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Three-stage variability-based reserve modifiers for enhancing flexibility reserve requirements under high variable generation penetrations

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ABSTRACT

The electric power system has continuously evolved in order to accommodate new technologies and operating strategies. As the penetration of integrated variable generation in the system increases, it is beneficial to develop strategies that can help mitigate their effect on the grid. Historically, power system operators have held excess capacity during the commitment and dispatch process to allow the system to handle unforeseen load ramping events. As variable generation resources increase, sufficient flexibility scheduled in the system is required to ensure that system performance is not deteriorated in the presence of additional variability and uncertainty. This paper presents a systematic comparison of various flexibility reserve strategies. Several of them are implemented and applied in a common test system, in order to evaluate their effect on the economic and reliable operations. Furthermore, a three stage reserve modifier algorithm is proposed and evaluated for its ability to improve system performance.

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1. Introduction

Power system operations are subject to inherent uncertainty and variability. For example, the system operator cannot have perfect knowledge of the system load and its characteristics; equipment failures are not scheduled; weather patterns and their implications on customer behavior cannot be perfectly predicted. The integration of variable generation (VG) technologies (e.g., wind and solar PV) and electric vehicles only compounds this issue. As a result, the methods with which system operators mitigate this variability and uncertainty must be refined to ensure that the system operates economically, efficiently and reliably. Along with improved forecasts, the use of operating reserves is a wide spread strategy. Operating reserves are defined as excess capacity scheduled above (for upward reserves) or withheld below (for downward reserves) the dispatch in order to meet the expected average electrical demand at subsequent temporal resolutions [1]. There are many types of operating reserves, each with its own objective in terms of system operation. This paper will focus on flexibility reserves (also known as “flex” or “ramping” reserves), which aim to mitigate large ramps in the net load with durations ranging from a few seconds to several minutes. Traditional load-following reserves are used to meet the expected variations occurring in the load profile. This new class of flexibility reserves are designed to help meet the unexpected variations occurring in the net load. The magnitude and ramp rate of these ramps are typically exacerbated by the presence of solar PV and wind generators.

Flexibility reserves are still in their infancy and there is not a set of accepted, industry-wide standards. This paper aims to propose a systematic methodology to compare several different types of flexibility reserve requirement calculation methodologies used in industry and literature with respect to their impact on system operations. By examining different reserve calculation methodologies and their effects on production cost and reliability, new operating strategies can be developed and tested. In this case, a new three-stage reserve modification algorithm is proposed to achieve an improved reserve requirement based on realized variability that can improve reliability metrics with minimal impacts on cost.

The rest of this paper is organized as follows: Section 2 provides a review of current flexibility reserve practices in industry and literature. Section 3 describes the simulation framework that will be used to perform the comparison. Section 4 describes the test

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system that is used for this study. Section 5 presents the reserve methodologies that are implemented and compared in this analysis, followed by the proposed new three-stage flex reserve modifier algorithm. Section 6 describes the numerical results, and Section 7 concludes the paper with conclusions and final remarks.

2. Literature review

Reserve strategies are typically developed in response to operating challenges in a given footprint, which has led to a lack of industry-wide standards regarding the calculation of operating reserve requirements and the effect that variable generation (VG) has on them. This is true for both contingency and, especially, regulation reserves. The authors of Ref. [2] present a modified price clearing model to be incorporated into the Midcontinent Independent System Operator's (MISO) market clearing models. This formulation allows the economic dispatch solution to be robust against potential operating conditions and reduces the number of real time scarcity pricing events. A scarcity event can occur when there is insufficient ramping capacity in the system. This is accomplished by positioning the system at the current time interval to adequately meet the demand in future dispatch intervals. The authors of Ref. [3] develop a modification to the California Independent System Operator's (CAISO) market clearing optimization that will schedule excess capacity. This capacity must be unloaded, ramp feasible, and dispatchable during any time interval. This capacity is scheduled in both the upward and downward directions. During the binding dispatch interval, this capacity is released and is no longer held in reserve. This method is also expected to be able to reduce the number of real time scarcity pricing events due to insufficient ramping capacity.

The authors of Ref. [4] present an additional ancillary service product in the form of scheduled excess capacity in the system. The magnitude of this reserve requirement is dependent on the wind and solar generation forecast errors. The geometric sum of forecast errors covering a 70% confidence interval is used to calculate the requirements. The main goal for this product is to provide a simple implementation into current market clearing optimizations that can account for the additional variability and uncertainty introduced by wind and solar generation. This method can be easily extended to account for load forecast errors as well. The Electric Reliability Council of Texas uses the non-spinning reserve service to address the forecast errors in the net load when there is not sufficient capacity already online to provide a secure dispatch [5]. First, the 95th percentile of net load forecast error from the previous 30 days as well as from the same month for the previous year are calculated. Then, the requirement is computed based on the maximum of these forecast errors. The requirement is limited to the capacity of the largest conventional generator within the region footprint.

There has also been some research regarding the scheduling of reserves in the presence of additional variable generation although not necessarily focusing on flexibility reserves. The authors of Ref. [6] propose a reliability-focused reserve product that is a function of the probability of load shedding. The authors of Ref. [7] present a general operating reserves product that aims to reduce the Energy Expectation Not Served (EENS). The authors of Ref. [8] present a methodology to determine the amount of spinning reserve required in systems with significant wind penetrations to account for potential generator outages and forecast errors. The authors of Ref. [9] develop a risk-based reserve management tool to aid system operators in setting the operating reserve requirements. This tool is designed to mitigate the Loss of Load Probability (LOLP) and determine reserve requirements that enforce the maximum allowable load shedding risk to the system operator. In Ref. [10], the operational effects of flexibility reserves on production costs and system imbalance are examined. By including the flexibility reserve requirements, additional thermal capacity is committed that could potentially eliminate scarcity price events while minimally impacting the system balance. The authors of Ref. [11] propose allocating the responsibility of generators for accommodating variability and uncertainty based on a new metric called the grid-balancing metric. This method does not assume any type of probability distribution regarding the variability so it can be generally applied.

While the above flexibility reserve methods [2–11] focus on deterministic reserve requirements, there is some research focusing on stochastic operating models under the assumption that these models better capture the inherent stochastic nature of power system variables including load, wind, and solar generation [12–18]. The authors of Ref. [19] explore the difference in operator dispatch decisions between using a deterministic reserve requirement and using a stochastic operating model without an explicit reserve requirement. While the solution with the deterministic reserve requirement may produce similar dispatch solutions if appropriately sized, the dispatch solution with the deterministic reserve requirement may not be the least-cost solution.

The main contributions of this paper can be summarized as follows. System operators design their reserve requirements based on their own needs. This paper compares several different reserve methods on a single system to extract the operational implications common to all methods. This analysis is performed with fine temporal resolution, down to 5 min dispatch with 4 s AGC control. Finally, a reserve modification method is adapted that can provide a net-benefit to all cases based on their common operation implications discovered in the analysis.

3. Reserve methodology

The reserve methodologies implemented for this comparison study can be divided into three different categories, depending on the nature of their calculations. The first category consists of reserve calculations that are only based on load characteristics. The flexibility reserve requirement is calculated so that it covers 70% of the hour-ahead load forecast errors (close to one standard deviation, if the underlying distribution was normal). This method was implemented a second time with the flexibility reserve requirement reduced to only cover 50% of the hour-ahead load forecast errors. This reduction is done to observe the implications of less conservative reserve requirements. One more case was developed to investigate the difference between a dynamic and a static requirement. Thus, the requirements with 70% coverage were averaged and that mean value is applied as a constant value across the year.

The second category of reserve requirements is based on the variability of power system. In order to compare this type of method, a reserve requirement inspired by Ref. [4] and utilized in the Western Wind and Solar Integration Study Phase 2 by the National Renewable Energy Laboratory [22] was used. This flexibility reserve requirement can be seen in Eq. (1). Again, this method was implemented a second time with a reduced level of coverage of 50% of the forecast errors. These methods examine the forecast errors independently and combine their total requirements as the root of sum of square of each requirement.

$$\text{Flex req} = \sqrt{\Phi 70_{\text{hour-load}}{}^2 + \Phi 70_{\text{hour-wind}}{}^2 + \Phi 70_{\text{hour-PV}}{}^2} \qquad (1)$$

The third category of these operating reserve methods is calculated based on the variability of the net load profile. Rather than calculating the individual contributions, all of the profiles are added together and the net load forecast errors are used to determine the actual reserve requirements. In order to compare this type of reserve method, a reserve requirement inspired by the MISO [2] and ERCOT [5] was developed. This method calculates the require-