Investigating Price Formation Enhancements in Non-Convex Electricity Markets as Renewable Generation Grows

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Increased Variable Renewable Electricity (VRE) supply to the grid results in more frequent and faster fluctuations in net demand. This increases the demand for operational flexibility, the ability of the grid to adjust to these conditions to ensure reliable and economically efficient supply of net demand. Conventional generators are called on to provide greater levels of operational flexibility, i.e., cycle more often and endure more frequent and significant ramp up and down events. It is not well-understood if the price formation process in wholesale energy markets today will appropriately remunerate and incentivize the greater levels of flexibility that will be required as VRE penetration levels grow.

Using a custom-built scale-model of the PJM electricity grid operations, we explore how greater wind penetration affects the efficiency of conventional marginal pricing and its ability to remunerate operational flexibility. We also explore the degree to which alternative pricing schemes that seek to minimize out-of-market payments, remunerate operational flexibility. To investigate these questions, we simulate and analyze wholesale electricity market operation outcomes for a continuous 365-day period with existing and alternative pricing schemes at different wind penetration levels.

We find that conventional pricing fails to adequately compensate the added operational flexibility needed at higher wind penetrations. Load-following generators that supply most of the cycling and ramping services do not recover their ramping costs. Moreover, they frequently rely on out-of-market uplift payments to recover their short-run generation costs. Our analysis also exposes an interesting paradox. The higher demand for operational flexibility triggers additional unrepresentative price events, dramatically increases price suppression, and limits the energy market's ability to remunerate flexibility. The above outcomes suggest that load-following generators have incentives to withhold their inherent flexibility under conventional pricing schemes so as to avoid additional ramping costs and minimize revenue shortfalls.

Minimum uplift pricing can largely overcome these deficiencies by yielding cost-representative prices that efficiently increase inframarginal revenues such that most load following generators have positive net profits after deducting their ramping costs. Among the alternatives we investigated, Approximate Convex Primal Prices (A-CPP), which closely approximate Convex-Hull Prices, is the most efficient alternative for minimizing the unrepresentative price events and out-of-market payments and enhancing incentives for flexible performance.

In anticipation of higher levels of VRE on grids, ISOs should closely monitor prospective changes in cycling patterns of load-following generators and introduce new pricing schemes that reward flexible performance in the energy market and discourage flexibility providers from submitting inflexible bids. Given that convex-hull pricing is challenging to implement in practice, the potential of load-following products in improving cycling patterns of conventional generators should be explored as an alternative for enhancing market remuneration of flexibility. Future market

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design enhancements must be able to encourage resource investment and retirement decisions that satisfy the grid's growing operational flexibility requirements for dealing with VRE generators. Finally, the impacts of new energy pricing schemes and/or load-following products are likely to be insufficient to deal with resource adequacy issues that emerge as wind penetration grows. To address such concerns, ISOs should consider other market constructs that ensure complete capital cost recovery for the investments that are essential for deeply decarbonizing electricity grids.