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A bottom-up approach to leverage the participation of residential aggregators in reserve services markets

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ABSTRACT

The increase of demand side participation in reserve service (RS) requires the extension of the markets' activity to the millions of consumers present in the residential sector. This paper proposes a method that performs a bottom-up aggregation of residential demand-side flexibility associated with domestic appliances, namely Thermostatically Controlled Loads (TCL). The flexibility profiles provided by each residential consumer are transformed into aggregated reserve bids to be offered in the day ahead tertiary reserve markets. A case study involving 1500 end-users associated with an aggregator bidding in the Portuguese tertiary reserve market will be used to illustrate the method.

1. Introduction

During the 1970s and 1980s of the 20th century many programs were launched by the utilities around the world with the objective of managing residential consumption either for lowering the average cost of electricity or for the provision of reserve services (RS) [1]. These programs encompassed Indirect Load Control (ILC) [2] and Direct Load Control (DLC) [3] strategies. Under ILC programs, utilities sent signals to the end-users in order to encourage them to decrease/increase the consumption in some periods of the day. In contrast, DLC programs consisted in the direct control of home devices through on/off signals sent by the utilities [4] that could generate unexpected payback consumptions in the subsequent hours [5].

After the electricity sector unbundling together with the advent of smart grids, ancillary services markets are being gradually extended to accommodate bids coming from the demand side. In [6] experiences on loads providing RS in five ancillary services markets were evaluated. The study concluded that the participation of loads occurs more often in the provision of replacement reserve—also called tertiary reserve in European Network of Transmission System Operators for Electricity (ENTSO-E) nomenclature. Nevertheless, this participation is still very small and, in most cases, it is restricted only to the consumers with a significant amount of load (minimum of 1 to 3 MW). Therefore, in order to increase the participation of the demand side in the reserve markets, it is necessary to expand the markets' activity to the millions of low capacity consumers, most of them in the residential sector, which have considerable potential for Demand Response (DR) [7], namely due to Thermostatically Controlled Loads (TCL), such as Electric Water Heaters (EWH), Air-Conditioners (AC) and refrigerators.

From the technological point of view, recent developments in building energy management technologies brought the center of the appliances' control to the building domain enabling an end user proximity-based management of electricity resources. For example, Home Energy Management System (HEMS) are capable of scheduling the appliances consumption [8] and control small micro-generation units according to the objectives and the comfort constraints of the end user. These objectives consist in simple energy savings [9], response to dynamic retail pricing [10] and the provision of ancillary services [11]. Specifically, in the context of the provision of RS, the authors of this paper proposed a method – to be run in the HEMS – that is capable of quantifying the flexibility for each hour of the day ahead at the household level based on the consumption habits and preferences as well as the physical characteristics of the appliances [12]. With such type of tools, it is expected that a significant number of households can communicate (during the previous day) the quantified day ahead flexibility to the aggregators allowing them to participate in day ahead reserve markets. However, for that purpose the aggregator needs to have a participation strategy based on bidding methods that take into account

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the specific nature of residential demand flexibility as well as the conditions of the day ahead reserve markets.

In the literature, recent bidding methods aiming at integrating DR in the markets are focused mainly on in the wholesale electricity sector: in [13], a demand-price model is developed and two optimal bidding functions for wholesale electricity markets (must-serve and price based demand) are presented; Alvarez et al. [14] proposed a methodology to generate demand side bids to be offered in the markets by large electricity consumers, such as commercial and services buildings; in [15], a price-based optimization model for aggregating DR contracts to allow the aggregator to bid in the day-ahead electricity markets is proposed. Regarding the participation in reserve markets, some methods also started to be presented. For example, Liu and Tomsovic [16] developed a demand side bidding model to participate in both energy and spinning reserve markets includes different characteristics for a price responsive shiftable demand bids for electricity markets and for the bids that a DR aggregator can submit to the spinning reserve market. In the electric vehicles (EV) field, Sortomme and El-Sharkawi [17] presented an optimal combined bidding method allowing EV to participate in the regulation and spinning reserve markets *via* an aggregator and, in [18], the day-ahead optimization problem for the participation secondary reserve, including an operational management algorithm capable of coordinating the EV charging in order to minimize differences between contracted and realized values, was formulated.

However, these bidding methods have a common characteristic: they result from a top-down approach, *i.e.*, the bids that are generated do not take into account the flexibility of individual consumers calculated within the home domain by the HEMS. This paper presents a bottom-up approach to the day ahead bidding problem, where the aggregators' remuneration in tertiary reserve markets is maximized through the scheduling of individual residential consumers' flexibility. The main contributions of the paper are the following: a bottom-up formulation of the aggregators' bidding problem in the day ahead reserve markets, considering not only the forecasted prices but also the probability of reserve dispatch; a heuristic method to deal with the problem. Finally, Section 4 presents a case study involving an aggregator that represents 1500 residential consumers and participates in the Portuguese day-ahead tertiary reserve markets.

2. Bidding residential flexibilities in day-ahead tertiary reserve markets

Typically, generators can participate in tertiary reserve by offering their capacity to increase or decrease the power output in each hour of the day ahead. Similarly, the provision of tertiary reserve from the demand side requires that aggregators offer potential capacity to increase or decrease the consumption in relation to a predefined baseline demand, which means the aggregated consumption (without any control action) associated with a certain number of residential end users. From the operational point of view, these upward and downward deviations correspond to load control actions at the residential level capable of changing the consumption (during a certain period) in relation to individual baselines [19,20]. Thus, aggregators should gather day ahead flexibility profiles from each HEMS and transform them into hourly bids for the day ahead tertiary reserve market.

2.1. The bottom-up approach for flexibility estimation

Several methods characterizing the residential flexibility have been proposed in the literature. For example, in [21] a model to forecast aggregated flexibility of residential consumers under incentive-based contracts was presented and in [22] the potential flexibility for the Italian scenario was assessed. These top-down approaches estimate the flexibility of a group of appliances without any information about specific characteristics of each appliance. This is reasonable in situations when the information regarding appliances and consumption is not available or a generic characterization of the flexibility profile is enough. However, for the participation of residential consumption in reserve markets through an aggregator, the top-down flexibility estimation is not adequate, namely due to two main aspects: first, the aggregator must know who are the individual end users that are providing flexibility in each moment so that they can be remunerated for this service; second, there is no reason to infer the appliances' consumption since the flexibility is enabled by the HEMS, which already has this information. In contrast, bottom-up approaches have been presented in the literature, namely comprising hierarchical control [23], agent-based methods [24] or flexibility forecasting tools [25].

In this paper, the bottom-up viewpoint regarding flexibility estimation is based on two steps: (1) each HEMS calculate the day ahead flexibility profile of each household (24 h) and communicate it to the aggregator; (2) based on the profiles received, the aggregator should present flexibility bids for each hour of the day ahead that maximize its profit. Regarding, the flexibility calculation at the HEMS level, recent work has started to answer this problem. For instance, in [26], battery models were used to characterize aggregated flexibility of TCL for the provision of RS, in [12], a method to quantify the 24 h flexibility profile of single domestic appliances was presented. These methods allow HEMS to estimate the flexibility for the day ahead by assessing the possibility to increase/decrease the appliances consumption in each hour. Afterwards, a 24 h residential flexibility profile containing the potential upward and downward consumption modifications can be provided to the aggregator, as shown in Fig. 1.

2.2. The aggregator perspective: Uncertain and sequential characteristic of residential flexibility

The RS aggregators establish contracts with a group of consumers from whom they are expected to receive a significant number of flexibility profiles for the day ahead. From the profiles, the aggregators should prepare their offers for the tertiary reserve markets. Thus, two aspects associated with the residential demand-side flexibility can be a barrier for the bidding activity of

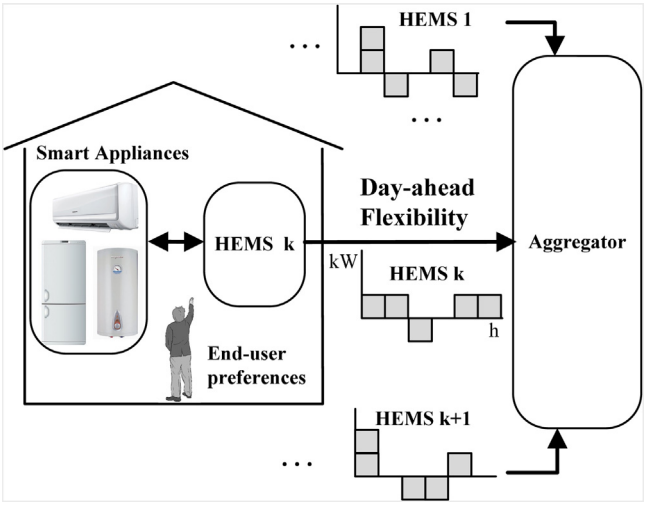

Fig. 1. The Bottom-up approach for flexibility estimation.