Potential Benefits and Current Limits in the Development of Demand Response

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INTRODUCTION

Once upon a time, for many families, electricity was a somehow magic and mysterious stuff allowing houses lighting and appliances operation, whose secrets began just behind the switch or the socket. Other, more informed, users knew that it came from generation plants and "travelled" along a grid towards houses or firms. Nowadays, the role of end users has changed a lot. They have a broader knowledge of the electric system, and a certain awareness of being part of it, in some cases not simply as consumption units. Distributed generation (such as residential photovoltaic production) and demand response mechanisms have transformed (residential, industrial or commercial) users in an active part of the electricity supply chain, so that they are often defined as "prosumer" (Crispim et al., 2014).

In particular, Demand Response (DR) is attracting increasing attention from regulators, policy makers and system operators due to its large potential in supporting and, in some cases, substituting generation in providing flexibility to the system. This corresponds, on the academic side, to an exponential growth of scientific production, with focus on the technical or on the socio-economic features of the issue. This chapter will provide a review of some recent contributions on this topic. Far from being exhaustive of the extremely wide related literature, the aim of this chapter is to provide a general presentation of the issue, briefly discussing the main benefits related to DR, as well as the most relevant regulatory, technological and socio-economic challenges that can slow down or hinder its development. Therefore, this work will provide an analysis of the impact and issues related to DR from a socio-economic perspective. Moreover, it will also briefly consider the role of technology (especially information and communication technology) in supporting DR implementation and, more in general, the evolution towards "smart" systems. The rest of the chapter is organized as follows. The next section defines DR and illustrates the most relevant benefits of its development. Subsequently, challenges to DR development are discussed and some recommendations are provided. Future research directions and conclusions close the work.

BACKGROUND

The literature provides a wide set of definitions of DR. Quite common across these definitions is the focus on end-users and on the modification in their electricity utilization patterns (see, for instance, the list provided in Eid et al., 2016). For example, in the FERC (Federal Energy Regulatory Commission) website[1] DR is defined as

Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.

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There are several typologies of DR mechanisms, which can be classified following different criteria (Vardakas et al., 2015). Here we propose the most common classification.

- Time-based retail rates (Cappers et al., 2012), also called rate-based or price-based programs (Siano, 2014), or implicit DR (SEDC - Smart Energy Demand Coalition, 2015), provide incentive to end-users to modify their consumption as response to price variations. Price fluctuations are designed to reflect the dynamics of the wholesale market price or the grid tariff, and ultimately, of the cost of the electric service. Prices can be predetermined but different for given time periods or move dynamically depending on the system and market contingencies.
- Incentive-based retail programs (Cappers et. al, 2012), also defined as event-based programs (Siano, 2014), reliability-based (Shen et al., 2014) or explicit DR schemes (SEDC, 2015) reward consumers through a payment or a bill credit for a reduction in their consumption. Such mechanisms are activated by the entity managing DR services (users can contract directly with the utility or with an aggregator) in response to particular events affecting the electric system, e.g. network congestion[2].

Examples of price-based DR programs are:

- Time of Use tariffs, where prices are different but fixed for given time periods (e.g. times of the day or days of the week).
- Critical Peak Pricing, that applies particularly high prices for a limited period (few hours) in response to critical technical or economic/market events.
- Critical Peak Rebate, where consumers are recognized a bill rebate if they reduce their consumption below a pre-specified baseline during critical hours.
- Real Time Pricing, where prices vary dynamically (e.g. every hour) following the wholesale market price and/or the actual generation costs.

Common forms of incentive-based mechanisms, instead, are:

- Direct Load Control, where the utility has the opportunity to manage directly some consumer's equipment (e.g. air conditioning or heating).
- Interruptible/Curtailable programs, where (usually large) users accept that (a part of) their load can be disconnected, in some cases even without notification.
- Emergency DR programs, which provide end-users a compensation to reduce their loads when the system reliability is endangered.
- Ancillary Service Programs, where consumers provide "reserves" by committing to reduce their load in case of necessity.

For further examples or deeper descriptions of DR programs, see, among the others, Cappers et al. (2012), Darby and McKenna (2012), Shen et al. (2014), Siano (2014), Hu et al. (2015), Vardakas et al. (2015). Figure 1 reports some examples of DR programs.

While some mechanisms are well suited even in "traditional" electric systems (e.g. Interruptible/Curtailable programs), other ones present important technological requirements, and can develop their full potential when implemented in smart grid contexts (e.g. Real Time Pricing).

Following Siano (2014; p.462), a smart grid (SG) is "an electric grid able to deliver electricity in a controlled, smart way from points of generation to consumers that are considered as an integral part of the SG since they can modify their purchasing patterns and behavior according to the received information, incentives and disincentives". This definition highlights some relevant peculiarities of SGs with respect to tra-

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