# 2014 ADVANCED GRID MODELING PEER REVIEW PROJECT SUMMARY

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| **Project Title:** | **Power Grid Optimization under Uncertainty: Formulations, Algorithms, and High-Performance Computing** |
| **Organization:** | Argonne National Laboratory |
| **Presenters:** | Jianhui Wang and Victor M. Zavala |
| **Collaborating Organizations:** | University of Chicago, University of Florida, University of Tennessee, Virginia Tech, ALSTOM Grid, PJM |

## Project Purpose:

This project develops optimization models, solution methods, and software implementations for decision-making under uncertainty. The methods and tools seek to address the high complexity of power grid applications by leveraging DOE's leadership computing facilities and by pushing the state of the art in optimization. In particular, we develop advanced power system operational procedures that incorporate increased physical fidelity, complex spatiotemporal uncertainties resulting from renewable energy, combinatorial decisions, and infrastructure interdependences. We also perform large-scale computational studies using realistic data sets to demonstrate economic impact under current and future grid scenarios with the intention of guiding new operational procedures, market designs, and pricing mechanisms.

## Technical Approach:

The national power grid is experiencing increasing operational complexity due to the increasing penetration of intermittent renewable energy. In addition, the emergence of extreme weather events and increasing dependency on cyberphysical, natural gas, and water infrastructures questions the grid's resiliency and reliability. The models and solution methods developed under this project seek to characterize the propagation of contingencies of different forms, to find new ways of mitigating them using different approaches to address risk (e.g., robust, stochastic, and chance-constrained optimization techniques), and to identify critical vulnerabilities. In particular, we develop methods that capture long-range spatiotemporal correlations, that exploit the use of gas storage, and that reroute power flows using transmission switching. Our vision is to ultimately integrate all these capabilities to enable coordination between subsystems.

## 2014 Results:

In FY14, we have made progress in two directions. The first direction has focused on extensions to our parallel optimization solver (PIPS) and on computational studies that demonstrate its scalability on DOE's leadership computing facilities. Along this direction, we have also incorporated graph-partitioning capabilities to enable decomposition of large-scale networks. Network decomposition enables us to address the complexity resulting from increasing power grid geographical domains and long-range interconnections with natural gas networks. We have also incorporated powerful nonlinear optimization capabilities that enable us to handle nonconvexities originating from natural gas network dynamics and AC power flow and to exploit model structures in a modular manner. Modularity is key in addressing emerging multiphysics models and in leveraging the use of hybrid high-performance systems offering GPU accelerators. We have performed a large-scale computational study of the Illinois transmission system in order to understand and assess the impact of capturing long-range spatial correlations of wind power on dispatch cost. We have used validated wind-speed forecasts over the entire state using the numerical weather prediction system WRF. Our study has found important cost biases resulting from neglecting long-range correlations. The biases are on the order of hundreds of millions of dollars a year in a system the size of Illinois alone. These biases are important because they open opportunities for arbitrage that can ultimately result in market inefficiencies. Our results advocate for the need of a dedicated weather forecasting system that captures correlations in a coordinated manner instead of allowing wind power suppliers to provide (and possibly manipulate) their own weather forecasts. Our studies have been performed on Argonne's Blue Gene/Q system "Mira" on up to 16,384 nodes. We have also performed studies to assess the flexibility gained by exploiting dynamic gas storage in pipelines (line-pack). We have found that highly dispatchable gas storage capacities equivalent to 1,000 MWh of electric power can be provided by interstate pipelines and that these, if properly coordinated with combined cycle plants, can be used to mitigate abrupt variations of wind power supply. This study was performed on Argonne's Fusion system.

The second direction of our work has focused on new model formulations that capture different attitudes toward risk and that consider different degrees of freedom. We believe that exploring different formulations is important because it enables industry to assess the benefits and drawbacks of approaches to perform different operational tasks (e.g., market clearing and reliability). The formulations developed include (1) scenario-based stochastic market clearing, which enables capturing probabilistic patterns of renewable energy and for which price fairness guarantees have been obtained; (2) robust optimization where an uncertainty set of prescribed forms is used instead of scenarios to guarantee the robustness of the solution and minimize the system cost in the worst-case scenario (robust optimization is particularly attractive because less information is needed to characterize uncertainty but can be conservative); and (3) chance-constrained programming where probabilistic constraints are used to impose explicit limits on resource utilization and reliability.

Our research on these areas has raised several interesting questions that are of relevance as we transition from deterministic to stochastic operational frameworks. In particular, it is not clear what are the economic incentives provided by different formulations. This information is important because we have shown that naïve approaches can bias incentives to a subset of suppliers and block the entry of emerging technologies into the market. In addition, it is not clear how to best share risk among market players in order to achieve fairness and enhanced market conditions. Moreover, it is not clear how to best exchange uncertainty information among market players and the ISO.

## 2015 Plans and Expectations:

In the direction of scalable solvers, our near-term goal is to develop mixed-integer capabilities to capitalize on our successes with PIPS. This, however, is extremely challenging because virtually no approaches are known that can tackle the domains and the physical (nonlinear) fidelity of interest. Our proposed approach will be to develop a mixed-integer global optimization framework based on Benders decomposition that exploits modular structures. Here, lower bounds will be obtained by using convex piecewise linear underestimators. We will solve the structured problem to obtain lower bounds using Benders decomposition while upper bounds will be obtained with PIPS. This type of Benders framework has been recently proposed in the literature and has showed promise in addressing stochastic nonlinear mixed-integer problems. We will seek to extend this framework to general problem structures. An attractive feature of Benders is that it can be extended to solve minmax robust formulations. Our extensions on solvers will ultimately enable us to implement scalable versions of our different formulations. We are also in contact with Levitan & Associates and DNV GL to leverage the use of our solver capabilities in order to address questions related to the interconnection of power grid and natural gas infrastructures.

On the formulation side, we continue to improve our work on transmission switching. One possible direction of the work is based on the idea of concentric relaxations for transmission switching. Concentric relaxation is an idea used in power systems to study the effects of contingencies and can be readily applied to transmission switching problems. We are also developing a distributionally robust congestion management method with dynamic line ratings. This approach will be capable of accounting for errors in forecasted values of dynamic line ratings. Such a method can ensure the reliability of the system while fully utilizing the benefits of dynamic line ratings. We are in discussions with PJM and ALSTOM Grid to test and implement some of the algorithms developed through this project.

## Published Papers and Presentations:


1. B. Chen, J. Wang, L. Wang, Y. He, Z. Wang, *Robust Optimization for Transmission Expansion Planning: Minimax Cost vs. Minimax Regret*, IEEE Transactions on Power Systems, In Press.
2. J. Ostrowski, J. Wang, C. Liu, *Transmission Switching with Connectivity-Ensuring Constraints*, IEEE Transactions on Power Systems, In Press, 2014.
3. C. Zhang, J. Wang, *Optimal Transmission Switching Considering Probabilistic Reliability*, IEEE Transactions on Power Systems, In Press, 2014.
4. L. Fan, J. Wang, R. Jiang, Y. Guan, *Min-Max Regret Bidding Strategy for Thermal Generator Considering Price Uncertainty*, IEEE Transactions on Power Systems, In Press.
5. C. Liu, J. Wang, Y. Fu, V. Koritarov, *Multi-area Optimal Power Flow with Changeable Transmission Topology, IET Generation, Transmission & Distribution*, In Press, 2014.
6. Y. Guan, J. Wang, *Uncertainty Sets for Robust Unit Commitment, IEEE Transactions on Power Systems*, In Press, 2014.
7. C. G. Petra, O. Schenk, M. Anitescu. *Real-time Stochastic Optimization of Complex Energy Systems on High Performance Computers*. Computing in Science & Engineering (CiSE), 2014.
8. Zavala, V. M.; Anitescu, M. and Birge, J. *A Stochastic Electricity Market Clearing Formulation with Consistent Pricing Properties*. Operations Research, Under Review, 2014.

9. C. G. Petra, V. M. Zavala, E. Nino, and M. Anitescu. *Economic Impacts of Wind Covariance Estimation on Power Grid Operations*, IEEE Transactions on Power Systems, Submitted, 2014.
10. Zavala, V. M. *Stochastic Optimal Control Model for Natural Gas Network Operations*. Computers & Chemical Engineering, 64(1), pp. 103-113, 2014.
11. R. Jiang, J. Wang, M. Zhang, Y. Guan, *Two-Stage Minimax Regret Unit Commitment Considering Wind Power Uncertainty*, IEEE Transactions on Power Systems, 28(3), pp. 2271-2282, 2013.
12. C. Zhao, J. Wang, J.P. Watson, Y. Guan, *Multi-Stage Robust Unit Commitment Considering Wind and Demand Response Uncertainties,* IEEE Transactions on Power Systems, 28(3), pp. 2708-2717, 2013.
13. J. Wang, J. Wang, C. Liu, J. Ruiz, *Stochastic Unit Commitment with Sub-hourly Dispatch Constraints*, Applied Energy, 105, pp. 418-422, 2013.
14. Q. Wang, J. Wang, Y. Guan, *Price-Based Unit Commitment with Wind Power Utilization Constraints, IEEE Transactions on Power Systems*, 28(3), pp. 2718-2726, 2013.