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A flexible ramping product: Can it help real-time dispatch markets approach the stochastic dispatch ideal?

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ABSTRACT

U.S. Independent System Operators (ISOs) are creating short-run markets for so-called "flexiramp". The aim of these markets is to ensure that enough flexible generation capacity is on-line to manage the increasingly volatile net loads resulting from growth in renewable energy. In particular, we assume that the purpose of flexiramp is to improve the expected performance, in terms of costs, prices, and reliability, of the ISOs' deterministic market models. Therefore, we compare the solutions of (1) a deterministic dispatch model with a flexiramp constraint that simulates ISO operations with (2) a stochastic dispatch model that, by definition, obtains schedules that minimize expected cost. Dispatch, prices, settlements, and market efficiency are contrasted in a simplified case study to explore the fundamental reasons for successes (and failures) of flexiramp markets. The results illustrate how flexiramp can enhance market efficiency. However, they also show that procuring flexiramp is insufficient to minimize expected costs, and that market parameters affect the quality of the solutions. The simulations furthermore show that deterministic markets with flexiramp can yield either higher or lower prices than the stochastic optimum. We propose a penalty-based approach to mitigate possible biases towards choosing capacity with high energy costs to provide flexiramp, and conclude that market operators will need to monitor market performance and adjust flexiramp parameters in order to maximize market efficiency.

1. Introduction

The recent rapid development of wind power poses challenges to operations in power systems due to its variability and uncertainty. As a result, power systems with large amounts of wind will require increased operating reserves to cover potentially steep ramps and large deviations from forecasted output [1]. Recently, there has been recognition that in some markets, traditional operating reserves will provide insufficient flexibility to respond to net load fluctuations and so additional reserves will be necessary [2–4]. For instance, the California ISO (CAISO) [2,5] has identified a need for additional up- and down ramping capability in the next decade as wind penetration increases. For this reason, the North American Electric Reliability Corporation (NERC) [6] has established a task force to evaluate power system flexibility, while the CAISO [7,8] and Midcontinent ISO (MISO) [9] have proposed to create markets for flexible ramping products.

These products, also called "flexiramp", identify and pay capacity in a given scheduling interval whose dispatch in later intervals could be changed if the system's net load ramps up or down differently than forecast. Flexiramp differs from the more familiar spinning and non-spinning reserves in two ways. First, capacity designated as flexiramp in one interval is held in order to respond to possible load changes in later intervals, while spinning and non-spinning reserves are held in case certain pre-defined system contingencies occur in the same interval. Second, flexiramp is dispatched to provide energy in the later interval based on least-cost principles, while spinning and non-spinning reserves only do so if one of the enumerated contingencies occur. Third, one type of flexiramp is "down" flexiramp, which is capacity that can move downward rapidly if the load decreases more than expected; spinning and non-spinning reserves are defined as a strictly "upward" product.

In general, there are two basic ways that uncertainty in net loads could be managed in system operations: (1) by imposing operating reserve requirements (regulation, spinning and non-spinning reserves, and now ramp) in deterministic models [10–13] and (2) stochastic programming, which explicitly attempts to minimize expected costs over possible net load realizations [14–16]. U.S. ISOs do not presently use stochastic models for generation scheduling because those models have extensive computational requirements. Instead, ISOs add constraints to deterministic scheduling models

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Nomenclature

Indices

i	index for thermal unit, $i=1\ldots I$
t	index for time interval, $t=1\ldots T$
s	index for scenario, $s=1\ldots S$
$S'(s,t)$	set of scenarios that are indistinguishable from scenario s from interval 1 to t

Parameters

C_i	variable operating cost, thermal unit i [$/MWh]
RR_i	ramping limit, thermal unit i [MW/interval]
$\overline{DEM_t}$	forecast value of reference load, interval t [MW]
DEM_{ts}	realized reference load, in interval t and scenario s
$\overline{Cap_i}$	capacity, thermal unit i [MW]
$\underline{Cap_i}$	minimum output, thermal unit i [MW]
$FRup_t$	up-flexiramp requirement, interval t [MW/interval]
$FRdn_t$	down-flexiramp requirement, interval t [MW/interval]
PR_0	reference price for demand curve [$/MWh]
$slope$	slope of demand curve [($/MWh)/MW]
Pr_{ts}	probability of occurrence of scenario s in interval t
ERR_t	range of possible net load forecast errors [MW] in interval t
DNL_t	expected net load change [MW] from t to $t+1$
w^u	penalty coefficient for up-flexiramp cost
w^d	penalty coefficient for down-flexiramp cost

Decision variables

g_{its}	generation [MW] thermal unit i, interval t and scenario s
d_{ts}	net load [MW], interval t and scenario s
ur_{it}	up-flexiramp [MW] provided by unit i, interval t
dr_{it}	down-flexiramp [MW] provided by unit i, interval t
λ_t	energy price, interval t (dual variable) [$/MWh]
μ_t^u	price of "up" flexiramp, interval t (dual variable) [$/MW/h]
μ_t^d	price of "down" flexiramp, interval t (dual variable) [$/MW/h]

to procure reserves so that the system can respond to deviations of load and generation from their scheduled amounts. The growth in renewable generation has increased the need for these reserves [17,18].

Flexiramp products are introduced to achieve two goals: to improve the expected cost (market efficiency) of energy schedules and to give incentives to generators to consider the value of ramp in both operating and investment decisions. It can readily be proven that if load forecasts are error free, then there would be no need for a separate flexiramp product. In particular, a market that schedules just energy, and pays that energy its marginal value in each interval (as defined by the shadow price or Lagrange multiplier of the energy balance constraint) would suffice to meet these goals, assuming that costs are convex. This result derives from a fundamental property of convex optimization models in which separate producers provide a commodity to meet a demand constraint.

This property is defined as follows: at the optimal solution, paying the demand constraint's shadow price to each provider of energy will "support" the optimal system solution, in that no provider could increase its profit (shadow price times production minus cost) by deviating from the optimal schedule [19]. (For instance, in the simplex method of linear programming, this property is equivalent to the familiar test for optimality for variables to enter or exit the solution.) This property applies for investment problems as well, if capacity can be added in continuous amounts so that the problem remains convex. Thus, even if the load is ramping rapidly up or down, as long as it is perfectly forecast, cost will be minimized and energy prices will appropriately reward generators for their flexibility. For example, rapid ramp events will be accompanied by large upward and downward price spikes, and flexible units will be better placed to profit from those spikes by increasing and decreasing, respectively, their output. It is primarily because of the presence of uncertainty that ramping products can improve the efficiency of solutions from deterministic ISO market scheduling software.

Because deterministic dispatch models do not explicitly model uncertainty in net load (either as probability distributions or scenarios), they should be viewed as heuristic approximations to the true stochastic problem. Consequently, the resulting dispatch may not be as economically efficient as the stochastic ideal. There is literature that compares the efficiency of solutions from stochastic and deterministic power scheduling models. Hargreaves and Hobbs [16] proposed a stochastic dynamic programming approach to unit commitment and compare its dispatch with those of deterministic and simulation models. Ruiz et al. [21,22] combined stochastic and reserve methods for managing uncertainties in unit commitment. Jianhui et al. [23] focused on the impact of wind forecasting error on power system operation and analyzed the possibility of using stochastic and deterministic scheduling methods to accommodate those errors. Finally, Papavasiliou et al. [24] compared the cost performance of a perfect foresight policy, a stochastic policy, and heuristic rules. However, this literature has not yet addressed the efficiency of using flexiramp as a heuristic in deterministic models. Further, these previous models have hourly time steps. Thus, they do not consider the value of flexibility over the shorter time intervals (15 min or less) that characterize real-time markets, even though the MISO and CAISO ramp products are designed to address ramping limitations on that short time scale.

The contribution of this paper is to explicitly model and quantify the efficiency of flexiramp products in deterministic market dispatch software, considering the short time intervals that are typical of real-time markets. We ask the following questions: to what extent does the creation of a flexiramp product improve the expected performance of the deterministic market compared to a market without such product? How do market efficiency and settlements compare between the deterministic market designs and the ideal stochastic solution? We propose stochastic programming as an ideal since such a model, correctly formulated and parameterized, will by definition minimize expected operating costs. A further question is: how sensitive are those conclusions to the particular parameters chosen for the flexible ramp product, such as the total quantity? What ramp requirement minimizes expected cost? Finally, when the deterministic flexiramp model is inefficient, can modifications to the dispatch model decrease those inefficiencies?

We address these questions in the context of system dispatch by considering a simplified real-time imbalance market for generation to which we apply both a deterministic energy and flexiramp dispatch model and a stochastic model. The simple case study illustrates the contributions of the flexiramp product, but also shows how it can fail to produce the least cost solution. This failure can occur because deterministic models disregard the expected cost of energy from capacity reserved for flexiramp; for instance, this can result in a bias towards taking flexiramp from units with high fuel costs. Since such units have a significant probability of actually generating, the system's expected costs can be higher than the stochastic optimum.

Another issue we address is the effect of flexiramp on consumer and generator surpluses. In a market with a flexiramp constraint, a generator can, in a sense, be paid twice for its flexible capacity – once for providing flexiramp in an interval t and then again for