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Time-based pricing and electricity demand response: Existing barriers and next steps

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ABSTRACT

Interest in Demand Response (DR) is increasing due to its potential to improve reliability and save costs for electricity systems. DR can provide a sustainable and cost-effective option for supply balancing, especially in a scenario with more volatile inflows from renewable energy sources. End-users can be incentivized to provide DR through time-based pricing in general and dynamic pricing in particular. This paper provides a theoretic framework and practice-oriented review of the status of DR in Europe, outlining the major challenges currently hampering further DR development. Important challenges involve the split-incentive issue for investments in enabling technologies, traditional market rules for flexibility that favor large generation units and the need for electricity market and network operation coordination.

1. Introduction

Increasing penetration levels of intermittent renewable energy sources (RES) in power systems are imposing new challenges for policy makers and regulators. These renewable resources can be located at locations within both high-voltage and low-voltage grids. The penetration of distributed energy resources (DER), such as distributed generation (DG), electric storage and electric vehicles (EVs), significantly affect the operations of distribution grids (Pérez-Arriaga and Bharatkumar, 2014; Pudjianto et al., 2007). Ensuring reliable electricity supply in this context is costly endeavor given the requirement for back-up flexible electric power generation combined with limited electricity transmission capacity. Regulatory authorities are increasingly considering load flexibility, also known as demand response (DR), for enhancing system coordination. DR refers in general to the ability of the demand side to be flexible, responsive and adaptive to economic signals.

Adequate price signals reflect the actual costs of various electricity supply activities. In response to prices, demand-load modification could have a positive economic impact on society as a whole by stimulating efficiency electricity system operations and markets. In the medium and short term, the signaling of DR can result in the adjustments of loads to network capacity constraints in order to remain within technical limitations and diminish the possibility of a system collapse. Alternatively, in the long term, DR is useful for lowering both generation and network investment requirements and minimizing permanent grid congestion (Batlle and Rodilla, 2009).

In the US, interest in demand response rose in the early 1970s from the penetration of air conditioning in American homes, resulting in needle peaks and reduced load factors in system demand profiles. At this time, there was increasing recognition of rising system costs to meet the peaking loads, and utilities began to view load management as a reliability resource (Cappers et al., 2010; Koliou et al., 2014). After the passing of the Public Utilities Regulatory Policy Act (PURPA) in the early 1980s, measures designed to reduce demand peaks were set forth via the promotion of load-management programs. Those involved both direct-control and price-based programs for large industrial users (DOE, 2006). Similarly, in Europe, large industrial customers provide demand response flexibility for balancing purposes in real-time system operation.

The value and necessity of DR is recognized by the European Commission (European Commission, 2013a). The Energy Efficiency Directive (EED), Art.15, explicitly urges EU national regulatory authorities to encourage demand-side resources, including DR, "to participate alongside supply in wholesale and retail markets", and also to provide balancing and ancillary services to network operators in a non-discriminatory manner (Directive 2012/27/EU)

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(European Commission, 2012a). Furthermore, main European Policies advocating for DR to participate alongside supply in wholesale markets calling for aggregation are the Directives 2009/72/EC regarding common rules for the internal market in electricity, the ENTSO-E 2013 Demand Connection Code, and the ACER 2012 Framework Guidelines on Electricity Balancing. Hence, mechanisms for implementing DR are receiving increasing attention by European regulatory authorities and institutions (CEER, 2011). DR potential in the EU electricity markets is believed to be high but currently underutilized (European Commission, 2013b), especially for residential consumers, on account of current institutional arrangements that cater to large generators and industrial customers.

The deployment of smart meters and information and communication technology (ICT) infrastructure enables a paradigm shift in the way electricity systems are operated, transforming traditionally passive end-users into active market players (Eurelectric, 2011; European Commission, 2013b, 2012b; Giordano et al., 2011; Hancher et al., 2013). Different tariffs promote an array of incentives for customers to modify consumption profiles that, accordingly aid the system in achieving reliability objectives. Price dependent DR refers to financial incentives or penalties to motivate customers to provide load flexibility (Wang et al., 2010).

A range of options is available for designing and implementing electricity tariffs (Reneses and Rodríguez Ortega, 2014). Due to the indirect incentives that result from tariff design, different types of load flexibility can be expected from different pricing methods. Until now, time-based pricing has been applied mostly to incentivize large industrial users, leaving the approach unclear for residential customers. The literature on time-based pricing focuses on demand response to serve the objectives of electricity supply (Nieto, 2012), balancing (Koliou et al., 2014), and network purposes (Bartusch and Alvehag, 2014). Consideration of network design and grid constraints is gaining momentum, especially in systems with high penetration levels of renewable energy sources (RES, both distributed and large scale). Conchado et al. (2011) defined bilateral benefits for both network and generation purposes (Conchado et al., 2011). However, most of the literature does not take into account the parallel effect of time-based pricing on the final electricity bill of electricity users.

Therefore, a relevant contribution of this paper is an update to the state of the art, in which both theoretical framework and practical experiences are described for Europe. Furthermore, we describe contemporary challenges today and provide recommendations for how to overcome them via amendments to existing European legislations as well as lessons learned from other policy contexts.

The paper is structured as follows. Section 2 provides a theoretical description of DR and Section 3 presents the necessary elements of electricity billing for incentivizing DR. Next, Section 4 presents examples of time-based prices for demand response in Europe. Lastly, Section 5 outlines major barriers for DR activation followed by conclusions and policy recommendations in Section 6.

2. Definition of demand response

The literature provides various definitions of demand response, but a clear common theme is that DR reflects electricity demand that is intentionally responsive (flexible) to economic signals (see Table 1 for frequently cited DR definitions in the literature and policy documents). An important difference between demand response and demand-side management is that demand side management (DSM) can be seen as the over-arching concept that can encompass demand response (in addition to energy efficiency and electricity storage), driven by DSM adapters and policies (Warren, 2014).

In the US, as of 2014, DR programs alone were estimated to have a potential of 28,934 MW consequently accounting for 6.2% of the total peak demand (FERC, 2015). Within Europe, there are long standing arrangements or programs to involve energy-intensive industrial customers in DR (mostly through interruptible tariffs or time-of-use pricing), and some system operators make use of large avoided loads as part of their system balancing activities (Torriti et al., 2010). Countries with large penetration of RES, such as Germany, currently use demand flexibility to maintain system-wide reliability (Koliou et al., 2014).

Conceptually, DR also can be defined as a flexibility service that is specified by (Eid et al., 2015):

- *Direction* (upward or downward);
- *Size* (kWh and kW);
- *Time;*
- *Location* (zone or node).

For example, an electricity network with congestion issues requires location-specific demand flexibility. When demand responsiveness is aimed at sustaining system balance via market arrangements, the location of DR is of less importance than the aggregated direction, size, and timing.

2.1. Types of DR and effects on the electricity system

Demand-side management programs could be aimed toward modifying traditional electricity demand in different ways (see Table 2 for a visual presentation of the types of adjusted load shapes). Demand response that is aimed at decreasing consumption during peak times can be categorized as peak clipping. Load shifting is mostly associated with usage reduction at peak that is offset by usage in off-peak hours. DR that is aimed at increasing consumption levels (for example at times with high renewable energy production) can be categorized as valley filling, load building, or flexible load.

2.1.1. Benefits of demand response to the electricity system

The potential benefits of DR rest upon the energy policy pillars associated with economic, environmental, and reliability objectives (see Aghaei and Alizadeh, 2013). Economic or market-driven DR reduces the general cost of energy supply while preserving adequate reserve margins and mitigating price volatility by means of short-term responses to electricity market conditions. Environmental-driven DR would serve environmental and social purposes by decreasing energy usage, increasing energy efficiency, defining commitment to environmentally friendly generation, and reducing greenhouse gas emissions. Lastly, network-driven DR aims to maintain system reliability by decreasing demand in a short period of time and reducing the need to enhance generation or transmission capacity.

Batlle and Rodilla classify DR benefits in accordance with time. For the short and medium terms, DR would decrease network peak and risk of system collapse by keeping electricity flows within technical constraints. In the long term, DR could decrease generation and network investment needs, relieve regular congestion, and increase energy efficiency (Batlle and Rodilla, 2009).

In this work we define additional DR benefits from a technical system perspective based on alignment with time-based pricing. Hakvoort and Koliou (2014) describe DR objectives associated with day-ahead optimization, hour-ahead optimization, network peak reduction, local balancing, real-time control, DG optimization and central RES optimization. Secondary forthcoming effects include CO_2 reduction and decreased need for distribution and transmission network investments. As discussed in Section 4, smaller,