The Application of Robust Optimization in Power Systems

Final Project Report

Power Systems Engineering Research Center

Empowering Minds to Engineer the Future Electric Energy System
The Application of Robust Optimization in Power Systems

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Power Systems Engineering Research Center

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Executive Summary

Power system operations are facing and will face new challenges as the level of variable resources increases along with higher levels of demand side uncertainty and area interchange. These added uncertainties make it harder for system operators to obtain robust solutions. Robust optimization allows for the modeling of an uncertainty set and ensures that the chosen solution can handle any possible realization based on this uncertainty set. This project has focused on the application of robust optimization for power system operations and operational planning. Part one of this project report provides an overview of robust optimization as well as it investigates two applications for robust optimization: robust unit commitment and robust corrective topology control. The optimal power flow models used within part one assume a linear approximation of the alternating current optimal power flow formulation. Therefore, part two is a complement to part one by providing a mechanism to test and validate the feasibility of the decision support tool solutions on nonlinear power flows. In summary, this research has developed new power systems decision making tools that utilize robust optimization as well as extensive analysis on the benefits and challenges to implement robust optimization within electric power systems.

Part I: Robust Optimization for Corrective Topology Control and Unit Commitment

In standard optimal power flow (OPF) formulations, the system parameters are assumed to be constant, i.e., they are assumed to be known. However, in real life, system parameters are uncertain, such as system demand, renewable generation, generator availability, and transmission availability. To capture the uncertainty in system parameters related to demand and renewable resources, robust optimization techniques are proposed. The presented report is divided into two parts; the first part discusses the effect of robust corrective topology control on system reliability and renewable integration while the second part deals with the application of robust optimization for the day-ahead security constrained unit commitment problem.

Robust Corrective Topology Control

This research presents three topology control (corrective transmission switching) methodologies along with the detailed formulation of robust corrective topology control. The robust model can be solved offline to suggest switching actions that can be used in a dynamic security assessment tool in real-time. The solution obtained from robust topology control algorithm is guaranteed to be DC feasible for the entire uncertainty set, i.e., a range of system operating states. The proposed robust topology control algorithm can also generate multiple corrective switching actions for a particular contingency, which provides multiple topology control (TC) options to system operators’ to choose from in real-time application.

Furthermore, this research extends the benefits of robust corrective topology control to renewable resource integration. In recent years, the penetration of renewable resources in electrical power systems has increased. These renewable resources add more complexities to power system operation, due to their intermittent nature. This research presents robust corrective topology control as a congestion management tool to manage power flows and the associated renewable uncertainty. The proposed day-ahead method determines the maximum uncertainty in renewable resources in terms of do-not-exceed (DNE) limits combined with corrective topology control. Corrective topol-
ogy control can increase DNE limits, for the renewable resources, by a significant amount. Furthermore, the DNE limit methodology, presented in this research, is capable of modeling different types of renewable resource, such as wind and solar, uncertainties simultaneously.

The results obtained from topology control algorithm are tested for system stability and AC feasibility. On IEEE-118 bus test case, significant number of topology control solutions obtained from robust topology control algorithm have produced AC feasible solution. At the same time, it is observed that the effect of topology control on bus voltages are localized around the neighborhood of buses connected by the switched transmission element. In addition to AC feasibility tests, a number of stability studies are carried out to understand the effect of topology control on system stability. It is observed that the perturbation caused by robust corrective topology control solution can be small enough and may not cause any stability issues to system operation; several topology control solutions have shown benefit to system operation.

The future work will involve testing the robust topology control algorithms on larger test systems and investigate the benefits of parallel computational of robust topology control algorithm. The scalability of the robust topology control algorithms, from smaller test systems to realistic systems, will also be studied. Future work will also involve in investigating effects of topology control actions on AC feasibility and system stability.

**Key Points**

- Three topology control methodologies are presented; out of them, the robust corrective topology control methodology is developed and tested for different scenarios.

- The robust topology control framework, presented in this research, can be used to analyze different types of uncertainties: demand uncertainty and renewable resource uncertainty. The framework can test the impacts of these uncertainties independently as well as simultaneously as well as with or without the proposed corrective transmission topology control actions.

- The methodology to determine the maximum allowable deviation in renewable resources, in terms of do-not-exceed limits, will help to integrate more renewable resources into the system without sacrificing system reliability.

**Robust Two-Stage Unit Commitment**

This research explored the robust two-stage unit commitment problem with polyhedral uncertainty set. The wind power generation is highly uncertain, which is modeled as a polyhedral uncertainty set. A two-stage robust optimization framework is proposed to find a robust unit commitment solution at the first stage and the dispatch decision can be adjusted in the second stage. Past work has modeled the two-stage decision process to minimize the worst-case total cost including the commitment cost and dispatch cost. In this work, the objective is to minimize the maximum regret for each scenario in the uncertainty set. The regret for a particular scenario refers to the difference between the minimal total cost by fixing the first stage unit commitment decision and the cost of single stage optimal unit commitment solution. Benders’ type decomposition algorithm is proposed to solve the problem. Numerical experiments demonstrate that the solutions obtained from this alternative objective function are less conservative comparing to traditional robust model. The
solutions has slightly higher expected cost with respect to the stochastic programming solution, but high reliability.

This research also examined the determination of polyhedral uncertainty sets prior to a robust formulation. With the increasing adoption of the robust programming formulation, the question of how to generate or select uncertainty sets remains open. This work studied two-stage robust unit commitment with polyhedral uncertainty set. With given set of historical data, two types of uncertainty sets based on statistic moments and empirical data are proposed. The computational experiments suggest the selection rule of of uncertainty sets for different confidence levels.

The future work will involve testing of robust unit commitment problem on larger test systems, including developing efficient heuristic and decomposition algorithms which can be implemented in high performance computing framework. Finally, the further work will consider minimax regret model with the n-k security criteria to capture the uncertainty in stochastic resources along with unpredictable contingencies.

**Key Points**

- The robust unit commitment framework is presented, while considering the uncertainty in renewable resource generation.
- The proposed two-stage robust unit commitment framework has demonstrated that the robust solution obtained from this methodology is less conservative compared with traditional robust model.
- Different types of uncertainty sets generated from historical data that are examined in this research, suggest that carefully selecting uncertainty sets have impacts on the performance of the robust solutions.

**Part II: A Zonotope-Based Method for Capturing the Effect of Variable Generation on the Power Flow**

In the last decade, there has been an increasing need for developing models to capture the uncertainty associated with electricity generation from renewable resources as they continue to penetrate into the current power system. Such penetration of renewable resources such as wind and solar introduces uncertainties in the power system static state variables, i.e., bus voltage magnitudes and angles. This report proposes a set-theoretic method to capture the effects of uncertainty on the generation side of a power system. Using this method, we can determine whether the power system state variables are within acceptable ranges as dictated by operational requirements. We bound all possible values that the uncertain generation can take by a zonotope and propagate it through a linearized power flow model, resulting in another zonotope that captures all possible variations in the system static state variables. Since the sizes of models of power systems systems have increased over the years, it is important for the developed method to scale easily and be computationally tractable. Zonotopes are easily represented by vectors and matrices, making them ideal candidates for use in large systems. Our method is applicable to both transmission and distribution systems. For verification, we test our proposed method on the IEEE 34-bus, IEEE 123-bus distribution system, and the IEEE 145-bus, 50-machine transmission system. We compare the performance of the proposed method against earlier results using ellipsoids and those solutions obtained through the nonlinear power flow and linearized power flow equations.
Project Publications:

Journal Papers:

Book Chapters:

Conference Papers:

Student Thesis: