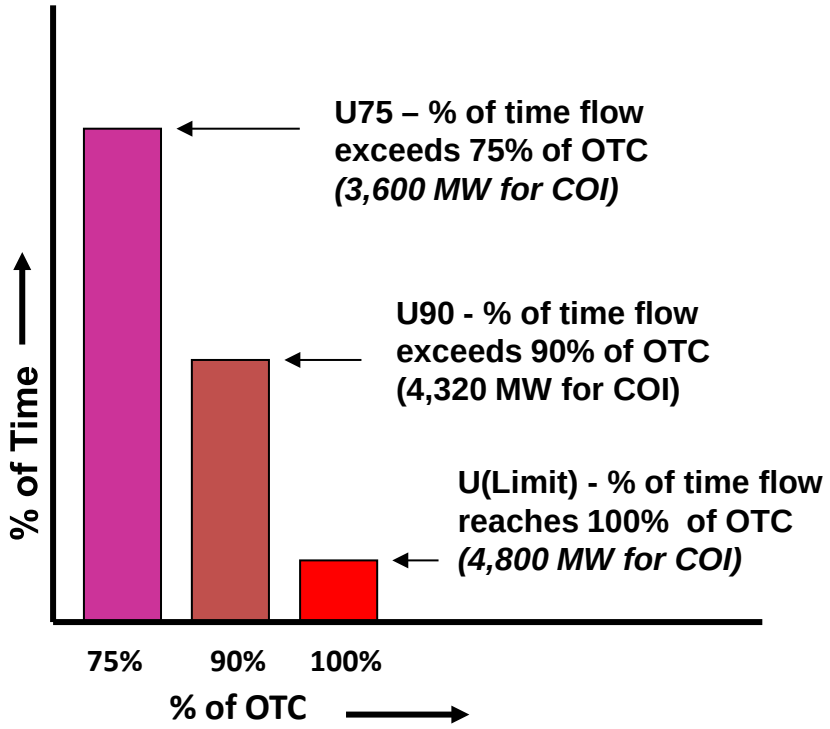
Example - California Oregon Intertie (COI) [5]

Path Ratings



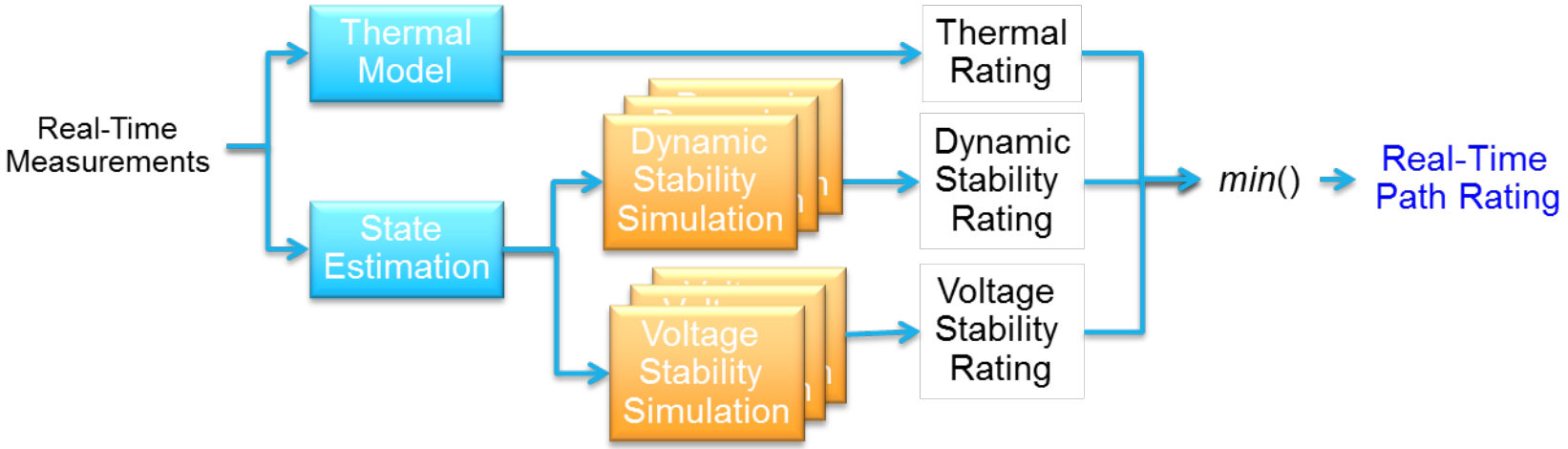
U75, U90 and U(Limit)



[5] Western interconnection 2006 congestion management study

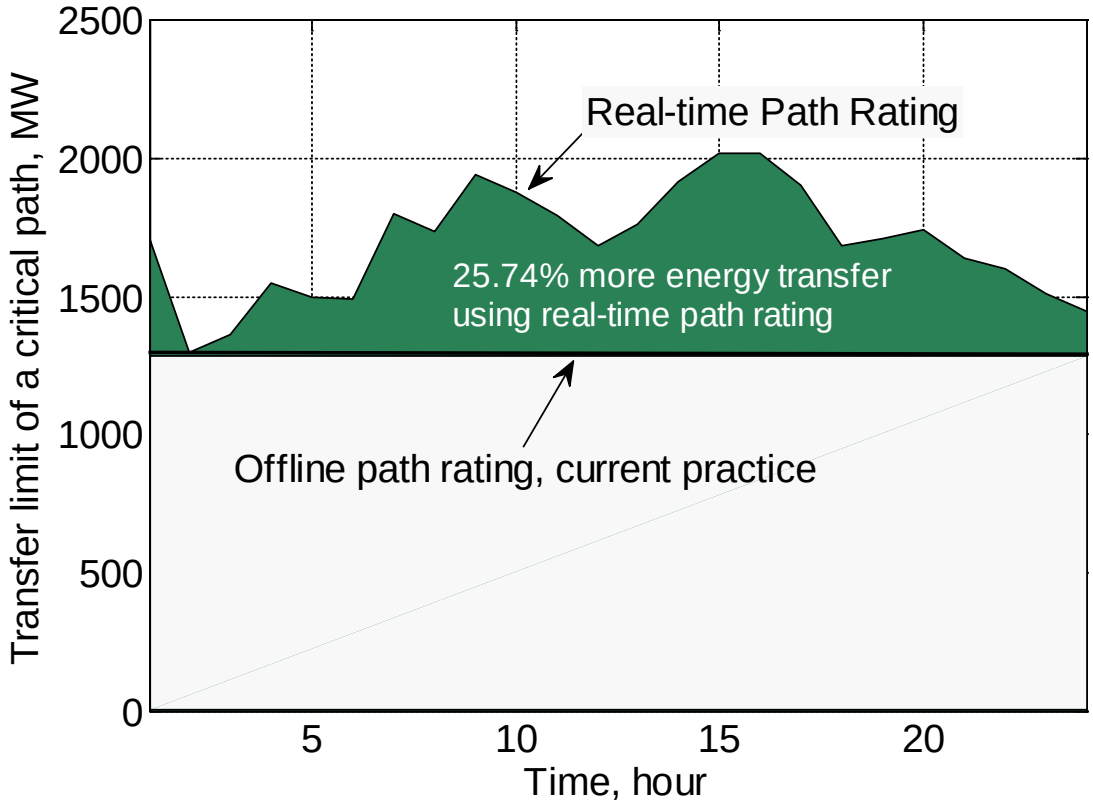
Real-Time Path Rating

- 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



Real-time Path Rating – Case Studies

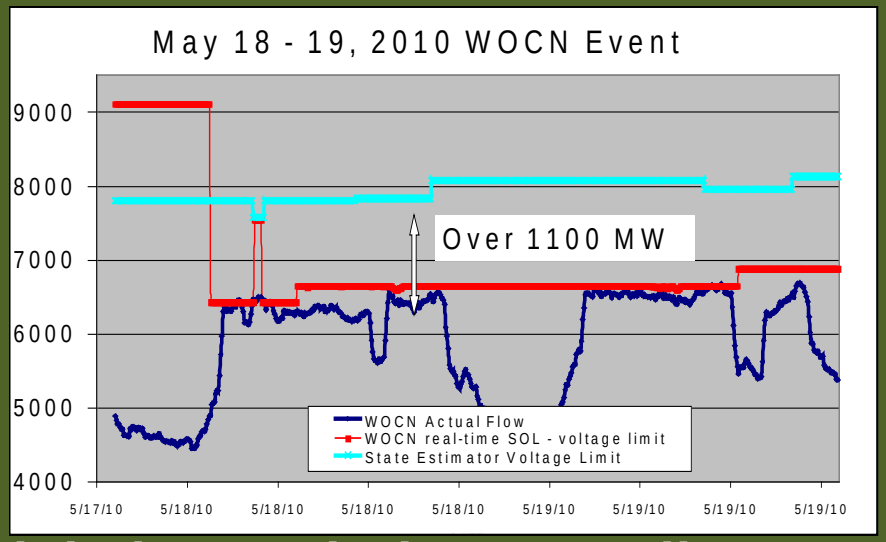
- IEEE 39-bus power system
  - 26% more capacity without building new transmission lines



Real-time Path Rating – Case Studies (BPA)

West of Cascades North

- Full-topology model compared to WECC planning model

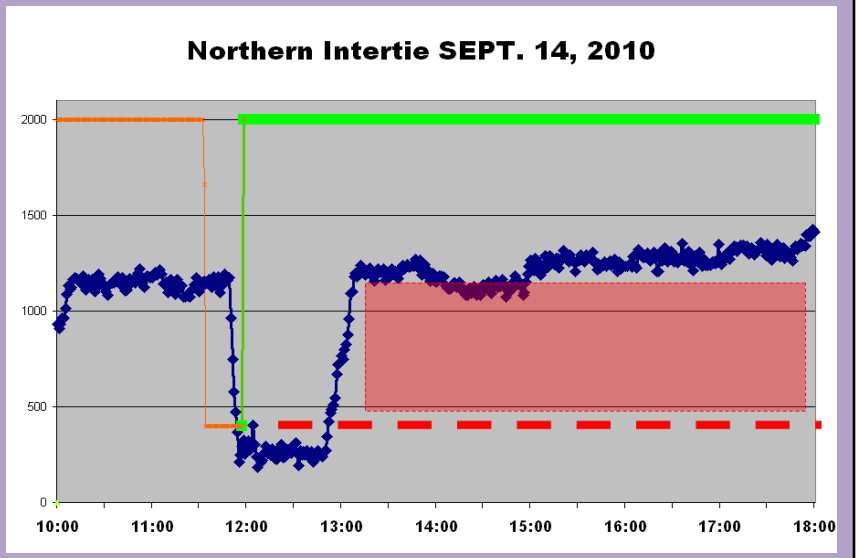


Minimize Real-Time Curtailments

- 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

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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

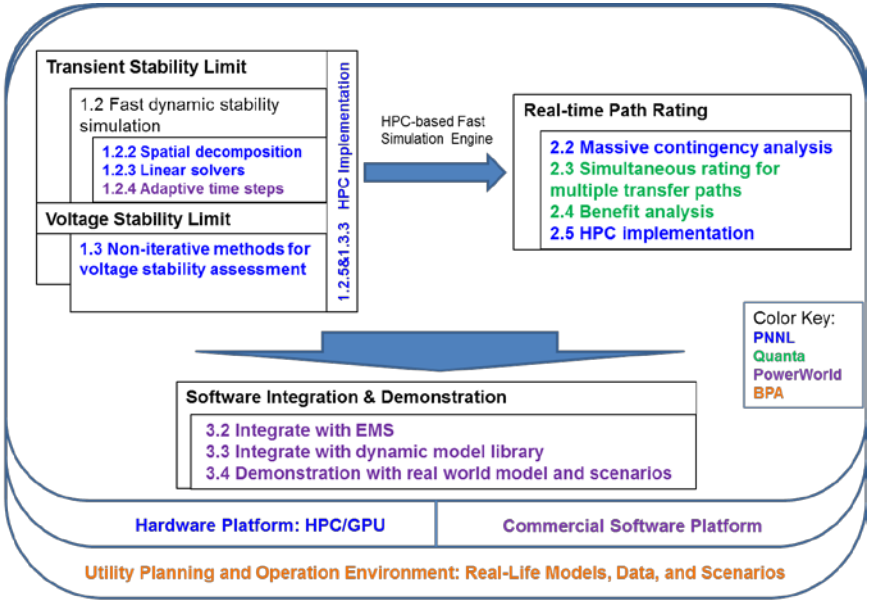
Technology Impact

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

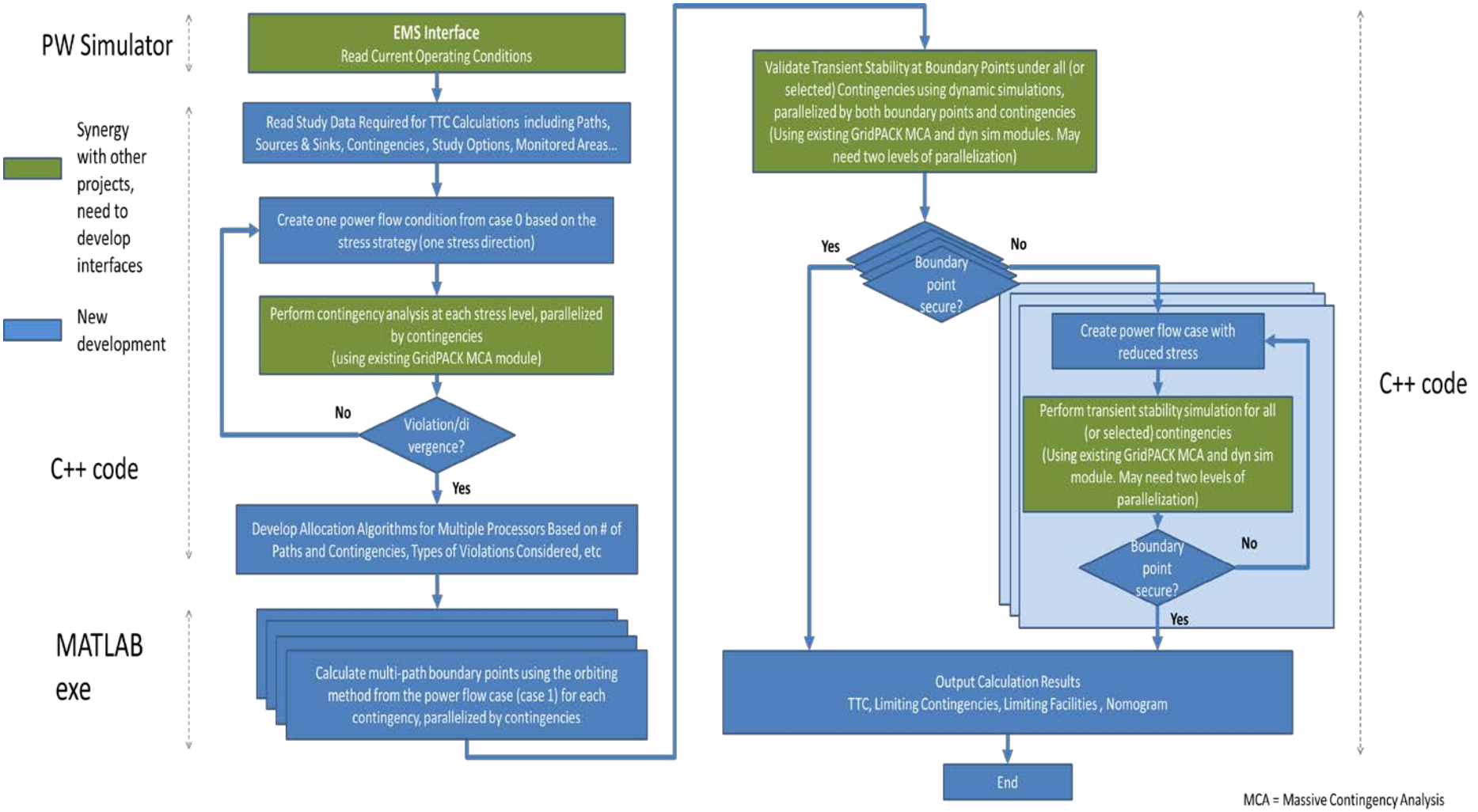
Proposed Targets

Metric	State of the Art	Proposed
Simulation speed	3-5 times slower than real time	10-20 times faster than real time
Path rating study internal	Months	<10 minutes
Uncertainty quantification	No	Yes
Asset utilization	Conservative	Enhanced by ~30%

- 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)

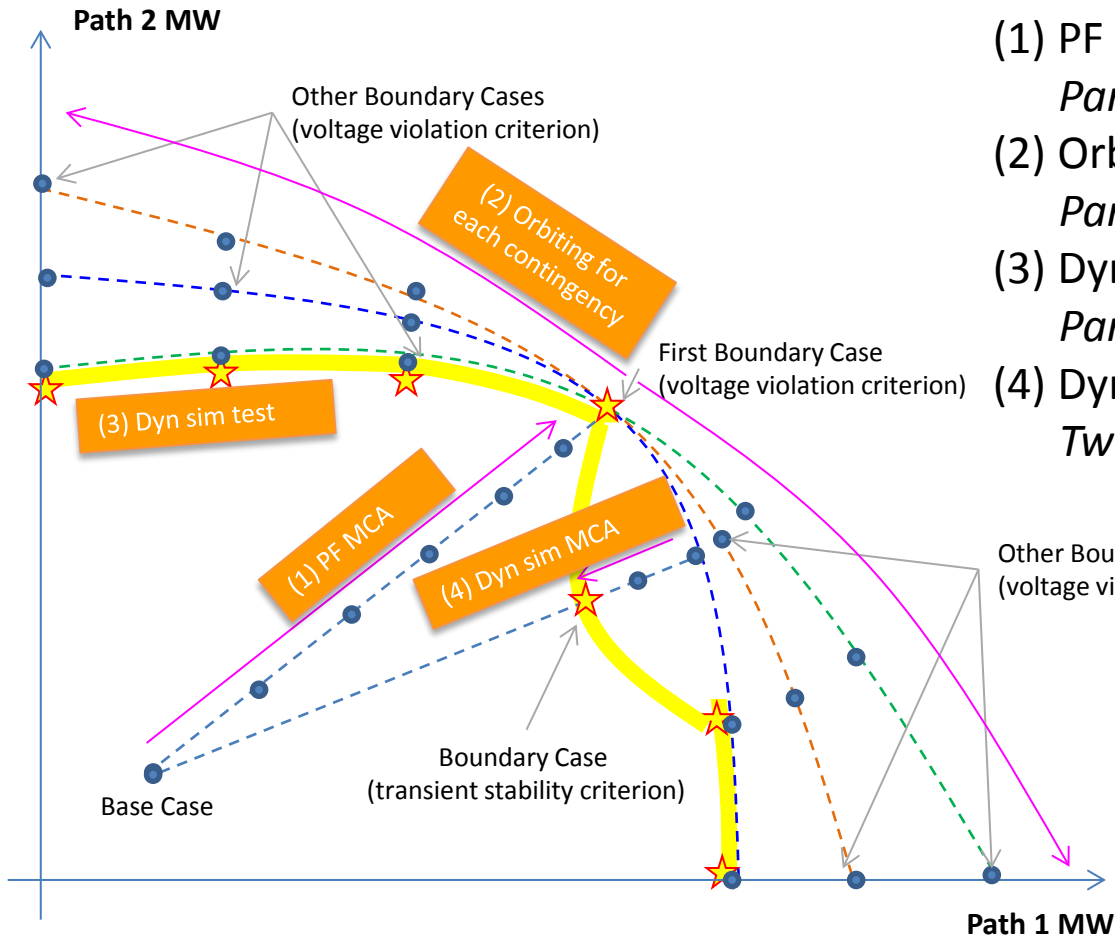


Main Flowchart



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

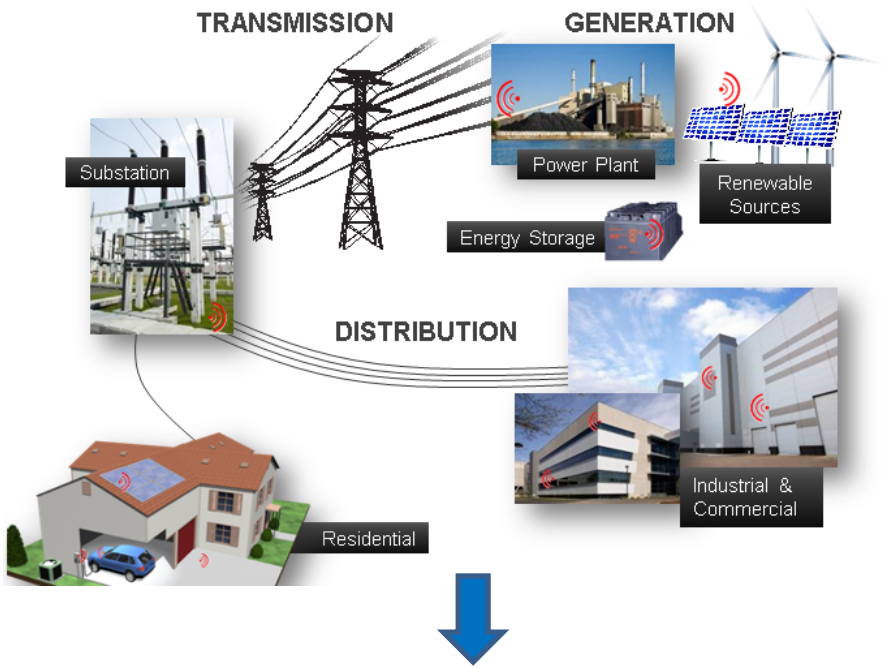
(3) Dyn sim test
Parallel over boundary points

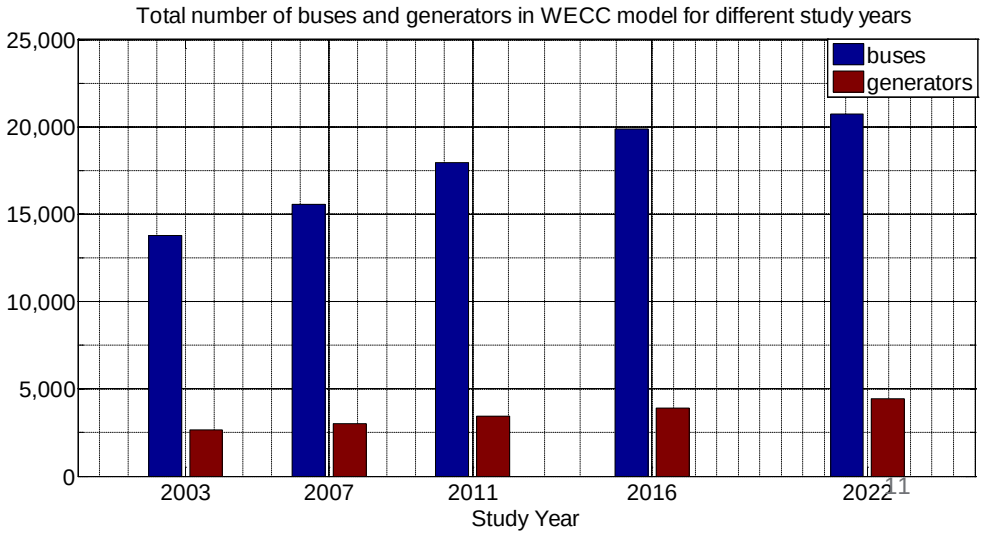
(4) Dyn MCA
Two-level parallel

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

Increasing Complexity to Run System Studies

- 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)

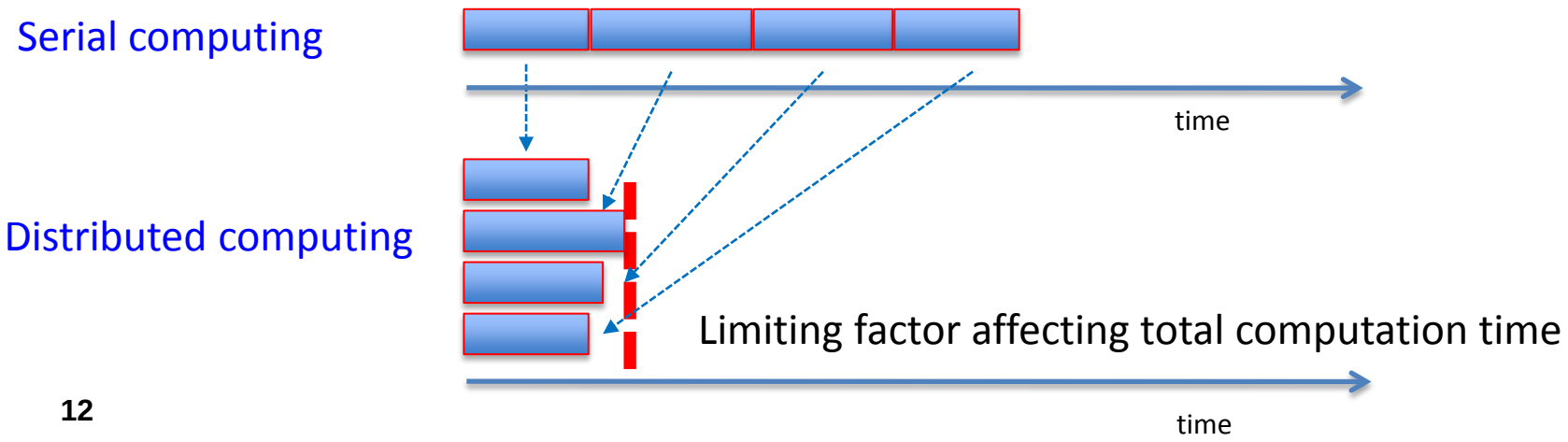




11

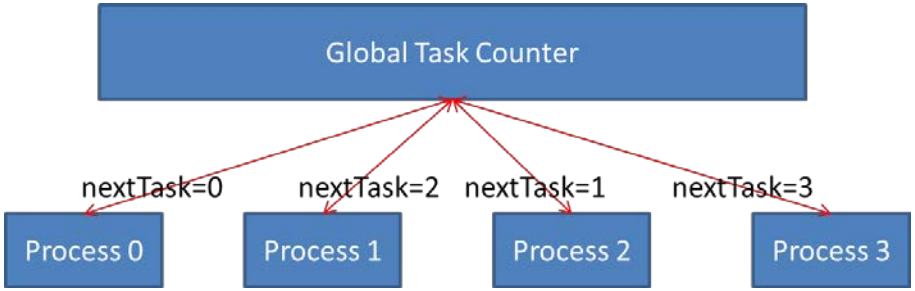
Bottleneck Identified

- 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

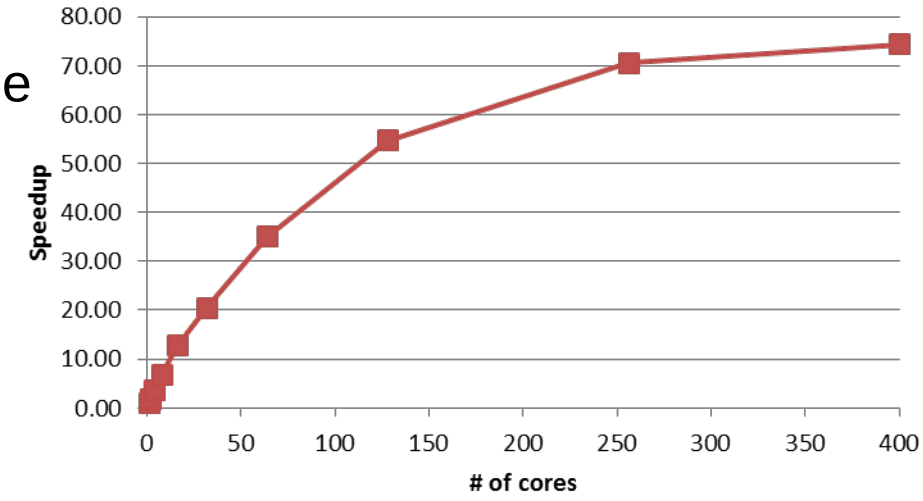


Performance of Massive Contingency Analysis

- 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

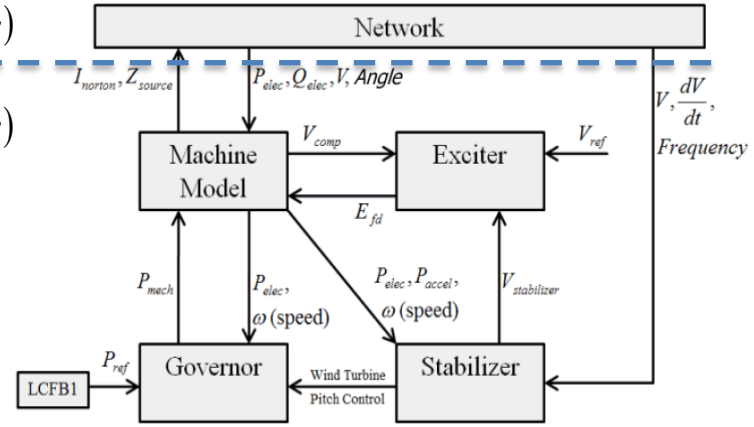


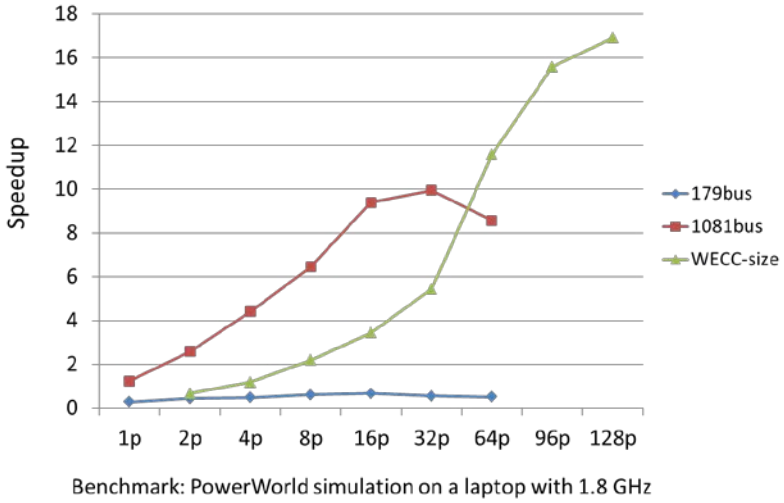
Performance of Parallel Dynamic Simulation

- Goal: Achieve 10x speedup over today's commercial tool
- Key algorithms:
  - Decoupled models for calculating states in parallel

$$0 = g(x, y)$$

$$\frac{dx}{dt} = f(x, y)$$





Benchmark: PowerWorld simulation on a laptop with 1.8 GHz

- 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

Parallel processing

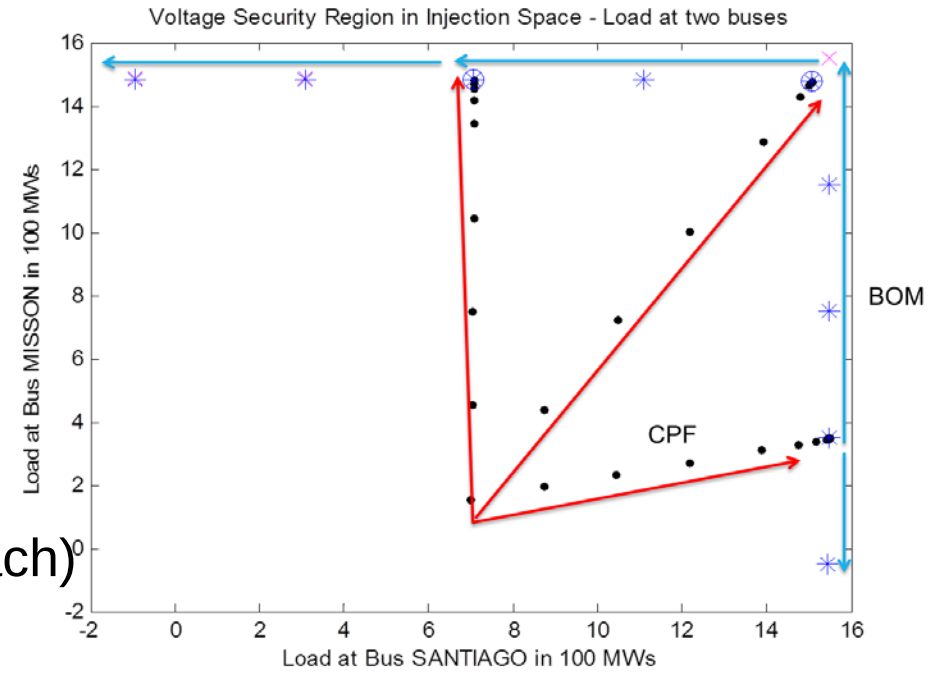
- Integration method: modified Euler

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

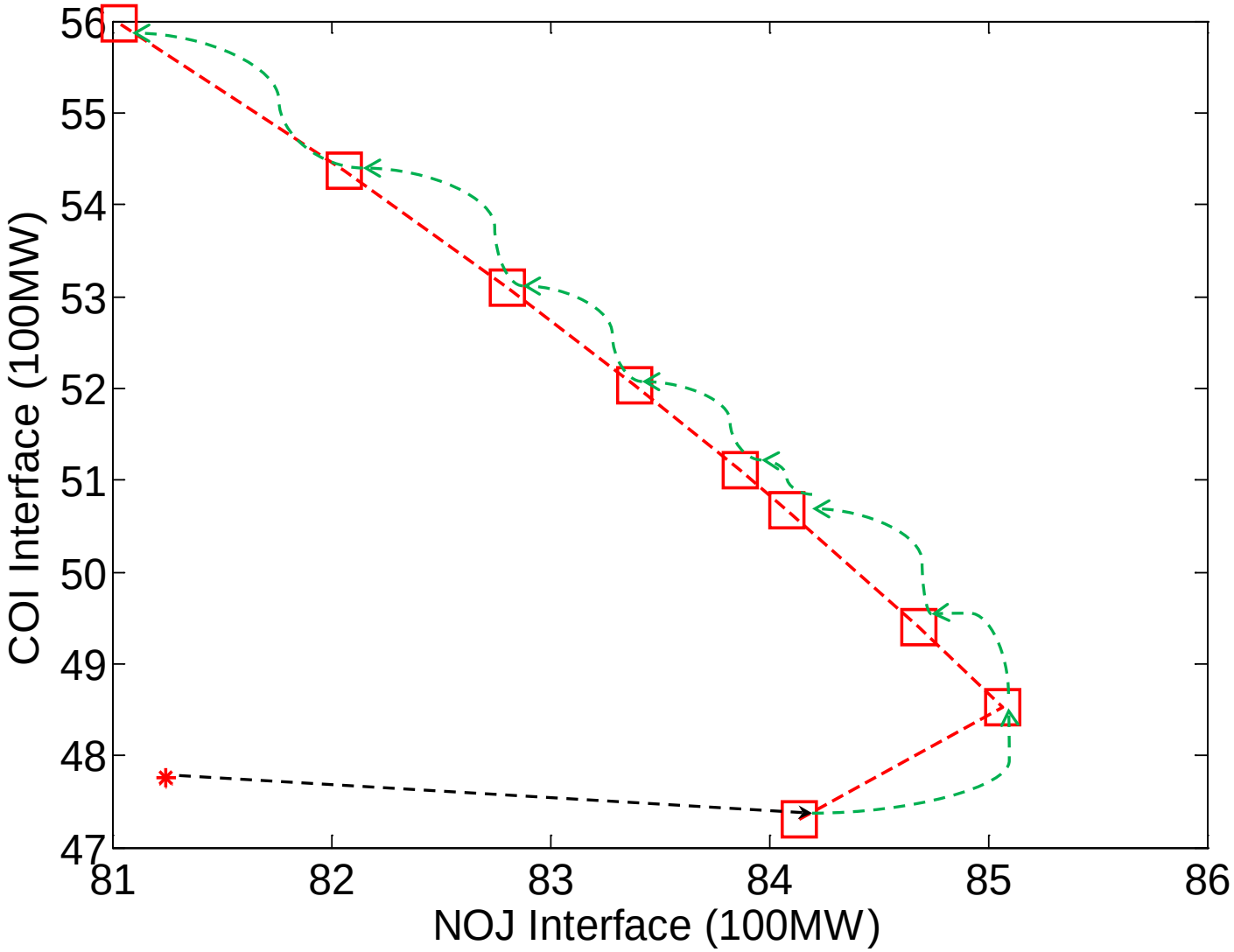
$$x_{n+1} = x_n + \frac{h}{2}(\dot{x}_{n+1}^{p} + \dot{x}_{n-1})$$

Fast Voltage Stability Simulation

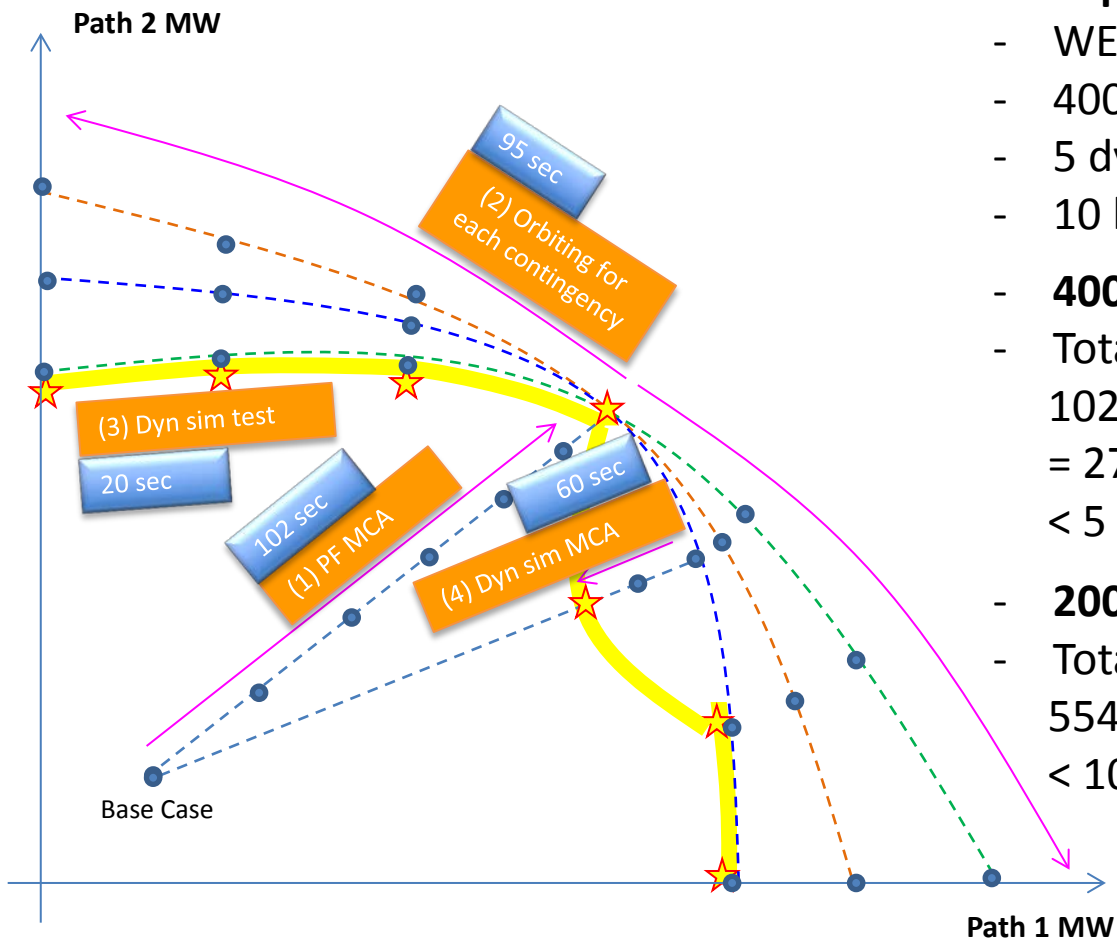
- Goal: Develop a non-iterative method to find voltage stability boundaries
- Developed and combined several methods
  - Continuation power flow
  - X-ray theorem
  - Orbiting method
  - High-order numerical method
- Accuracy validated against PW
- Only 9.5 s to find a new boundary point after initial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



Nomogram Generation



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.

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