



Markets for Ancillary Services in the Presence of Stochastic Resources

Final Project Report

M-31

Power Systems Engineering Research Center

*Empowering Minds to Engineer
the Future Electric Energy System*



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Project Team

Kory W. Hedman, Project Leader
Arizona State University

Muhong Zhang
Arizona State University

Marija Ilic
Carnegie Mellon University

Graduate Students:

Joshua Lyon, Fengyu Wang, Chao Li
Arizona State University

Jose Fernando Prada
Carnegie Mellon University

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For information about this project, contact

Kory W. Hedman
Arizona State University
School of Electrical, Computer, and Energy Engineering
P.O. BOX 875706
Tempe, AZ 85287-5706
Phone: 480 965-1276
Fax: 480 965-0745
Email: kory.hedman@asu.edu

Power Systems Engineering Research Center

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For additional information, contact:

Power Systems Engineering Research Center
Arizona State University
527 Engineering Research Center
Tempe, Arizona 85287-5706
Phone: 480-965-1643
Fax: 480-965-0745

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Executive Summary

This project focuses on the challenge of managing added variability and uncertainty due to stochastic resources, resources (e.g., wind, solar, demand response products) that are not fully dispatchable or controllable like conventional generators. Market models that are inherently imprecise at capturing uncertainty and voltage limitations lead to market prices (for ancillary services) that do not accurately reflect the value provided by market participants. Ancillary services products that are procured by an ISO may not be deliverable as existing market models do not adequately capture post-contingency (or post-event) congestion. For example, MISO conducts a procedure known as *reserve disqualification* following its day-ahead market; the process disqualifies units that were scheduled to provide reserve after further analysis identifies that congestion or a lack of voltage support inhibits the delivery of the procured reserve.

While many efforts have and are being made to address this challenge, one barrier to adoption is the challenge to modify existing market models and settlement policies in such a way that is transparent and achieves stakeholder approval. Therefore, the primary objective of this work is to enhance existing market software to better predict reserve deliverability issues. More importantly, the goal is to demonstrate that enhancements to market software leads to prices that reward market participants that provide higher quality ancillary services and are more dependable. The results show that the change in compensation is aligned with the likelihood that the market participant's procured reserve is, indeed, deliverable (without violating network limitations) when needed.

The report is broken into two volumes, with three parts to volume 1 and one part to volume 2. Each part is summarized in the following subsections.

Volume 1 Summary, Parts 1-3:

Volume 1 consists of the work conducted by Arizona State University. This project leveraged the prior work conducted by Dr. Kory Hedman under the PSERC Future Grid Initiative, which ended in August 2013. Volume 1 of this project report is focused on enhancing the modeling of ancillary services requirements within existing market based security constrained unit commitment and security constrained economic dispatch tools. Volume 1 also focuses on analyzing the market implications of these adjustments. Ongoing and future efforts are now focused on leveraging this work within a project funded by the DOE Advanced Research Projects Agency – Energy (ARPAE) Network Optimized Distributed Energy Systems (NODES) program. With the assistance of industry partners, the goal is to develop a prototype tool that can run alongside energy management systems and provide guidance to operators in real-time on the adjustment of needed ancillary service products.

Part I: Market Implications and Pricing of Dynamic Reserve Policies for Systems with Renewables

Static reserve policies are used within security-constrained unit commitment (SCUC) and security constrained economic dispatch (SCED) to ensure reliability. A common policy is that ten-minute reserve must exceed the largest contingency. However, this condition does not guarantee reliability because voltage and thermal limits can hinder reserve deliverability. Many operators use zonal reserve markets to ensure reserves are dispersed across the grid. Such zonal models attempt to anticipate transmission bottlenecks, which is a difficult task due to uncertainty. This report examines the market implications of dynamic reserve policies used to mitigate uncertainty from renewable resources and contingencies. We study the market implications of policies recently proposed in the literature, such as hourly zones within day-ahead SCUC and an algorithm that formally disqualifies reserves that are expected to be undeliverable. A locational reserve pricing scheme is also proposed in connection with scenario-based reserve disqualification. Analysis on the RTS-96 test case shows that dynamic zones and reserve disqualification, along with the proposed compensation scheme, help direct reserve payments toward resources that more effectively respond to contingencies.

Part II: A Statistical Evaluation of Dynamic Reserve Policies with Consideration of Stochastic Resources

In order to reduce greenhouse gas emissions, more non-dispatchable or semi-dispatchable renewable resources are being integrated into the grid. Due to the uncertainty and variability of renewable generation, additional operating reserve may be required to ensure reliability. System reliability must be maintained by not only acquiring a sufficient quantity of reserve but also ensuring the reserve is deliverable, i.e., transmission bottlenecks must not restrict the deliverability of reserve. Existing deterministic reserve requirements locate reserve blindly inside reserve zones. Additional uneconomic adjustments, such as reserve disqualification, are necessary if the solution is unreliable due to undeliverability of reserve caused by congestion. However, such uneconomic adjustments may lead to inefficient dispatch solutions and they distort market price signals. An hourly reserve zone determination method is proposed in this report to distribute the reserve across the system efficiently and to reduce the use of uneconomic adjustments such that market efficiency and system reliability are improved. The hourly reserve zone determination method is tested on the Reliability Test System 1996 (RTS-96) with consideration of wind and load uncertainties. The market results, as well as confidence intervals after reserve disqualifications, are compared between the proposed hourly reserve zone and existing seasonal reserve zone procedures.

Part III: Market Implications of Security Requirements

Regional transmission organizations and independent system operators include different types of security requirements to ensure system security. In this report, a set of security constraints to withstand single-generator-failure contingencies are presented and the

market implications are studied. A new component of locational marginal prices, a marginal security component, which is a weighted shadow price of the security constraints, is proposed to better represent energy prices. A simple 3-bus system example is given to illustrate clearly the advantages of the new pricing scheme. The results are confirmed on a 73-bus system test case.

Volume 1 Project Papers and Publications:

- [1] J. Lyon, F. Wang, K. W. Hedman, and M. Zhang, "Market implications and pricing of dynamic reserve policies for systems with renewables," *IEEE Transactions on Power Systems*, vol. 30, no. 3, pp. 1593-1602, May 2015.
- [2] F. Wang and K. W. Hedman, "A statistical evaluation of dynamic reserve policies with consideration of stochastic resources," working paper.
- [3] C. Li, K. W. Hedman, and M. Zhang, "Market implications of security requirements," *IET Generation, Transmission, and Distribution*, under review.
- [4] J. Lyon, M. Zhang, and K. W. Hedman, "Capacity response sets for security constrained unit commitment with wind uncertainty," *Electric Power Systems Research*, vol. 136, pp. 21-30, Jul. 2016.
- [5] F. Wang and K. W. Hedman, "Dynamic reserve zones for day-ahead unit commitment with renewable resources," *IEEE Transactions on Power Systems*, vol. 30, no. 2, pp. 612-620, Mar. 2015.
- [6] J. Lyon, M. Zhang, and K. W. Hedman, "Locational reserve disqualification for distinct scenarios," *IEEE Transactions on Power Systems*, vol. 30, no. 1, pp. 357-364, Jan. 2015.
- [7] C. Li, M. Zhang, and K. W. Hedman, "Extreme ray feasibility cuts for unit commitment with uncertainty," *European Journal of Operations Research*, under review.

Volume 1 Student Theses:

- [8] Fengyu Wang, "Improving deterministic reserve requirements for security constrained unit commitment and scheduling problems in power systems," PhD Dissertation, Arizona State University, Tempe, AZ (partially supported by the PSERC Future Grid Initiative and NSF project CMMI 1333646).
- [9] Joshua Lyon, "Deterministic scheduling for transmission-constrained power systems amid uncertainty," PhD Dissertation, Arizona State University, Tempe, AZ (partially supported by the PSERC Future Grid Initiative and NSF project CMMI 1333646).
- [10] Chao Li, "Unit commitment with uncertainty," PhD Dissertation, Arizona State University, Tempe, AZ (partially supported by the NSF project CMMI 1333646).

Volume 2 Summary, Part 4:

Volume 2 reports work conducted by Carnegie Mellon University. Dr. Marija Ilic's research focused on exploring the use of stochastic SCUC models to represent the uncertainty of resource availability and provide better allocation of ancillary services. In particular, the work concentrated on the optimization of contingency reserves.

Part IV: Day-Ahead Stochastic Co-optimization of Energy and Locational Contingency Reserves

Scheduling spare generation capacity as contingency reserve in power systems is necessary to preserve the security of real-time operations. In this report we develop a stochastic security-constrained unit commitment model to co-optimize energy and the contingency reserves required to respond to a set of likely but uncertain generation contingencies. This model is used to allocate contingency reserves throughout a power grid in order to strictly comply with the N-1 security criterion under transmission congestion, minimizing expected pre contingency dispatch and post contingency redispatch costs. The proposed method efficiently assigns locational reserves in day-ahead markets and it is based on a compact formulation of the stochastic unit commitment problem that is consistent with actual operational practices. We simulated the distribution of locational contingency reserves on the IEEE RTS96 system and compared the results with the traditional global and deterministic allocation method. We found that assigning locational spinning reserves can guarantee an N-1 secure dispatch with transmission congestion at a reasonable extra cost. We also tested the effect of including downward spinning reserves and of co-optimizing spinning and nonspinning reserves. The simulations showed little value of having downward reserves but sizable operating savings from co-optimizing locational spinning and nonspinning reserves. Overall, the results indicate the computational tractability of the proposed method, which can be applied by system operators to improve the reliability and efficiency of scheduling generation and contingency reserves in bulk power systems.

Volume 2 Project Papers and Publications:

- [1] J. F. Prada and M. D. Ilic, "Locational allocation and pricing of responsive contingency reserves," *IEEE Power & Energy Society General Meeting*, Denver, Colorado, July 26-30, 2015.
- [2] J. F. Prada and M. D. Ilic, "Day-ahead stochastic co-optimization of energy and locational contingency reserves," CMU EESG Working Paper, 2016 (manuscript being submitted to the *IEEE Transactions on Power Systems*).

Volume 2 Student Thesis:

- [3] J. F. Prada, "Markets for electricity ancillary services under uncertainty: stochastic allocation and pricing of energy and locational contingency reserves," PhD Dissertation, Engineering and Public Policy Department, Carnegie Mellon University, Pittsburgh, PA.