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Integrating short-term demand response into long-term investment planning

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Planning models have been used for many years to optimize generation investments in electric power systems. Those models, mainly formulated as linear programming optimizations, have initially simplified technical constraints and even fully neglected demand-side management opportunities. In this paper, these models have been extended to incorporate two considerations that are increasingly important as increased amounts of intermittent renewable energy are provided.

The first consideration is the inclusion of operational constraints that limit the flexibility of thermal generation facilities. Large-scale integration of intermittent renewable energy generation reduces the net demand profile. Additionally, due to the variable generation output profile, mostly originating from wind power, fluctuations in net demand are significantly increasing. The resulting net demand profile must be covered by conventional power generation facilities. Technology specific operational constraints must include technical limitations as non-compliance with those constraints would harm the efficiency of the generation unit, increase maintenance costs or even reduce its lifetime.

The second consideration is the representation of the demand-side. Since the need for system flexibility is increased, demand-side management opportunities should also be incorporated. Smart grid technology developments create opportunities for short-term demand response to spot electricity prices. Consequently, demand-side management is treated on an equal footing with sources of flexibility offered at the supply-side of the system. The integration of demand response even creates opportunities to more efficiently balance supply and demand.

This paper has illustrated methods for integrating real-time price responsiveness into electric energy models. Elastic demand functions are constructed based on historic hourly demand levels and assumed

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levels of elasticities. These include own-price elasticity as well as cross-price elasticities with respect to prices in other hours in order to incorporate consumers' willingness to adjust the demand profile in response to price changes. These elasticities respectively capture direct response and load shifting effects. Three numerical approaches to accomplish this supply-demand integration are presented. In addition, as energy efficiency programs sponsored by governments or utilities also influence the load profile, the interaction of energy efficiency expenditures and demand response is also modelled. In particular, reduced responsiveness to prices can be a side effect when consumers have become more energy efficient

Numerical results show that considering operational constraints in an investment model results in less inflexible base load capacity and more mid-range capacity offering higher flexibility. Model results also show that the integration of demand response decreases system peaks, decreasing the required investment in peaking generation capacity. Additionally, demand response creates valley filling effects, lessening over-generation problems during the night or high wind generation periods. Demand response also increases system flexibility, facilitating the integration of intermittent wind power generation. Simulations show that for higher demand elasticity, it is optimal to install a higher amount of wind power capacity. This suggests that demand-side management can result in environmental benefits not only through reducing energy use, but also by facilitating integration of renewable energy.

Furthermore, price responsive consumers increase consumption during low price hours and decrease consumption during high price hours. As a consequence, the weighted average electricity price is reduced. However, the inclusion of cross-price elasticities reduces these effects as consumption during high price periods is shifted to other hours instead of being indefinitely postponed.

Finally, the impact of energy efficiency is analyzed. Increased emphasis on energy efficiency reduces demand levels and therefore the total required installed generation capacity. This effect is reduced when the negative interaction of energy efficiency investments and responsiveness of demand is included. If this interaction is significant, the optimal amount of installed wind power capacity is reduced.

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