2014 Advanced Grid Modeling Peer Review Project Summary

Project Title:	**High Fidelity Faster Than Real-Time Simulator for Predicting Power System Dynamic Behavior**
Organization:	Illinois Institute of Technology
Presenters:	Alex Flueck, IIT (Project PI)
Collaborating Organizations:	Electrocon International, Argonne National Laboratory, Alstom Grid, McCoy Energy, ComEd, AltaLink

Project Purpose:

The objective of this project is to accelerate performance and enhance accuracy of dynamic simulations to enable operators to maintain reliability and mitigate cascading blackouts. This project will achieve the following primary objectives:

- Develop a high fidelity "faster than real-time" dynamics simulator capable of predicting complex, large-scale power system behavior.
- Improve speed of dynamics simulations by leveraging Portable, Extensible Toolkit for Scientific computation (PETSc) linear solvers, nonlinear solvers, time stepping algorithms, memory management, multi-core, many-core and possibly Graphical Processing Unit (GPU) processors.
- Improve fidelity of dynamics simulations with new three-phase unbalanced network models, single-phase induction motor models, and protection system models.

Technical Approach:

The proposed framework will aid operators in their true time of need, when there is a significant risk of cascading outages. The project will accelerate performance and enhance accuracy of dynamics simulations, enabling operators to maintain reliability and steer clear of blackouts. In the long-term, the simulation framework will form the backbone of the newly conceived hybrid real-time protection and control architecture for coordinating local controls, wide-area measurements, wide-area controls and advanced real-time predictive capabilities.

The path forward begins by extending IIT's existing "faster than real-time" dynamics simulators to achieve faster solution speed, increase the scale of the power system models, integrate finer granularity network, generator and load models, as well as more detailed protection models. The dynamics simulation framework will include:

1. Unbalanced three-phase dynamics model based on a differential-algebraic equation representation of a realistic large-scale power system, including detailed generator models, maximum excitation limiters, detailed network models, and control devices.
2. Argonne National Laboratory's PETSc or similar package for high-performance scientific computing, including state-of-the-art memory management for parallel computing.
3. New computational techniques for variable time step integration, nonlinear equation solvers and linear equation solvers.
4. Induction motor models with rotor-stall failure mode to accurately represent air conditioning load under fault-induced low-voltage conditions.
5. Protection (relaying) models, including special protection schemes, remedial action schemes and system integrity protection schemes.

The team is conducting independent verification and validation studies with realistic operating scenarios and actual utility data to ensure the dynamics simulator addresses the needs of the industry. Also, the team has formed a Utility Advisory Group (UAG) to provide guidance from other electric utility experts outside the current project team.

2014 Results:

Significant Results

The team continues to investigate the need for detailed large-scale modeling to capture cascading outage dynamics. Society suffers during widespread blackouts. At the other extreme, society suffers from inefficient grid operations due to overly conservative constraints. Both of these undesirable outcomes have a common root cause: a failure to understand grid dynamics, including generators, grid controls, protection systems and loads.

The team has begun testing on actual utility dynamics data with roughly 18,500 buses. Unfortunately, these cases are not available without an NDA. There is an urgent need to study power system dynamics in large cases with modeling that extends down to lower kV levels and across wider footprints.

In addition the team is testing and verifying the proposed TS3ph simulator using Alstom Grid's ESCA60 case (approximately 100 buses, 25 generators). This case is available to all of the project team members, which is critical for sharing contributions and improving performance of the various subsystems.

Areas for Research Exploration

- Test systems for dynamics simulation benchmarking,
- Wide-area protection and control: RAS/SPS/SIPS,
- Renewable generation: detailed dynamics of wind turbines and PV arrays,
- SVC controls: independent single phase operation,
- Distribution systems: load response to transmission-level disturbances,
- New technologies: demand response, microgrids, storage.

Successful Collaboration

- Argonne National Laboratory's Mathematics and Computer Science Division (*PETSc, algorithm development*),

- Electrocon, the developer of CAPE, protection system modeling and simulation tool (*protection engine development, verification & validation*),
- Alstom Grid, Energy Management System vendor (*verification & validation*),
- Commonwealth Edison, a large metropolitan utility (*verification & validation*),
- AltaLink, a large provincial transmission owner (*verification & validation*) ,
- McCoy Energy (facilitate Utility Advisory Group).

2015 Plans and Expectations:

Near-Term Plans and Next Steps

The team is looking forward to the following milestones at the end of Year 2 (Sep 2014):

1. Evaluation of TS3ph simulator performance on utility data.
2. Implementation and testing of variable time-stepping algorithms.
3. Integration of TS3ph with CAPE.
4. Verification of realistic unbalanced faults and stressed system conditions.

In Year 3, the team will focus on performance enhancements and validation studies. The current utility partners (ComEd and AltaLink) are gathering various datasets from historical events. Some events are related to major storms and others are related to unusual operating conditions.

Expanded Collaboration and Industry Engagement

The team is actively seeking additional industry partners. McCoy Energy will be returning to previous prospects for the Utility Advisory Group. At the end of the summer, the team will have simulation results and case studies to share with potential collaborators.

In addition, the team will be represented at the upcoming 2014 IEEE PES GM panel session on "faster than real-time dynamics simulation". This will be an opportunity to gather additional feedback from industry experts and practitioners.

Risk Management

The most significant risk is that the team will not be able to achieve faster than real-time dynamics simulation on actual large utility models. The two main obstacles are the added computational burden of the proposed three-phase network models and the added communication and computational burden of the proposed detailed relay protection models.

CAPE relay evaluation may need to be skipped to achieve faster than real-time dynamics simulation. In that case, the team will identify the bottlenecks in the processing of the relays.

Also, the three-phase network models may need to be removed. If necessary, the team will drop back to use traditional per-phase models (single phase representation assuming balanced three-phase). This would reduce the computational load by roughly an order of magnitude.

Published Papers and Presentations:

1. "DOE IIT Synchrophasor Engineering Research and Training", North American SynchroPhasor Initiative Workshop, Rosemont, October 2013. [included an overview of the DOE AGM project on "faster than real-time dynamics simulation"]

2. “High Fidelity Faster Than Real-Time Simulator for Predicting Power System Dynamic Behavior”, Advanced Grid Modeling Workshop, poster session, Knoxville, February 2013.
3. “Power Grid Dynamic Security”, Midwest Energy Forum, University of Chicago, February 2013.
4. G. Soykan, A.J. Flueck, H. Dağ, “Parallel-in-space implementation of transient stability analysis on a Linux cluster with Infiniband”, Proceedings of the IEEE PES North American Power Symposium (NAPS), 2012. [faster than real-time simulation on 7935-bus system]
5. S. Abhyankar, A. Flueck, X. Zhang, H. Zhang , “Development of a parallel three-phase transient stability simulator for power systems”, HiPCNA-PG '11: Proceedings of the first international workshop on High performance computing, networking and analytics for the power grid, November 2011.
6. S. Abhyankar, B. Smith, H. Zhang, A. Flueck, “Using PETSc to develop scalable applications for next-generation power grid”, HiPCNA-PG '11: Proceedings of the first international workshop on High performance computing, networking and analytics for the power grid, November 2011.