Quantifying the Benefits of Imperfect Demand Response

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Introduction

There are great expectations for demand response (DR), which encompasses the idea of an electricity consumer reducing or shifting their load in response to signals that are linked to market or operational conditions. The greater flexibility that DR could provide could be very valuable on a low-carbon grid. DR could help integrate intermittent renewables and help utilities meet resource adequacy requirements, which will be harder as the share of generation from variable renewables increases [1].

To realize the potential value of DR to a decarbonizing grid, we must understand how its properties affect its system-wide value. DR resources have different limitations from traditional generators in that they must respect the preferences of the customers whose load is being reduced or shifted. Customers have a limited appetite to shed or shift their load and may need advance notice to do so. This study examines DR that has different properties that may reflect customer preferences. Other studies have looked at one or a few of these properties, but in this study we compare many properties in the same modeling framework, so that we can identify their relative importance.

We identify the properties that result in more valuable DR, which may help guide investors and entrepreneurs in developing new products. This information can also help identify the properties of DR that wholesale markets should explicitly represent to encourage the best balance of system-wide value and consumer limitations.

Methods

A unit commitment model, based on [2], is used to simulate the ERCOT electricity system. This model represents ramping constraints, startup costs, and minimum load values for each generator. It simulates day-ahead and real-time decisions through two-stage stochastic optimization. Uncertainty comes from the demand forecast; commitment and production decisions made in the day-ahead stage are the same for all realizations of demand, while those made in the real-time stage are made uniquely for each demand realization. Slow generators have day-ahead commitment, while fast generators have real-time commitment; both have real-time production decisions.

We assume a total of 1000 MW of DR is made available in the form of many homogeneous smaller resources, which we model together as a single 'pseudo-generator' with a relaxed binary commitment variable, an optimistic marginal cost of $35/MWh, and a minimum load of 1 MW to impose a small commitment cost. This study only considers load reduction from DR, not load shifting.

We compare several limited versions of DR to 'perfect' DR resources that would be available all the time with no advance notification required. The modeled DR is subject to five different types of limitations: (1) number of startups, (2) number of hours of operation, (3) amount of energy shed, (4) which hours DR is available to be dispatched, and finally (5) how far in advance DR providers must be given notice for commitment and production decisions. There are two advance notice options: advance commitment (AC) in which commitment decision are made in the day-ahead stage, or advance production (AP) in which both commitment and production decisions are made in the day-ahead stage.

Results

Value of advance notification limited DR

Over the ranges modeled, both types of advance notification limits have a similar impact to usage restrictions on system-wide cost reduction (Table 1). The cost reduction per MWh shed is also in a similar range. These results indicate that advance notification limits and usage limits can be valued similarly by DR developers.

The benefits of AC DR come at the cost of being committed in more than twice the number of hours, due to the low cost of commitment. These operational characteristics indicate the need for other usage restrictions, or a higher commitment cost, if customers cannot tolerate this level of commitment.

A few hours provide the most value

As shown in Table 1, the marginal value of DR drops off as it is used more. DR provides the most value during a small number of peak hours and the associated steep ramps. As a result, DR that is unavailable during these key hours has a dramatically lower value. For example, summertime peaks in Texas often begin before 3pm, so DR that is restricted to the hours of 3pm - 9pm, when some consumers may be home after school or work, is notably less valuable than unrestricted or daytime-only DR.

Under typical structures for DR, a utility may wish to focus on DR that only operates during a small number of hours with the highest value. This is because DR customers typically are compensated twice for reducing their load: once through the incentive in their DR program, and again through a reduction in the amount of electricity they purchase. If we assume that retail customers are paying the average energy cost as their tariff, approximately $43/MWh in the modeled system, then all of the modeled DR programs would result in a net loss for the utility, although they reduce operating costs. DR that is only operated during an extremely limited set of very valuable hours mitigates this issue for now.

Startup limits alone cannot represent customer preferences

Startup restrictions are, in theory, a practical way of implementing a restriction on the number of unique 'events' that a DR resource experiences. However, in practice they do not work well in the absence of other restrictions. Startup limits can be met by simply never 'shutting down' DR as their modeled commitment cost is low. Consequently, when we restrict the modeled DR to only one startup per 5-day period, DR sheds slightly more MWh than unlimited DR but is committed in five times the number of hours.

Additional restrictions like a no-load cost or a response-duration constraint are needed for a startup restriction to create a desired number of unique 'events'. A higher commitment cost would help but remain imperfect. However, startup-based limits should be avoided for resources with low commitment costs and potential for customer fatigue from over-use.

Energy- or hour-based limits may be a more effective alternative for representing consumers' limited desire to shed load. The two have similar effects in this model, though future work should explore if this result holds when DR has a true binary commitment variable, as this variable is used for the hour-based limit.

Conclusion

These results inform a discussion about what types of 'imperfect' DR are preferable, a question that developers of demand response programs must address, given that consumers' preferences regarding how much load they will shed must be represented. Given our results, we suggest that developers of DR should be able to balance system needs with customer preferences better if they can focus on an hour- or energy-based limit to the usage of DR, rather than a startup-based limit.

These results suggest that entrepreneurs and developers of DR should pursue DR that has advance notification limits just as much as they pursue other usage-limited types of DR, and that system operators should enable such resources to participate in markets. More types of customers may be able to provide DR with advance notification, especially those without automation. To take advantage of the full range of cost-effective DR, the industry should identify ways to incentivize DR without compensating participants twice.

There are other types of DR characteristics that should be studied, like how reliably it responds to dispatch, how long it can shed load for, and sensitivity to marginal cost. Combinations of characteristics might represent known DR resources. Improved understanding of this nascent resource will enable the electric industry to take the best advantage of demand flexibility, which could enable integration of renewables and lower environmental impacts.

References

[1] Anthony Papavasiliou and Shmuel S Oren. "Multiarea Stochastic Unit Commitment for High Wind Penetration in a Transmission Constrained Network". In: *OPERATIONS RESEARCH* 61 (3) (2013), pp. 578–592. ISSN: 1526-5463. URL: http://dx.doi.org/10.1287/ opre.2013.1174.

[2] U.S. Department of Energy. *Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them*. Tech. rep. U.S. Department of Energy, 2006. URL: https://eetd.lbl.gov/sites/all/files/publications/report-lbnl-1252d.pdf.

Scenario	**Cost Savings from adding DR**	**Cost Reduction Per MWh Shed**	**Total MWh Shed**
Advance Production	0.1531%	$ 8.85	415,404
1 Startup	0.1727%	$ 12.78	324,807
Advance Commitment	0.1730%	$ 12.84	323,714
5 Startups	0.1730%	$ 12.85	323,463
Unrestricted	0.1730%	$ 12.85	323,454
7a-10p Availability	0.1730%	$ 12.86	323,376
3 Startups + 30 Hour Limit	0.1612%	$ 15.60	248,318
3p-9p Availability	0.1129%	$ 13.02	208,378
Energy Limit (10 GWH)	0.1408%	$ 21.71	155,808
Hour Limit (10)	0.1407%	$ 21.75	155,381
Energy Limit (5GWH)	0.1096%	$ 32.33	81,429
Hour Limit (5)	0.1343%	$ 39.64	81,427

Table 1. Key statistics for modeled types of DR.
Scenarios are sorted by descending amount of MWh shed by the DR resource. Startup, energy, and hour limits are applied over a 5-day period. Hour limits refer to the number of hours in which DR is producing.