The Announcement Effect: The Dependency of Demand Response on Timely Information and the Impact on Efficient System Operation

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Overview

Power systems with high shares of renewable energies are facing problems like temporary system imbalances or congestion on the distribution level. To relieve temporary system stress, system operators are taking advantage of reserve control or Critical Peak Pricing (CPP). With the increasing number and heterogeneity of participating flexible load types, however, it is becoming less certain when how much response can actually be achieved.

In this work, we develop a methodology for the analysis of time- and state-dependent flexibility potentials of loads and present guidance for the design of CPP programs, i.e. programs which aim to change demand in critical periods (‘events’) by a net price change. Those net price changes (‘flexibility payment’) are announced by the system operator a certain time before physical dispatch (‘notification period’) and can be positive or negative, depending on the desired direction of response. One example is the PG&E peak pricing program. We define the difference between the aggregate load under a CPP and the fictive load without CPP *demand response*, referring to the response in price change.

We identify relevant flexible load types and model their stochastic dispatch behaviour, using an optimal control approach. We show that, in general, a more pronounced DR can be achieved with longer notification periods about future events. This is particularly true if information about future need for DR is asymmetrically distributed between the system operator and the flexible load operator, e.g. if load operators do not have access to (low-cost) forecasts. We furthermore illustrate the aggregate DR supply function (see Figure 1) for an exemplary distribution system and argue that an appropriate DR program design needs to take information about the system of interest into account. This information includes the portfolio and parametrization of available flexibility types, beliefs of load operators, congestion patterns, etc.

In contrast to previous work, which dominantly evaluated flexibility potential based on aggregate load and price data or analysed specific single load types, we develop an agent-based approach. This allows us to generate specific DR supply curves which can be used by system operators to design CPP programs and estimate time-, grid area- and voltage level-specific DR behaviour.

Methods

We identify flexible load types based on the available literature (Barth et al. 2018): purely elastic loads (e.g. change of temperature settings for the HVAC system), storage (e.g. batteries), interruptible (e.g. charging of an electric vehicle) and non-interruptible loads (e.g. industrial process) with a defined start and end time. We formulate the stochastic optimization problem, i.e. minimization of expected electricity costs, using a unified optimal control framework with load types ranked according to complexity in constraints. To determine optimal dispatch, we apply a model predictive control (MPC) framework and solve each period using stochastic dynamic programming. We control for congestion patterns and analyse dispatch behaviour of different load types under different expectations for future events and parametrization of loads.

To validate the approach, we use hourly curtailment data of Schleswig Holstein Netz AG (Schleswig-Holstein Netz AG 2018), a German distribution system operator, for December 2016. It operates the 110kV high voltage grid in Schleswig Holstein where in 2016 two thirds of total curtailed energy from renewable energies in Germany were shut down (Bundesnetzagentur 2017). The grid area would benefit from a (load-increasing) CPP scheme, with lower net prices in congestion times. We assemble an exemplary industrial load portfolio characteristic of the high voltage grid, in particular interruptible and non-interruptible load types. For future research, we aim to calibrate consumption profiles and shifting costs using available industrial data bases and studies such as (Shoreh et al. 2016).

Results

We find the following results for individual load types: *Storage* devices can provide flexibility at all times if they are in the appropriate state (i.e. full or empty). A longer notification period is beneficial to be in the right state. Flexibility provision cannot be increased by higher flexibility payments and is limited by the maximum charge/discharge period defined by the storage volume divided by the ramping constraint (‘operation capacity’). *Interruptible* loads can provide flexibility within their active time but not during off-periods or when congestion periods are longer and cover the whole activity period. A longer notification period is helpful to identify optimal dispatch slots since approaching the termination period reduces degrees of freedom. A higher flexibility payment can unlock more flexibility if load shifting is associated with additional costs. The results hold for *non-interruptible loads*. Notification periods, however, need to be longer because changed net prices have to be anticipated before starting the load. Often, net load can only be adjusted at the beginning and end of the process which reduces the ability to provide flexibility during the core period of the process.

We furthermore simulate system operation for a small distribution system with five interruptible and five non-interruptible load as well as two storage devices. We build the DR supply function, as shown in the following Figure 1. It shows the DR supply functions for different notification periods. It can be seen that, for increasing notification periods, the steepness of the DR curve increases and, therefore, the absolute response to a specified flexibility payment.

We conclude that increasing notification periods and flexibility payments can increase DR. Futher simulations reveal that steepness ability is low in times of low activity (e.g. at night) and the shape of the DR supply among flexibility types differ greatly. Future research will analyse other settings, e.g. a residential area with some elastic load, photovoltaics, dominance of storage and electric vehicles, with short and low-persistent congestion patterns.

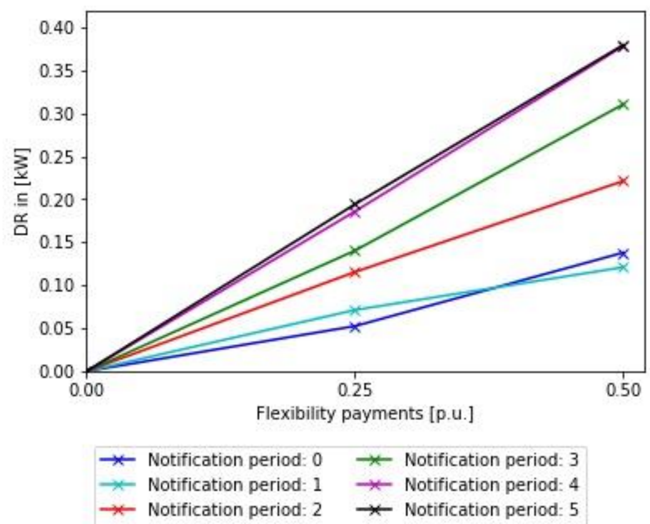

Figure 1. Demand response supply function for different notification periods; assumptions: portfolio of twelve loads and congestion data of SH Netz AG (Dec. 2016)

Conclusions

We model the response of flexible load types to CPP and represent their aggregate DR supply function. We find that, in general, longer notification periods and higher flexibility payments can increase steepness and elasticity and, therefore, DR. The aggregated DR supply function depends on the portfolio of flexibility types in the system and their parametrization, expectations of load operators, time, congection patterns, etc. Those characteristics have to be taken into account when designing an effective, welfare-maximizing, and cost-efficient CPP program.

References

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