



Risk-Sensitive Security-Constrained Economic Dispatch via Critical Region Exploration

Final Project Report

S-88G

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

Power system operation faces two kinds of uncertainties. The first type relates to failures of system components such as generators and transmission lines. Such events (or contingencies) are rare. However, when they occur, their impact on the power system can be substantial, affecting a large population. The second kind of uncertainty emanates from renewable generation from resources such as wind and solar. Given the aggressive integration of such resources, the supply side is becoming increasingly uncertain. Electricity markets must accommodate their variability in everyday operations. Market design must effectively model these two types of uncertainties, find efficient algorithms to clear the market and find meaningful ways to design settlements for market participants.

Power system often adopts one of two ways to tackle uncertainty. The first among these approaches aims to define plans for the average case prior to the uncertainty being realized. Such an approach leaves the system vulnerable to potentially large operational costs required to handle attending deviations in real-time. On the other extreme, the second approach aims to plan for the worst-case scenario. This robust approach to forward planning is overly conservative and prioritizes reliability at the expense of possibly large operational costs. This PSERC project advocates for an in-between—the risk-sensitive approach to electricity market design under uncertainty. Risk defines an attitude towards uncertain outcomes. Suitably defined risk measures can effectively explore the cost-reliability tradeoff.

With roots in mathematical finance, risk measures abound in the literature. Some measures are more amenable to algorithm and pricing design than others. The works presented in this final report leverages the conditional-value-at-risk (CVaR) measure. CVaR-based market clearing formulations with both kinds of uncertainties and linearized power flow models become convex optimization problems. It is this convexity that makes algorithm and pricing design easy. With contingencies, the market clearing problem becomes a large linear program that can be efficiently decomposed, and its computation can be parallelized. With renewable generation, the CVaR-based market clearing problem can be solved with wind data. The mature duality theory of convex programming allows derivation of meaningful prices from these convex optimization-based market clearing formulations.

Concretely, this final report collects three lines of work, described below.

A. Risk-Sensitive Security-Constrained Economic Dispatch (SCED): This work considers uncertainty in transmission line failures and proposes a risk-sensitive security-constrained market clearing formulation that allows an SO to tradeoff between cost of nominal dispatch and the extent of possible load-shedding. The formulation provides a tunable parameter that allows the SO to systematically explore this tradeoff. The CVaR-based optimization problem for market clearing is then solved via an algorithm that leverages the problem structure. More precisely, the optimization problem is a large linear program where the corrective action in each contingency is only coupled to the nominal dispatch and not the actions in other contingencies. This nature of coupling allows a decomposition of the problem that permits parallelization. The work in this area has largely revolved around finding suitable ways to exploit the problem structure to design a fast algorithm.

B. Risk-Sensitive Economic Dispatch with Random Wind: This work proposes a framework to compute a risk-sensitive dispatch that defines a forward dispatch against uncertain wind power production. Wind renders power draws from generation assets and power flows over the transmission lines uncertain. The proposed market-clearing formulation penalizes constraint violations and random costs via their conditional value at risks (CVaRs). This formulation with linear power flow equations is a convex optimization problem. A data-driven solution architecture is proposed to solve the problem. This algorithm generates uncertain wind scenarios across the network and moves the solution iterates accordingly. The mathematical analysis reveals how increased risk aversion leads to higher sample complexity, and hence, longer solution time.

C. Pricing Risk-Sensitive Economic Dispatch with Wind. This work defines prices from the risk-sensitive market clearing formulation that guards against uncertain wind. These prices depend on the assets connected to the network, their uncertainties in power injections and the risk attitudes in dealing with said uncertainties. Properties of these risk-sensitive locational marginal prices (risk-LMPs) are derived using duality theory of convex programming. Specifically, these prices are shown to be the risk-sensitive extensions to traditional LMPs in that zeroing out the wind variance reduces these prices to traditional LMPs. They are shown to equal the sensitivity of the optimal cost of the risk-sensitive economic dispatch problem to nodal demands. Sufficient conditions are derived for revenue adequacy to be non-negative. A data-driven algorithm using wind scenarios is designed to approximate these prices.

Project Publications:

- [1] A. N. Madavan, S. Bose, Y. Guo and L. Tong, “Risk-Sensitive Security-Constrained Economic Dispatch via Critical Region Exploration”, Proceedings of the IEEE Power and Energy Society General Meeting, 2019.
- [2] A. N. Madavan, and S. Bose, “Risk-Sensitive Energy Procurement with Uncertain Wind”, Proceedings of the IEEE Global Conference on Signal and Information Processing (GlobalSIP), 2019.
- [3] A. N. Madavan and S. Bose, “A Stochastic Primal-Dual Method for Optimization with Conditional Value at Risk Constraints”, Accepted in the Journal of Optimization Theory and Applications, 2021.
- [4] M. Ndrio, A. N. Madavan and S. Bose, “Pricing Conditional Value at Risk-Sensitive Economic Dispatch”, Accepted for presentation at the IEEE Power and Energy Society General Meeting, 2021.

Student Theses:

- [1] A. N. Madavan, “Risk-Sensitive Optimization for Power Systems”. Ph.D. thesis. University of Illinois at Urbana-Champaign. (Expected) June 2022.
- [2] M. Ndrio, “Equilibrium and Learning in Electricity Markets: A Scalar-Parameterized Supply and Demand Function Approach”. Ph.D. thesis. University of Illinois at Urbana-Champaign. January 2021.