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Locational-based Coupling of Electricity Markets: Benefits from Coordinating Unit Commitment and Balancing Markets

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Electricity markets can be coupled in several ways. At present, interconnection capacity between most European countries is auctioned day ahead or earlier, and not explicitly coordinated with the operation of energy markets. The amount of available transmission capacity, called Net Transfer Capacity (NTC), is determined by transmission system operators (TSOs). An alternative, which is implemented in several markets around the world and is currently being considered by the European Union, is locational marginal pricing (LMP) in both day-ahead and real-time markets. A nodal pricing system defines a marginal price at each location and time period that reflects the cost of delivering power to that location at that time, given the transmission constraints. These prices are obtained by clearing energy and transmission markets simultaneously in a single optimisation model, recognising the impact of all network constraints. If LMP could be implemented Europe-wide, international transmission would not have to be auctioned off. Instead, transmission capacity could be allocated by pricing constraints efficiently in multicountry day-ahead and real-time energy markets.

Another inefficiency in present market designs that locational-based pricing can address is the lack of coordination of balancing mechanisms in different markets. Presently, TSOs in adjacent European countries manage transmission constraint violations and unscheduled imbalances by redispatch within their own market areas, while attempting to maintain day-ahead schedules of international power exchange. If neighbouring operators could coordinate their balancing markets while respecting locational constraints, redispatch

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costs could be reduced and additional trading opportunities taken advantage of.

We formulate a series of stochastic models for committing and dispatching electric generators subject to transmission limits. The models are used to estimate the benefits of LMP that arise from better coordination of day-ahead commitment decisions and real-time balancing markets in adjacent power markets when there is significant uncertainty in demand and wind forecasts. The unit commitment models optimise schedules under either the full set of network constraints or a simplified net transfer capacity (NTC) constraint, considering the range of possible real-time wind and load scenarios. A subsequent redispatch model then creates feasible real-time schedules.

Benefits of LMP arise from decreases in expected start-up and variable generation costs resulting from consistent consideration of the full set of network constraints both day-ahead and in real-time. Meanwhile, using LMP to coordinate adjacent balancing markets provides benefits because it allows intermarket flow schedules to be adjusted in real-time in response to changing conditions. These models are applied to a stylised four-node network, examining the effects of varying system characteristics on the magnitude of the locational-based unit commitment benefits and the benefits of intermarket balancing. Although previous studies have examined the benefits of LMP, these usually examine one specific system, often without a discussion of the sources of these benefits, and with simplifying assumptions about unit commitment.

We find that, firstly, coupling international day-ahead and real-time power markets using nodal pricing can lead to significant benefits compared to NTC-based market coupling only day-ahead. This has already been shown in many other studies. However, these studies do not consider the combined effect of unit commitment constraints and uncertain load and wind forecasts. Our simulations indicate that LMP can significantly improve unit commitment decisions, saving between 0% to 1% of the fuel costs of non-baseload plants, depending on the assumed parameters.

Secondly, full LMP-based market coupling both day-ahead and in real-time will, at least in theory, lead to the lowest costs. However, international coordination of balancing while respecting transmission constraints can provide significant benefits even if unit commitment decisions consider only NTC constraints rather than the full network. Such coordination would allow adaptation of power schedules between markets to depend on real-time load and wind scenarios and would encourage trade. In our system, the benefits of international redispatch are at least an order of magnitude greater than the unit commitment benefits of LMP under most assumptions.

Finally, although both benefits can be significant, their magnitudes greatly depend on the exact load, generation, and transmission characteristics of the electricity markets. Generator sizes, demand levels at the various nodes, installed transmission capacity, load asymmetry and load correlation can all influence these benefits, and a small change in one of these parameters can result in significant increases or decreases, especially for unit commitment benefits. These effects are often non-monotonic, and are unlikely to be generalisable; thus, the benefits for specific systems need to be estimated by using parameters appropriate for those systems, considering the variation of loads and other parameters over the year. For our test systems, at their largest, benefits can amount to more than 25% of optimal production costs for non-baseload plants when international redispatch is not possible, and more than 2% when it is, although they are more typically around 8% and 0.8%, respectively.

Although our numerical results cannot therefore be viewed as definitive statements of the effect of various parameters, some trends are evident. When international redispatch is possible, smaller generators, higher minimum run levels and more symmetric, and positively correlated loads at different locations (net of wind) usually lead to higher benefits. When international redispatch is not possible, the effects of parameter choices often have a pronounced trend. In that case, smaller generators, higher minimum run levels, larger transmission capacities, and loads that are lower, more symmetric or positively correlated generally result in higher benefits. In both cases, continuous approximations of binary commitment variables can significantly overstate the unit commitment benefits of LMP-based market coupling for small systems.

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