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Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium

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HIGHLIGHTS

- Experiences and findings regarding the flexibility of smart appliances are shown.
- The flexibility quantification is based on measurements.
- Measurements were executed in 186 households, during 3 years on 418 smart appliances.
- The flexibility potential calculated can be used to determine the impact of demand response.

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ABSTRACT

This paper presents a well-founded quantified estimation of the demand response flexibility of residential smart appliances. The flexibility from five types of appliances available within residential premises (washing machines, tumble dryers, dishwashers, domestic hot water buffers and electric vehicles), is quantified based on measurements from the LINEAR pilot, a large-scale research and demonstration project focused on the introduction of demand response at residential premises in the Flanders region in Belgium. The flexibility potential of the smart appliances, or the maximal amount of time a certain increase or decrease of power can be realized within the comfort requirements of the user, is calculated. In general, the flexibility potential varies during the day, and the potential for increasing or decreasing the power consumption is in general not equal. Additionally, an extrapolation of the flexibility potential of wet appliances is presented for Belgium. The analysis shows that, using smart wet appliances, an average maximum increase of 430 W per household can be realized at midnight, and a maximum decrease of 65 W per household can be realized in the evening. The resulting flexibility potential can be used as an instrument to determine the impact or economic viability of demand response programs for residential premises.

1. Introduction

Four evolutions cause an increased need for flexibility in the electricity system. Firstly, the share of intermittent renewable energy is growing. Secondly, renewable electricity generation is increasingly injected in a decentralized manner. Thirdly, an increase of the electrical load is expected, caused by a shift from fossil fueled systems toward high efficient electrical equipment for transport and heating [1]. Fourthly, the number of traditional controllable power plants is stagnating or even decreasing [2]. Due to the combination of these four evolutions, maintaining the electricity power balance while respecting electricity grid constraints is becoming increasingly challenging [3]. Demand response, i.e. intentional modifications to consumption patterns of electricity of end-use customers that are intended to alter the timing, level of instantaneous demand, or the total electricity [4], is being deployed to cope with above mentioned evolutions [5].

For such consumption changes to be acceptable, they may not impact the correct functioning of the appliances, nor reduce the comfort level of the users. This is what defines 'the flexibility' of the appliances: the power increases and decreases that are possible within these functional and comfort limits, combined with how long the changes can be sustained.

LINEAR (large-scale implementation of smart grid technologies in distribution grids) was a large-scale research and demonstration

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project focused on the introduction of demand response technology at residential premises in the Flanders region in Belgium [6]. The project ran from 2009 until 2014. The LINEAR project included a large-scale pilot in which residential demand response technology was validated in real-life conditions. In this the pilot, smart appliances were installed in 239 households and tested during a period of 36 months. The appliances used were smart washing machines, dishwashers, tumble dryers, electric hot water buffers and electric vehicles. Dishwashers, washing machines and tumble dryers are further in the paper referred to as 'wet appliances'.

During the pilot, a wide selection of potential applications or business cases of residential flexibility were investigated. (1) Portfolio management achieved a better day-ahead production/consumption balance using the flexibility offered by the households [7] (2) Real-time intra-day balancing of wind production used residential demand response to cover the mismatch between predicted and actual wind production [8]. (3) Residential flexibility was used to decrease voltage deviations on the distribution grid, caused by local production as well as increased consumption [9]. (4) The lifetime of distribution transformer was increased by using demand response to lower transformer temperature and sustained current peaks [10].

The flexibility of all users taking part in the LINEAR pilot was used for all business cases. Experiments for the different business cases were executed consecutively at various user clusters. Participants were not aware which business cases ran at which instant in time, and rather were rewarded using a capacity fee which stimulated the participants to offer as much flexibility as possible.

This paper describes the experiences and findings from the LINEAR pilot regarding the flexibility of the smart appliances that can be achieved without reducing the user's comfort.

Well-founded and sound quantifications of flexibility of residential appliances are hard to find in literature. Most studies give flexibility potential quantifications based on rather rough assumptions and simulations, such as e.g. in [11–13]. In [11] the flexibility potential of residential appliances is estimated, and the availability of these flexible appliances is based on survey data. No information is given in the paper on how the user behavior is modeled. In [12], the flexibility potential of residential households is estimated as a fixed percentage of the household consumption. How this percentage is obtained is not mentioned. In [13], the flexibility potential estimation of residential appliances is executed more in depth. However, the user behavior is based on survey data obtained to study the usage of non-flexible appliances. In some studies the flexibility potential of residential appliances is based on the extrapolated consumption of residential smart appliances, such as in [14–16]. In [14], the future flexibility potential of GB is estimated as the extrapolated future electricity demand from some selected residential appliances (wet appliances, refrigerators, etc.). Also in [15], the flexibility potential of the residential sector in Denmark is estimated as the future consumption of certain residential appliances. In [16], the flexibility potential of residential A/C systems is extrapolated from hourly electricity consumption data. In [17–20] impacts and quantifications of residential flexibility are given. However, the flexibility measured in these works was specifically for users that participated to dynamic tariff schemes. Such tariff schemes have a strong impact on when and how smart appliances are used. As a capacity fee is time of day independent and stimulates the user at offering as much flexibility as possible, the work presented here is a better estimation of the flexibility potential, independent of a specific business case or energy tariff structure. In [21,22] quantification methods for flexibility potential in residential premises are discussed. In [21] the flexibility potential of households is quantified based on data from only one household with flexible appliances. In [22] is discussed how demand response opportunities of a building can be identified based on its energy measurements.

In [23], the results of a pilot test with smart washing machines combined with dynamic tariffs is discussed. In this work is stated that the smart appliances were only used with smart configurations for 14% of the time, and the question is raised whether this number could be increased by using a different reward for offering flexibility, i.e. different than the dynamic tariff incentive. In this work is shown that by using a capacity fee, an increased smart use can be obtained.

The analysis given in the work presented here is based on *measured* flexibility from appliances in the LINEAR pilot. As mentioned before, the flexibility each participant of the pilot offered, was independent from the demand response application making use of the flexibility and gives a better estimation of the total potential.

The paper is further structured as follows: in Section 2 the flexibility offered by the participants in the LINEAR pilot is discussed for every type of appliance. In Section 3, the flexibility potential is calculated. Section 4 concludes the work.

2. Flexibility offered by pilot participants

Comfort protection is an essential requirement for residential demand response. Therefore, LINEAR has selected and deployed two types of smart appliances that offer a large amount of flexibility and that can be automated to minimize comfort impact: postponable and buffered appliances. Buffered appliances are here defined as appliances that inherently have a buffer in which energy (in any form) is stored or buffered. The presence of an energy buffer allows for a flexible operation of the appliance. Postponable appliances have flexibility because their operating cycle can be postponed or shifted within a time window defined by a user defined deadline.

In all business cases tested within LINEAR, user comfort had absolute priority over the technical objective of the business cases. The user comfort protection in case of postponable appliances means that any user is guaranteed that the appliance he has configured will have performed its cycle by the deadline he has given at configuration.

In the LINEAR pilot, a total of 418 postponable appliances, such as dishwashers, washing machines and tumble dryers, were deployed at 186 households. The appliances used were supplied by two manufacturers. The user interface of these smart wet appliances supports smart configurations: when users configure these appliances, they are requested to set a deadline for the end of the appliance's program as far as possible in the future, with a maximum of 24 h delay. This gives the LINEAR system a 'flexibility window' between configuration time and deadline. Within this window, the start of the selected program can be freely chosen at the time optimal for the technical target of the experiment in execution. Once started, the appliance's program cannot be interrupted.

Smart domestic hot water (DHW) buffers (15 deployed) and electric vehicles (7 deployed) were the buffered appliances used in the project. The DHW buffers all have a 200 l tank filled with water that is kept between a minimum and maximum temperature [24]. These settings ensure that the comfort of the user is protected. The DHW buffers have a nominal power of 2.4 kW when heating. Within the comfort settings, the demand response control system freely decides when the buffer is charging.

The electric vehicles are configured similarly to the postponable appliances, i.e., the user is requested to set a departure deadline as late as possible. However, contrary to the wet appliances, configuration of the smart charging required the user to log in on their Linear portal site and submitting the expected departure time