



A Framework for Transmission Planning Under Uncertainty

Final Project Report

Power Systems Engineering Research Center

*Empowering Minds to Engineer
the Future Electric Energy System*



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Power Systems Engineering Research Center

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Executive Summary

The current transmission planning practice in the electric power industry is mainly based on the deployment of deterministic techniques. However, transmission planning, by its very nature, is faced with a wide range of sources of uncertainty, including growth in demand, renewable energy generation, fuel price, environmental requirements and legislation and new generation investment, to name just a few. In addition, the restructuring of the electric power industry, the drive for energy independence and the push for a cleaner environment have led to additional sources of uncertainty in all aspects of power system operations and planning. The competitive electricity markets, the more decentralized decision making and the new federal and state initiatives introduce additional sources of uncertainty. A particularly good example is the FERC Order No. 1000 requirements. The analytic characterization of the various sources of uncertainty is often a challenge and, typically, cannot be expressed in terms of probability distributions. Past data may allow the estimation of the ranges of values that the uncertain variables may attain so as to make possible the deployment of robust optimization approaches. We make use of such approaches to develop a decision-support system for transmission planners to allow the explicit consideration of uncertainty in the formulation of transmission plans.

We discuss our studies of two optimization criteria for the transmission planning problem with a simplified representation of load and the forecasted generation investment additions within the robust optimization paradigm. The objective is to determine either the minimum of the maximum investment requirement or the maximum regret with all sources of uncertainty explicitly represented. In this way, transmission planners can determine optimal planning decisions that are robust against all sources of uncertainty. We use a two-layer algorithm to solve the resulting tri-level optimization problems. We also construct a new robust transmission planning model that considers generation investment more realistically to improve the quantification and visualization of uncertainty and the impacts of environmental policies. With this model, we can explore the effect of uncertainty in both the size and the location of candidate generation additions. The corresponding algorithm we develop takes advantage of the structural characteristics of the model so

as to obtain a computationally efficient methodology. The two robust optimization tools provide new capabilities to transmission planners for the development of strategies that explicitly account for various sources of uncertainty.

We illustrate the application of the two optimization models and solution schemes on a set of representative case studies. These studies give a good idea of the usefulness of these tools and show their practical worth in the assessment of “what if” cases. We compare the performance of the minimax cost approach and the minimax regret approach under different characterizations of uncertain parameters. In addition, we also present extensive numerical studies on the IEEE 118-bus test system and the WECC 240-bus system to illustrate the effectiveness of the proposed decision-support system. The case study results are particularly useful to understand the impacts of each individual investment plan on the power system’s overall transmission adequacy in meeting the demand of the trade with the power output units without violation of the physical limits of the grid.

The decision-support system consisting of the two optimization models and solution approaches has wide applicability to transmission planning studies. The so-called minimax criterion models determine the set of planning decisions that result in the least-cost or the least-regret solution with the explicit consideration of uncertainty during the planning horizon. The set of planning decisions are optimal under the ranges of uncertainty given for the uncertain variables. The ability to represent the uncertainty in the investment decisions for generation addition together with the uncertainty in the retirement of units in the resource mix and the environmental regulatory requirements is a major development for the tools available to transmission planners.

Project Publications:

- Bokan Chen, Jianhui Wang, Lizhi Wang, Yanyi He, and Zhaoyu Wang, “Robust Optimization for Transmission Expansion Planning: Minimax Cost vs. Minimax Regret”, *IEEE Transactions on Power Systems*, vol. 29(6), p. 3069-3077, 2014.

- Dongbo Zhao, Sakis Meliopoulos, Zhenyu Tan, Rui Fan, "Probability State Sequence Method for Reliability Analysis of Wind Farms Considering Wake Effect," 45th North American Power Symposium (NAPS), KS, 2013.

Student Theses:

- Bokan Chen, "Three essays on the application of robust optimization to power system planning problems," Ph.D. dissertation, Iowa State University, expected September 2016.
- Dongbo Zhao, "Reliability modeling and analysis of wind turbine systems and wind farms in bulk power systems," Ph.D. dissertation, Georgia Institute of Technology, July 2015.