



Reliability Metrics for Renewable Resources and Self-Reserve

Final Project Report

M-33

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

With the significant growth in the integrated capacity of wind power generation, the variability of wind energy production poses new challenges to power system operations. The need for flexible resources is higher than ever. More rapid reserve is required, which results in the scarcity of balancing services. While existing practices rely predominantly on conventional generators to provide the flexibility to sustain reliable operations, with the push to integrate more renewables, there is a need for a paradigm shift. In particular, it is expected that, at some point, these renewable sources will have to take part in the electricity system balancing tasks. In this report, the focus is on the ability for renewables to provide reserve and ramping capabilities in order to address this challenge of integrating high levels of semi-dispatchable resources into the grid. The primary goal is to develop models to determine the optimal amount of reserve margins that such renewable resources can provide. Due to its significance as one of the most common forms of renewable generation, the work is focused on wind farm generation.

Part I: Flexible Dispatch Margin Optimization

Part I of the report investigates new methods to improve the energy and reserve scheduling in presence of renewable resources and develops an approach to enhance the reliability of service from renewable resources in real-time operation.

While the share of renewable generation is increasing, existing market structure does not adequately account for uncertainty that such renewables impose. Uncertainty encourages the use of stochastic approaches. However, stochastic programming is complicated, time consuming, and poses new challenges for market integration including market pricing issues. Operators prefer to use approximate models to schedule energy and operating reserves and the operating reserve is usually determined based on an ad-hoc deterministic rule.

In this report, stochastic models are used offline to derive deterministic operation policies for scheduling energy and reserve from renewables. This concept is an extension and enhancement of the existing deterministic procedures. Such an offline approach eliminates real-time computational burden and market pricing issues, while accounting for uncertainty in the operating conditions of the system.

The proposed approach is based on creating policy functions for real-time operation of the system. A policy function is an operation rule which is a function of the operating state of the system. In the report, the reserve margin policy is derived through stochastic analysis based on the forecast of the wind generation.

Given an operating state, the policy function structure can return a scheduling decision for the renewable generator, which takes into account both the current and look-ahead operating conditions. By shifting computational complexity to offline analysis, the prediction-based policy approach has minimal added computational complexity to the existing energy management systems in real-time. The results presented for the case study indicate that the policy function based approach has performance close to that based on stochastic programming. By using the proposed

approach, the risk is reduced with minimal added computational complexity to the existing market management structure.

In summary, the key takeaway points of this project are as follows:

- A flexible reserve margin based algorithm is applied to generate offline policies for discounting wind generation and scheduling energy and reserve in the presence of wind generation. A two-phase framework is described to obtain appropriate policies for scheduling wind generation. In the first phase, a generation dispatch is performed to obtain the energy and reserve schedule for generation units. This phase leverages a scenario-based stochastic programming approach to capture the effect of the representative wind generation scenarios based on short-term forecast. This initial phase minimizes the aggregate operating costs and risk costs relative to the modeled scenarios. In the second phase, the decision from the first phase is tested against a larger set of scenarios to ensure the adequacy of the scheduled energy and reserve.
- A testing method is derived based on the real-time scheduling procedure to assess the performance of the policies obtained through the proposed training procedure for scheduling wind reserve margin. The performance of the proposed policy training algorithm is compared with its counterparts without applying the trained policies.
- A SCED (security constrained economic dispatch) model is derived for both the prediction-based method and the no-policy method to enable comparison of the behaviors of the two models. A notion of quality of service is derived for assessing the performance of the reserve from renewables.
- The market implications of deploying the proposed prediction-based policy are analyzed and compared with its counterparts without applying the trained policies. The results confirm that the prediction-based policy along with a proper market structure can improve the quality of service for scheduling energy and reserves from renewables.
- While a stochastic approach is used to generate the reserve margin policy functions in this report, the policy functions can also be derived using other techniques or be designed using various forms of data mining approaches. The policy function based approach has tractable computational complexity for a large-scale power system and can also effectively enhance the operation of renewable generators. The policy function based approach is a scalable approach that can be applied to power systems and energy market.

Part II: The Value of Flexible Wind Dispatch in Stochastic Unit Commitment

Renewable power generation, such as wind power, is commonly considered a must-take resource in power systems and only curtailed in cases where technical feasibility is compromised. This prioritization is currently in force in the European Union (Directive 2009/28/EC), even though the discussion to amend it is currently ongoing. We attempt to show that, given the technical capabilities of current wind turbines, this approach could lead to major economic inefficiency as wind integration levels in power systems increase. More specifically, our methodology consists of the following basic steps:

- We explore the expected benefit from dispatching wind resources at a lower level than their available output in a Stochastic Unit Commitment (SUC) setting. We provide a complete framework to understand and evaluate the expected benefit from flexible wind dispatch in the SUC setting.
- We present small motivating examples to offer intuition regarding the most common setups where such benefit may occur.
- We utilize existing wind speed modeling techniques, which we enhance with a non-parametric modeling methodology for the aggregate power curve.
- We extend a decomposition technique from recent literature that utilizes global cuts and Lagrangian penalties to reach an optimal solution and adapt it to solve the problem.
- We propose a combined scenario reduction and decomposition algorithm to provide a quicker answer by eliminating similar scenarios throughout the iterations of the decomposition algorithm. The main idea behind this elimination is evaluating the similarity of two scenarios based on them having comparable impacts when applied to the specific problem as the decomposition algorithm iterations progress.
- We test our framework on a reduced model of the Western Electricity Coordinating Council (WECC) system.

Part III: Risk-aware Optimal Bidding for Renewable Farms

To help renewable farms be marketable while keeping the grid reliable, the focus of a significant amount of research in the literature is on devising better methods of integrating renewable energy sources (RES) to the existing power grid.

We derive a criterion for renewable farms' participation in the grid reliability efforts. The renewable energy farms' bidding strategy is formulated as a portfolio optimization problem assuming a storage system. The portfolio is made of the day-ahead, real-time and reserve offers.

- We formulate the renewable farm's day-ahead bidding decision as a newsvendor problem.
- We evaluate renewable farm's reliability performance assuming the derived news' vendor based optimal policy.
- We provide further market opportunity to the renewable farm by assuming it can participate in the reserve market as well. We assume the farm dispose of energy storage.

The approach developed in this work has two original defining concepts. First, its principal aim is not to arbitrage the day-ahead versus the real-time markets. Rather, it purposes to provide a reliable and yet economically sound day-ahead energy offer. Second, it provides risk-sensitive real-time and reserve offers that account for all possible imbalance penalties and real-time prices along with reasonable storage size and cost function.

Project Publications:

- [1] M. Hedayati, J. Zhang, and K. Hedman, “Wind Power Dispatch Margin for Flexible Energy and Reserve Scheduling with Increased Wind Generation,” *IEEE Transactions on Sustainable Energy*, vol. 6, no. 4, pp. 1543-1552, Aug. 2015.
- [2] M. Hedayati, K. Hedman, and J. Zhang, “Reserve Policy Optimization for Scheduling Wind Energy and Reserve,” *IEEE Transactions on Power Systems*, accepted for publication.
- [3] M. Hedayati, P. Balasubramanian, K. Hedman, and J. Zhang, “Market Implications of Wind Reserve Margin,” *IEEE Transactions on Power Systems*, under review.
- [4] G. Patsakis and S. Oren, “Value of Flexible Wind Dispatch in Stochastic Unit Commitment,” *IEEE Transactions on Power Systems*, to be submitted.
- [5] K. S. Sedzro and A. J. Lamadrid, “Renewable Self-Reserve and Storage Management Under Market and Generation Uncertainties: Application to Ocean Wave Energy Farms,” *USAEE Annual Conference*, October 2016.

Student Theses:

- [1] Mojgan Hedayati. *Flexible Reserve Margin Optimization for Increased Wind Generation Penetration*, Ph.D. Dissertation, Arizona State University, Tempe AZ, December 2016.
- [2] Kwami Senam A. Sedzro. *Reliability and Resiliency Driven Solutions for Power Systems Operation and Planning*, Ph.D. Proposal, Lehigh University, Bethlehem, PA, January 2016.