



New Operation Tools for Improving Flexibility and Reliability of Systems with Variable Resources and Storage Devices

Final Project Report

M-32

Power Systems Engineering Research Center

*Empowering Minds to Engineer
the Future Electric Energy System*



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Executive Summary

The real-time economic dispatch (ED) in the current practice relies on a combination of optimization tools and operating rules. The dominant optimization tools used in practice for ED are deterministic models, which dispatch the power system to satisfy a single forecast value of future demand and renewable uncertain output, and keep reserve capacities to account for unexpected disturbance or outages. With the presence of significant variable resources such as wind and solar power, system operators will frequently face undesirable conditions such as lack of reserves, insufficient ramping capabilities, and cycling of thermal units as the variable resources experience sudden strong drop of output. Under these conditions, the real-time electricity markets may suffer temporary price spikes. These risky scenarios have already occurred in the US as well as other major electricity markets in the world. To deal with reserve and ramp shortages, the current operation tools restrict system operators to a limited set of actions such as increasing reserve margins, deploying fast-start units, and out-of-market dispatch. These actions usually incur high costs, create market distortions, and do not guarantee high level of system reliability.

With the recent advances in storage technologies, grid-level storage devices are becoming a viable resource to participate in system operation. Energy storage systems, such as utility-scale batteries, pumped hydro, and demand-side response can be important resources for providing flexibility into the system. How to best deploy and operate different types of energy storage systems and demand response resources and to assess their economic value in a system with significant variable resources is an important issue for utilities and system operators.

Facing these challenges and opportunities, system operators have recently started looking into new operational models for their economic dispatch and real-time energy markets. This also motivates the central objective of this project to provide a set of new operational tools for operators to improve system flexibility as well as reliability and at the same time to maintain an efficient energy market. This requires us to develop new optimization tools, uncertainty modeling methods, and system flexibility and reliability metrics that can be integrated into the operational model.

In this project, we have focused on adaptive robust optimization as the central paradigm for optimization under uncertainty, and developed new dispatch tools that improve robustness of the dispatch operation for large-scale systems. In particular, robust optimization provides several features that are particularly appealing to applications in power systems. For instance, robust optimization seeks to optimize system performance in a controlled manner against the worst-case scenario, which is consistent with the philosophy of operational practice; robust optimization can provide a rigorous way to identify the worst-case or near worst-case scenarios out of practically infinitely many potential scenarios, rather than restricting to a finite, usually small, number of preselected scenarios; robust optimization also offers a data-driven approach to model uncertainty, which scales well with the increasing dimension of data.

The final report is consisted of three parts, reflecting the three main objectives of the project: 1) Develop new robust optimization models and uncertainty modeling tools for real-time dispatch and day-ahead unit commitment; 2) Develop new metrics for quantifying power system

flexibility in real-time operation and construct new market models for the procurement of flexibility from flexible resources; 3) Develop new and more accurate models for flexible components, including energy storage, responsive demand, distributed energy resources, and ramp-constrained generation, in AC look-ahead OPF, and develop new tools for remedial action and contingency filtering for real-time security analysis.

1. Part I first develops two-stage robust optimization based models for multi-period economic dispatch and proposes a new type of uncertainty modeling method, called the *dynamic uncertainty sets*, for modeling temporal and spatial correlations of wind and solar power. Part I also develops a simulation platform which combines the proposed robust economic dispatch model with statistical prediction tools in a rolling horizon framework. Extensive computational experiments are conducted on this platform using real wind data. The results are promising and demonstrate the benefits of the proposed approach in both reducing cost and increasing system reliability over existing robust optimization models as well as recent look-ahead dispatch models. Part I then turns to the unit commitment problem and studies effective algorithms for solving the two-stage robust optimization model for the unit commitment problem. Part I also provides insight to the worst-case uncertainty scenarios for the robust UC problem both under static and dynamic uncertainty sets.
2. Part II focuses on developing flexibility metrics and market construct for improving flexibility in power systems. It first develops a new probabilistic metrics, called the *lack of ramp probability* (LORP), for quantifying power system flexibility in real-time dispatch. LORP determines the level of risk of ramp capacity shortage associated with a dispatch decision. The LORP metric can also be used independently of the proposed robust dispatch model, to assess the system flexibility under existing and other proposed real-time economic dispatch models, such as conventional dispatch, look-ahead dispatch and dispatch with ramp capability constraints. Part II then proposes a two-step multi-period robust optimization based framework as a market construct for the procurement of flexibility from various flexible resources while observing inter-zonal transmission constraints.
3. Part III focuses on expanding the modeling of the short-term look-ahead dispatch to include new flexible components, such as energy storage, responsive demand, distributed energy resources, and ramp-constrained generation, as well as more accurate network models. Part III also proposes two remedial action schemes to resolve infeasibility in AC OPF with flexible devices. Finally, at a given optimal solution, a filtering & analysis framework is developed for identifying critical outages with a lowered computational cost.

Project Publications:

- [1] Lorca, A.; and A. Sun. "Adaptive Robust Optimization and Dynamic Uncertainty Sets for Multiperiod Economic Dispatch with Significant Wind." IEEE Transactions on Power Systems 2016.
- [2] Thatte, A. A.; and L. Xie. "A Metric and Market Construct of Inter-temporal Flexibility in Time- coupled Economic Dispatch." IEEE Transactions on Power Systems 2015.

- [3] Polymeneas, E.; and A.P. Meliopoulos. “Aggregate Equivalent Models of Flexible Distribution Systems for Transmission-Level Studies.” IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26-30, 2015.
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- [5] Thatte, A.; A. Sun, and L. Xie. “Robust Optimization Based Economic Dispatch for Managing System Ramp Requirement.” 47th Annual Hawaii International Conference on System Sciences (HICSS-47), pgs. 2344-2352, Waikoloa, Hawaii, January 6-9, 2014.
- [6] Thatte, A.; and L. Xie. “A Two-layered Framework for Robust Dispatch with Transmission Constraints.” 48th Annual Hawaii International Conference on System Sciences (HICSS-48), Kauai, Hawaii, January 5-8, 2015.
- [7] Sun, A; and A. Lorca. “Adaptive Robust Optimization for Daily Power System Operation.” Invited paper at 18th Power Systems Computation Conference (PSCC 2014), Wroclaw, Poland, August 18-22, 2014.
- [8] Thatte, A. A; Li, Y and Xie, L. “Managing System Ramp Flexibility by Utilizing Price-Responsive Demand: An Empirical Assessment” 48th Annual Hawaii International Conference on System Sciences (HICSS-49), Hawaii, January 5-8, 2016.
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Student Theses:

- [1] Alvaro Lorca. *Robust Optimization for Renewable Energy Integration in Power System Operations*, PhD thesis, Georgia Institute of Technology, May 2016.
- [2] Evangelos Polymeneas. *Optimal Operation and Security Analysis of Power Systems with Flexible Resources*, PhD thesis, Georgia Institute of Technology, May 2016.
- [3] Orestis Vasios. *Optimal control of Thermostatically Controlled Loads*, PhD thesis, Georgia Institute of Technology, expected graduation date, end of 2018.