2014 ADVANCED GRID MODELING PEER REVIEW PROJECT SUMMARY

Project Title:	**Dynamic Paradigm for Grid Operations**
Organization:	Pacific Northwest National Laboratory
Presenters:	Henry Huang
Collaborating Organizations:	Binghamton University, Powertech Labs

Project Purpose:

This presentation combines multiple research efforts to establish a dynamic operation paradigm in contrast to today's real-time operation built on static system states. Such a dynamic paradigm aims to address the challenge of capturing power system dynamics in the emerging complexity due to new mix of electric generation and consumption. Essentially, this dynamic paradigm provides a complete picture of the current, future and potential dynamic states of a power system, improving the grid transparency in an unprecedented finer time resolution. Recent developments in phasor technology make estimating dynamic states possible with high-speed, time-synchronized measurement data. Advancements in high performance computing enable the associated computation to be finished within the short time intervals required for real-time power grid operation. This is a timely effort in terms of both the emerging needs and supporting technologies.

Technical Approach:

The electric power grid has been evolving over the last 120 years from a single power line to today's large networks. The evolution has continued at an accelerated speed with extensive smart grid development worldwide. In the next 10-15 years, a significant percentage of electricity will come from intermittent renewable sources, and a vast number of loads will actively respond to grid conditions and incentive signals. This development is largely driven by environmental and economic factors, such as reducing carbon emissions and saving electricity costs for consumers. But this results in emerging stochastic behaviors and dynamics that the grid has never seen nor been designed for. Operating such a dynamic grid with sufficient reliability and efficiency is a challenge. A new paradigm to capture such emerging dynamics is essential.

The technical approach for the proposed dynamic paradigm is built on three fundamental components: dynamic state estimation, look-ahead dynamic simulation, and dynamic contingency analysis of transient and voltage stability. Dynamic state estimation combines high-speed phasor measurements with power grid dynamic models to estimate dynamic system states such as rotor angles and speeds—direct indication of system dynamic stability. Look-ahead dynamic simulation then predicts the future system dynamic trajectory from the estimation dynamic states in a faster-than-real-time manner. Dynamic contingency analysis studies the impact on transient and voltage stability in what-if scenarios. New methods in formulating voltage stability analysis minimize the need for time-consuming iterative processes as used in traditional voltage stability analysis. Advanced computing hardware and software are leveraged in all three elements to maximize the computational performance to meet real-time requirements. These three components enable the visibility for where the grid is now, where the grid is going, and where the grid could end up with potential scenarios. It provides an opportunity for actions to mitigate any emergencies and optimize grid configuration. From these three components, other applications such as wide area control, real-time transfer capability assessment, and special protection systems can then be developed for enhanced reliability and efficiency.

2014 Results:

In the fiscal year of 2014, all three components advance with significant progress. Specific emphases are on dynamic state estimation, look-ahead dynamic simulation, and voltage stability analysis. Highlights are as follows:

1. **Dynamic state estimation**: Fundamental algorithms from prior ASCR[1]-funded research efforts are adopted for formulating the estimation problem considering practical constraints. Initial parallel computing software has been developed to implement the algorithms. Though it is promising to achieve high computational performance, the challenge lies in how to optimize parallel data allocation and eventually meet real-time requirements.
2. **Look-ahead dynamic simulation**: For large interconnection-scale systems, the computational performance of the developed parallel computing codes is multiple times faster than today's commercial tools, and more than three times faster than real time. The parallel codes have been transitioned onto the GridPACK™[2] platform for maximum extensibility. Efforts were also spent on expanding the software codes to integrate more comprehensive component models in collaboration with Powertech Labs.
3. **Dynamic contingency analysis**: Prior work established a framework for large-scale contingency analysis on thousands of computing cores for several hundred thousand contingency scenarios. Recently this framework is extended for flexible interface with commercially available tools. Significant progress has been made in developing new mathematics for efficient voltage stability analysis, aiming for fast, near-real-time assessment of accurate multi-dimensional voltage stability boundary. The current version of the voltage stability tool is 6.5-11 times faster than traditional methods on a single processor computer.

[1] ASCR: DOE Office of Advanced Scientific Computing Research.
[2] GridPACK™: Grid Parallel Advanced Computing Kernels, an open-source high performance computing library for power grid applications, available at https://www.gridpack.org/.

2015 Plans and Expectations:

Fiscal year 2015 focus will be on continuing to improve computational performance for real-time applications, further integrating the three components, and developing use cases to demonstrate the value of the dynamic paradigm. Notable milestones include:

1. Dynamic state estimation: achieve real-time performance for medium-size 1000-bus systems, considering realistic noise properties in phasor measurements
2. Look-ahead dynamic simulation: demonstrate faster-than-real-time performance with extensive component models and flexible interface with commercial simulation tools
3. Dynamic contingency analysis: implement the new voltage stability analysis methods on parallel computing platforms with the expectation of 100 times speedup.

Published Papers and Presentations:

1. Ning Zhou, Zhenyu Huang, Da Meng, Steve Elbert, Sh Wang, and R Diao, "Capturing Dynamics in the Power Grid: Formulation of Dynamic State Estimation through Data Assimilation." Technical Report PNNL-23213, Pacific Northwest National Laboratory, 2014.
2. Jinghe Zhang, Greg Welch, Gary Bishop, and Zhenyu Huang, "A Two-Stage Kalman Filter Approach for Robust and Real-Time Power System State Estimation." IEEE Transactions on Sustainable Energy, Volume: 5, Issue: 2, Page(s): 629 – 636, 2014.
3. Ning Zhou, Zhenyu Huang, Greg Welch, and Jinghe Zhang, "Identifying optimal measurement subspace for ensemble Kalman filter," Electronics Letters, Volume: 48, Issue: 11, Page(s): 618 - 620, May 2012.
4. Ning Zhou, Zhenyu Huang, Yulan Li, and Greg Welch, "Local Sequential Ensemble Kalman Filter for Simultaneously Tracking States and Parameters," in: Proceedings of the 2012 North American Power Symposium, Urbana-Champaign, IL, USA, September 9-11, 2012.
5. Yulan Li, Zhenyu Huang, Ning Zhou, Barry Lee, Ruisheng Diao, and Pengwei Du, "Application of Ensemble Kalman Filter in Power System State Tracking and Sensitivity Analysis," in: Proceedings of the 2012 IEEE Power and Energy Society Transmission and Distribution Conference and Exposition, Orlando, FL, May 7-10, 2012.
6. K. P. Schneider, Zhenyu Huang, Bo Yang, M. Hauer, and J. Nieplocha, "Dynamic State Estimation Utilizing High Performance Computing Methods," in: Proceedings of PSCE09 – the IEEE Power and Energy Society Power System Conference and Exposition 2009, Seattle, WA, March 15-18, 2009.
7. Zhenyu Huang, Kevin Schneider, and Jarek Nieplocha. "Feasibility Studies of Applying Kalman Filter Techniques to Power System Dynamic State Estimation," in: Proceedings of IPEC2007 – the 8th International Power Engineering Conference, Singapore, 3-6 December 2007.
8. Zhenyu Huang, Shuangshuang Jin, Yousu Chen, and Ruisheng Diao, "Predictive Dynamic Security Assessment through Advanced Computing," accepted by the 2014 IEEE Power and Energy Society General Meeting, Washington, D.C., USA, July 27 – 31, 2014.
9. Zhenyu Huang, Kevin Schneider, Ning Zhou, and Jarek Nieplocha, "Estimating Power System Dynamic States Using Extended Kalman Filter," accepted by the 2014 IEEE Power and Energy Society General Meeting, Washington, D.C., USA, July 27 – 31, 2014.
10. Yousu Chen, and Zhenyu Huang, "A High Performance Computing Platform for Running High Volume Studies With Windows-based Power Grid Tools," accepted by the 19th World

Congress of the International Federation of Automatic Control (IFAC), Cape Town, South Africa, August 24-29, 2014

11. Yuri Makarov, Bharat Vyakaranam, Di Wu, Jason Hou, Steve Elbert, Zhenyu Huang, “On the Configuration of the US Western Interconnection Voltage Stability Boundary,” 2014 IEEE PES Transmission and Distribution Conference and Exhibition, Chicago, IL, USA, April 14 – 17, 2014.
12. Shuangshuang Jin, Yousu Chen, Zhenyu Huang, Ruisheng Diao, and Di Wu, “Parallel Implementation of Dynamic Simulation in Power Grid,” In: Proceedings of the 2013 IEEE Power and Energy Society General Meeting, Vancouver, BC, Canada, July 21 – 25, 2013.
13. Zhenyu Huang, Shuangshuang Jin, and Ruisheng Diao, “Predictive Dynamic Simulation for Large-Scale Power Systems through High-Performance Computing,” in: Proceedings of the SC12 2nd International Workshop on High Performance Computing, Networking and Analytics for the Power Grid, Salt Lake City, UT, USA, November 11, 2012.
14. Yousu Chen, Zhenyu Huang, and Mark Rice, “Evaluation of Counter-Based Dynamic Load Balancing Schemes for Massive Contingency Analysis on Over 10,000 Cores,” in: Proceedings of the SC12 2nd International Workshop on High Performance Computing, Networking and Analytics for the Power Grid, Salt Lake City, UT, USA, November 11, 2012.
15. Zhenyu Huang, Yousu Chen, and Jarek Nieplocha, “Massive Contingency Analysis with High Performance Computing,” in: Proceedings of PES-GM2009 – the IEEE Power and Energy Society General Meeting 2009, Calgary, Canada, July 26-30, 2009.