U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability

Advanced Grid Modeling
2014 Peer Review

Improving Real-Time Operation with Advanced Computing

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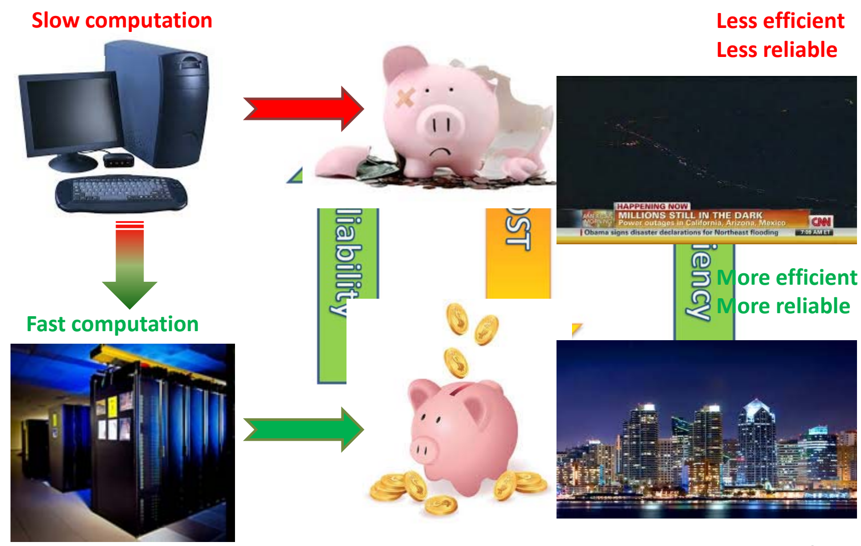
Vision: Advanced computing will help increase grid reliability and efficiency



Outline

- Project purpose
  - Significance and impact
- Technical approach
- Technical accomplishments
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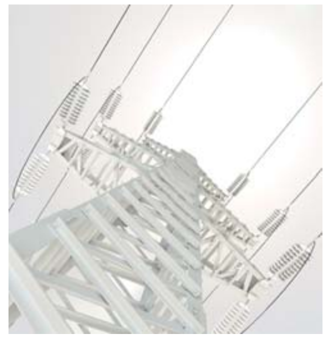
  - Massive contingency analysis (MCA)
  - Optimization techniques
- Summary
- Contacts



Project purpose: To provide faster and more effective decision support for future grid operation

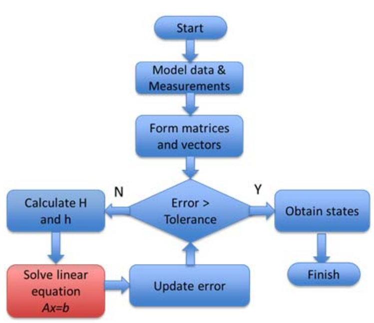
- Today's practice: Sequential algorithm-based programs are widely used in power utilities
- The grid is becoming far more complex: More complicated model and more data
- The need for advanced computing: To significantly increase the computational speed for grid applications

Technical approach

- The project is utilizing advanced computing and visual analytics techniques for power grid operation and optimization functions
  - Developing full-cycle parallel state estimation to know system states earlier
  - Implementing massive contingency analysis to minimize the risk of overlooking harmful contingencies
  - Integrating state estimation and contingency on a graphical tool for easy use of High Performance Computing (HPC) resources and visualization techniques
  - Using the parallel adaptive dynamical system (PADS) solver to address the linear programming (LP) portion of mixed integer programming (MIP) problems
  - Benchmarking PADS results against other solvers with Federal Energy Regulatory Commission (FERC) unit commitment test systems

Parallel state estimation (PSE) process

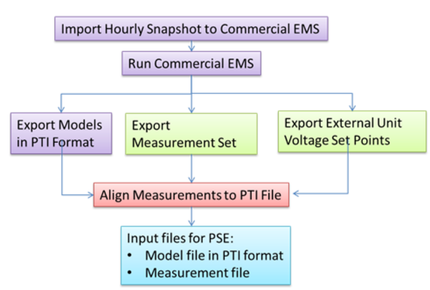
- Focus: Decrease the solution time of linear algebraic equation, the most time-consuming part of weighted least square based state estimation (SE)



State Estimation Flow Chart

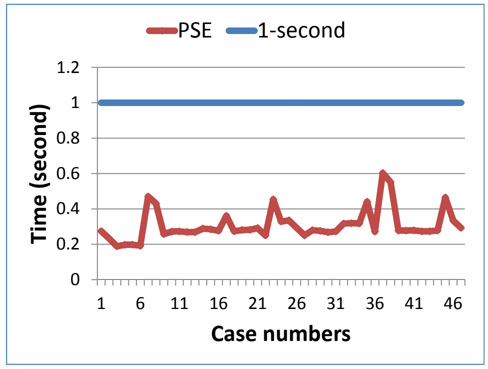
- Extract state estimation model and measurements from a commercial Energy Management System (EMS) tool and import them to PSE for testing

The data flow of data extraction from EMS to PSE



PSE performance

- Property of the test system
  - 7,500-bus, 9,300-branch system
  - 27,000 measurements
  - The ratio of maximum to minimum value in measurement weights is on the order of 10^6
- Adapted a parallel solver to handle extremely sparse matrices in power system applications
- Achieved sub-second solution time for the Bonneville Power Administration system with real measurements

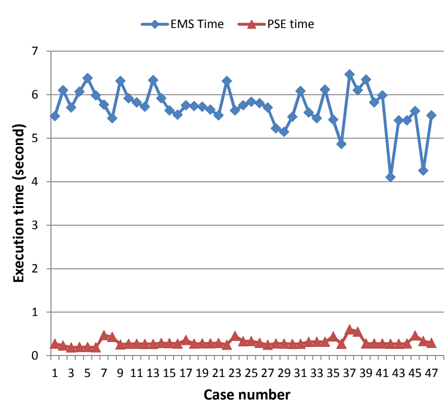


PSE benchmarking

- 10 to 20 times faster than today's commercial SE tool

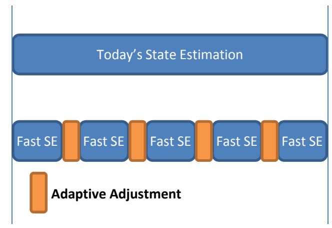
Time (second)	PSE	EMS
Max.	0.60	6.46
Min.	0.19	4.1
Average	0.31	5.7

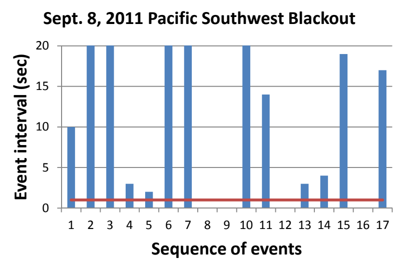
- Advantages:
  - Much faster than SCADA cycle
    - Allows multiple runs with one SCADA cycle
  - Suitable for large systems and more measurements



PSE benefits

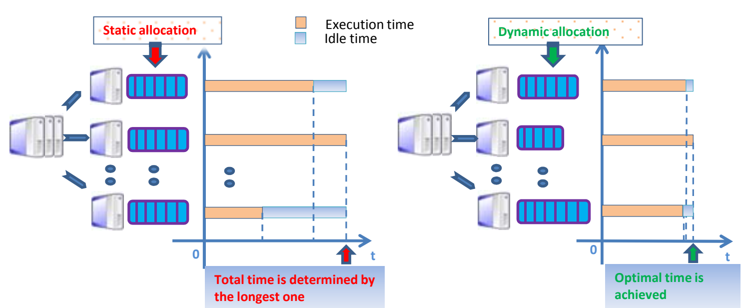
- Enhances the robustness of state estimator by running SE multiple times with adjustment within time allowance
- Detects and removes bad data more quickly
- Allows a closer monitoring of the system for early detection of disturbance
- Used as inputs to local or wide area control schemes for better accuracy and reduced operator interactions





Massive contingency analysis (MCA)

- Motivation: Today's contingency analysis (CA) is for a pre-selected set of contingencies, which might overlook some critical contingencies due to system operation condition changes
- Focus: To implement a counter-based dynamic load balancing scheme for optimal speed-up



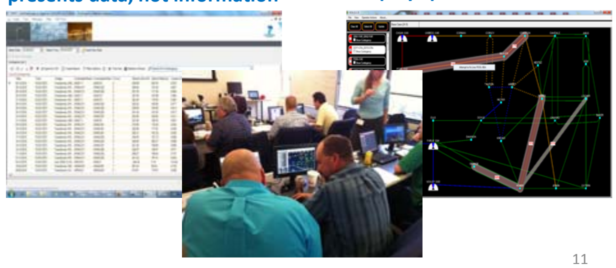
MCA performance

Contingency	# of scenarios	Serial on 1 core	Parallel on 512 cores	Parallel on 10,240 cores
WECC N-1 (full)	20,000	39 minutes	4.8 seconds	
WECC N-2 (partial)	1,000,000	68.5 hours	8 minutes (511x speedup)	25 seconds (9871x speedup)

- Excellent scalability observed with up to 10,240 cores
- Computation and visualization in tandem for actionable info
- Operators reported 30% improvement in emergency response

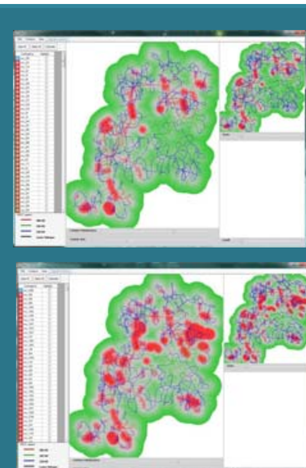
Current tabular format presents data, not information

New visualization tool displays prioritized risks



MCA benefits

- Allows operators to examine more contingency cases in a shorter time
- Reduces the risk of overlooking critical contingencies
- For planning:
  - More planning scenarios can be considered to determine a minimum cost strategy of a system extension
  - Prepare annual maintenance plans and schedule system outages more efficiently and effectively



More contingencies can help achieve an increasingly comprehensive view of system status.

PSE + MCA

- Motivation:
  - Utilize the power of advanced computing with minimal training
  - Enable faster and better decision support
- Advantages:
  - Launch HPC applications from a desktop computer through job launcher to allow flexibility of computing resources
  - Transfer HPC outputs to a desktop computer to allow in-depth analysis
  - Perform visual analytics to help operators gain wide-area situational awareness

Advanced optimization motivation

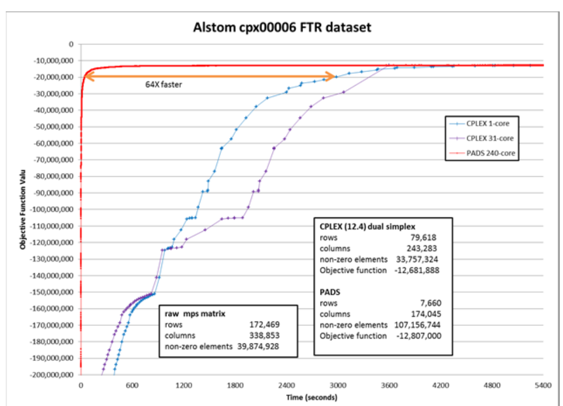
- EMS functions that require optimization technique
- Market/Operation requirements put bound on solution time
- Constrained optimizations are fundamentally hard
- Current solvers do not parallelize easily, limiting the size and/or accuracy of large regional problems needed to be solved by ISOs
- Large-scale standard benchmarks do not exist

Research approach

- Novel use of PADS to solve constrained LP problems
- Validation: Financial Transmission Rights (FTR) problem
- Exploring suitability, with additional infrastructure for MIP, for use with
  - Alternating Current Optimal Power Flow (AC OPF)
  - Unit Commitment (UC)

Optimization performance on FTR

- 64 X faster for close result than CPLEX on large commercial data sets
- Used a range of synthetic and commercial data sets

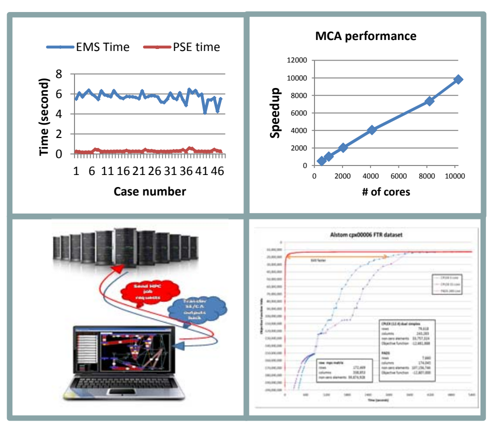


Optimization performance on UC and AC OPF

- Three FERC systems have been tested and compared against FERC results
- Analyzing the result differences
  - Optimization programs are different: SCIP (Solving Constraint Integer Programs) and CPLEX vs. Gurobi optimizer
  - Some overlap of the MIP gaps between CPLEX and SCIP, but not with Gurobi
  - The General Algebraic Modeling System (GAMS) version used is newer than the one FERC used and detected undefined transmission lines that GAMS was told to ignore
  - The FERC problem may not be well posed, resulting in multiple possible results
- Working with relatively small problems mastering issues of convergence for PADS
- Anticipated improvements on large UC problems: > 10 X

2014 accomplishments

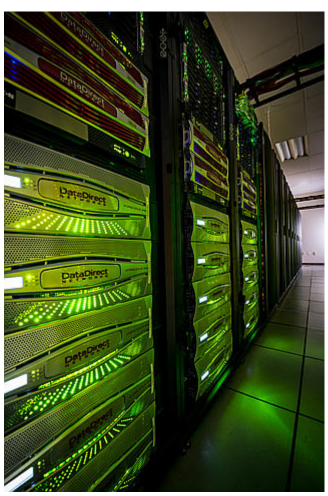
- PSE
  - Solve the SE problem 10-20x faster than today's tool
- MCA
  - Excellent scalability up to 10,000+ cores
  - Run 1 million N-2 contingencies for a WECC model within 30 seconds
- PSE and MCA Integration
  - Build a seamless link between HPC machines and desktop applications to utilize the power of HPC with minimum training
  - Help gain faster and better wide-area situational awareness for better grid reliability
- Optimization
  - Three FERC test systems have been tested and compared against FERC results and we are analyzing the differences between the FERC results and our results



Summary

- HPC techniques are needed to significantly increase the computational speed for grid applications
- The project achievements can help grid operations
  - PSE allows understanding of system status quickly
  - MCA aids better wide-area situational awareness in a short timeframe
  - PSE and MCA integration builds a seamless link between HPC and desktop applications for ease of use of HPC
  - Optimization technologies help minimize the cost of electricity production and maximize social welfare
- The developed algorithms can be leveraged by other HPC power system applications for a more secure and greener power grid

Project teams and contacts



- Parallel state estimation and massive contingency analysis
  - Yousu Chen, Mark Rice, Henry Huang, Shuangshuang Jin, Kurt Glaesemann, Craig Allwardt, Patrick Mackey
  - Contact: Yousu Chen: yousu.chen@pnnl.gov
- Advanced optimization
  - Stephen Elbert, Kurt Glaesemann
  - Contact: Stephen Elbert: steve.elbert@pnnl.gov

Questions?

Back-Up Slides

Improving real-time operation with advanced computing techniques

- Purpose: To provide faster and more effective decision support using advanced computing and visual analytic techniques
- Technical achievements:
  - Parallel state estimation (PSE): 10-20X times faster than today's tool
  - Massive contingency analysis (MCA): excellent scalability up to 10,000+ cores
  - Integrated PSE and MCA with a visualization tool for ease of use of HPC and better decision support
  - Optimization: 64X faster for close result than CPLEX on a large commercial data set for FTR problem